AUSTRALIAN WETLANDS

Ballina Shire Urban Water Management Strategy
- Stormwater and Wastewater Wetlands -

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Prepared for

Ballina Shire Council

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EXECUTIVE SUMMARY

This report examines the potential benefits, constraints, characteristics and main issues surrounding the use of wetlands in different forms as part of a holistic effluent and general water management strategy (Ballina Shire Urban Water Management Strategy) in Ballina Shire.

PART I: STORMWATER WETLANDS

INTRODUCTION

Combating the environmental impacts of stormwater runoff on waterways requires a coordinated approach by government, technical specialists and the community. For effective management, a strategy to minimise the impacts of stormwater runoff on waterways needs to reduce the present impacts and formulate long-term strategies ensuring both economic and environmental sustainability.

STORMWATER PROCESSES

The concentration and type of "critical pollutants" such as phosphorus, nitrogen and pathogens, carried to waterways in stormwater is related to the degree of urbanisation in the catchment. This is a result of vegetation modification, altered drainage lines and the introduction of large areas of impervious surfaces. Treatment strategies should be designed according to the major form of pollutants present at the site.

MANAGEMENT

As part of a catchment management plan, stormwater management initiatives should target the following objectives:

(i) reducing loads of contaminants at the source;

(ii) physically obstructing stormwater runoff; and

(iii) intercepting, retaining and transforming the contaminants.

Such a plan should include an integrated treatment system utilising a combination of measures including gross pollutant traps, sedimentation ponds and wetlands.

OPTIONS FOR PRIORITY SITES

Ballina Island urban area:

This area presents practical difficulties for stormwater treatment due to the low fall of the land, its proximity to the river, and an existing subsurface pipe system. Litter cages and nets, and gross pollutant traps will provide a feasible alternative to a constructed wetland in this area.

Ballina elevated area:

The *Enviropod* filter system currently being trialled by council is to be installed at the Shelly Headland Lookout car park.

Shaws Bay:

A series of *Enviropod* stormwater filters are being installed around Shaws Bay.

Lennox Head:

Presently, stormwater runoff from the village area is piped to the beach and due to the risk of beach erosion, the system is not amenable to treatment techniques except possibly sand filters or reed-beds at the beach. Runoff from the newer subdivisions is pumped into the North Creek drainage system. Wetlands are a practical option for this area. A recent proposal to redirect the village stormwater into the North Creek system is not feasible using the existing pipes. Future proposals for upgrading the stormwater system in the area should consider replacing part of the pipe network with surface swale drainage and piping the stormwater to an area where a constructed wetland would be and effective treatment option.

Wardell:

This area presents a relatively low pollution risk due to minimal areas of commercial and residential developments. The main open drain alongside Wilson Street may be amenable to a modification to a surface swale drain with in-stream wetlands. A consultation process is required to inform local residents of the issues and options so that a satisfactory solution can be reached.

Alstonville:

Presently, a large proportion of the residential and commercial district stormwater runs off along a grassed swale-floodway. This is thought to be moderately effective in reducing suspended solids and phosphorus and pathogens but is unlikely to be capturing significant quantities of nitrogen. Constructed wetlands are an option for the Crawford Park area and the central playing fields south of the South Street bridge. Other stormwater pipes entering the swale-floodway should be assessed for litter interception with possible wetlands.

Wollongbar:

Wetlands and gross pollutant traps along several points of the grassed floodways may be amenable, following community consultation, detailed site assessment, surveys, flow and performance modelling, approvals and construction.

CHICKIBA MELALEUCA WETLAND AT BALLINA

Preliminary Rehabilitation Assessment:

As a result of recent community concern regarding the perceived loss of melaleucas from this wetland, a survey of the area was carried out. The wetland was observed to be affected by the impacts of:

(i) flows channelled around the sports fields and associated berm;

(ii) drains channel water more rapidly than under natural conditions;

(iii) natural flows are obstructed by the Coast Road;

(iv) possible presence of nutrient-rich water in the drain; and

(v) weed infestation.

Works recommended be undertaken to halt the degradation of the wetland include clearing the drain to lower the water level in the wetland and allow recovery time for the melaleucas. A series of short, medium and long-term recommendations should assist in rehabilitating the wetland.

PART II: WASTEWATER WETLANDS

INTRODUCTION

Council has formed a Project Reference Group (PRG) to assist the development of the Strategy, and the PRG in conjunction with the Project Managers have recommended assessment of the potential use of constructed wetlands at all Shire Sewage Treatment Plants (STPs) for enhanced sewage treatment and effluent management. This Report is a preliminary assessment and will form the basis of further consultation with the PRG and the wider community, after which decisions may be made to proceed to a second stage of detailed assessment of the preferred options.

Wetlands are defined by the EPA as "Land on which a shallow water body is formed; land that is flooded in cycles, intermittently or permanently, by water that is fresh, brackish or saline; land on which the flooding determines the type and productivity of the soils, and the type of plant and animal communities that live there".

A constructed wetland is a man-made complex for human use and benefits. The benefit we are seeking in this instance is treatment of wastewater prior to releasing it back into the environment, whether to waterways or via evapotranspiration to the atmosphere.

The NSW EPA's Guidelines covering the reuse of effluent by irrigation, although oriented towards agricultural reuse, has value for the consideration of effluent treatment and reuse by wetlands: "The EPA's wastewater management policy is to encourage the use of effluent where it is safe and practicable to do so, and where it provides the best environmental outcome. In cases where wastewater cannot be used this way, the EPA recommends that alternative methods be used to return effluents to the water cycle in an environmentally and socially responsible way." Wetlands are one of those alternatives available to Ballina Shire.

WASTEWATER WETLAND FUNCTIONING

Wetland functions are based on a combination of physical, chemical and biological processes. Constructed wetlands are essentially shallow bodies of slow-moving water in which water-tolerant plants grow. The wetland environment provides a favourable physical setting for complex chemical reactions between the effluent and sediment and plant surfaces similar to those operating in natural marshes, but occurring at higher rates. Bio-chemical processes in constructed wetlands also resemble some of those operating in sewage treatment plants, but are spread over a larger area.

TYPES OF WASTEWATER WETLANDS

1. Free Water Surface Wetlands

Free Water Surface (FWS) wetlands are those in which the "shallow bodies of slow-moving water" are above ground and visible. The advantages of FWS wetlands include:

- relatively low cost, particularly when effluent flows are more than about 300 kilolitres (kL) per day;
- larger areas have better effluent buffering capacity;
- flood detention capacity;
- wildlife values are usually significant; and
- aeration capacity is substantial where effluent is effectively pre-treated.

The main disadvantages include the need for periodic resting to ensure plant health, and the fact that effluent is above ground. Where soils are porous, as at Alstonville, liners will usually be needed. Where an impermeable "floor" of clay or indurated sand is present, negligible accession of effluent to groundwater can be predicted. Detailed soil assessment of each site is required.

2. Subsurface Wetlands

Subsurface wetlands (sometimes called "reedbeds") are those in which the effluent is entirely below ground, running through a matrix of gravel and plant roots that provide the treatment substrate. They have some similar properties to FWS wetlands, but entail very much larger costs because of the need for a gravel substrate. Experimental work is being carried out on alternative substrates such as shredded tires, artificial plastics and others.

Three main advantages of subsurface wetlands are:

(i) effluent is below ground;
(ii) slightly higher treatment efficiency for comparable area; and
(iii) potential for reuse of effluent through uptake into water-tolerant plants, but the cost efficiency would depend heavily on the use of an inexpensive substrate.

3. Composite wetlands

Composite treatment wetlands involve a mix of Free Water Surface and Subsurface wetlands, usually in series - that is, one type sequentially following another to take advantage of the particular strengths of each system. The ratio and configuration would be determined for each combination of site and effluent characteristics. The main advantage of a composite system would probably lie in maximising the beneficial use of a limited available area. The disadvantage would be in the extra cost.

4. Reuse/Restoration Wetlands.

A recent development in the field of effluent management using wetlands involves irrigating large areas of degraded wetlands with tertiary-treated effluent. A multitude of sustainability outcomes are achieved through effective management of effluent through wetland systems that can remove or transform virtually all pollutants into environmentally benign forms, evapotranspire large quantities of the water component, and provide other complementing outcomes at relatively low cost. One of the key elements in this model is the very high evapotranspiration rate of native wetland trees, which in conjunction with wet season storage capacity makes possible the elimination of effluent discharge to waterways.

FLOW MANAGEMENT

FWS treatment wetlands are normally isolated from the open environment by berms - low walls of earth. The first generation of Australian wastewater wetlands often had many berms, but a revised approach is now being applied, in which one large outside berm about one meter high is constructed around the wetland, with smaller internal cell dividers to enable separate flow management. Cell isolation for the purpose of renovating an individual cell is most useful in dry weather when depths are relatively low.

In flood rainfall the entire wetland can fill with water and effluent in a controlled operation. The outside berms function as low dam walls, and the dense vegetation provides stability against erosion. Many observations of flood situations in wastewater wetlands have shown that the main response to high rainfall is simply a rise in water depth. There is a natural flow retention caused by the low slope and many plants, and this is further controlled by restriction of outflow rates to a design flow using pipes or weirs of appropriate size.

MOSQUITOES

There is no doubt that wetlands can provide a favourable environment for both adult mosquitoes and their larvae because of the constant presence of water. The risks and some of the risk management options are listed in the Constructed Wetlands Manual (Russell et al. 1999). These include elimination of stagnant water zones, wetland edge design, and drying of the wetlands to strand the larvae. These strategies should be addressed in detail at the wetland design stage.

Further understanding of mosquito dynamics has accrued from observations in North Coast wastewater and natural wetlands over the recent period. Mosquito risk is a function of the numbers of larvae that survive to the adult stage, and this depends to a large degree on whether a healthy natural ecosystem exists in the wetland. A diverse wetland environment with dense plant cover features a large population of mosquito predators, and mosquitoes are rarely observed in significant numbers in well-functioning wetlands.

WETLANDS IN THE USA

Comprehensive study by the U.S. EPA of the performance of the large number of constructed wetlands in the United States forms the main theoretical basis for the design modelling of Australian constructed wetlands. Recent developments in wetland design thinking in the U.S. are also relevant to this study. These were reported to the National Wetland Conference in Queensland in November 2001 by Professor Bill Mitsch, who also listed some very large wetland restoration projects including the $US8bn Everglades Project, and the Mississippi Basin project of 10 million hectares.

EXISTING WETLANDS IN NSW AND QUEENSLAND

Constructed wetlands built during the 1990s in the Northern Rivers region and Queensland are assessed in the larger Report as potential models for the design of treatment and polishing systems at the Ballina Shire STPs.

REVIEW OF STP DATA

The data records of effluent flows from each Sewage Treatment Plant (STP) have been reviewed for compatibility with Constructed Wetland design and operation. Dry weather flows through Lennox and Alstonville STPs have generally increased steadily over recent years, whilst Ballina has increased only slightly, and Wardell flow has remained fairly static. Wet weather has a marked influence on flows. Effluent flows at the first three plants have been significantly larger over the period 1999-2002, and it is recommended to use this period for wetland sizing.

Analysis of statistical classes of flows also suggests that in general, designing for 90th percentile flows, that is, including most of the larger flows, would incur larger wetland areas and higher costs than is necessary. Designing for median (the middle figure of the data) flows would not cover many of the higher flow periods. It is therefore recommended to use the mean flow figures.

WETLAND AREAS REQUIRED

Comparison of nutrient and hydraulic modelling provides insights into possible treatment train design that maximises environmental and economic benefit by taking advantage of the strengths of the different processes. Wetlands are less efficient at oxidation and phosphorus removal, but very cost-effective at denitrification, pathogen removal, effluent buffering, and ecological conditioning of the outflow water.

If the STPs are designed to maximise aeration efficiency, phosphorus removal, and preliminary pathogen treatment using UV, then wetlands can cost-effectively remove high loads of nitrate and suspended solids, and provide large areas of natural plant systems for buffering and final removal of residual pathogens such as viruses. Comparison of principal nutrient- and hydraulic-driven area requirements suggests several important conclusions:

- if chemical dosing for phosphorus is carried out, TKN-ammonia is the critical nutrient parameter for wetland sizing;
- reducing ammonia concentrations from the STPs to 1mg/L or less will result in wetland area requirements that will achieve ideal wetland hydraulic detention times; and
- wetland sizing according to the Reed Model indicates that high nitrate concentrations can be accommodated in the wetlands.

Further detailed modelling and consideration is required to balance TKN, nitrate and hydraulic parameters. An ideal sizing principle based on hydraulic load is that of the "5-day detention model" - effluent takes five days to pass through a wetland that is 20cm deep and has pore space of 65%. Using this principle, the present Ballina load would require a treatment wetland of 15ha in area, Lennox 18.4ha, Wardell 0.9ha, and Alstonville 6.2ha. Growth in effluent loads would incur an increase in these required areas roughly proportional to the growth in load. Large reuse wetlands require more comprehensive assessment than mathematical modelling, but will clearly involve several hundred hectares for Ballina-Lennox.

LEGISLATIVE AND APPROVALS REQUIREMENTS

Planning and building of constructed wetlands is predominantly covered by State legislation, and would normally be treated as Part 5 matters requiring Environmental Impact Studies. Local Councils have particularly strong roles through the development consent process under the Environmental Planning and Assessment Act 1979. Other important legislation and Policies include the Fisheries Management Act 1994, Heritage Act 1977, National Parks and Wildlife Act 1974, Threatened Species Conservation Act 1995, Water Act (Regulations still under consideration), and SEPP 14 - Coastal Wetlands. The major EPA licensing of treatment wetlands would be carried out under the Protection of the Environment Operations Act 1997.

WETLAND PLANTS

Common native plants found locally are suitable for constructed wetlands in the Ballina Shire. Planting considerations are detailed in the report.

WETLAND OPTIONS

The following options are suggested for preliminary assessment. All options at all treatment plants should be considered in conjunction with assessment of the cost-efficiency of wet season storage of effluent.

Lennox Head

- Detailed site investigation to determine suitability of identified areas in the North Creek catchment upstream and downstream of the STP for a constructed treatment wetland of up to 30ha, plus a larger area for wetland restoration using high quality effluent from the treatment wetland. A general buffer zone of at least 40 meters is required from Nature Reserves and natural wetlands.
- Consideration of purchase or lease of at least one property for a pilot project to provide detailed information on all issues of interest. It may be beneficial to assess a first property more distant from sensitive areas such as the oyster leases near McGough's Flat, or the airport.

Ballina

- If the STP remains at the present site: rationalisation of the tertiary pond with changed flow arrangements, with effluent then going to wetlands.
- Investigation of the tertiary pond area for reconstruction as part of a larger constructed treatment wetland before reuse of effluent through restoration wetlands.
- Pilot Project to apply effluent to tea-trees around the STP if arrangements for use of the site could be made. Tea-tree (*Melaleuca alternifolia*) not to be harvested, but maintained as a natural wetland.

Wardell

- Integrate with agricultural reuse.
- Implement a constructed treatment wetland with larger restoration wetland.

Alstonville

- Several constraints to constructed wetlands
- Integrate with agricultural reuse
- Further assessments when agricultural reuse plans are better known.

Part I

Ballina Shire Urban Water Management Strategy
- Stormwater Wetlands –

1.0. INTRODUCTION

The impact of stormwater runoff on waterways has become a major environmental issue in developed countries and is now widely viewed as an urgent problem requiring a co-ordinated management approach by government, technical specialists and the community. The task is twofold: to reduce the present impacts, and formulate long-term runoff management strategies that will satisfy the needs of economic development while ensuring environmental sustainability.

In parallel with community concerns, a governmental drive towards achieving effective management of stormwater in Australia has resulted from the 1992 Intergovernmental Agreement on the Environment, when representatives of all levels of Australian governments agreed on the National Strategy for Ecologically Sustainable Development - which requires the use and management of land and water in ways that are consistent with maintaining ecological processes now and into the future (COAG, 1992a).

Another major outcome of national government policy was The National Water Quality Management Strategy, which set a new course for management of land and water resources. The Strategy was based on the recognition that a continent as vulnerable to dry conditions as Australia requires the conservation of both the quantity and quality of water supply for its people to survive and prosper. Management policies and plans are expected to follow the principles of integrated catchment management, consideration of all known benefits and costs, and an inclusive approach to stakeholder involvement.

In line with these national decisions the NSW Environment Protection Authority (EPA) issued a Directive to local governments (EPA, 1998) to prepare Stormwater Management Plans for towns with a population of more than 1,000 people. Accordingly, Ballina Shire Council commissioned Consultants Gilbert and Sutherland to prepare a plan of stormwater management for the Shire towns. The Plan sets out the general issues, values and approaches required to work towards fulfilling the principles outlined above, and provides an overview of stormwater management techniques. The main thrust of the Plan is towards education and source controls.

This Options Report provides a more detailed examination of priority issues and sites identified by the Project Reference Group during its deliberations over the past year. This section of the Report begins with a review discussion of the nature and impacts of urban stormwater runoff and examines options for management.

1.1. STORMWATER PROCESSES

Management actions in any field must be based on accurate understanding of a problem, and the processes of stormwater pollution need to be analysed so that priorities can be set. Stormwater is made up of "critical pollutants" such as phosphorus, nitrogen and pathogens that are carried to waterways at rates and in volumes of runoff water determined by catchment topography, vegetation and rainfall (ARMCANZ and ANZECC 1996; Lawrence and Breen 1998).

The most influential factor is usually the degree of urbanisation of the catchment, because the development process clears vegetation, modifies drainage ways from the curves of natural streams to straight lines, and introduces large areas of impervious surfaces such as roofs and roadways - leading to increased peak runoff rates. Where hardening of creeks and channels is also carried out the increase in flow-rates usually produces a hydraulic and environmental impact zone near to where the stormwater stream meets the unmodified downstream environment.

Most urban areas introduce excess nutrients, hydrocarbons, pesticides and heavy metals to the water stream (EPA 1997, 1998). Table 1 lists a range of typical pollutant levels in urban stormwater and shows that this type of runoff can be a large source of pollution. The form of the pollutants has a strong influence on the types of strategies suitable for each site. Nitrogen for example is often found as nitrate in runoff from garden suburbs where fertilisers are used by householders, and is efficiently removed in wetlands. If the nitrate is allowed to collect in ponded "traps" along a watercourse, the breakdown of accompanying litter and organic matter can result in conversion of the nitrate to ammonia, which then has a high oxygen demand in the water column when the next rainfall mobilises the water.

