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Rehabilitation of a salt affected wetland

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Rehabilitation of a
Salt Affected Wetland

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USE OF THESIS

ABSTRACT

There exists an urgent need to rehabilitate salt-affected and degraded wetlands in the south-west of Western Australia, particularly in water resource catchments. Various rehabilitation techniques have been developed for such areas, which address the problem of integrating water catchment management and surrounding land use. Despite this, there has been limited success in restoring salt affected wetlands in the south west region of Western Australia. This project was established to develop a method for the rehabilitation of wetlands in the south west of Western Australia, using the western Coollangatta Farmland wetland as a case study. This site was chosen because of its broad application in assessing rehabilitation potentials. It is on the western side of the new Collie Power Station, under construction in Collie. The site has been degraded by salinity, grazing and clearing. This study reviews rehabilitation practices in salt-affected wetlands and maps the physical features and vegetation of the catchment. It also examines the hydrology, distribution of salinity, and assesses nutrient sources of the site. Studies showed a deficit of 1189 m^3 between inflow and discharge of water in the wetland in July, and discharge exceeded input by 7623.4m^3 in August. Interpretations of the hydrology of the wetland was made. Mean concentrations of total phosphorus were 21.9ug/L and total nitrogen was 5821.9 ug/L. Sources of the high total nitrogen concentrations were investigated. This study found that the methods used were suitable to prepare a rehabilitation plan within the time frame of this study. Areas that required specific treatment for revegetation were identified and an appropriate plan for separate management areas was formulated. The methods used in this study could be applied to formulate rehabilitation plans for similarly affected wetlands. However each site has its own unique problems and restrictions that need to be addressed. The landowner is very enthusiastic about the rehabilitation of the wetland, and community involvement in the project. The understanding gained by the methods of this study, enabled the development of an appropriate rehabilitation plan, which could be utilised in other areas of the south west of Western Australia.

Declaration

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education; and that to the best of my knowledge and belief it does not contain any material previously published or written by any other person except where due reference is made in the text.

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Chapter 1 Introduction

Over 5.3 million ha of Australian pastoral land has been affected by salinity and this is still increasing (Aplin *et al* 1995). It has been found to degrade water supplies, agricultural land and remnant vegetation (George *et al*, 1995). This has been a cause for concern both at a community and an economic level. Salinity has also resulted in a loss of agricultural productivity and biodiversity in badly affected areas.

Several attempts are being made towards restoring salt affected wetlands in Australia (George *et al*, 1995). There exists an urgent need to rehabilitate salt-affected and degraded wetlands in the south-west of Western Australia, particularly in water resource catchments (Schofield *et al*, 1989). Various techniques have been developed that address the problem of integrating water catchment management and surrounding land use. Despite this, there has been limited success in restoring salt affected wetlands in the south west region of Western Australia. Lakes Toolibin and Towerrinning are recent examples (George *et al*, 1995; Froend *et al*, in press). Studies carried out on these wetlands have attempted to control salinity through engineering solutions, reforestation and agronomic manipulation. Intensive hydrological research has been central to the solutions in both cases.

An approach is required to rehabilitate wetlands effectively. Cooke *et al* (1993) and the EPA (USA) (1988) have discussed a successful approach used extensively in the United States. This can be seen to have useful but limited applicability to the Australian (especially south western) situation.

The approach used encompasses a series of components:
1. Description of specific problems.
2. Questions raised by investigation and diagnosis of problems.
3. Description of the area, with maps and details of hydrological data, including a summary of sampling methods and sites.
4. Presentation of results with analysis and discussion of their significance.
5. Recommendations, their costings and impacts on goals.
6. & 7. Summary and references.

Cooke *et al* (1993) have identified key factors that need investigation prior to developing a restoration plan:
1. Obtain or develop maps with as much detail as possible. Tributaries and groundwater seeps need to be located so they can be sampled. The catchment boundary needs to be determined and divided into land-use cover to proportionate results. The existing environment should be assessed and mapped.
2. Constructing an accurate water budget. The quality of the system is dependant on the water entering it.
3. Water quality should be determined to identify the problems of the system.

These diagnosis factors are collected and analysed in two steps; assessment of existing information, and collection of new data (EPA (USA), 1988).

A site was chosen to apply the components described previously to facilitate the rehabilitation of a south western wetland. The site had many advantages which made it suitable for a case study. There existed a variety of influences that have lead to the degradation of the wetland so many aspects of rehabilitation could be studied. The owners are enthusiastic about the rehabilitation of the site and have objectives that need to be considered in the rehabilitation plan. A reasonable amount of information is available on the site.

Study site

The wetland is approximately 8km east of Collie and is situated on the western side of the new Collie Power Station, (under contruction for the Western Australian state government electricity supply agency, Western Power): Figure 1.1 (location of western wetlands), 1.2 (copy of aerial photo of site). It is located in the Collie River Basin which supplies water to the Wellington Reservoir. The stream from the wetland discharges through a culvert underneath Scots Way and flows to Collie River East Branch (CREB). The wetland is seasonal, drying almost completely every summer.

The Collie Power Station site was previously the Coollangatta Farmstead and has been acquired by Western Power. The farm was cleared of most native vegetation in 1957 and used mainly for stock grazing. Stock have had unrestricted access to the wetland (Dames and Moore, 1994). The wetland reserve was recently fenced (March 1996) with feral proof fencing, to exclude stock and feral animals from the site.

As a result of the clearing of natural vegetation, saline groundwater has risen and discharged into the northern area of the wetland. Salt precipitates on the soil surface of the northern areas of the wetland in summer. Remnant trees and emergent vegetation still survive close to the wetland channel. A remnant paperbark forest which exists in the southern area of the wetland has always been protected from grazing, and is in good condition (Dames and Moore, 1994).

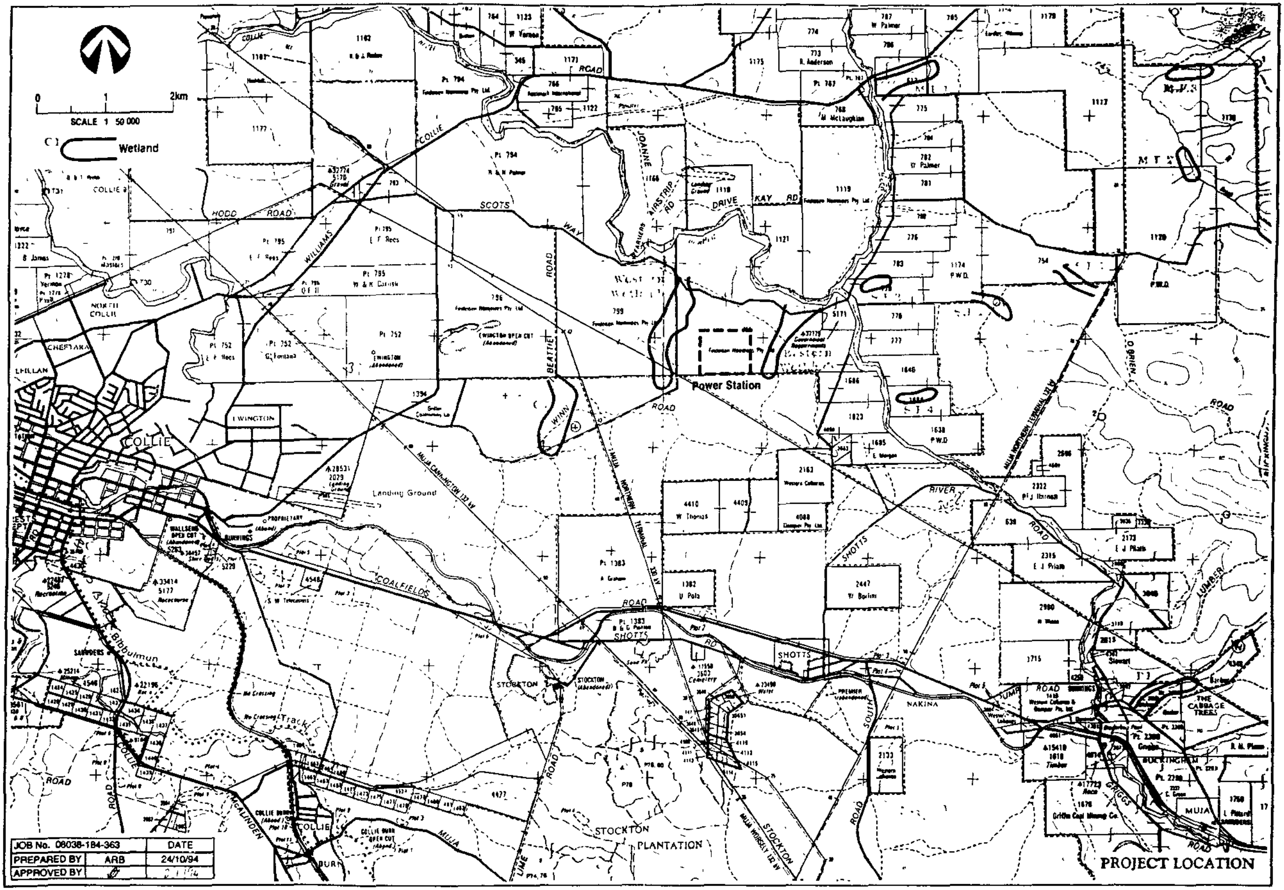

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FIGURE 1-1

The size of the fenced reserve is 31.5ha and is linear in shape. Linearity is a common feature of saline affected wetlands. Therefore, this site encompasses a broad variety of environmental problems. It also presents an example of the opportunity for industry to involve the community in environmental management. Desires to promote community involvement and other objectives could be assessed to understand the constraints of management objectives on rehabilitation.

Aim of study

The aim of this project is to develop a method for the rehabilitation of wetlands in the south west of Western Australia using the western Coollangatta Farmland wetland as a case study.

Specifically to:

1) review rehabilitation practices in salt-affected wetlands.

2) to map the physical features and vegetation of the catchment.

3) examine and understand the hydrology of the site.

4) determine the distribution of salinity sources.

5) assess nutrient sources.

6) develop a rehabilitation plan for the site.

Chapter 2 Review of the rehabilitation of salt affected areas.

Introduction

Reclamation of salt affected wetlands is important to protect conservation values, water resources and agricultural productivity. To develop effective rehabilitation of these areas it is necessary to review current practices and theories, and assess their applicability to the study site. It is also important, during this assessment, to understand site salination characteristics and associated problems.

Salinisation can happen through natural processes (primary salinity) or by human-induced changes (secondary salinity) to the environment (Williams and Bullock, 1989). About 87% of salinised land in Australia is from naturally occurring processes (SVAC, 1982). While only 13% of land in Australia is suffering secondary salinity, it's progress is far more rapid (SVAC, 1982).

Secondary salinisation of soil and water is toxic to vegetation and affects agricultural production. Watercourses and wetlands become saline, reducing the quality of water resources and aquatic habitats (Schofield *et al*, 1989; Froend and McComb, 1991). Rehabilitation of these areas will improve water quality and conservation values (Anon, 1994).

Secondary salinity is the result of replacing native deep-rooted perennial vegetation with annual shallow rooted agricultural crops and pasture (Schofield *et al*, 1988). Native vegetation transpires large amounts of water into the atmosphere and restricts groundwater recharge which effectively keeps deep aquifers well below the surface. With reduced transpiration and increased recharge, water tables begin to rise and mobilise accumulated soil salt deposits (Schofield *et al*, 1988).