A similar process occurs with faecal coliform bacteria that appear to be able to increase in number in aquatic sediments in some circumstances. Initial high loads of bacteria and phosphorus are usually associated with suspended solids, and are reduced to much lower levels if the solids are removed from the flow by grassed swales, ponds and wetlands of appropriate size.

Table 1. Typical Event Mean Concentrations of three potential pollutants for three types of land use (EPA 1997)

Pollutant	**Rainfall Event Mean Concentration (EMC) (mg/L)**		
	Forest	Rural	Urban
Total Phosphorus	0.01-0.42	0.03-1.3	0.12-1.6
Total Nitrogen	0.27-0.66	0.23-5.1	0.6-8.6
Faecal coliforms (cfu/100mL)	260-4,000	700-3,000	4,000-200,000

1.2. MANAGEMENT

Stormwater management measures are targeted at the following objectives:

1. reducing loads of contaminants at source through communication with the community, source management, and enforcement of regulations;

2. physical management of runoff through slowing and reducing of flow peaks and volumes; and

3. the interception, retention and transformation of contaminants.

These measures should form an integral part of a catchment management plan that identifies downstream waterways and environmental and economic values, with an estimate of pollutant reduction goals and sustainable pollutant loads. Such a plan should include the construction of integrated treatment systems employing gross pollutant traps (GPTs), sedimentation ponds and wetlands - now widely recognised as an effective way to control contamination from urban runoff (ARMCANZ and ANZECC, 1996; EPA, 1997; Land Systems EBC, 1993).

Sedimentation ponds work by allowing time for pollutants, particularly solids, to settle out. Ponds accumulate sediments over time, and are normally maintained by removing the sediment at a design load level. Oxygenation of ammonia by algae is also common in ponds and can be used to advantage in treatment systems. Ponds can require somewhat closer management than wetlands, can incur higher risks of child safety, and if incorrectly designed can produce odours and algal blooms.

Wetlands are efficient at sedimentation of finer solids in the flow, and adsorption of very fine solids - the process of electrochemical attraction of pollutants to plant surfaces. Wetlands also generally produce minimal algae, and if correct depth and flow control devices are installed no odours will be generated.

Wetlands are referred to as "on-line" and "off-line" (Figure 1). On-line means being installed within a watercourse. Advantages include the potential to capture and treat a majority of flows, and the capacity to detain some of the higher runoff volumes. Disadvantages include exposure to scouring flows, rubbish and weeds from upstream. Off-line systems are usually installed to one side of a watercourse, with offtake structures such as small weirs to allow low flows into the wetlands for treatment while larger flows are bypassed along the watercourse. The chief disadvantage is the possible failure to capture pollutants in high flows and the main advantage the avoidance of damage and weeds, with lower maintenance requirements. High flows are more difficult to manage with on-line systems, with a risk of scouring and other damage.

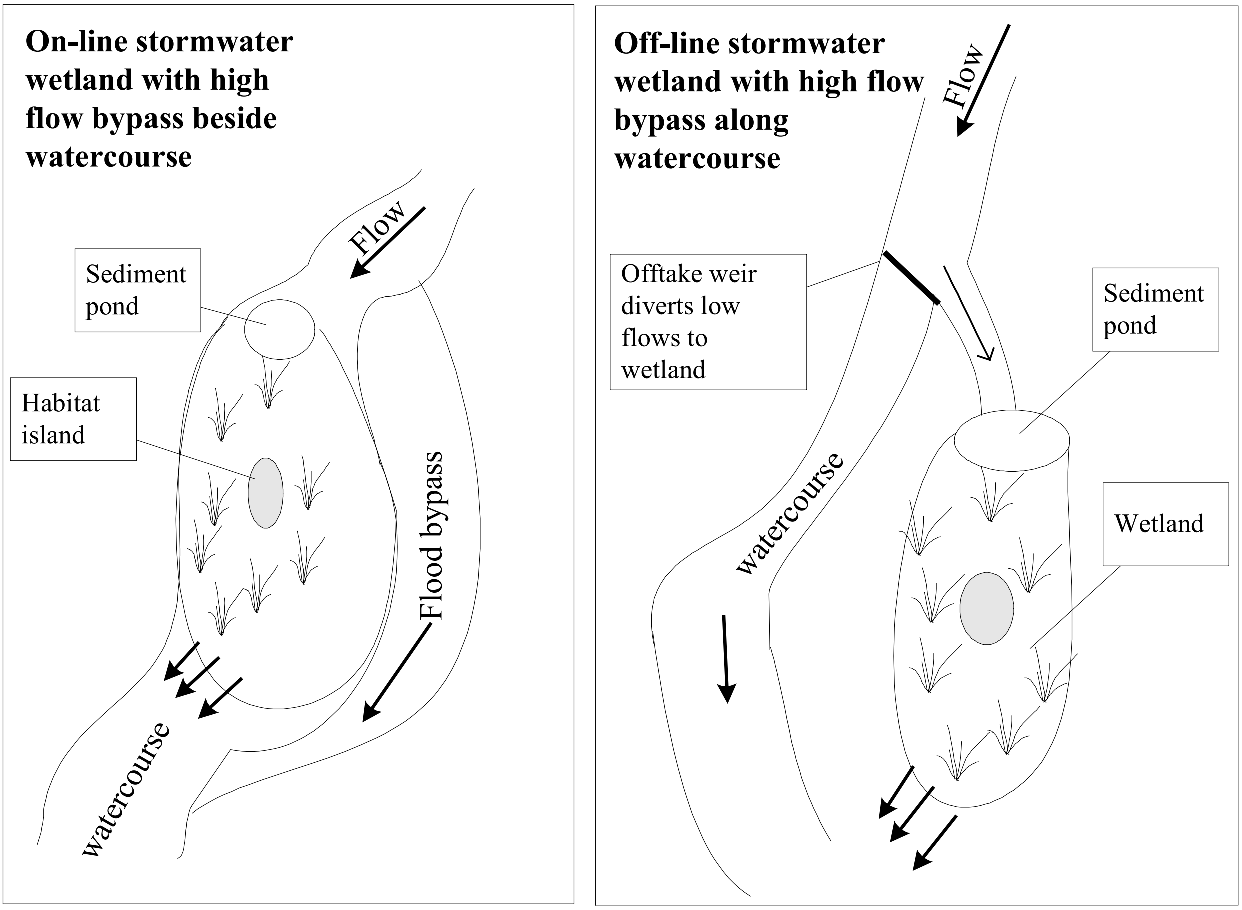

Figure 1. A simple comparison of typical on-line and off-line wetlands.

The design of these systems is based on identifying typical discharges of stormwater and pollutants from the catchment, measured by stream gauge and water quality monitoring, or estimated by mathematical models and values from the literature, with procedures detailed in Australian Rainfall and Runoff (IEA, 1987). Local rainfall event frequency probabilities are calculated from analysis of rainfall records. These are combined with Intensity-Frequency-Duration (IFD) design curves to provide an estimate of the likely peak discharges and volumes of runoff water for different sized events.

Intensity-Frequency-Duration curves are graphical representations of the intensity of rainfall for particular frequencies (termed Average Recurrence Interval) of rainfall events, for a particular duration such as one hour, or 24 hours, and so on. These curves are based on measured rainfall intensity from the area of interest over a long period. A general Rule of Thumb using 2% of catchment area is usually applied for initial feasibility assessment. For example, one hectare is required for a 50ha catchment.

All these parameters can be compiled and computed in accepted mathematical models for each situation that produce a rational basis for a catchment-based runoff management plan, and a "treatment train" design approach for dealing with runoff quantity and quality issues (Lawrence and Breen 1998; Wiese 1998). A treatment train approach involves applying specific management techniques to identified problems in the most cost-effective configuration. For example nitrification of ammonia in ponds or sand filters usually precedes denitrification in wetlands, and removal of suspended solids early in the process will reduce the need for later wetland treatment of associated faecal coliform bacteria. Reduction of peak discharge rates and all pollutants at source through education and system re-design will reduce the size and cost of downstream treatment. All measures to achieve environmental objectives must be integrated with correct sizing and placement of hydraulic mechanisms such as pipes, pits and weirs by consulting accepted authorities such as Jenkins (1987).

1.3. OPTIONS FOR PRIORITY SITES

BALLINA ISLAND URBAN AREA

Generally featuring intensive commercial and residential development on a flat low-lying estuarine delta landscape with high water-tables, the Ballina Island area presents practical difficulties in treating stormwater because of the low fall, proximity to the river, and an existing subsurface pipe system that was not built with environmental values as a design aim. On particular priority sites such as shopping centres and car-parks, certain main drainage outlets and possibly upstream stormwater pits are suitable for placement of proprietary devices such as litter cages and nets in pits and on pipes, or tank-type gross pollutant traps that require little fall in order to function. Ongoing maintenance costs must be addressed at an early design stage. Council's present trial program at Shaw's Bay will provide valuable information. Constructed wetlands will generally not be suitable for this environment.

BALLINA ELEVATED AREA

The higher elevations around East Ballina provide more opportunities for integrated treatment because of adequate fall. The *Enviropod* filter system is being trialled by Council (see below), as is a locally-made inclined perforated plate litter interceptor that is to be installed at the Shelley Headland Lookout car-park with the aim of catching litter, mainly cigarette butts, that is presently being washed into the sea below. A major aim of this small project is to illustrate with a transparent cover the quantity of rubbish generated by car-park users.

SHAWS BAY

A series of stormwater filters are being installed around Shaws Bay at Ballina. The *Enviropod* filters consist of a 0.2mm nylon weave filter, and are installed in some 16 drains following modelling of stormwater flows to size the devices. They are designed to intercept cigarette butts, garden waste and other litter, along with some nutrients. The aim is to store the litter dry, and clean out as required. "Wet" litter is now classed as contaminated waste requiring a higher grade of assessment and management. The $100,000 project will be integrated into Ballina High School Marine Studies, and students will analyse the system. The *Enviropod* company will maintain and develop the system for six months then a plan for future installation and operation will be devised. Council won a State government grant for $50,000 for the project (pers. comm. Graham Plumb, Ballina Shire Environmental Health Officer).

LENNOX HEAD:

(i) Outline

Stormwater runoff from the village area is piped to the beach, whilst runoff from the newer subdivisions flows to the west and into the North Creek drainage system. In general the subsurface drainage to the beach is not amenable to treatment techniques except through the use of underground litter interceptors close to the village, and possibly removable sand filters and/or reedbeds at the beach. Beach erosion is a serious constraint. Wetlands are a practical option for the western system. Each pipe or group of pipes can be assessed for catchment size, likely peak and total discharges for design rainfall events, and an appropriately sized wetland, with or without other treatment train components such as wet or dry drainage swales or sand filters.

Wetlands on the western side of the Lennox Head Bypass show signs of deterioration in places, with acidic drains and some tree dieback. This area can be rehabilitated in conjunction with management as a receiving system for treated stormwater.

A stormwater control pond in the Lakeside subdivision appears to be intercepting sediments, but the fringe of sedges and reeds is unlikely to be sufficient to carry out fully effective interception of colloidal solids, the water is marked by different colours (possibly algae), and the pond has been colonized by water lilies which in these types of systems often degrade pond water quality by reducing oxygen transfer at the surface and by harbouring faecal coliforms and sometimes mosquitoes. More detailed assessment would include water quality sampling, and investigation of changes in water depths to enable shallower water, more sedges and reeds, and fewer lilies.

(ii) Preliminary Assessment of a Proposal to Redirect Lennox Head Stormwater

A submission regarding stormwater pipes on Lennox Head Main Beach, among other issues, has been forwarded to Ballina Shire Council by Mr. Don Apps, a Lennox Head resident and long-time Dunecare member. Mr. Apps has identified issues relating to the pipes and has proposed consideration of redirecting stormwater runoff from the beach to the west, towards the North Creek system. As part of the Ballina Shire Urban Water Management Strategy, *Australian Wetlands* has been requested to consider the issues raised, the feasibility of the proposal, and whether stormwater treatment can be applied to any redirected water.

A half-day inspection in company with Mr. Apps was carried out by David Pont on May 21 2002, with a follow-up visit to confirm initial observations. There are six main stormwater pipes entering the Lennox Main Beach surf zone at or just above the high tide level. The northern four pipes are 450-600mm in diameter, and appear to drain the suburban streets north of the Lennox Point Hotel, as far west as Gibbon Street. Erosion gullies are scoured in the beach at some of the pipes, with severe erosion at the sides of the pipes and indentations in the fore-dune line. Mr. Apps' main concern is with this obvious erosion and its effect on beach stability. Weeds infest some of the pipes.

In the recent low-energy and dry conditions most of the pipes were not running, and the sand at each outfall was dry. In larger swell and rainfall conditions an accumulation of polluted water on the beach is likely.

The proposal to run this stormwater west will be impossible using the present pipe layout, with the pipe system obviously sloping down to the beach. Any structure on the beach such as a treatment device is likely to cause interference with beach processes unless well above the high tide mark. This is technically possible if small-scale interceptor pits were installed at the ends of pipes, with for example a sand filter above and a reedbed wetland below in a two-tier arrangement. Such a system would need either to be heavily stabilised against beach erosion, or removable. As with almost all stormwater options, the next step would be characterisation of the runoff by sampling, and measurement of the particular catchment area to determine runoff rates and volumes.

Aside from this treatment possibility there appears therefore to be no practical alternative to retaining the present system for the near future. However, any future upgrade proposal for the stormwater system in this area should consider replacing at least part of the pipe network with surface swale drainage, possibly with pipes to take flows beneath the highest part of the small north-south sand ridge at Gibbon Street, and redirection of flows to the west, where wetlands can be installed to treat the runoff. This step may become necessary in any case if damaging beach erosion occurs with damage to pipes and/or erosion of dunes. Installation of household rain-water tanks for water conservation and stormwater detention should also be considered.

A 1,200mm outfall pipe at the southern end of the beach appears to be carrying runoff from the village shopping district and surrounding residential areas. This water runs first to pits at a low point behind the dune - probably a former dunal wetland - then onto the beach through the large pipe. The beach is a popular swimming area. Sand covered about one-third of the pipe opening at the inspection, and a flap valve was held closed by the sand. Waves were breaking around the end of the pipe. The intensity of development and routing of pipes precludes the use of wetlands.

No remediation of this situation appears practical at present, except a communication strategy to inform residents of the situation, to urge minimal fertiliser use, and to collect and properly dispose of dog faeces. Water quality sampling would provide information about pollution levels, and subsequently Council and the community may wish to consider the purchase of one or more of the lowest-lying properties for a treatment system if they become available over time.

WARDELL

This small village represents a relatively low pollution risk from stormwater because of the small area of the commercial and residential districts, and absence of large shopping centres or carparks. The stormwater system is based on pipes and floodplain drains, again on a flat and low-lying landscape. One main open drain runs alongside Wilson Street, and this environment may be amenable to modification to a surface swale drain with in-stream wetlands. However, some residents have expressed a desire to have stormwater pipes installed to eliminate the open drain situation. In this case a consultation effort could inform all residents about the issues, listen to concerns, and reach a consensus that could reasonably satisfy the needs of the community as well as the environment. A larger low-lying area just behind the village area can be investigated for wetland rehabilitation and/or stormwater management.

ALSTONVILLE

A large proportion of Alstonville residential and commercial district stormwater runs off along a central grassed swale-floodway that broadly bisects the village through Crawford Park and other playing fields and out to the north. Water flows to Branch Creek thence to Maguires Creek and the Richmond River. The catchment contains about 40-50ha of developed areas, although this has not been measured in detail. The grassed swale is likely to be moderately effective in reducing suspended solids and associated phosphorus and pathogens, but is unlikely to be capturing significant quantities of nitrogen. The swale is crossed by two bridges, at Ballina Street and South Street. At the bridge at South Street about halfway down the swale-floodway, the swale becomes wetter, with the development of marshy conditions over the next 700 meters downstream (Figure 2). A pond was once situated at the bridge but has been removed.

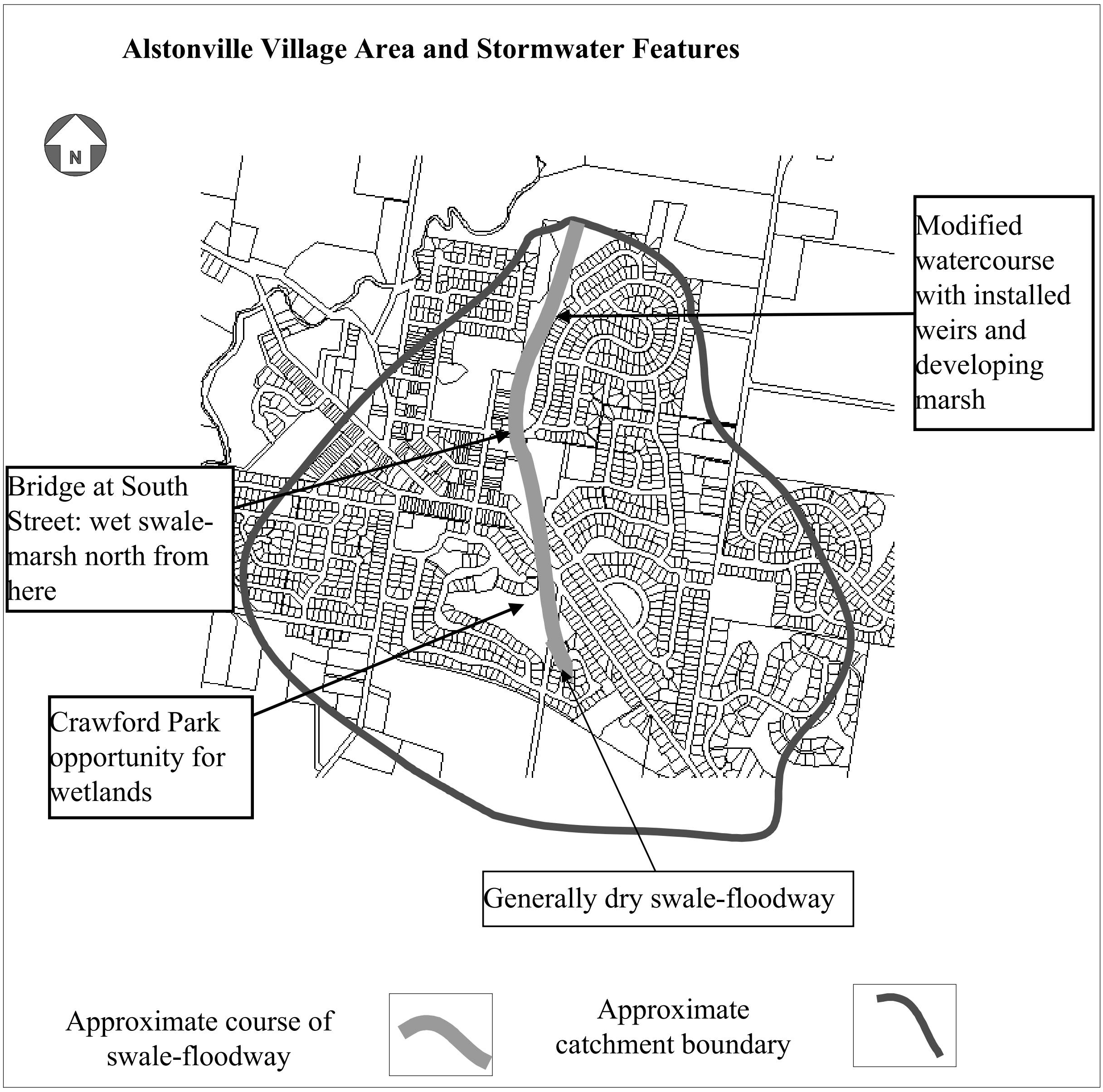

Figure 2. Alstonville catchment features

The marsh situation has developed following installation of concrete weirs along the northern portion of the swale-floodway after litigation involving the potential impacts of stormwater quantity and quality from the "Fairfield" subdivision upon the downstream property "The Alstonville Tree Farm". Any further stormwater management work in that area would need to accord with the court judgement. The issue was also the subject of a Report to Ballina Shire Council by Gutteridge Haskins and Davey Pty. Ltd. (GHD) in September 1998. The Report considered both stormwater quantity and quality questions, but was limited primarily to consideration of stormwater from Fairfield Estate.