Secondary salinity is not a problem unique to Australia. It has been recognised in South Africa, Thailand, USA and Canada (Hillman, 1981; Schofield *et al*, 1988). Dryland salinity (non-irrigated agricultural land) is more widespread and evident in the south west of Western Australia than anywhere else in the world (Schofield *et al* 1988). Water resources have been affected as a result, the Western Australian Water Resources Council (1986) reported that less than half of the 43% of divertible surface waters in the south-west of Western Australia remain fresh. Prior to European settlement, all of these surface waters were considered fresh (Schofield *et al*, 1989).

Methods

There are 3 well documented rehabilitation projects in salt affected areas in the south west of Western Australia. These projects are the Wellington Reservoir Catchment reforestation project, and Lakes Toolibin and Towerrinning recovery plans. The objective of this review is to assess methods that are most applicable to rehabilitation of the study site.

Results

Wellington Reservoir Catchment reforestation project

The Wellington Reservoir Catchment (WRC) is located in the Collie River Basin. The Wellington Reservoir has the largest water intake of any dam in the south west of Western Australia (approximately 100 x $10^6 m^3$) (Schofield *et al*, 1989).

There has been agricultural development in the low rainfall zone (less than 900mm/yr) on the eastern side of the catchment. Despite legislated controls on clearing (Country Water Supply Act, 1976) the increasing salinisation of streamwater from this zone has made the waters of the WRC unpotable. More than 75% of the catchment is supporting native vegetation (Schofield *et al*, 1989).

In an effort to reduce the salinity levels in the Wellington Reservoir, a major reforestation project has been underway since 1979. The reforestation project targeted areas in the medium rainfall zone (600mm/yr to 900mm/yr) where water is considered of marginal quality. In the lower rainfall zone, streamflow is saline and considered too difficult to reclaim (Schofield *et al*, 1989). Reforesting in high rainfall zones would reduce streamflow (and dilution) without addressing saline discharge from the lower rainfall areas, so is not recommended (Schofield *et al*, 1989).

The Wellington catchment reforestation programme was aimed at planting (800 trees per hectare) in discharge and lower slope areas covering 25-40% of cleared land. Saline seepages and scalds may cover up to half of the area being planted (Pettit and Froend, 1992; Pettit and Ritson, 1991).

Saline seepage areas are where saline groundwater flows to the surface and although this is usually seasonal, seepage can occur throughout the year at some sites. Often only salt and waterlogging tolerant species survive in these areas, (Williams and Bullock, 1989) which is found to be the case in the south-west of Western Australia where *Hordeum marinum* (sea barley grass) persists (Pettit and Froend, 1992; Schofield and Scott, 1991). Scalds are a progression from saline seeps. They may have salt tolerant vegetative growth at margins, however the core is usually a dry area with dead trees and no or little vegetation. Scalds usually suffer wind and water erosion and the subsoil is exposed with salt precipitating on the surface in summer (Conacher, 1982; Williams and Bullock, 1989).

Revegetation on seeps and scalds is often difficult and requires a correct strategy to ensure success (Steering Committee for Research on Land Use and Water Supply, 1989). However, the WRC reforestation programme saw replanting of these areas as the best way to lower salinity with minimal appropriation of agricultural land. Research has shown that discharge planting can reduce the water table and still allow agriculture upslope (Schofield *et al*, 1989). Planting on lower slopes above saline seeps addresses water movement and reduces discharge. Planting around seeps can progressively lower groundwater levels so that plantings can progress into the seepage or scald area (Schofield *et al*, 1989).

In the Wellington Reservoir catchment, areas of saline seeps would have originally supported *Eucalyptus wandoo* or *Eucalyptus rudis*. However, *E. wandoo* cannot handle high salinity and waterlogging and *E. rudis* suffers from insect attack (Pettit and Ritson, 1991; Schofield and Scott, 1991; Schofield *et al*, 1989). These species are recommended to plant upslope from saline seeps, with *Eucalyptus marginata* and *Eucalyptus calophylla* on well drained sites (Pettit and Ritson, 1991).

Schofield and Bar (1991) describe the results of reforestation experiments of valley floors and adjacent lower slopes in the Wellington Reservoir catchment. It was shown that the groundwater level was lowered by 1.5m and reduced salinity by 30% after 10 years. There was also no evapoconcentrative effect of salt beneath the trees. The objective of the WRC reforestation is to increase evapotranspiration to lower groundwater tables. Groundwater levels must be lowered below the critical depth of water capillary which is approximately 2m (Pettit and Froend, 1992). Due to the harshness of the sites, the Wellington Catchment reforestation has lead to considerable research into increasing success of planting in discharge areas (Pettit and Froend, 1992).

Correct species selection is essential for successful reclamation of saline areas. Many studies have been carried out in the WRC reforestation project to determine species which are able to survive in saline and waterlogged conditions (Schofield and Scott, 1991; Schofield *et al*, 1989; Pettit and Froend, 1992). The importance of provenance among species, in the ability to cope with the stress of these sites has been demonstrated by Pettit and Ritson (1991).

Ridge mounds, particularly double ridge mounds, have been found more successful in the revegetation of saline seeps and harsh sites, than standard mounds. Ridge mounding (mound height up to 0.75m) improves seedling survival due to increasing drainage, reducing waterlogging and preventing salt accumulation (Schofield *et al*, 1989; Pettit and Ritson, 1991; Pettit and Froend, 1992). Mounds are usually best formed in late summer to early autumn, after the rain has leached some salt from the mounds. By planting during winter rather than pre-winter, seedlings do not have to withstand waterlogging for their entire first season (Pettit and Froend, 1992).