The GHD Report suggested water quality was being maintained by the wetland vegetation in the floodway, and approximated pre-drainage conditions of the creek-wetlands watercourse. Specific water quality testing at the time was suggested by GHD (1998) as unreliable. The Report also concluded that "investigations…indicate only modest increase in flow in the un-named waterway" above the pre-development farmland situation. The small wetlands that have developed in the swale in response to the weir installation illustrate the way that stormwater treatment wetlands can be encouraged by appropriate design.

This Options Report must consider the entire catchment area, which includes most of the Alstonville developed zone. The swale-floodway in the Crawford Park area receives runoff from suburbs, and two large pipes near the Ballina Street Bridge appear to be carrying runoff from the main shopping centre. There are sites in and along the swale-floodway where wetlands may be a practical option. These could be 400-500 square meters in area. It is envisaged that such wetlands would be of shallow depth, designed to harbour no mosquitoes, and probably be sited just off-line from the swale-floodway, although the downstream marsh near the weirs suggests in-line wetlands would be practical.

The primary aims would be removal of nitrogen, and interception of pathogens, phosphorus and other pollutants both dissolved and associated with colloidal sediments. Detailed consultation with residents would be a pre-requisite. Wetlands of appropriate size and design would enhance the landscape qualities of the area, and fit the garden suburb theme as water features.

The central playing fields section has a less-suitable low fall, but the area immediately south of the South Street bridge may be suitable for a wetland. Other stormwater pipes enter the swale-floodway at several points, and each entry should be assessed for litter interception, with a possible wetland. Given the catchment size, a total area of about one hectare of wetland is indicated. The areas of smaller wetlands can be summed, but this total required area for treatment of Alstonville urban stormwater is probably only achievable by considering the northern section.

The northern portion of the swale-floodway-marsh is limited in width by the shape of the channel. From the wetland design point of view, the practical options are basically limited to optimising the present on-line wetland operation, which appears to have no detrimental effects, and several beneficial effects such as flow detention and pollutant removal. The present situation appears to be permanent, following the litigation. Inspection of the channel shows terrestrial grasses and weeds have colonised the edges, whilst the aquatic plant populations do not have a high diversity. Optimisation of the wetland following detailed assessment could therefore logically include:

(i) widening the channel to enable higher detention capability with more efficient sedimentation and removal of pollutants;

(ii) slightly increasing the height and width of the weirs; and

(iii) carefully removing weeds and planting more plant species.

WOLLONGBAR

The stormwater runoff situation in this village parallels that of Alstonville in some ways. Runoff from the main shopping centre flows via subsurface pipes to the east, and is brought to the surface near Eskimo Court. One large pipe conveys the runoff over a steep eroding gully where no treatment is possible except perhaps a GPT to intercept litter. Runoff from some of the Wollongbar suburbs however flows northeast through Hillpark Oval and a grassed floodway that appears to have sufficient area for GPTs on pipes and culverts, and on-line or off-line wetlands at several points along the swale. Residents would be consulted at an early stage, with detailed assessment of sites, followed by survey, modelling of flows and performance, approvals and construction.

1.4. CHICKIBA MELALEUCA WETLAND AT BALLINA

PRELIMINARY REHABILITATION ASSESSMENT

Background

Community concern has been expressed over the perceived loss of melaleuca trees from this wetland over recent years, with a subsequent proposal for assessment of the wetland nominated by the Project Reference Group established under Ballina Shire Council's Urban Water Management Strategy.

The wetland as a whole has been fragmented by earlier construction of a sports field in about 1993-4 that appears to have split the wetland into two parts. A reasonably healthy remnant wetland forest, thought to be part of the same wetland complex, is situated nearby on the other side of the sports field to the west (Figure 3). The eastern wetland under discussion drains a catchment of about 30 hectares extending from the south, from just west of Black Head. The Coast Road separates the wetland on the south side of the road from the cleared wetlands and salt marsh complex on the north side. The wetland is classified under SEPP 14 legislation, and as 7A Zone under Ballina Shire Council's Local Environmental Plan.

A one-day survey was undertaken by walking the perimeter, by inspection of the wetland by entering from the south, west and east sides, and by crossing most of the wetland west to east from a point 100m south of the Coast Road. The wetland has also been assessed from aerial photographs. An initial site diagram has been drawn (Figure 4), although the scale is approximate.

Observations

- fallen melaleuca trees, most dead and lying in water; appearance of wind-throw - in melaleucas this is usually an indication of excessive inundation;
- no signs of tree disease; leaf cover is sparse;
- a 1m deep drain about 3m wide runs south to north through the wetland from the bikepath to the Coast Road, and is blocked by reeds at the northern end; heavy sulfide gas in sediments and water column;
- the northern section of the melaleuca wetland as a whole appears to be dying, although a few young trees are growing on high spots;
- housing subdivisions on the east and southwest sides;
- many terrestrial and some aquatic weeds around the margins;
- stormwater pipes enter the wetland at several points, uncontrolled, with no water quality management;
- no biting mosquitoes in the wetland, and no larvae observed;
- Azolla (native aquatic fern, sometimes indicating elevated nutrients) is thick in the drain and surrounds;
- water quite deep (>1m) in northern area nearer to coast road;
- 3 metre wide culvert under Coast Road, with approaches blocked by *Typha* and *Phragmites* reeds;

- areas of sedges and reeds inside wetland, also indicating constant inundation;
- the wetland between the bikepath and the Coast Road is about 300m N-S, 110m E-W, and about 3ha in area;
- frogs (*Litoria fallax*) heard, possible habitat for *Litoria olongburensis* and other frogs, but is not high-grade frog habitat because stagnant sulfide-rich water covers much of the area;
- the drain was flowing very slowly, and water flowing under the road indicated a gradient; and
- no signs of acid sulfate runoff.

Conclusions from Observations

The wetland appears to be suffering impacts from:

1. Channeling of flows around the sports fields and associated berm;
2. The south to north drain that conveys water from the upper catchment and subdivisions more rapidly than under natural conditions;
3. Hydraulic back-up caused by the Coast Road obstructing natural wetland flows to the north;
4. Obstruction of the drain and culvert at the Coast Road exacerbating Point 3;
5. Possibly nutrient-rich water in the drain;
6. Weeds.

Issues

The wetland appears to be seriously degrading and is likely to deteriorate further if no action is taken. Zoning constraints and ESD principles incur a requirement for considered assessment of likely impacts of any management actions. Simple clearing of the northern end of the drain to allow lower water levels in the wetland would assist melaleuca recovery in the inundated area, but would trigger other changes - for example the area near the bike-path to the south would become drier and the trees there may suffer from lack of water. If the drain is permitted to function by being fully cleared, some oxidation of potential acid sulfate soils may occur. Habitat values appear poor because of the stagnant Azolla-covered water and sulfide gas accumulation.

Values

The wetland values that would be likely to be enhanced by rehabilitating the wetland include frog and bird habitat, improvement in water quality, and re-establishment of a more natural connection between the freshwater wetland and the nearby estuary.

Recommendations

Short-term

- Liaise with NPWS on management actions
- Begin a careful removal of accumulated vegetation in the drain, beginning at the Coast Road culvert to enable a gradual lowering of the water levels and further observation; undertake further assessment when this occurs
- Consider a management plan, with further refinement of features, issues and values
- Assess placement of simple drop-boards at one to three points along the drain to enable more natural flows through the whole wetland rather than down the drain

Medium-term

- assess the need for re-planting melaleucas or wait for natural regeneration
- consider planting melaleucas along Coast Road drain to reduce severe terrestrial weed (e.g. Para grass) problem
- consult with nearby residents
- consider need for stormwater filters/wetlands on pipes

Long-term

- assess feasibility of filling drain to restore wetland function
- assess natural regeneration rate and weed infestation
- recognise damage to wetland from partial clearing, bikepath, road, inundation, weeds, and apply remediation strategies over time

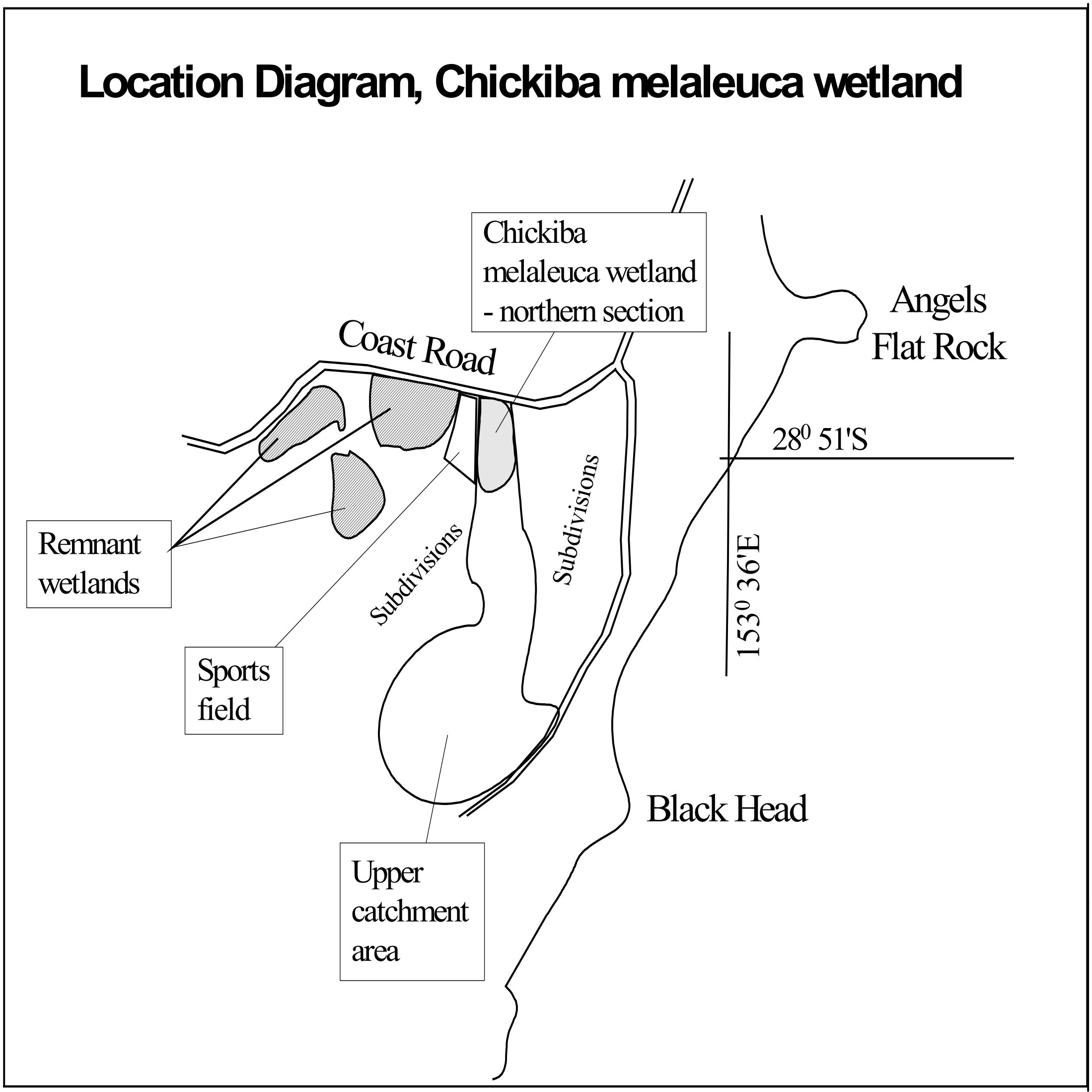

Figure 3. Location diagram of Chickiba melaleuca wetland, not to scale

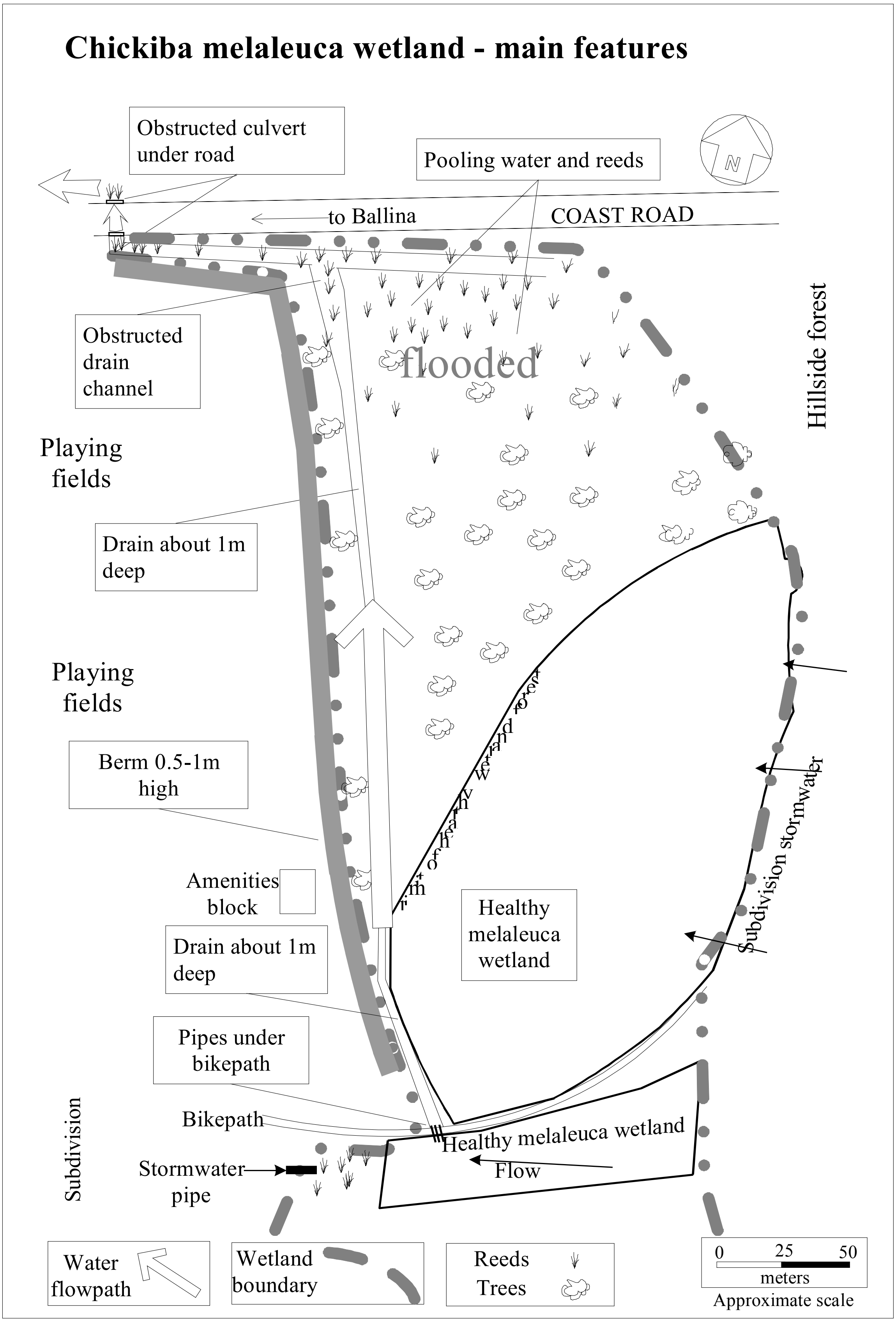

Figure 4. Initial site diagram, approximate scale

Part II

Ballina Shire Urban Water Management Strategy
- Wastewater Wetlands -

2.1. CONSTRUCTED WASTEWATER WETLANDS IN NSW AND QUEENSLAND

The use of constructed wetlands to polish effluent from various wastewater treatment processes increased in Australia in the 1990s after an earlier university-centred research phase. The environmental and economic advantages of using natural systems for cost-effective effluent polishing where land was available attracted some Councils and Government agencies. Free Water Surface wetlands were favoured over subsurface systems, and the design approach usually emphasised length of flow-path and detention time.

Constructed wetlands built during this period in the Northern Rivers region and Queensland are assessed here as potential models for the design of treatment and polishing systems at the Ballina Shire STPs.

QUEENSLAND

Pilot Free Water Surface (FWS) constructed wetland systems were constructed in Queensland during the 1990s as joint projects between State and local authorities. Free Water Surface means surface flow. Although the eight pilot-scale wetlands are situated in tropical areas, well-directed wetlands research is of interest to water managers in cooler climates because although lower temperatures can reduce wetlands efficiency, the processes and plant types are often the same and can be adapted to local conditions.