Deep ripping (1.5m) aids drainage and improves growth compared to shallow ripping (0.6m) (Peck, 1979; Pettit and Froend, 1992). This improvement appears minimal for height growth of planted seedling (approximately 28cm after 3 years) although crown cover is increased by more than 37% over three years. Ripping is considered imperative to site preparation for all revegetation in discharge zones in the Wellington Reservoir Catchment (Pettit and Ritson, 1991).

Site preparation for saline seep areas involves ripping across contours rather than along them. This assists in prevention of waterlogging as water is able to drain into valley floor or stream channel. Ripping is usually to 30cm depth and mounds are 4m apart. Ripping in non-saline soils is along the contour to retain moisture and prevent erosion. Although this may cause some increased recharge initially, new seedlings require the water for success.

Mulching (hay, sand, sawdust or commercial mulch) reduces evaporation which permits increased leaching of salt from soil in the harshest sites, although this treatment isexpensive for large sites. Mulching on severe saline and waterlogged sites (for example; bare areas with less than 10% sea barley grass cover) improved survival by about 25%. (Pettit and Froend, 1992; Pettit and Ritson, 1991).

Herbicide application has found to increase success in seedling growth in salt affected areas (Schofield *et al*, 1989). In May, after pasture germination, an area of approximately 1.5m either side of rip line is sprayed with a combined rapid and residual herbicide (for example Vorox AA with amitrole [post-emergent], and atrazine [pre-emergent]). Fertilising is done within one month of planting (Schofield *et al*, 1989). Seedlings have been found to be generally more successful than direct seeding (Schofield *et al*, 1989).

Schofield *et al* (1989) suggest that reforestation in the WRC is only one process that can help to control salinity. There is a need for more integrated catchment management with cooperation between government agencies, land owners, and community. This would involve mapping land capabilities, and integrating agricultural manipulation and reforestation strategies. This encourages land owners to replant areas by including commercial possibilities (for example *E. globulus* [Tasmanian bluegum]) which may hasten catchment rehabilitation (Schofield et al, 1989).

Lake Toolibin

Lake Toolibin is an ephemeral wetland in the wheatbelt of Western Australia. It is in the Shire of Wickepin approximately 50km east of Narrogin and forms part of a wetland chain which drains into the Arthur River (Froend *et al*, 1987). Lake Toolibin is characterised by *Casurina obesa* and *Melaleuca strobophylla* growing on the lake bed (Bell and Froend, 1990).

The Lake Toolibin catchment retains only 3% of its original vegetation. Excess recharge to groundwater from agricultural land practices has increased the salinity of most land and wetlands in the catchment (Froend *et al*, 1987).

However, Lake Toolibin remains relatively fresh and its vegetation provides habitat for breeding birds. It is one of the most important wetlands in the south-west of Western Australia and is listed as a RAMSAR wetland (ANCA, 1996; Halse, 1987).

Increased effects of salinisation on the wetland and its reserves had been noticed in the catchment in the 1970s and lead to the formation in 1977 of the Northern Arthur River Wetlands Rehabilitation Committee (NARWRC). The NARWRC incorporated a wide range of experience from various fields and government agencies (Froend *et al*, in press). Extensive research has been carried out determining hydrological influences, measuring vegetation decline and predicting impacts on the wetland biota (Bell and Froend, 1990; Halse, 1987; Stokes and Sheridan, 1985). Groundwater tables were within 0.5m of the surface beneath dying vegetation on the western side of the lake. Surface salinity levels had increased due to capillary flow from shallow saline shallow groundwater as well as saline catchment runoff. Shallow groundwater has exacerbated the problem by preventing the leaching of salt into below ground storage from the lake bed (Froend *et al*, in press).

It was evident that addressing the management of the whole catchment was essential in controlling groundwater recharge and increased inundation to protect Lake Toolibin from further degradation (Froend *et al*, 1987). Local landholders formed the Wickepin Land Conservation District Committee (WLCDC) in 1985 and with support from various agencies, established the Toolibin Flats Rehabilitation Project (Hearn, 1988). To rehabilitate Lake Toolibin a variety of strategies including conservation farm management, planting strategies for soil types and salt affected land were initiated to increase productivity and decrease waterlogging. Areas of saline discharge and groundwater recharge were targeted. Plans to improve drainage were being considered (Hearn, 1988). Further catchment and subcatchment groups have been formed by community members to continue and extend the revegetation started by the WLCDC (Froend *et al*, in press).

The NARWRC completed its research in 1986 and made recommendations to pump saline groundwater from the western side of the lake to lower water table from plant root zone, and for the acquisition of a 200m buffer around the pumping area for revegetation (Froend *et al*, in press). Australian Nature Conservation Agency funding lead to the preparation of the Toolibin Lake Recovery Plan and Recovery Action (Anon, 1994). Many rehabilitation projects were already underway, however the recovery plan addressed objectives of the project in relation to physical and biological criteria and further examined hydrological controls in the catchment.

Strategies used for the recovery of Lake Toolibin incorporated both long and short term solutions. Engineering works for short term salinity control include surface drainage improvements and groundwater pumping. The Recovery Plan primary recommendation was the urgent pumping to lower groundwater beneath the lake's emergent vegetation. A staged pumping programme has commenced since the release of the recovery plan in 1994 (Froend *et al*, in press). In 1994/95, two separator drains were constructed that would divert low saline stream flows (less than 3 m^3/sec) around Lake Toolibin into Arthur River. The separator can be closed to allow faster, fresher streamflows to enter the lake (Froend *et al*, in press). This remedial work is essential to prevent further decline of vegetation and habitat in the lake in the near future. However these methods need to be agumented by long term measures (Froend *et al*, in press).