Greenway (1997) and Greenway and Woolley (1998) examined the performance of these FWS wetlands. Normal parameter monitoring was carried out, as well as nutrient accumulation in plants. General information is given about the status of the wetlands including number of channels, depths (300-600mm), and residence time - which varied from 2.5 to 20 days.

No information is given about the ratio of open water to densely vegetated zones - an important issue discussed below. The worst performing wetland in relation to phosphorus retention was the Cairns wetlands (inflow 8.2mg/L, outflow 6.4mg/L), which also featured the longest retention time - reflected in the good nitrogen performance (inflow 9.5mg/L, outflow 1.3mg/L). When phosphorus outflow loads are higher than inflow loads, a release of stored phosphorus is indicated - usually as a result of anoxic conditions arising from the loss of plants or high wastewater loading. The lowest performing wetland in relation to nitrogen was Blackall (inflow 15.9mg/L, outflow 12.8mg/L), which was also the deepest at 600mm. Some wetlands had a distinct nutrient gradient downstream along the bed as the nutrients, particularly nitrogen, were removed early in the wetland process.

The results are quite variable among the wetlands, which goes some way to explaining the past reluctance of many effluent managers to incorporate constructed wetlands into treatment trains. However the results clearly indicate that wetlands with short retention time and deeper water tend to perform less well, and vice versa. The unknown element in these Queensland wetlands is the health of the vegetation.

Sixty plant species were also analysed for nitrogen and phosphorus content. These results demonstrated the ability of wetlands plants to tolerate and accumulate nutrients in their tissues.

Common species such as *Eleocharis sphacelata*, *Baumea articulata* and *Typha domingensis* accumulated average nitrogen concentrations of ~13-18mg of nitrogen per gram of plant tissue, and average ~3-5mg of phosphorus per gram of tissue. This resulted for example in a measured plant uptake by Typha of about 2.2g of phosphorus per square metre for a four-month growth period (Greenway and Woolley, 1998). Greenway (1997) concluded that her study indicated both the great potential of many aquatic plants for use in constructed wetlands, and the effectiveness of nutrient content of plants as an indicator of different species' ability to remove and store nutrients as biomass.

If the uptake result for Typha were conservatively extrapolated to larger areas, phosphorus uptake by reeds could be expected to approach 22kg/ha/year - a figure in line with known uptake rates for other plants. Some of this phosphorus will be used in normal ecosystem metabolism, and over time will be exported from wetlands in low quantities, bound with carbon and other nutrients and with very low bioavailability.

Some phosphorus would also accumulate in wetlands, incorporated into sediments, and may need to be addressed at a future time. This point depends almost entirely on the phosphorus loads from the STP. Phosphorus accumulation rates in particular wetlands would be addressed at Concept Design stage. Wastewater wetlands can also be planned for a design life, after which phosphorus can be removed and reused by stripping surface sediment with machinery. However, this process disrupts wetland function and most importantly removes the litter layer - a key element of the wetland process.

A logical conclusion is therefore that large wastewater wetlands should not be used for phosphorus accumulation, and accordingly the lowest phosphorus concentrations possible should be allowed into the wetlands, consistent with cost-effective pre-treatment processes. This conclusion accords with the view of the NSW EPA (EPA 1995).

NORTHERN RIVERS

Four STP constructed wetlands are known in the northern rivers region - at Ocean Shores, Casino, South Lismore and West Byron sewage treatment plants. These wetlands were built over the last twelve years, and have been assessed by Australian Wetlands over the past two years. All the wetlands had common problems of poor plant cover, short-circuiting of the effluent stream, variable regulatory compliance performance, and accumulated pollutants in organic sediments (sludge).

Water birds were a serious problem, particularly purple swamp hens, which prefer a mix of open water and plants in the wetlands. The birds can introduce nutrients and pathogens to the effluent stream, but have a larger impact through damage to plants. The birds eat, pluck from the soil, and squash young plants, and can destroy large plantings. They maintain an access tunnel through vegetation, causing effluent short-circuits. Birds also often keep sediments in suspension through wading activity, resulting in lower effluent quality. The most effective strategy to combat all these problems in sewage wetlands is to ensure complete plant coverage by appropriate design and operation.

Open water areas also tend to be algae sources, with subsequent export of suspended solids and associated nutrients and pathogens. Any ponded areas should be well upstream in the treatment train.

OCEAN SHORES

A redesign of the Ocean Shores Wetlands has been considered, and extensive work was carried out by Council to address the problems. However, serious constraints still apply in the wetland's relatively small area, configuration, and the surrounding sensitive environment. The wetlands configuration was typical of early design concepts involving a serpentine flowpath around multiple berms. The concept appears to simulate meandering creeks, and although reasonably effective in the first years of operation, saturation of the system with sludge occurred with subsequent periodic release of nutrients and pathogens, leading to questions about the ability of the systems to "retain" effluent materials.

Figure 5 shows the wetland layout, illustrating the meander effect, and the way that beds of reeds developed predominantly outside the actual effluent flowpath. The "wetland" was in fact a long pond. Byron Shire Council is now assessing other sites for larger wetlands of appropriate design to receive Ocean Shores STP effluent.

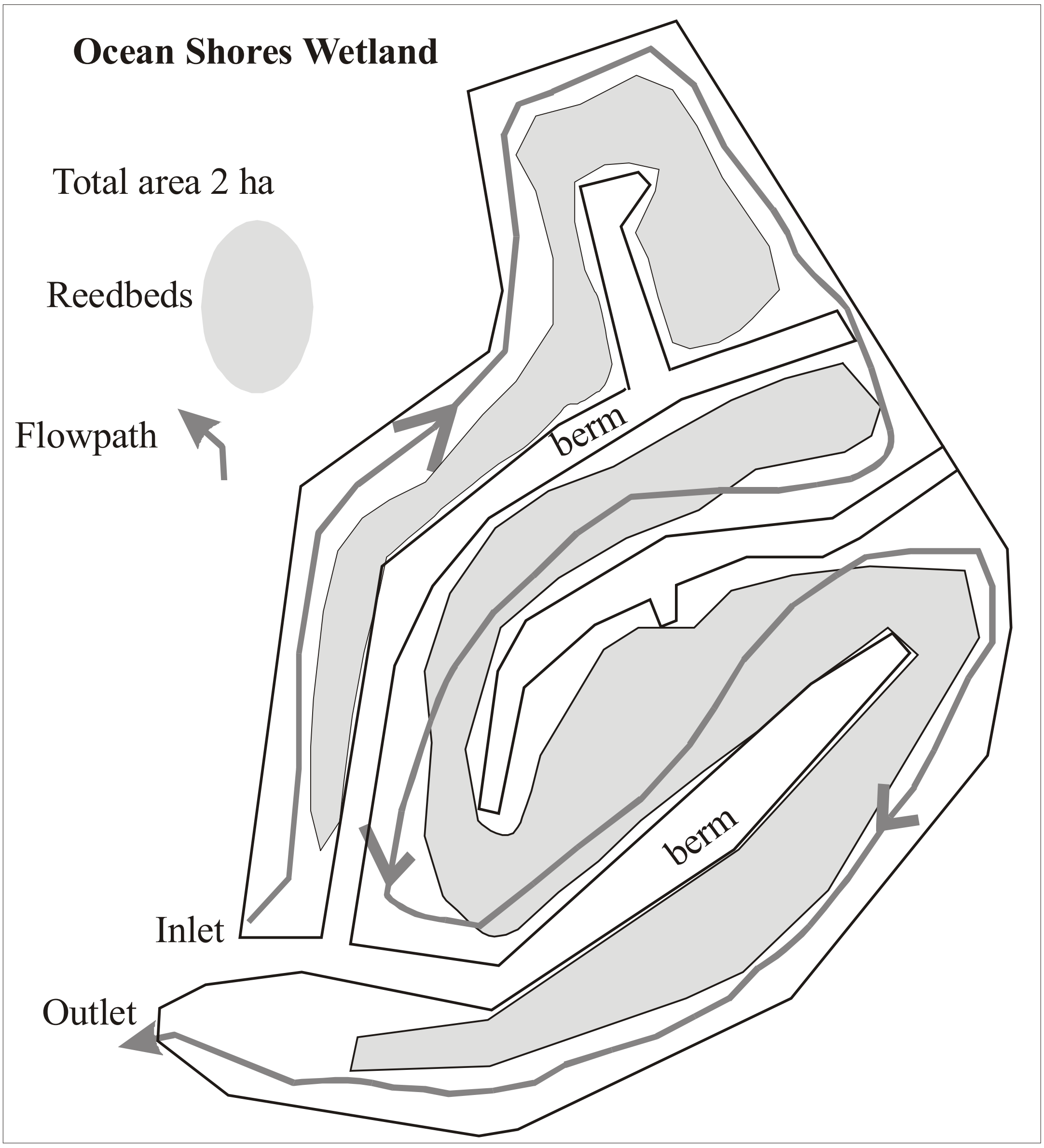

Figure 5. Ocean Shores STP Wetland in 2000.

SOUTH LISMORE

The South Lismore Wetland has an area of 12ha, and normally receives wet weather flows of 4-20ML per day from a 20,000 e.p. trickling filter STP that has received substantial upgrading work over recent years. An effluent reuse scheme takes all dry weather flow. The wetlands were retrofitted to the plant in 1994-5, but have not functioned satisfactorily since construction. Several earlier plantings have failed, with the main problems identified as no slope, deep holes in cell floors, outlets too high for effective drainage, inefficient design of cell shape leading to hydraulic backup and deeper water, accumulation of organic sediments and excessive numbers of waterfowl.

A full redesign is necessary over the long term to enable proper operation as a planted wetland with a slope. Lismore City Council has accepted a staged rehabilitation strategy. Effective drainage capacity has been installed in two cells, and an intensive planting has been carried out in a one hectare section of one cell in early 2002.

CASINO

The Casino Wetland of 5ha (built about 1990) receives effluent (about 2.5 ML/day) from a trickling filter plant with added aeration tanks. Alum dosing for phosphorus is not carried out, nor is disinfection. The wetland was originally designed to operate at a depth of 200mm, regulated by weirs of gravel that although meant to be permeable were causing effluent to back up, increasing the permanent water depth to about 400-500mm. Richmond Valley Council approved a rehabilitation plan, and an excavator dug channels in the weirs of one group of cells at logical points for drainage. Oxidation of the saturated sediments took several weeks to months. Experimental planting of several species began immediately.

Two years later over half the wetland is densely vegetated. Although the effluent load is still considered to be over double the desirable level, satisfactory results have been measured at the outlet, with Total Nitrogen concentrations commonly below 2mg/L, Suspended Solids often below 10mg/L, and Biochemical Oxygen Demand of 5mg/L or less. Two parameters will require larger wetland areas to obtain satisfactory results: faecal coliforms are commonly in the hundreds, and only some 20% of phosphorus is retained in the wetland. Plans for expansion of the wetland areas are under consideration. This wetland and its rehabilitation have provided an excellent model of resolution of practical wetlands issues such as plant regeneration methods, effluent flow control through wetlands, and collaboration between professional specialists and Council staff.

WEST BYRON

The West Byron Wetland was built with the STP in 1989-90 to polish the effluent, with the added aim of enhancing wildlife values in the West Byron area. The wetland functioned very well in earlier years but deteriorated when cells could not be effectively drained for plant regeneration. A Wetland Design Panel of professionals and community representatives examined the wetland performance and provided a range of recommendations in 1999-2000.

This work has been followed up over the last two years by practical management and design work by Australian Wetlands, leading to improvement in operation, and a Concept Design (Pont 2002) for a system redesign and upgrade, and enlargement of the wetland to 17.5 hectares. Selected cells will be re-graded to provide drainage capacity, replanted and fitted with rationalised inlet and outlet structures. The wetland has been designed for wet season operation as a priority, with a design stormflow detention capacity of about one week. Detailed modelling indicates a very high effluent polishing performance. The treatment wetland will be integrated with wildlife wetlands, effluent reuse in agriculture, and large-scale wetland restoration projects.

2.2. PRELIMINARY ASSESSMENT OF STP DATA AND MODELLING OF PRESENT AND FUTURE STP FLOWS

EFFLUENT QUANTITY

The data records of effluent flows from each Sewage Treatment Plant (STP) have been reviewed for compatibility with Constructed Wetland design and operation. Ballina Shire Council (BSC) has carried out daily flow monitoring and fortnightly chemical monitoring of outflows from all STPs as part of EPA licensing conditions. Dry weather flows through Lennox and Alstonville STPs have generally increased over recent years, whilst Ballina has increased only slightly, and Wardell has remained fairly static.

Wet weather periods result in marked increases in effluent flows. The linear trend-line on Figure 6 shows for example the steady rise in Lennox daily outflows over seven years from 1994 to the end of 2001, and the strong influence of wet seasons in 1996, 1997, 1999 and 2001, not only in wet periods but the high individual events.

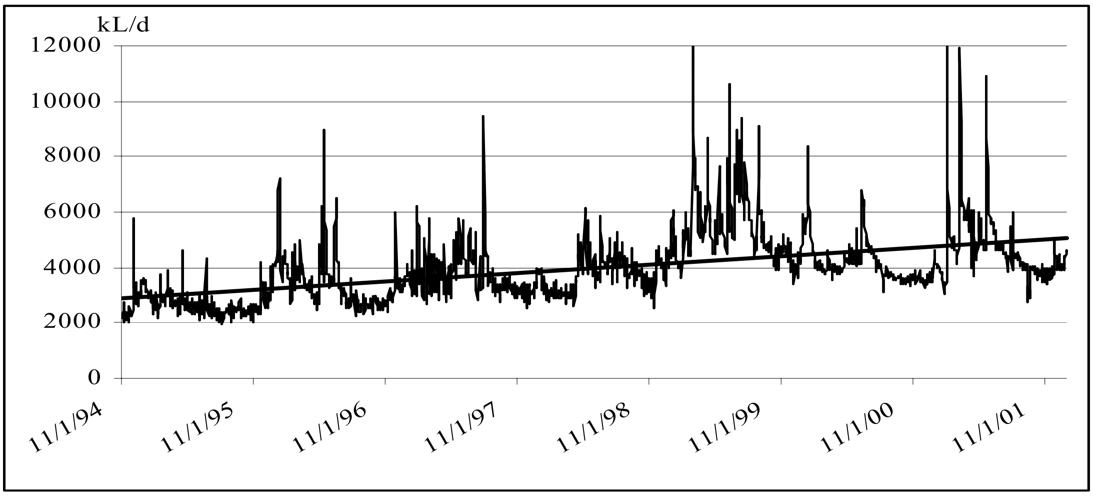

Figure 6. Lennox STP daily outflows, 1994-2001

There is some difficulty in deciding on an average flow for each STP for the purposes of constructed wetland design. Table 2 lists daily flows for different periods over the medium term, and shows that the 90th percentile data include many of the higher rainfall events, particularly at Lennox and Ballina. Using wetland models to design for these events would entail larger wetland areas than may be justified, although no problems are foreseen because of running lower flows through a larger wetland. In general larger wetlands are better than smaller where land is available and costs are reasonable. With rationalised wetland berm design, wetland construction costs per unit area decrease substantially with increases in total wetland area.

Table 2. Three flow categories from the four STPs

Daily effluent flow (kL)	Ballina (Nov 94-Dec 01)	Lennox (Nov 94-Dec 01)	Wardell (Apr 97-Nov 01)	Alstonville (Nov 94-Dec 01)
90 percentile	4,391	5,479	537	1,800
Median (50 percentile)	3,550	3,796	278	1,441
Mean	3,671	3,972	239	1,499

Further, Figure 7 shows the flows that would be covered by the different statistical classes. Using the median figure to size the treatment wetland would cover the dry periods, but may be inadequate for the "shoulder" wet periods, when flows are elevated but not high. Using the mean figure will cover many of these shoulder periods and is recommended for Lennox.

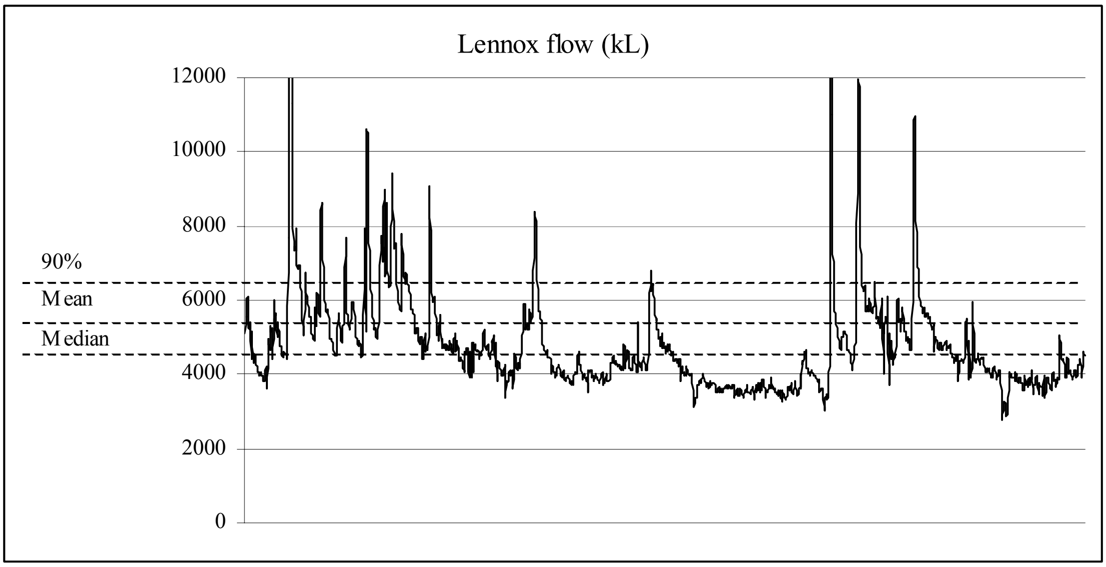

Figure 7. Relationship of three flow classes to Lennox flow records, 1999-2002

Examination of Wardell flow records (Figure 8) suggests however that using the mean would not have covered the elevated flows in late 2000 - early 2001, and the 90 percentile figure is more appropriate. There may be a case for closer investigation of the river flow meter records for the purpose of more detailed design work. A wetland at Wardell would be relatively small and some discrepancy in sizing would not be as critical financially.

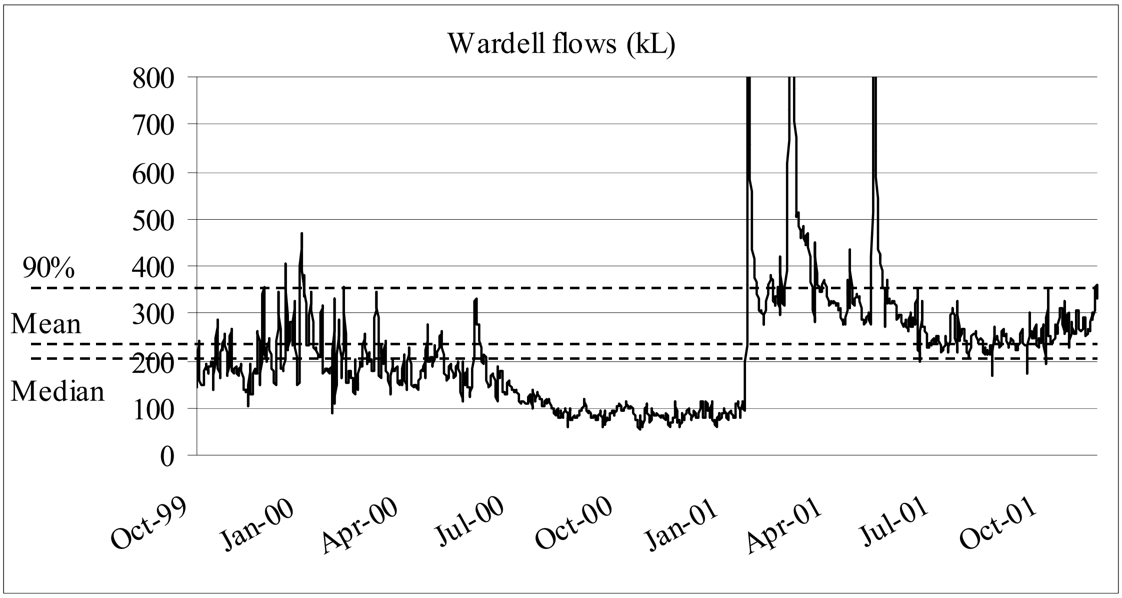

Figure 8. Wardell flow figures1999-02, with mean, median and 90 percentile levels

Analysis of Ballina STP flows suggests that using the mean figure would cover most of the wet period shoulder flows (Figure 9).

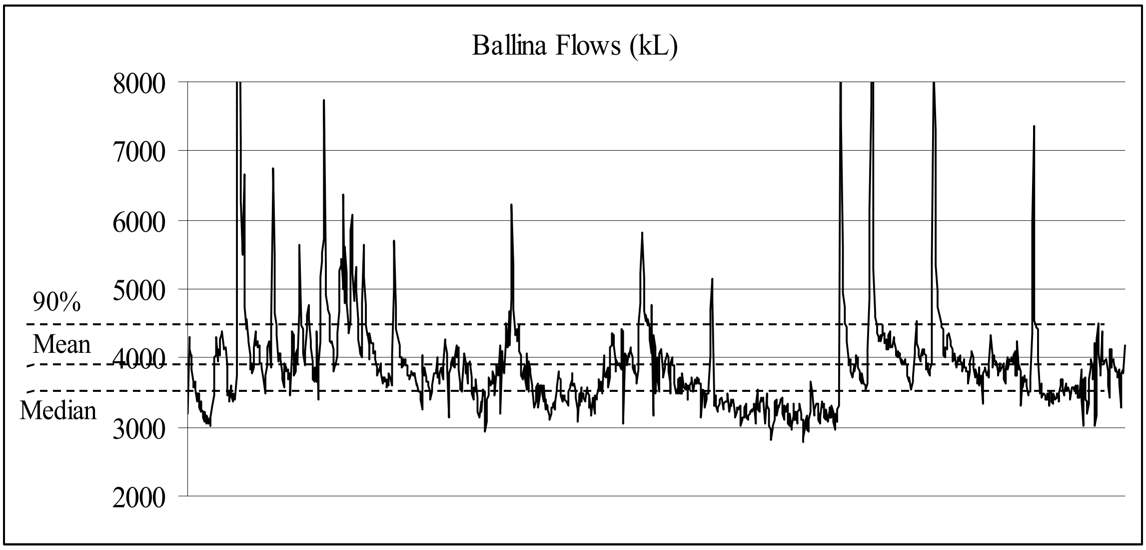

Figure 9. Ballina flow figures 1999-02, with mean, median and 90 percentile figures

Similarly at Alstonville the mean figure will cover the wet season shoulder period flows, and it is recommended to use the mean for modelling and sizing purposes.

A further question involves what historical period to design for. Table 3 presents a comparison of Ballina STP effluent flows during the 1994-2001 period with the later, wetter period beginning in January 1999. The table shows the slight increase in volumes during the wetter period, perhaps as well as an increase in population load. The other STP flow records show a similar pattern, except at Wardell, where the daily flow has decreased slightly over the last three years. It is recommended to use the more conservative later period figures, with the mean flow figure, for sizing.

Table 3. Comparison of longer term flow figures with 1999-2001 records at Ballina STP

Daily flow (kL)	**Ballina (Nov 94-Dec 01)**	**Ballina (Jan 99-Dec 01)**
90 percentile	4,391	4541
Median	3,550	3777
Mean	3,671	3908

Table 4 presents an assessment of required treatment wetland areas for each STP, based on hydraulic load, and using four sizing scenarios. The Rule of Thumb is a first-cut method described in the Constructed Wetlands Manual, and is based on providing 1-2 hectares of wetland for every megalitre per day of effluent flow. Recent experience on the north coast indicates the higher figure is appropriate, and ideally even larger. Checking this result against a "detention time" model involving 3, 4 and 5 days detention time assuming an operational wetland depth of 0.2m, and a porosity of 0.65 (Reed 1999), indicates that aiming for a desirable 5 days detention in the wetland will entail an area roughly twice as large as the Rule of Thumb. At this stage of wetland design knowledge, the higher area is an ideal goal, but 3 days detention would be adequate for an effluent with a high degree of pre-treatment, particularly if larger reuse or restoration wetlands are downstream of the treatment wetlands. Nutrient modelling below provides further perspective.

Table 4. Median daily flows from the four STPs and areas required for treatment and polishing wetlands based on hydraulic load under different detention time models

	Ballina (Jan 99-Dec 01)	*Lennox (Jan 99-Dec 01)*	*Wardell (Jan 99-Nov 01)*	*Alstonville (Jan 99-Dec 01)*
Median daily flow (kL)	3,908	4,783	229	1,621
Area required - Rule of Thumb (ha)	7.8	9.6	0.5	3.2
Area required - 3d detention model (ha)	9.0	11.0	0.5	3.7
Area required - 4d detention model (ha)	12.0	14.7	0.7	5.0
Area required - 5d detention model (ha)	15.0	18.4	0.9	6.2

Assumptions: 0.2m depth, 0.65 porosity.

Equation: Area required (ha) = Volume of effluent x No. of days detention / Depth (m) / Porosity / 10,000.

NUTRIENT MODELLING

Two models are in common use: the model group developed by Reed, Crites and Middlebrooks (1995), generally referred to as Reed's Method, and the Kadlec and Knight (1996) model. Reed's Method is based like Kadlec and Knight's on equations derived from first-order plug flow kinetics identified by analysis of the US EPA's North American Data Base of constructed wetland performance, although Kadlec and Knight's modelling is based on plug flow assumption for all pollutants, whilst Reed has separate temperature-related equations for pollutants that are removed mainly by biological processes: BOD, ammonia and nitrate.

"Plug flow" means a pollutant transformation/removal process in which the pollutant reduces along the flowpath through a reactor such as a wetland (Mitchell, Wiese and Young 1998), and pollutant removal efficiency increases accordingly, compared with a theoretical completely mixed reactor such as a fill-and-draw pond.

The primary determinant of wetland area is nearly always ammonia, because oxygen needed for nitrification of ammonia is often depleted in wetlands, particularly in sediments. Total Keldahl Nitrogen (TKN) is ammonia plus organic nitrogen, both un-oxidised, and is used for ammonia modelling because it must be assumed the organic N will be broken down by microbes to ammonia during passage through the wetland.

Winter temperatures (18^0C is common in the northern NSW coastal area) are used for the Reed model to ensure a conservative approach. In summary, these models are "black box" methods, and both will produce effective wetlands, but are based on non-ideal hydraulics and caution must be used near the limits. Reed's Model is most often used for general sizing, and it is proposed to employ this method for this initial task in the Ballina situation. A second stage of individual wetland size modelling should use the Kadlec and Knight Model to cross-check the Reed Model.

It should be kept in mind that mathematical modelling does not provide complete certainty. In general, well-designed and managed wetlands may be capable of removing nitrogen compounds down to 0.5mg/L and phosphorus down to 0.1mg/L (Mitchell, Wiese and Young 1998) - a high quality effluent. This estimate is supported, based on observations in recovering wastewater wetlands at Casino and Lismore.

The nutrient data records from the four STPs have been collated and examined, and three primary nutrients of concern - ammonia (as TKN), nitrate and phosphorus - have been modelled to determine wetland sizes required to process the nutrients to design background levels. It is assumed that all STPs will have UV disinfection, and therefore that low faecal coliform concentrations will enter the wetlands. US models indicate that larger wetlands will probably add wildlife coliforms to the effluent stream, and that pathogen numbers will never reach zero. This is an open question to be answered by future research, but monitoring of particular wetlands has indicated faecal coliform concentrations near to zero may be achievable. What is certain is that sedimentation and adsorption processes in larger wetland ecosystems are highly likely to remove and destroy the large majority of other, usually unmeasured, pathogens found in sewage effluent.

The last decision to be made on modelling is what statistical class to use for sizing of the treatment wetlands based on nutrient removal. Figure 6 shows that at Wardell over the recent period using the mean figure would be sufficient, particularly if the STP process is operated for minimal ammonia outputs. This pattern applies at all four STPs.

The wetlands will cope with occasional surges in nutrient or hydraulic loads by intercepting the loads and providing time for physical and microbial activity to remove the nutrients - one of the strengths of these systems. In this context Figure 10 indicates that designing for the 90th percentile concentration would probably be over-design, whilst sizing for the median may not be adequate.

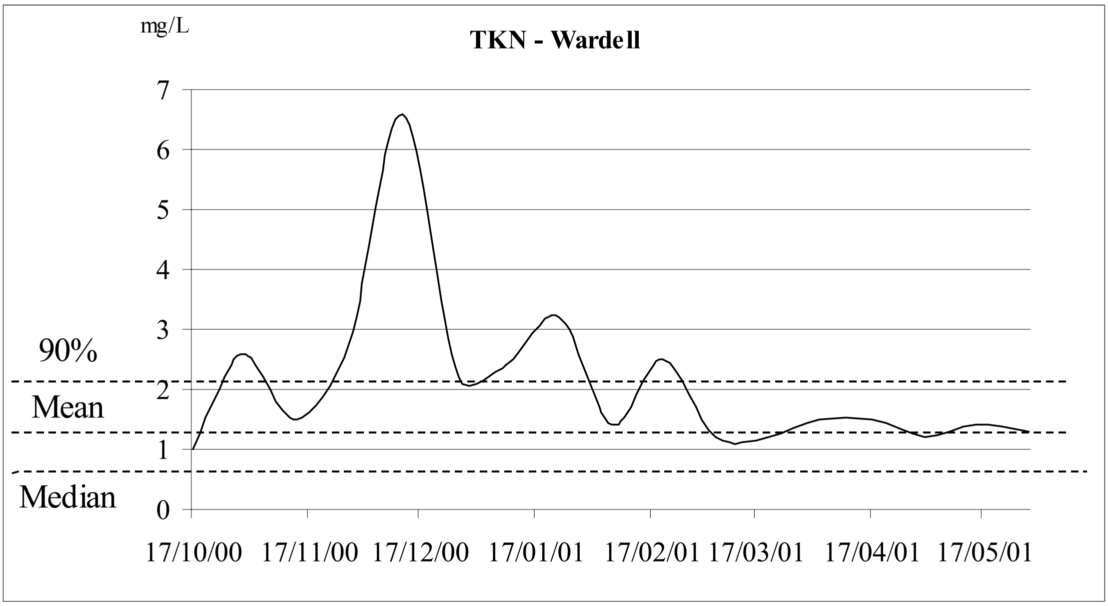

Figure 10. TKN concentrations at Wardell STP 1999-02, with mean, median and 90 percentile concentrations.

WETLAND SIZING FOR NUTRIENTS

Preliminary modelling of required treatment wetland area for each STP has been carried out using Total Keldahl Nitrogen (TKN) data recorded fortnightly from October 2000 to May 2001. The data are reasonably homogeneous for modelling purposes, with an occasional concentration spike that would be absorbed by a wetland of appropriate size. As explained above, TKN includes organic nitrogen, ammonium and ammonia, all requiring oxidation, and thus usually incurring the highest wetland area requirement.

Table 5 presents required area calculations based on mean inflow TKN concentrations, and outflow concentrations of 0.2mg/L - the minimum achievable according to the Reed Model. The TKN is modelled as NH4-N, using the Reed Model as prescribed in the Constructed Wetlands Manual. The TKN results for Wardell, Alstonville and Lennox plants are remarkably similar, and reflect the modern oxidation process at these plants, whilst the higher Ballina figure of 5.27mg/L reflects the older trickling filter-Passveer Channel technology and possibly the influence of the poorly-functioning tertiary pond.

The TKN figure from any modern oxidation-ditch STP represents an operational decision about the balance of nitrate and ammonia. If aeration is increased, nitrate increases and ammonia (and TKN) decreases. The wetland area requirement suggests that where wetlands are used the maximum aeration should be applied in the STP process in order to produce the minimum TKN concentrations possible.

Table 5. Wetland areas required at present TKN inflow concentrations to produce an outflow TKN at the background limit according to the Reed Model.

STP	*Mean daily flow (kL)*	*Mean TKN concentration in inflow to wetland (mg/L)*	*Predicted outflow concentration (mg/L)*	*Required area (ha)*
Wardell	229	2.1	0.2	2.07
Alstonville	1,621	2.03	0.2	14.5
Lennox	4,783	2.02	0.2	43
Ballina	3,908	5.27	0.2	49.5

Comparison of nutrient and hydraulic modelling provides insights into possible treatment train design that maximises economic and environmental benefit by taking advantage of the strengths of the different processes. Wetlands are less efficient at oxidation and phosphorus removal, but very cost-effective at denitrification, pathogen removal, effluent buffering and ecological conditioning of the outflow water. If the STPs are designed to maximise aeration efficiency, phosphorus removal and preliminary pathogen treatment using UV, then wetlands can cost-effectively remove large loads of nitrate and suspended solids, and provide large areas of natural plant systems for buffering and final removal of residual pathogens such as viruses. Table 6 compares principal nutrient and hydraulic area requirements and suggests several important conclusions:

- if chemical dosing for phosphorus is carried out, TKN-ammonia is the critical parameter for wetland sizing;
- reducing ammonia concentrations from the STPs to 1mg/L or less will result in wetland area requirements that will achieve ideal wetland detention times;
- wetland sizing according to the Reed Model indicates that high nitrate concentrations can be accommodated in the wetlands. Further assessment of particular STP effluents will be needed to confirm sufficient carbon is available for bacterial denitrification. Wetlands generally produce abundant carbon; and
- further detailed modelling and consideration is required to balance TKN, nitrate and hydraulic constraints. For example if the Lennox 5-day model requirement of 18.4ha is used, an inflow ammonia concentration of 1mg/L would result in 0.37mg/L in the outflow. The community and regulatory authorities may consider this level sustainable if for example areas for wetlands are difficult to procure.

Table 6. Areas required under different chemical and hydraulic sizing scenarios

STP	*Area required if inflow NH_4-N is 1mg/L*	*Area required if outflow TP is 0.3mg/L (EPA Sensitive Waters Standard)*	*Area required according to "Rule of Thumb" (ha)*	*Area required according to 5-day detention model*	*Maximum permissible inflow nitrate concentrations if using ammonia-limited area (mg/L)*
Wardell	1.4	1.69	0.5	0.9	33
Alstonville	10	7.1	3.2	6.2	15
Lennox	30	49	9.6	18.4	>40
Ballina	24	24.5	7.8	15.0	40

GROWTH IN STP LOADS

Growth projections for the Shire indicate a need for STP augmentation if the growth eventuates. Projections have tended to overestimate growth rates, but a set of data for predicted effluent loads are contained in the Urban Water Opportunities Discussion Paper (Anderson 2000). These indicate that the equivalent person load in 2003 at Lennox would be 17,841, resulting in an effluent load of 4,281kL per day at an equivalent person (ep) rate of 240L per day, rising to 28,000ep at Stage 2, then 58,000ep at Stage 4. The Lennox plant is already handling a mean throughput of 4,783kL per day (January 1999-December 2001).

The original Plan to close Ballina STP is now under review, so for the present, it is of interest to model a population of 28,000ep at Lennox, producing a load of 6,720kL per day. Table 7 shows a straight 40% increase in area required based on hydraulic load. Modelling TKN with the increased load by contrast indicates about a 30% increase in area required. If nutrients are processed through the STPs in an optimum balance for treatment wetlands - that is, low ammonium and phosphorus, the area requirements will depend mainly on hydraulic load. This principle will apply to all growth projections at all STPs. Reed (1999) also suggests applying a conservative 25% enlargement to modelled wetland sizes for the purpose of allowing for the uncertainties inherent in mathematical modelling of natural processes. This principle is incorporated in the broad predictions presented in this Report, particularly in the "5-day Detention Model" approach.

Table 7. Comparison of areas required according to hydraulic modelling.

	Lennox mean flows (Jan 99-Dec 01) (kL)	*Predicted future load (kL)*	Increase (%)
	4,783	*6,720*	40
Area required - Rule of Thumb (ha)	9.6	13.4	40
Area required - 3d detention model (ha)	11.0	15.5	40
Area required - 4d detention model (ha)	14.7	20.7	40
Area required - 5d detention model (ha)	18.4	25.8	40

SIZING OF REUSE WETLANDS

For broad sizing of constructed wetlands, the 5-day detention model is recommended. This means that at a notional depth of 0.2m and using Reed's porosity factor of 0.65, a parcel of effluent should take 5 days to travel from inlet to outlet at a velocity of ~1-3mm/s, ideally about 4ha/ML/day.