Revegetation and agronomic manipulation have been assessed and encouraged as long term solutions in the Toolibin catchment (Hearn,.1988; Anon, 1994). On agricultural properties, appropriate species have been recommended for planting in various soil types including salt seepage and scalds to increase transpiration and decrease recharge. Species utilised are valuable for fodder and are perennial.

The rehabilitation projects and recovery plan have required substantial community involvement necessary to ensure that protection of Lake Toolibin is achieved. Problems in communication between government departments and community groups had to be resolved (Froend *et al*, in press). Although many local landholders wanted earlier action, the project and the recovery plan has taken so many years to develop (George *et al*, 1995). This may be seen as a deficiency in the project, however the research carried out can supply beneficial information for the rehabilitation of other salt affected wetlands and their catchments.

Lake Towerrinning

Lake Towerrinning is a permanent lake in the south-west of Western Australia and is 32km south of Darkan. Historically, it has been a freshwater, recreational resource and is important for waterbirds during dry periods (Froend and McComb, 1991). Concern over the deteriorating vegetation and water quality in Lake Towerrinning has existed since 1973 (Froend and McComb, 1991).

Almost all of the fringing vegetation has been killed by increased inundation and salinity. The lake is turbid with Secchi disc transparency down to only

0.5m due to decomposing organic matter, loss of stabilising emergents (*Baumea articulata*) and wind mixing due to lack of sheltering fringing vegetation (Froend and McComb, 1991). Water quality assessments have shown the lake to be eutrophic and suffering with algal blooms as a result of nutrient rich runoff from surrounding agricultural areas.

The lake has an increasing salt load with inputs from saline groundwater and runoff (Froend and McComb, 1991). Research into the groundwater systems of the Lake Towerrinning catchment have shown geologic formations that contribute to the salinisation of the lake (George *et al*, 1994). The Towerrinning palaeochannel and fault lines in the area are the principal sites involved in groundwater recharge. Planning with farmers to alter agricultural practices in these areas is underway (George *et al*, 1994).

The Lake Towerrinning Catchment Group (LTCG) was formed by local community members concerned with restoration of Lake Towerrinning and the use of conservation farming practices (George *et al*, 1995). In 1991, the LTCG developed plans to redivert drainage into Lake Towerrinning that had been channelled into another catchment. The project was supported by the Environmental Protection Agency, and local government and businesses and the diversion dam and channel was constructed in 1992/93 (George *et al*, 1995). The salinity levels in the lake decreased by 50% within six months.

This project is an example of how informed local land holders can initiate rapid plans cost-effectively and that community and government agency support can be involved (George *et al*, 1995).

Discussion

Methods to combat stream salinity include planting trees and shrubs, changing agricultural practices and engineering solutions such as drainage. Planting is seen as the most effective means and site preparation can greatly increase the preformance of species in saline areas (Pettit and Froend, 1992; Schofield *et al*, 1989).

The reforestation approach for saline affected areas is not without critics. Conacher (1982) suggests that these sites are the harshest to revegetate and require considerably more work. He also theorises that soil salinity might increase beneath reforestation. This is due to evapotranspiration removing water while salt remains in the near surface soil zone. Peck (1979) also claims that saline valley floor revegetation may not be viable in the long term due to soil salt accumulation. Leaching of residual salts from soil may take many years (Peck, 1979). Reforestation of saline seeps may lead to the development of seeps at other sites (Conacher, 1982).

However, more recent studies have shown that salinity has not increased beneath reforestated areas ten years after (Schofield and Bar, 1991). Pettit and Ritson (1991) suggest that reforestation in the WRC is not yet old enough to determine if salts have become concentrated beneath plantings in discharge areas.

Conacher (1982) and Peck (1979) recommend that discharge zone planting should be supplemented with planting in recharge areas, although recharge zones can be difficult to locate and may cover a substantial area of the catchment (Sharma *et al*, 1982).

Agronomic manipulation to increase evapotranspiration in crops and pasture has been researched but is unlikely to be taken up without government incentives (Schofield *et al*, 1989).

Drains can reduce waterlogging and salinity but need to have safe disposal sites (Schofield *et al*, 1989). Small banks, ditches and cultivation along the contours can help to prevent runoff which may alleviate waterlogging and increasing water table levels (Peck, 1979).

Conacher (1982) suggests that revegetation requires too much farmland and is not economically viable for agricultural landholders. He recommends engineering solutions as a better method for salinity control. George *et al* (1995) also argues that revegetation and agricultural manipulation are long term solutions and can not protect imminently threatened land and vegetation. In these situations, engineering solutions are essential for short-term success. Interceptor banks can control throughflow, however drains are not recommended due to the expense and possibility of increasing salt loads in streams with residual salts flowing into the streams rather than collecting in the salt scald, particularly in water resource catchments (Conacher, 1982).

Integrated catchment management (ICM) aims to address land and water use in a catchment that is suitable for land capabilities, and long term community and environmental values. This is done through liaison between government and local agencies, landholders and interested community members (Schofield *et al*,1989). Remnant vegetation is an important component of ICM for salinity control and soil conservation (Schofield *et al*, 1989).

Conclusion

It can be seen that there are a variety of approaches that can be utilised in rehabilitating a salt affected wetland.

It is necessary to understand the causes of decline in wetlands to assist in planning for their rehabilitation. Areas will have different histories and influences on their hydrology and degradation.

Due to lag times in controlling salinity by revegetation and agronomic manipulations, engineering solutions are often essential to save remnant vegetation including wetlands. Groundwater monitoring is required to identify remnants at risk of deterioration by salinisation and hydrological modifications so that early intervention can assist in their protection.

It is difficult to establish absolute guidelines as each site must be examined and assessed on an individual basis.