For reuse/restoration wetlands, sizing principles are related to a broad range of factors including evapotranspiration rates of wetland forest, the percentage of organic matter in the soils, community expectations, ecological sustainability, available land and others. Water use calculations are usually derived from accepted mathematical models using local rainfall, evapotranspiration and other climatic conditions. For preliminary sizing, a range based on standard reuse guidelines such as the Queensland Department of Natural Resources general guide of 5ML/ha/year or 1.35mm/day as a minimum should be followed, with a projected potential maximum figure of 15ML/ha/year or 4mm/day over a year.

In area terms, Lennox STP at present output of about 4.5ML/day would require some 330ha at the former rate, but about 110ha under the latter higher application rate. These figures require refinement using accepted modelling techniques, in conjunction with effluent storage assessment. Assigning areas to reuse-restoration wetlands is not as much of a mathematical exercise as it is with treatment systems, although modelling will be valuable. Substantial data are available at this point from the West Byron Regeneration Project. Guidance is available from a limited number of texts such as Roberts et al. (2000).

Assessment of complex factors such as unpredictable climate cycles, forest nutrient and hydrological dynamics, community expectations, and cost efficiency of storage dams must also be considered for sizing. A broad preliminary sizing exercise follows:

Bolton (2001) measured evapotranspiration rates of 22mm per square meter per day in hot dry weather in a maturing melaleuca grove, and this equates to 220kL per hectare per day in ideal conditions. Conservatively halve this rate to 110kL per day.

To average the figure over the year, either halve it again, or assume a storage dam that would hold wet season effluent for application in dry weather, effectively doubling the required irrigation area. This results in an application rate of about 55kL per hectare per day, or an area requirement for example of 86ha for Lennox effluent at the current mean daily output of 4,783kL per day. Further area will be needed for resting and renovation of soils and plants, since the overall aim is ecological sustainability. If a further conservative tripling for this factor were applied, and to incorporate medium term projected growth requirements this still equates to about 250ha, compared with about 350ha using a land requirement of 5ML/ha/year commonly employed for agricultural reuse in Southeast Queensland. Detailed site modelling and pilot projects will provide more information and understanding. Features of the regeneration model include:

- comprehensive sustainability outcomes;
- relatively inexpensive effluent application infrastructure;
- low management costs; and
- effluent to the system must be high-quality.

The use of sewage effluent to restore large-area wetlands and potentially enable elimination or significant reduction of discharge to waterways also entails overcoming several serious constraints such as:

- the capital cost of land;
- social implications of large-scale change in land use;
- environmental assessment, including threatened species issues where essentially terrestrial species have populated degraded wetlands that have become suitable habitat through drainage and consequent drier conditions; and
- the possibility of impacts on downstream water and land users.

Each of these constraints requires detailed consideration, but all have been addressed in other projects and resolution of issues is possible at later stages

2.3. OPTIONS REPORT

LENNOX

Landscape

The Lennox STP is situated about 4km northeast of Ballina within a wetland environment below and west of North Creek Road, which runs along a north-south ridge of Lismore Basalt soils. The STP site is also adjacent to the melaleuca floodplain wetlands of Ballina Nature Reserve to the west. Other wetlands exist on the east side of the ridge, with drainage lines to the south that enter North Creek a few hundred meters upstream of Chickiba Creek.

Several hundred hectares of drained wetlands presently under some type of agriculture exist within 6km of the STP. To the south, the McGough's Flat area of about 100ha is 0.5-2km distant. To the southwest across North Creek in the general vicinity of the airport, is a further 100-150ha area of drained floodplain. To the north, about 70ha south of Ross Lane are suitable for wetlands, with a further 300-400ha north of Ross Lane within accepted economic pumping distance. The wetland potential of all these areas depends heavily on more detailed consideration of land use and the attitude of landowners.

Situation

The current capacity of the Lennox plant is likely to be exceeded by 2003. The present mean effluent load (January 1999-December 2001) is 4,783kL per day, and may rise to 6,720kL/d if growth projections are carried through. This increased load will require a treatment wetland area of about 30ha, depending on further decisions to be made about wetland sizing. Reuse/restoration wetlands may be conservatively sized on the basic principle of 5ML/ha/year, similar to low-range agricultural reuse effluent application rates, or as outlined in other sections of this report, by a more realistic use of the very high potential evapotranspiration rate of wetland trees. The yearly effluent load of 2,450ML would require about 500ha under the former model, and about half that area under the latter. More detailed assessment is required.

The STP area itself is constrained by surrounding wetlands and Nature Reserve. Some suitable constructed wetland areas are located downstream within economic distance of the plant; and may be further assessed. Low-lying areas of former wetlands often feature subsoils of acid sulfate estuary clays with low permeability, and are generally suitable for wetland purposes. Elevated lands near the STP are less suitable physically, and are also constrained by urban development pressures.

Constraints

One issue to consider is the risks associated with bird-strikes near the airport. The risk of damage to aircraft from collision with birds has been examined in formal studies over the years. Over a dozen bird-strikes have been recorded around Ballina airport since 1980 – a relatively high rate per 10,000 aircraft movements. Over 50% have involved the Masked Lapwings that used the grassed areas around the runways for breeding and feeding. The other strikes involved a range of species, including many that are attracted to the landfill nearby.

FWS wetlands may pose a risk if flocks of birds were to use the wetlands in significant numbers. If areas near the airport become available for wastewater wetlands, further detailed assessment would include advice from bird specialists along with an assessment of alternative effluent application strategies – for example subsurface irrigation. General principles discussed elsewhere in this document cover the specific issue of wetland design to discourage large numbers of birds from using wetlands that receive effluent.

A further risk to be considered is contributing to the pre-existing severe mosquito nuisance in the area by increasing the area of wetlands. The presence of acid sulfate soils in most of the areas of interest is virtually certain. All actions, plans and remediation procedures should follow the guidelines as set out in the Acid Sulfate Soils Manual. Land acquisition may also pose a problem and oysters are grown in North Creek, with leases close to the outlet of the McGough's Flat drainage area.

Opportunities

- Attaining a sustainable strategic approach to effluent management;
- Gaining support from the community;
- Reducing the mosquito nuisance by regenerating healthy wetlands and bringing acid drains under management. Ballina Shire Council has co-ordinated mosquito sampling over recent years by two Ballina-Lennox residents, and it is anticipated that mosquito monitoring as part of wetland installation would be integrated with this study;
- Creating an opportunity for landowners to either divest of unwanted land or enter an agreement with Council for sustainable use wetlands due to the current questionable economic base of agriculture in drained wetlands;
- Creating the possibility of mutually beneficial trade-offs in regard to land use in some circumstances. Oyster-growers may see the benefit in rehabilitating at least part of the catchment water flows that underpin their industry; and
- Addressing the issue of effluent presently entering the Richmond River and Estuary at several points.

Options

1. Site investigation to determine the suitability of identified areas upstream and downstream of the STP for a constructed treatment wetland of 30ha, plus a larger area for wetland restoration using high quality effluent from the treatment wetland. A general buffer zone of at least 40 metres is required from Nature Reserves and natural wetlands.

2. Consideration of purchase or lease of at least one property for a pilot project to provide detailed information on all issues of interest. It may be beneficial to assess a first property more distant from oyster leases than around McGough's Flat or the Airport for example.

BALLINA

Landscape

The STP and surrounds are situated on flat and low-lying deltaic soils between the western residential and industry precincts of Ballina to the south, and the Pacific Highway to the north. Remnant vegetation suggest that most of the area was melaleuca and casuarina wetland forest before European settlement. The surrounding area of several hundred hectares is presently under agriculture, mainly sugar cane, but with some tea-tree plantings adjacent to the STP. Potential acid sulfate soils probably underlie the surface soils, although high water tables are also likely, and only the surface soils are likely to be oxidised.

Situation

The Ballina STP features older trickling filter technology and Passveer Channel, and discharges to a poorly-flushed section of estuary. The future of the STP is currently under consideration, with the issue being whether to close the plant and pipe the effluent to Lennox, or retain the site with a new STP. The large tertiary pond has had problems with algal counts. A Southern Cross University study has found elevated nutrients in Fishery Creek, the receiving waters for the effluent. The area required for a treatment wetland is conservatively some 20 hectares using the 5-day detention model with an allowance for growth.

Constraints

Constraints include the likely presence of acid sulfate soils, the very low slope to the land, and the high demand of the area close to Ballina CBD for urban development.

Opportunities

- Restoration of the lower floodplain wetlands with beneficial impacts on the health of the river;
- Promoting the sustainable use of constrained, flood-prone land;
- Attracting likely support from the community; and
- Reducing effluent load to Lennox coastal area and thus ensuring that the effluent from a community is effectively managed near that community.

Options

1. Rationalisation of the tertiary pond with changed flow arrangements, with effluent then going to wetlands.

2. Investigation of the tertiary pond area for reconstruction as part of a larger constructed treatment wetland before reuse of effluent through restoration wetlands.

3. Pilot Project to apply effluent to tea-trees around the STP. Tea-tree (*Melaeuca alternifolia*) not to be harvested, but maintained as a natural wetland with accumulation of a beneficial litter and peat layer.

WARDELL

Landscape

The Wardell STP and surrounds is situated several kilometers north of the village, partly on Wardell sandplain soils commonly overlying indurated sand, and partly on upper floodplain wetland soils, possibly with acid sulfate soils at depth. A melaleuca wetland valley runs southwest from the STP area with drainage lines towards Bingal Creek and the Richmond River near Wardell.

Situation

The surrounds are used for horse-riding and a turf farm. Agricultural reuse of Wardell effluent (mean daily flow 229kL) is a valid option. About 2ha of treatment wetlands would be recommended for the foreseeable future.

Constraints

Present land use of the area may be a constraint and sandy soils may present a problem, but site design would address this.

Opportunities

Gaining community support for an integrated system of agricultural reuse followed by wetlands, or by wetlands alone.

Options

1. Integrate wetlands with agricultural reuse
2. Constructed treatment wetland with larger restoration wetland

ALSTONVILLE

High landscape on Alstonville Plateau; STP capacity reaching limit, with discharge to sensitive inland stream; basalt-derived soils means permeability/groundwater issues, with a need for liner; the effluent and the landscape are suitable for agricultural reuse: wetlands can be installed for wet season precautionary discharges or downstream of reuse areas.

2.4. PLANTS SUITABLE FOR FREE WATER SURFACE (FWS) WETLANDS

SPECIES LIST

The following list of native wetland plants common in the Ballina area have been assessed for use in constructed wetlands, following confirmation of their suitability by consulting the texts Sainty and Jacobs (1994) and Romanovski (1998):

Phragmites australis

Characteristics: 2-4m tall, large biomass, strong root system with rhizomes, good sediment aeration capability, good litter production, occasionally temperamental growth, seeds in autumn, dormant in winter, birds only attack young seedlings, difficult to germinate seeds, plant nursery seedlings or rhizomes, good anti-weed plant.

Typha orientalis

Characteristics: 2-3m tall, strong growth habit, thick stem but not as many stems as some other plants, heavy litter layer, occasional seeding success in cells, excellent bio-filter, good sediment aeration capacity, periodic wetting and drying needed for health, good anti-weed plant.

Typha domingensis:

Characteristics: smaller version of *T. orientalis*, with similar features.

Bolboschoenus fluviatilis:

Characteristics: excellent FWS plant, proven at Casino, strong growth, 1.5-2m tall, heavy litter production, best species so far for propagation, spreads quickly, plant from bulbs, good for wastewater and stormwater.

Cyperus exaltatus:

Characteristics: attractive, strong seeder, lot of growth goes into seed stalks with low litter production, not worth a lot of planting effort.

Eleocharis sphacelata

Characteristics: 1m tall, good habitat plant, spreads from rhizomes, needle-sedge, not as much litter as reeds, not as large, can use reeds for support and grow taller.

Eleocharis acuta

Characteristics: smaller version of *E. sphacelata,* good in swale wetlands and wet meadows.

Schoenoplectus validus

Characteristics: good medium plant, very strong growth at West Byron and coastal areas, spreads from rhizomes and seeds, highly vulnerable to waterfowl when young but protected plants do well, good mosaic plant to intersperse with others for diversity.

Schoenoplectus mucronatus

Characteristics: similar to *S. validus*, triangular stem, good to make up diversity and in stormwater wetlands.

Baumea articulata

Characteristics: to 2m tall, spiky sedge, good for diversity and bird habitat, rhizomatous, plant from nursery seedlings or rhizomes.

Paspalum distichum

Characteristics: water couch, common, easy to grow, can be a weed, not good aeration capacity, can produce "blackwater events" if water is stagnant.

Philydrum lanuginosum

Characteristics: common name "Frog's Mouth", attractive yellow-flowering succulent-type plant, efficient seeder, small biomass, not a useful wastewater wetland plant, but attractive in stormwater wetlands.

General

For FWS wastewater wetlands the most suitable types of plants are those that aerate the sediments, are relatively easy to propagate and plant, spread quickly, keep out aquatic and terrestrial weeds, are strong competitors, cope with constant inundation, and produce abundant litter. The most favourable species for these purposes are Typha, Phragmites and Bolboschoenus species, whilst a few others can be added for diversity. A larger range of species is suitable for stormwater wetlands, but each site suits a particular set of species that can be chosen as needed. Seedlings can be produced by local nurseries - allow about $3,000 per hectare for planting in intensive situations, but this can vary with the site. In the case of large wetlands and where weeds are a low risk, wetland conditions can be managed to encourage the relatively inexpensive natural development of wetland plants.

Weeds

The major problem weeds for a planting at Ballina will be grasses such as Setaria and Para Grass – aggressive introduced grasses with an efficient seeding or vegetative spreading capability and a liking for damp soil, and well established in the Ballina-Alstonville area, and Commelina, which will spread from small vegetative pieces coming in from upstream. These plants do not generally grow in the wetlands themselves but are a danger on the berms or on high points in wetlands. Good design can reduce the risk to negligible. Other lesser threats are from Persicaria (Smartweeds), and Groundsel. Wetlands may also be vulnerable to the four noxious weeds of the region: Alligator Weed, Water Lettuce, Salvinia and Water Hyacinth, although none have been found in the other wastewater wetlands of the area.

Weeds are managed by a combination of wetland design, water depth settings, and occasional targeted herbicide application if necessary. Most wetland plants have a vegetative spread mechanism through rhizomes that is more effective and manageable than seeding, and if encouraged through flow and depth management, will keep weeds to a minimum.

BIRDS

Purple swamphens are the main potential threat to planted seedlings – they are fairly large birds with a life-cycle that includes a habitat preference for water near plants (plants provide nesting material, food and protection from predators). Swamphens are notorious for destroying new plantings of seedlings. A range of strategies is advisable, such as: (i) not planting a lot of seedlings at once where water level control cannot be guaranteed; (ii) planting a lot of seedlings at once if soils can be kept at the required moisture levels; (iii) use larger plants, and (iv) rhizomatous plants with cage protection are a good first defence against bird attack.

Individual cages of simple wire netting are effective – the number required per hectare for reasonable cost-effectiveness is dependent on the total area - about $3 per cage in material, plus labour. A reasonably dense planting of one caged clump per 20 m^2 would require some 500 cages per ha. Planting density is again a matter of site characteristics. The cages are usually required for about eight weeks if plant growth is vigorous, then they can be reused. A detailed planting plan is usually written for particular wetlands, and will include using a mix of nursery plants, transplants from the site and elsewhere, and natural plant generation over time, particularly in large wetlands.

PLANTS FOR SUBSURFACE WETLANDS

Two plants are so far suitable for this wetland type on the north coast: *Phragmites australis* and *Melaleuca quinquenervia* trees. Both have strong underground root or rhizome systems. Melaleucas have a denser root mass as compared with Phragmites rhizomes, have a greater evapotranspiration potential, and have an advantage by being larger - with potentially greater performance. Phragmites has been used for a longer period, particularly in Europe. Melaleucas may also have greater pathogen-killing performance (Bolton and Greenway 1999) and nitrification capacity.

2.5. WASTEWATER WETLANDS - FUNCTIONS AND TYPES

WETLAND DEFINITIONS:

1. "Land on which a shallow water body is formed; land that is flooded in cycles, intermittently or permanently, by water that is fresh, brackish or saline; land on which the flooding determines the type and productivity of the soils, and the type of plant and animal communities that live there" - NSW EPA 1995.
2. "An area of marsh, fen, peatland or water, either natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" - Ramsar Convention.
3. A constructed wetland is "a designed and man-made complex of saturated substrates, emergent and submergent vegetation, animal life, and water that simulates natural wetlands for human use and benefits" - Hammer 1989
4. "Wetlands are areas that are permanently or periodically inundated or saturated by surface water or groundwater, and support the growth of aquatic vegetation" - Greenway 1996.

EFFLUENT TREATMENT AND MANAGEMENT:

A good description of a holistic approach to effluent management is found in the NSW EPA's "Effluent Reuse by Irrigation", which although oriented towards agricultural reuse has value for the consideration of effluent treatment and reuse by wetlands: "The traditional approach to disposing of wastewaters has been to apply them on land, using the land as a cheap means of treating (or 'renovating') the wastewaters. The EPA Guidelines for the utilisation of treated effluent by irrigation (EPA 1979; EPA 1986) represent a conceptual shift towards accepting treated wastewater as a resource available for use, rather than a waste that needs to be disposed of. They aim to help designers and operators optimise the value of effluent in an agronomic system that is ecologically sustainable.

However, do not assume that irrigation of treated effluents is always the best solution for the environment. Every effluent irrigation proposal should be compared with alternative discharge and use options on the basis of environmental, social and economic costs and benefits.

The EPA's wastewater management policy is to encourage the use of effluent where it is safe and practicable to do so, and where it provides the best environmental outcome. In cases where wastewater cannot be used this way, the EPA recommends that alternative methods be used to return effluents to the water cycle in an environmentally and socially responsible way."

WASTEWATER WETLAND FUNCTIONING:

An excellent general statement of wetland processes is found in Reed et al. (1995): "Treatment processes occurring in wetlands are a complex and interrelated sequence of biological, chemical and physical responses. Low flow velocities cause particulate matter to settle out or be trapped in the submerged matrix of plants. Algae are also trapped and cannot regenerate because of the shading effect in the densely vegetated wetland. These deposited materials then undergo anaerobic decomposition in the benthic (bottom) layers, and release dissolved and gaseous substances to the water."