Chapter 3 Wetland catchment, hydrology and salinity

Introduction

Assessment of the catchment of the wetland site was made to determine land use cover types and their impact on the wetland. Understanding the salinity inflows and outflows of the site is also important to be able to develop a recovery plan that will be successful. This information will enable the selection of plant species, densities and locations which is suitable for the saline condition and for control of the groundwater table (Pettit and Froend, 1992).

Salt-affected wetlands are harsh environments that require particular revegetation and management strategies suitable for their conditions (Schofield *et al*, 1989). This study proposes that measurement of possible sources of salt should be assessed to determine their location and extent so that the most strategic rehablilitation can occur. The two methods used were 1) measuring streamflow and salinity level flucuations during winter and 2) soil salinity surveys.

Methods

Wetland catchment

The catchment divide was determined from a contours map supplied by Western Power. The divide was established in relation to the point of interest (Schofield *et al*, 1989). The point of interest was the discharge stream entering the culvert at the northern end of the site. Contours that would have supplied runoff to the wetland in the northern area of the catchment had to be excluded from the catchment divide due to alterations in flow as a result of new road construction.

A transparency film of the catchment divide was overlaid onto an aerial photograph of the same scale as the original contour maps. The land cover types were delineated and traced onto film. Land use cover types were determined by consulting literature and visual groundtruthing (SECWA, 1990). The film was then used to digitise land cover boundaries into a computer geographical information system (GIS). Microstation Design software was used for digitising and editing according to methods in Microstation (1995).

The digitised design files were converted into the GIS ArcView system to enable manipulation to obtain spatial data and produce maps (ESRI, 1992; ESRI, 1994).
a map of the catchment is presented in Figure 3.1.

The vegetation communities within the fenced study area had been mapped broadly by other reports (Dames and Moore, 1994; Evans, 1996). Further site assessment was carried out by this project. Broad- and fine-scale maps of vegetation communities of the wetland were mapped on site. Communities were classified according to the dominant species or community type (Keighery, 1994). Coverage of each community was measured on the ground and plotted onto aerial photographs. Salt scalds were also mapped and is shown with the vegetation community maps. Spatial information and maps were produced by GIS as described above.

Environmental stresses were also mapped. The extent of waterlogging was recorded in July, although these boundaries are variable throughout the season and Figure 3.2 shows waterlogging from July field trip. The waterlogged area in the southern forested area of the site had notably increased by August field trip.

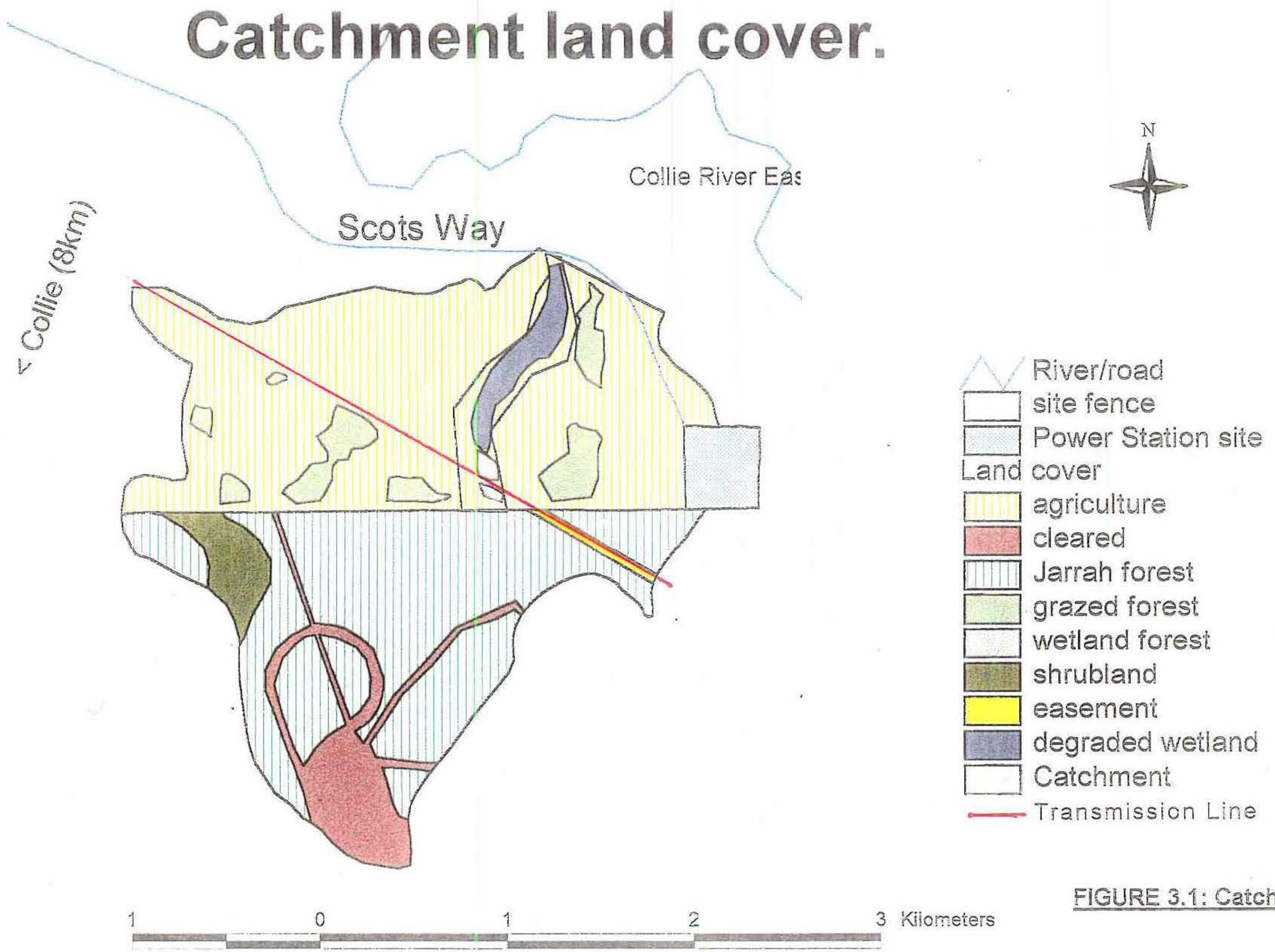


FIGURE 3.1: Catchment Land Cover.