"All of these dissolved substances are available for sorption by the soils, and interaction with the microbial and plant populations throughout the wetland. Oxygen is transported from the atmosphere through the plants to microsites on the living plant surfaces and the root and rhizome surfaces so that aerobic reactions are also possible within the system. Biological conditions in wetlands are similar, in some respects, to those in facultative ponds. The water near the bottom is in an anoxic or anaerobic state, and a shallow zone near the water surface tends to be aerobic" (Reed et al., 1995).

Wetland functions are thus based on a combination of physical, chemical and biological processes including filtration (interception), sedimentation (settling), adsorption (electrochemical attraction), precipitation (change in electrochemical state from liquid or gas to a solid), decomposition (break-down into component parts), absorption and assimilation (uptake into organisms), bacterial metabolism (use of materials by microbes for life processes), plant uptake, and evapotranspiration.

MOSQUITOES

The issue of determining mosquito risk in wastewater wetlands is complicated by common public perceptions. There is no doubt that wetlands can provide a favourable environment for both adult mosquitoes and their larvae because of the presence of slow-moving water and nutrients. The risks and some of the risk management options are listed in the Constructed Wetlands Manual (Russell et al. 1999). These include elimination of stagnant water zones, wetland edge design, and drying of the wetlands to strand the larvae. These strategies are normally addressed in detail at the wetland design stage.

Further understanding of mosquito dynamics has accrued from observations in North Coast wastewater and natural wetlands over the recent period. Mosquito risk is a function of the numbers of larvae that survive to the adult stage, and this depends to a large degree on whether a healthy natural ecosystem exists in the wetland. A diverse wetland environment with dense plant cover features a large population of mosquito predators.

Adult mosquitoes can lay many eggs, but heavy predation begins immediately, and few larvae survive. Larvae can usually only survive where open water pools with low flow rates exist, where predators such as dragon-flies and other insects, tadpoles and frogs do not have plant cover. These conditions have for example been commonly observed in the acidified drains common in acid sulfate areas, and these drains may be significant sources of mosquito "plagues". Larvae require water for five days to develop, and if a larval "bloom" occurs in open water, a well-designed wetland can be isolated and dried, destroying the larvae.

FLOW MANAGEMENT

FWS treatment wetlands are normally separated from the open environment by berms - low walls of earth or sand. The first generation of Australian wastewater wetlands often had many berms with the aim of providing longer flow-paths, options for flow control, and isolation of individual cells for maintenance purposes. Rehabilitation work has shown that maintenance access for machinery is not required in a well-designed wetland with dense vegetation. Any unforeseen major work can be performed by drying the cell out to allow machinery access. Berms should be kept to a minimum in order to minimise capital outlay and mowing costs.

A revised approach to berms is being applied to the extensive upgrade of the West Byron Wetland (Pont 2002), in which one large outside berm about one meter high is constructed around the wetland, with smaller internal cell dividers to enable separate flow management (Figure 11). Cell division is only useful in dry weather when depths are relatively low.

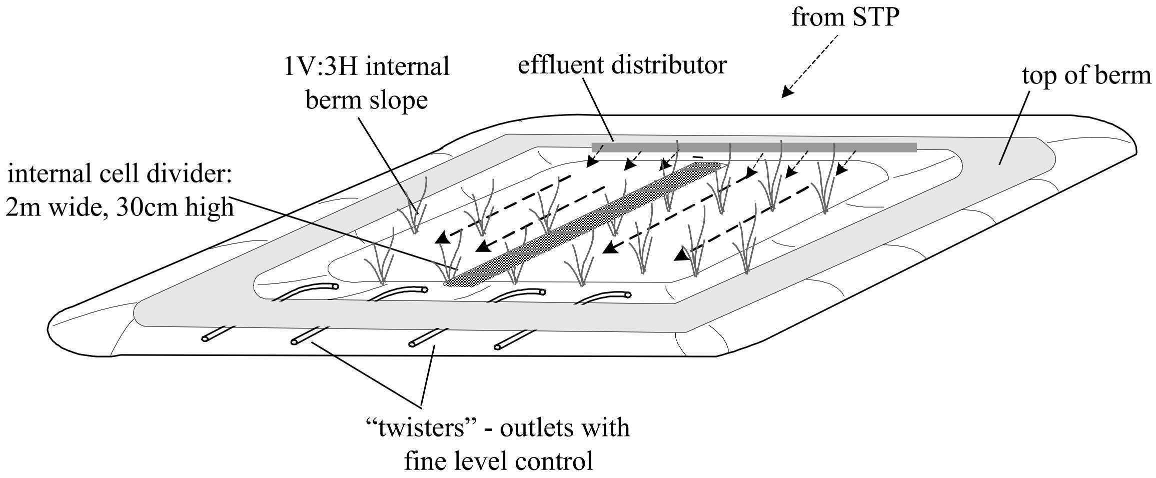

Figure 11. Simplified general wetland cell configuration

In flood rainfall the entire wetland can fill with water and effluent in a controlled operation. The outside berms function as low dam walls, and the dense vegetation provides stability against erosion. Many observations of flood situations in wastewater wetlands have shown that the main response to high rainfall is simply a rise in water depth.

There is a natural flow detention caused by the low slope and many plants, and this is further controlled by restriction of outflow rates to a design flow using pipes or weirs of appropriate size. Flood detention should be kept to about one to two weeks both to ensure optimum retention of pollutants and to avoid drowning of plants. As the wetland depth subsides the stress to plants reduces and the second half of the flood volume can be allowed to flow out more slowly if appropriate.

Figure 12 graphs this concept as applied to the West Byron Wetland. The hydrograph shows the likely pattern of outflows in a Probable Maximum Flow following an extreme 500mm of rain in 24 hours, and indicates that the design detention period of about one week can best be met by allowing an outflow of a little more than 12ML per day in a wetland with average dry weather flow of 4.2ML per day. The water in the wetland is predominately rain-water that dilutes the effluent. Initial flows can also be held for one to two days before beginning floodwater discharge. Detailed modelling of this process indicates the dilution effect and detention time produces an outflow that contains negligible nutrients.

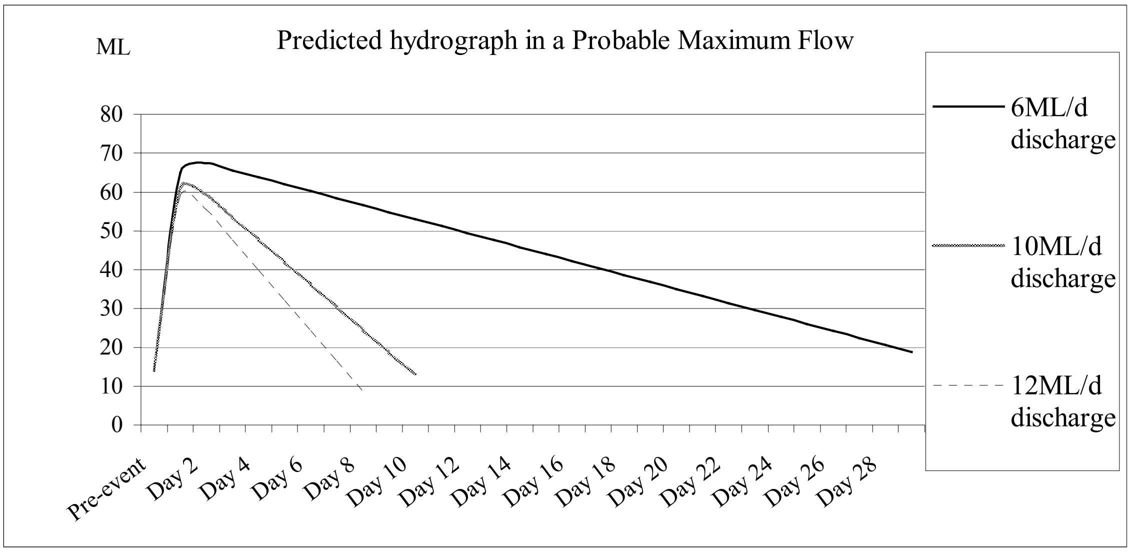

Figure 12. Predicted flood hydrograph at West Byron Wetland under three discharge rates

TYPES OF WETLANDS

Four broad wastewater wetland types are in use: Free Water Surface, Subsurface, Composite, and Reuse/Restoration Wetlands. These are described in turn, with benefits, advantages and disadvantages.

1. Free Water Surface (FWS)

FWS wetlands are essentially shallow bodies of slow-moving water in which water-tolerant plants grow. This environment provides a favourable physical setting for complex chemical reactions between the effluent and sediment and plant surfaces similar to those operating in natural marshes, but occurring at higher rates. The sediment provides "substrate" - a base on which microbes can anchor their cell membranes and gain stability, then access and metabolise materials passing in the water column and use them to multiply.

Generally the finer the sediment the greater the area of substrate available and the more efficient the process. The plant leaves and stems and litter surfaces also provide substrate. Adsorption to these surfaces is very effective in densely planted wetlands, where small solids floating by can be observed to "stick" to plants or litter, and where microbes then have the chance of processing these solids and dissolved materials - of breaking down the complex molecules and drawing on the available energy for their own purposes. Figure 13 illustrates broad processes and design features.

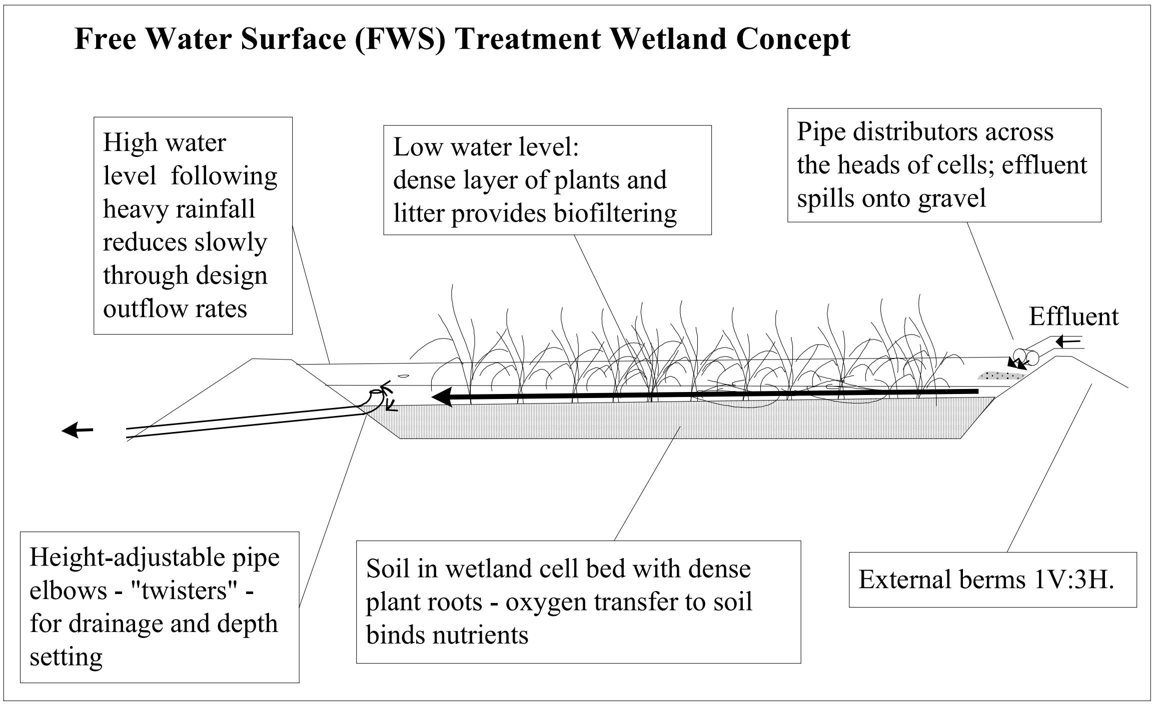

Figure 13. The Free Water Surface treatment wetland concept

The advantages of FWS wetlands include:

- relatively low cost, particularly when effluent flows are more than about 300 kiloliters (kL) per day;
- larger areas have better effluent buffering capacity;
- flood detention capacity;
- wildlife values are usually significant; and
- aeration capacity is substantial where effluent is effectively pre-treated.

The main disadvantages include the need for periodic resting to ensure plant health, and the fact that effluent is above ground - increasing the risk of (i) infection and consequent need for restriction of public access, and (ii) possible mosquito breeding because of above-ground water. An important issue is the need for a liner. Where soils are porous, as at Alstonville, liners will usually be needed. Where an impermeable "floor" of clay or indurated sand is present, negligible accession of effluent to groundwater can be predicted. Most soils are suitable unless a clear pathway exists to deep groundwater. Detailed soil assessment is required. The shape of FWS wetlands is generally not critical to performance providing effluent is introduced in appropriate quantities at sustainable rates. Effluent management through the wetland is tailored to the site.

2. Subsurface Wetlands

Subsurface wetlands (sometimes called "reedbeds") are those in which the effluent is entirely below ground, running through a matrix of plant roots that provide the treatment substrate. They have some similar properties to FWS wetlands, but entail very much larger costs because of the need for a gravel substrate. Gravel on the North Coast can cost in the region of $50 or more per cubic metre, although bulk purchase of lower grades can reduce this to $20 per cubic metre. The substrate cost can therefore be in the order of $100,000 per hectare, and the systems are usually lined with waterproof liner material at about $100,000 per hectare.

Experimental work is being carried out on alternative substrates such as shredded tyres, artificial plastics and others. Processes in subsurface systems are more centred on microbial activity in the gravel/plant root matrix (Figure 14). Much of the treatment efficiency appears to be related to the effective interception of suspended solids, and subsurface wetland effluent is often extremely clear, in spite of still carrying a dissolved nutrient load. Denitrification of a well-nitrified effluent is also very efficient. This wetland type is used extensively in onsite treatment systems.

Three main advantages are seen in this type:

- (i) effluent is below ground;
- (ii) higher treatment efficiency for comparable area (Reed 1999); and
- (iii) potential for reuse of effluent through uptake into water-tolerant plants, but the cost efficiency would depend heavily on use of an inexpensive substrate

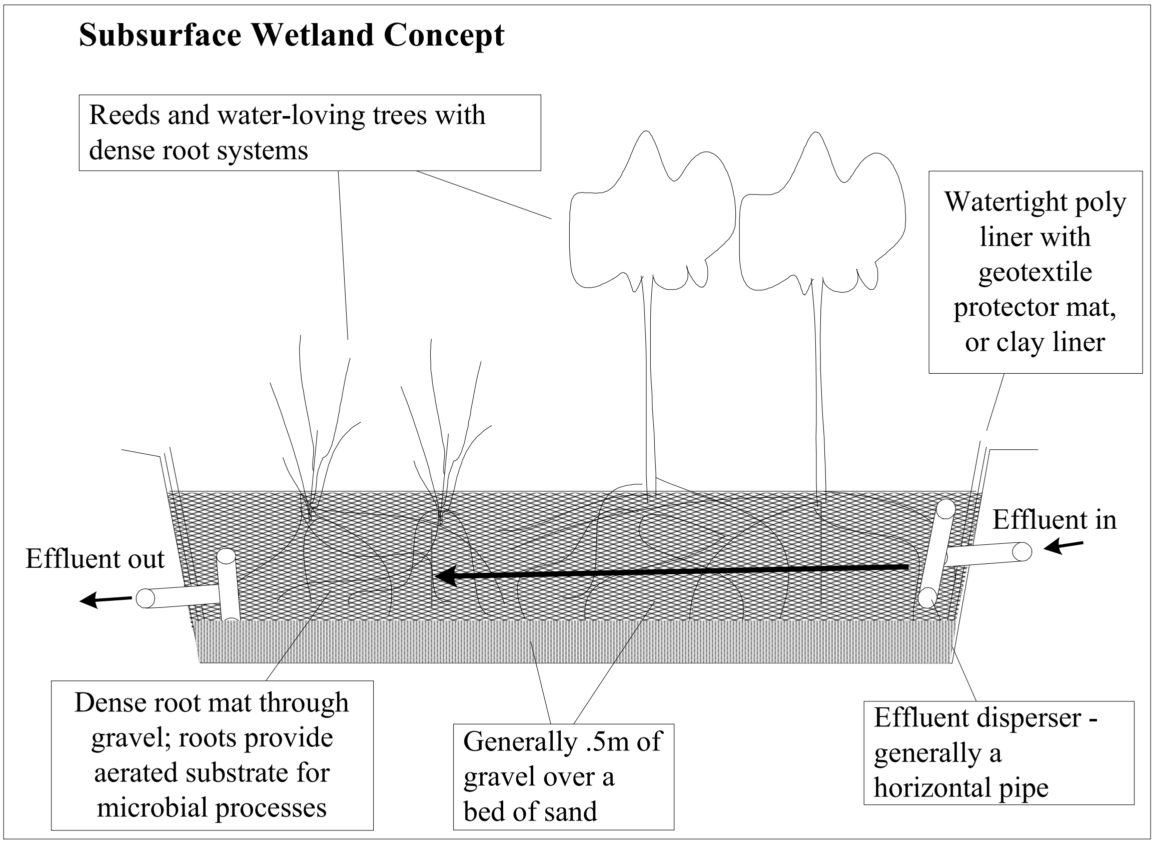

Figure 14. Subsurface treatment wetland concept

3. Composite systems

Composite treatment wetlands involve a mix of Free Water Surface and Subsurface wetlands, usually in series - that is, one type sequentially following another to take advantage of the particular strengths of each system (Figure 15). The ratio and configuration would be determined for each combination of site and effluent characteristics. The main advantage of a composite system would probably lie in maximising the beneficial use of a limited available area. The disadvantage would be in the extra cost.

A good small-scale example of a composite wetland can be seen in the Brooklet Nursery Wetlands approved by Ballina Shire Council and constructed in October 2001. This system manages nutrient-contaminated runoff from a one-hectare nursery shade-house and stormwater runoff from a hillside above, through a series of 20 small swale wetlands, then two subsurface wetlands planted with melaleuca trees, followed by a FWS pond-wetland that has also been designed as frog habitat. The system was designed by Keith Bolton, Phillip Wallace and David Pont for Brooklet Northern Rivers Nursery Pty. Ltd.