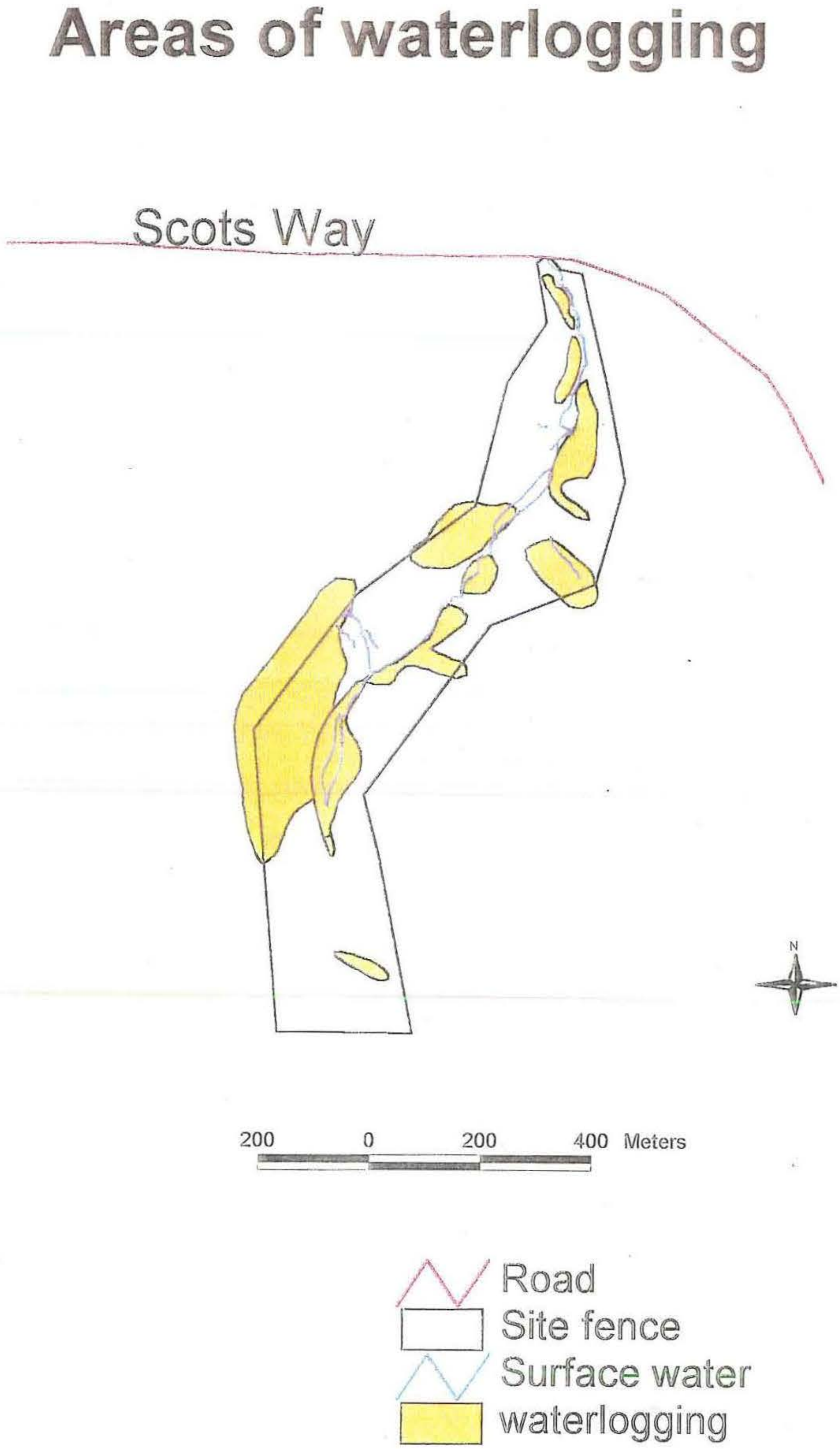


FIGURE 3.2: Areas of Water logging

It is necessary for residual ash from the Collie Power Station to be stored within the boundaries of the Western Power site and in close proximity to the power station (SECWA, 1990). Original plans to develop the western wetland into an ash disposal site were altered as a result of ministerial conditions placed on the project after environmental impact assessment (Dames and Moore, 1994). Ministerial conditions 9(1) and 9(3) required that ecological surveys of the wetland be carried out and location of ash disposal sites to be altered to reflect the findings of the surveys.

The proposed locations of the ash disposals sites were assessed from reports to Western Power and mapped using the GIS methods of this study. The proposed locations are presented in Figure 3.3. The slopes on either side of the western valley will be used for ash storage with naturally occurring clay can serve as lining for the disposal sites (HGM, 1994). The ash disposal sites will be developed in stages and as each cell is filled it will be capped and rehabilitated (HGM, 1994). The eastern valley slope will be the first ash disposal site developed in six cells which shall each be rehabilitated when they reach capacity (Preston, 1995). The eastern valley disposal site will be filled in approximately 20 years of the power station's operation and then the north-western valley slope will be utilised for the remaining 20 years of the power station's operation (HGM, 1994).