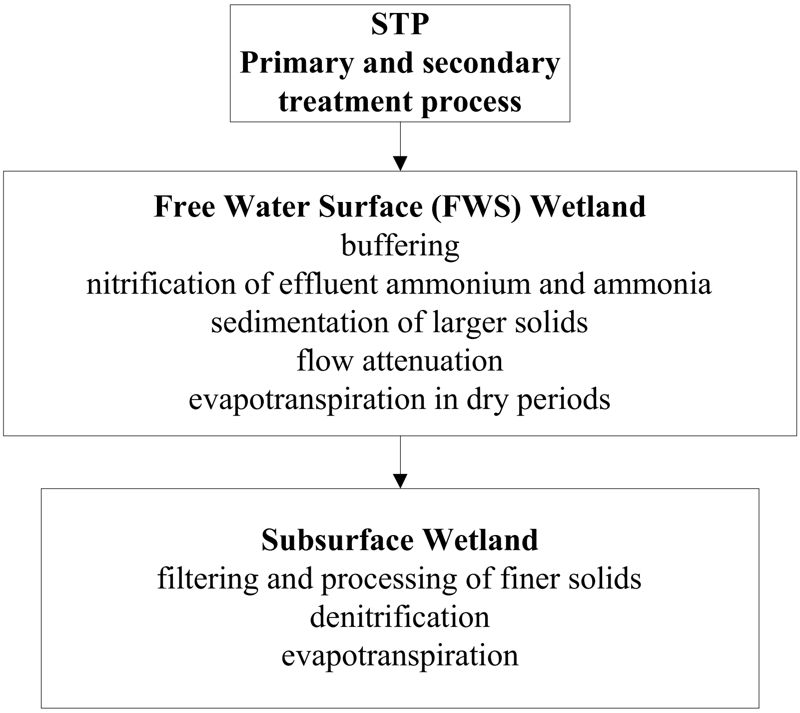

Figure 15. Simple outline of the composite wetland concept, showing main functions.

The subsurface system can be installed before the FWS wetland for reuse, or initial processing - for example of a nitrate-rich effluent.

4. Reuse/Restoration Wetlands

A recent development in the field of effluent management using wetlands involves employing tertiary-treated effluent to achieve multiple sustainability outcomes through:

(i) effective management of sewage effluent through large-scale wetland systems that can remove or transform virtually all pollutants into environmentally benign forms, evapotranspire large quantities of the water component, and provide other complementing outcomes at relatively low cost.

(ii) use of effluent to grow wetland trees, particularly melaleuca species, which before European settlement formed an extensive ecosystem type on eastern Australian floodplains. The wetland forests are closely coupled to the mangrove/mudflat ecosystem. They produce large quantities of biomass which in turn is broken down by fungi and bacteria on the forest floor. A proportion is retained as peat, and much of the remainder is exported to the detrital food chain of estuaries, predominately as Dissolved Organic Carbon with a high-energy value and long-term breakdown rates (McComb and Lake 1990, Saenger and Hutchings 1987, Wetzel 1999).

(iii) use of effluent to remediate active acid sulfate soils that underlay most drained coastal wetlands, and are often actively exporting damaging acid and iron related pollutants to estuaries, causing large fish kills and chronic ecosystem degradation.

(iv) restoration of coastal wetlands to function as large-scale filters of diffuse runoff.

(v) restoration of coastal wetlands in the interests of biodiversity - that is, a wide range of organisms such as birds, bats, insects, larger terrestrial animals such as wallabies, and fish.

(vi) restoration of coastal wetlands to provide flood protection to downstream communities where upstream communities will not suffer adverse impacts.

A number of issues associated with the large-scale application of this concept are yet to be resolved. The principal question arises over the storage of wet season effluent flows - should a storage dam be built for each system, how big should it be, and where should it be? The answer will determine the detailed operation of restoration wetlands, particularly whether the effluent will be applied to the wetlands through the wet periods, or only in an orthodox reuse pattern in dry weather. The West Byron model at present involves only a dry season evapotranspiration function, based on evapotranspiration rates more than double those achievable in agricultural reuse systems. The concept, originated locally by D. Pont, is currently the subject of an intensive research project at West Byron as a shared undertaking between Byron Shire Council, Southern Cross University, NSW Agriculture and Environment Australia. The outcomes of this research will be a valuable tool in the future management of wetlands in other areas such as Ballina.

This increases the cost-efficiency of the system, but the economic benefits of ecosystem recovery and unpolluted recreational waters are still poorly understood, especially in relation to well-managed fisheries. The community may wish to set values on these aspects.

At the November 2001 National Wetlands Conference on Stradbroke Island, eminent American ecologist Professor Bill Mitsch reported on developments in natural resource valuation in the U.S. Professor Mitsch discussed the Constanza *et al*. Paper in the journal Nature a few years ago that placed dollar values on ecosystem services and natural capital of the earth. The team of economists asked the question "what would it cost us to provide the services nature does for free, such as air and water, flood management and fish"? Estuaries were rated highest at US$23,832 per hectare per year; second were wetlands, especially floodplain wetlands, at US$14,785/ha/year - equating to about AUS$28,000 per year.

Bill reported the case of a power company operating in Delaware Bay. The company was funding the restoration of 5,800 hectares of salt marsh as compensation for the yearly toll of fish killed by being sucked into the cooling water turbines. It is common in these kinds of tradeoffs for the US Government to apply a safety factor of four in assessing an appropriate reparation for environmental damage. Bill described the $8bn Everglades Project - the rehabilitation and restoration of 16,000ha of degraded Florida wetlands with the dual aims of ecosystem repair and sustainably managing the residual nutrient runoff from agriculture - the residual being that which cannot reasonably be reduced by source controls.

The Mississippi Basin is another large restoration project that is getting under way as peoples and governments realise the cost of past mistakes in following narrow parameters rather than a holistic approach, particularly when whole ecosystems and the survival of biodiversity is at stake. In the whole Basin the plan is to restore 10 million hectares of wetlands in 80 projects.

2.6. CONSENT AND APPROVAL ISSUES

PLANNING FRAMEWORK

The legislative and planning framework pertaining to constructed and restoration wetlands is comprehensively addressed in the Constructed Wetlands Manual (White 1998), which is used as a primary source of information for this section, along with recent communications with relevant authorities during preparation of this Report, and wetland rehabilitation work discussed elsewhere in the document.

Planning and building of constructed wetlands is predominantly covered by State legislation. Local Councils have particularly strong roles through the development consent process under the Environmental Planning and Assessment Act, 1979 (EP&A Act). The Commonwealth Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) covers larger issues of protection of the environment and the conservation of biodiversity, and contains an assessment and approvals system for:

(i) actions that have a significant impact on matters of national environmental significance;

(ii) actions that have a significant impact on the environment of Commonwealth land; and

(iii) actions carried out by the Commonwealth Government.

If Commonwealth funding is involved in projects such as acid sulfate soils remediation programs, the Federal Government may carry out assessment under this legislation. Most State Government Agencies have had recent input to the West Byron Project, and are familiar with most relevant issues.

STATE LEGISLATION LIKELY TO BE INVOLVED:

- EP&A Act 1979: Agency - Department of Urban Affairs and Planning; issues of extent and type of environmental assessment required; generally, constructed wetlands for sewage treatment can trigger several categories of "Designated Development" status under Part 4, Schedule 3, of the Act. This is typically determined through environmental assessment of any proposal by Council.

- Fisheries Management Act 1994: Agency - NSW Fisheries; main issues will involve maintenance of fish access in waterways. Support for projects that restore significant fish habitat should be expected.

- Heritage Act 1977: Agency: Planning NSW; heritage can refer to indigenous or European Australian heritage sites or items; standard checks should be done at site investigation stage.

- National Parks and Wildlife Act 1974; Threatened Species Conservation Act, 1995: Agency - NPWS; threatened and endangered species issues would be foremost, but the first Act affects all native flora and fauna. Species Impact Statements probably required for any substantial wetland project.

- Water Act: Agency - Department of Land and Water Conservation; the Regulations under the new Act are still under consideration at time of writing. This Act will replace the old Water Act 1912 and the Rivers and Foreshore Improvement Act 1948, and other legislation, and will cover works in or near waters, including wetlands.

- SEPP 14 - Coastal Wetlands: Agency - Planning NSW; effluent should be kept clear of SEPP 14 wetlands; this can be achieved by berm construction, or installing flow controls into drains that usually exist alongside these wetlands. Similarly any adverse impacts on groundwater conditions in these wetlands must be avoided.

- SEPP 26 - Littoral Rainforest: Agency - NPWS; unlikely to be impacted, but specific site assessment should be carried out.

- SEPP 44 - Koala Protection: Agency - NPWS; possibility of impacts, but wetland restoration would normally substantially benefit koalas, particularly with melaleuca forests.

- Native Vegetation Conservation Act 1997: Agency - DLWC; only involved if existing vegetation is impacted.

- Protection of the Environment Operations Act 1997: Agency - EPA; the Authority licenses STPs and wastewater wetlands, and has issued a specific manual related to the use of wetlands for treating wastewater. The EPA would examine and license any treatment wetland as part of standard assessment.

The following main points for guidance are summarised from the EPA manual:

(i) the use of wetlands must be sustainable over the long term. The integrity of natural wetlands should be protected from wastewater impacts. The design of wastewater treatment wetlands should be scientifically valid, derived from scientific studies where possible. One strategy encouraged by the EPA is to restore natural wetland systems by including more natural wetting and drying cycles in their management;

(ii) constructed wetlands require pollution control approval from the EPA. The licensed discharge point will generally be before the effluent enters the wetland. However the discharge point can be downstream of the wetland in some cases. Pollutants that tend to accumulate, such as phosphorus, should meet the licence limit before the effluent enters the wetland. The EPA has adopted a conservative approach to the use of wetlands, and any plan to treat wastewater will have to show that the wetland will perform reliably. Generally however, constructed wetlands will improve water quality. Limited data are available on the long-term performance of constructed wetlands under Australian conditions. There may be problems with wildlife using wetlands;

(iii) there remains a need for a high level of technical confidence in design and management and a need for sound management over the long-term. Wetlands should be designed to discourage water birds, particularly in heavily polluted areas and to reduce resting habitats and eliminate open water. The wetland must not be relied upon to remove phosphorus and site-specific variables must be covered in the design;

(iv) the following details must be supplied to the EPA: flows into affected creeks and natural wetlands downstream of the constructed wetland; design loading to the wetland and the justification for this; water and pollutant management within the wetland (water depth and how it is controlled, residence times, anticipated pollutant retention). Short-circuiting must be prevented;

(v) the existing and anticipated concentrations of organics, metals and nutrients in the substrate of the wetland; and appraisal of the risk of groundwater contamination. The applicant should know of any possible interaction between the proposed wetland and the groundwater in order to prevent groundwater contamination; and

(vi) management should prepare for: abnormal flows and loads; maintenance of nutrient removal; the detection and management of possible increasing phosphorus discharges from wetlands by harvesting vegetation; and estimates of capital and operating costs. Monitoring will include sampling of chemical, physical and biological parts of the wetland. Licences will be renewed only where components of the process continue to be effective. (EPA 1995)

2.7. BILL OF QUANTITIES

BROAD CONSTRUCTION COSTS

Some local costs: earthmoving in Ballina area, estimates supplied by experienced local operator: about \$3 per m^3 for easy shifting of sand or soil using scrapers and dozers/excavators; rises to \$6/m^3 for more difficult wet or soft conditions. Berm earth requirements amount to about 6m^3 per lineal meter of berm, or about 6,000m^3/km. For a hypothetical 25ha constructed wetland, and using a broad range of local area costs that will change with landscape type and wetland size, a cost of \$12,000 per hectare should be allowed. This covers earthmoving, effluent management infrastructure, environmental assessment and planting. Depending on the site, soil can be sourced from the site, or in very low flat landscapes would have to be imported.

Figure 16 shows the fall in costs as wetland size increases. The decreasing perimeter to area ratio means earthmoving costs decrease substantially. Larger wetlands tend to be more cost effective, depending on land cost.

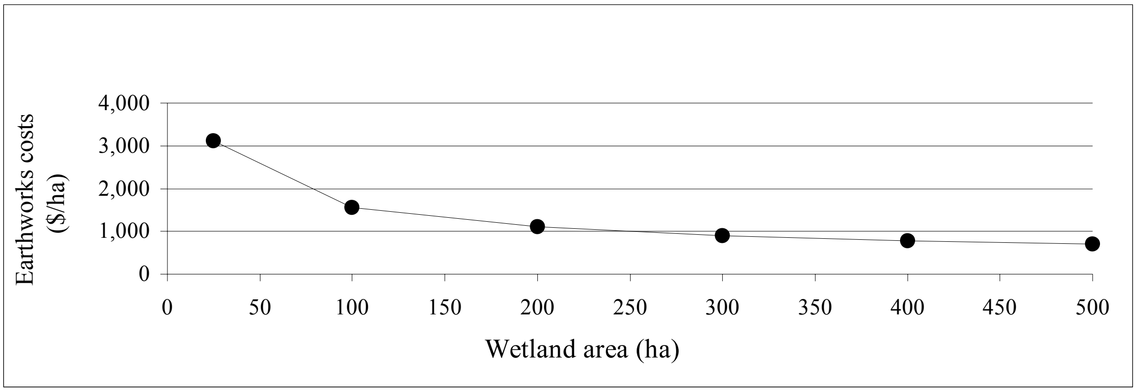

Figure 16. The relationship between earthworks costing and wetland size

PVC pipe outlets ("twisters") cost about \$130 per 6m length, with one needed about every 15 meters along outlet berms - in the hypothetical 25ha wetland these will cost about \$5,000. Allow similar for horizontal inlet pipes.

WETLAND MAINTENANCE COSTS

Wetland maintenance costs (including all life cycle costs) for constructed wetlands are not high. The main task is regular observation and effluent flow management. Allow one day per week for an operator for a large wetland - say \$10,000 per year. One targeted operation per year for weed removal - allow \$5,000. Mowing of external berm - allow one day per month over a year at \$60 per hour - allow \$10,000 per year. Therefore a total annual maintenance cost of \$25,000 (for a 25 ha wetland). Allowances should also be made for infrastructure maintenance e.g. pumps, pipes, etc.

NUTRIENT BUDGET

Monitoring of outlets to follow the recommendations of the EPA. Composite sampling has been agreeable to them, or targeted sampling of one or two outlets can be done. Alternatively, a dedicated outlet channel downstream of multiple outlets can be monitored.

Table 8 shows the predicted Total Phosphorus inflow concentrations and wetland accumulation rates for a hypothetical 25ha constructed wetland receiving a TP concentration of 0.5mg/L. The predicted wetland TP uptake and sedimentation rate of 19kg/ha/year is well within the range suggested in past studies as sustainable, e.g. 50kg/ha/year by Bavor and Andel (1994).

Table 8. Predicted total phosphorus inflow concentrations and wetland accumulation rates

TP intercepted (mg/L)	Effluent volume (ML/day)	Days	Wetland area (m^2)
0.2	6.5	365	250,000

TP concentration in inflow (mg/L)	0.5
Projected outflow TP concentration (mg/L)	0.3
TP accumulation (kg/day)	1.3
TP load (kg/ha/year)	19.0
TP load per m^2 /yr (g)	1.9

WATER BUDGET

Broad predicted water fluxes for a hypothetical 25ha constructed wetland (Table 9), based on mean Alstonville rainfall and evapotranspiration rates and a notional effluent load sized for 5-day detention. This summary table is derived from the monthly water balance. Crop factor 1.0.

Table 9. Predicted water fluxes for a 25ha constructed wetland

Annual rainfall on a 25ha wetland (ML)	Annual evapotranspiration from a 25ha wetland (ML)	Annual effluent load to a 25ha wetland at 6.5ML/d (ML)	Effluent load per ha/year (ML)
465	390	2,373	95

Note: storage is required to contain effluent during the 4 wet months of the year. Monthly water balance model required during detailed design.

3.0. CONCLUSIONS AND RECOMMENDATIONS

This options report is based on accepted texts, the best available knowledge, and recent practical experience in the design and management of wetlands in the treatment of wastewater and stormwater, and in the general management of the water cycle for healthy rivers, estuaries and coastal seas.

CONCLUSIONS

The following conclusions were reached following the investigations:

- constructed wetlands are suitable for final treatment and for polishing effluent from all Ballina STPs, reducing nutrients and other effluent materials to low levels;

- assessment of present and broad future hydraulic and nutrient loads suggests a range of appropriate wetland areas for each STP, with a recommendation to use the general sizing principle of the "5-day detention model". This means that any particular effluent will take a theoretical five days to pass through a densely planted wetland 200mm deep;

- larger reuse/restoration wetlands are an option in the low-lying coastal landscape where orthodox agricultural reuse is generally not practical;

- detailed modelling and other assessment is required for all sites but these wetland systems can be viewed as a spectrum from small area-high percentage discharge to waterways on one hand, and large area-low percentage discharge on the other. Several hundred hectares would be required to obtain effectively total reuse in the Lennox and Ballina areas

- storage of effluent in the wet season can be assessed on the basis of either dedicated deep storage dams, or on large bermed wetlands, or on both. This is strongly site-dependent;

- good project planning and management is essential to address the constraints evident at all sites;

- the stormwater systems in all locations studied present problems for water quality management because of pipe networks that often discharge at low points near waterways. Options include re-designing drainage ways using the principles of "Water Sensitive Urban Design" such as grassed swales and infiltration systems, and constructing wetlands in suitable areas such as the more elevated areas around Ballina, the western drainage outlets of Lennox village, the valley floors along the North Creek Road subdivisions and in the village drainage ways of Alstonville and Wollongbar; and

- natural wetlands such as at Chickiba can be assessed for health and function, and managed for long term sustainability under a committed management approach.

RECOMMENDATIONS

Following the investigation, these points are recommended:

- implementation of a working group of Council staff, *Australian Wetlands* staff and Project Reference Group representatives - the "Ballina Wetlands Working Group". This group would be responsible for considering landowner responses to council's letters regarding purchasing suitable land near STPs;

- compilation of an integrated land-use strategy incorporating wetlands, beginning with Ballina and Lennox STPs. However decisions must first be made about the long term future of Ballina STP;

- detailed options should be developed for each STP site;

- development of a concept design for each STP site;

- Chickiba Melaleuca Wetland Rehabilitation Project to be progressed by the Chickiba Wetland Working Group - a funding application has been lodged with the Environmental Trust; and

- stormwater site assessment to progress on a priority basis, derived from community and regulatory agency concerns and funding availability.

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