The ash is supplied by pipeline in a slurry of 70% ash with 30% water. Rainfall that falls directly onto the disposal sites will be contaminated and contained in storage dams (Preston, 1995). This will prevent contaminated water entering the wetland from surface runoff. A cutoff drain will be constructed on the upslope side of the disposal sites to prevent soil water throughflow from entering into the ash storage. Probable leachate from the sites has been

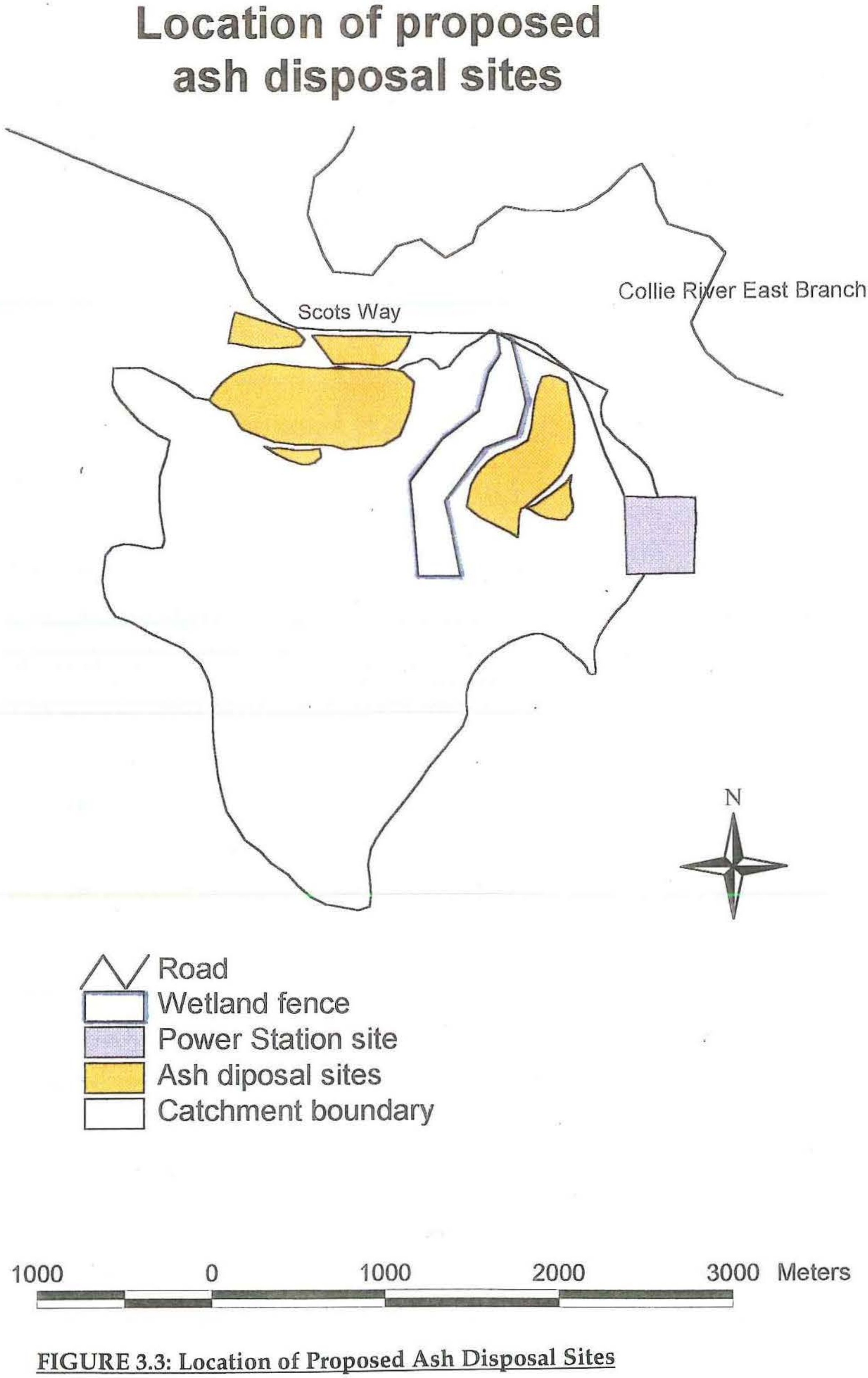


FIGURE 3.3: Location of Proposed Ash Disposal Sites

assessed and found that the quality of the leachate will not be detrimental to existing groundwater (Preston, 1995). Monitoring bores will be established to ensure that this is true.

The resultant effects of runoff containment and throughflow channels will restrict recharge to the groundwater during the ash disposal sites' operation. Subsequent rehabilitation will intercept rain and have higher transpiration rates than existing pasture. Although the ash disposal sites may decrease groundwater tables, the hazard of leachates into the wetland should be well monitored.

The soil types of the catchment were adapted and mapped based on SECWA (1990) and are shown in Figure 3.4. Alluvium sands occur along the drainage line of the valley. This soil type covers most of the wetland site and consists of grey alluvial sands overlying clay subsurface soils.

The lateritic soils of the northern part of the catchment have yellow podsolic soils overlaying laterite. Caprock does occur on the valley ridges while gravelly colluvial soils are on the surface of this soil type on the valley slopes. Deep sands of the Nakina formation occur in the south of the catchment. This area is the northern margin of the Collie Coal Basin. It's deep sands are a known recharge area for the groundwaters contained within the coal basin (Preston, 1995). It is interesting to note that the margin of the coal basin extends into the southern portion of the wetland site. Also the deep sands of the Nankina formation occur on the south west area of the wetland reserve.

Feral-proof fencing was erected around the wetland site during February and March, 1996. Fencing the wetland was seen as essential to exclude stock grazing and for protection of native fauna from feral animals (Dames and

Catchment soil types

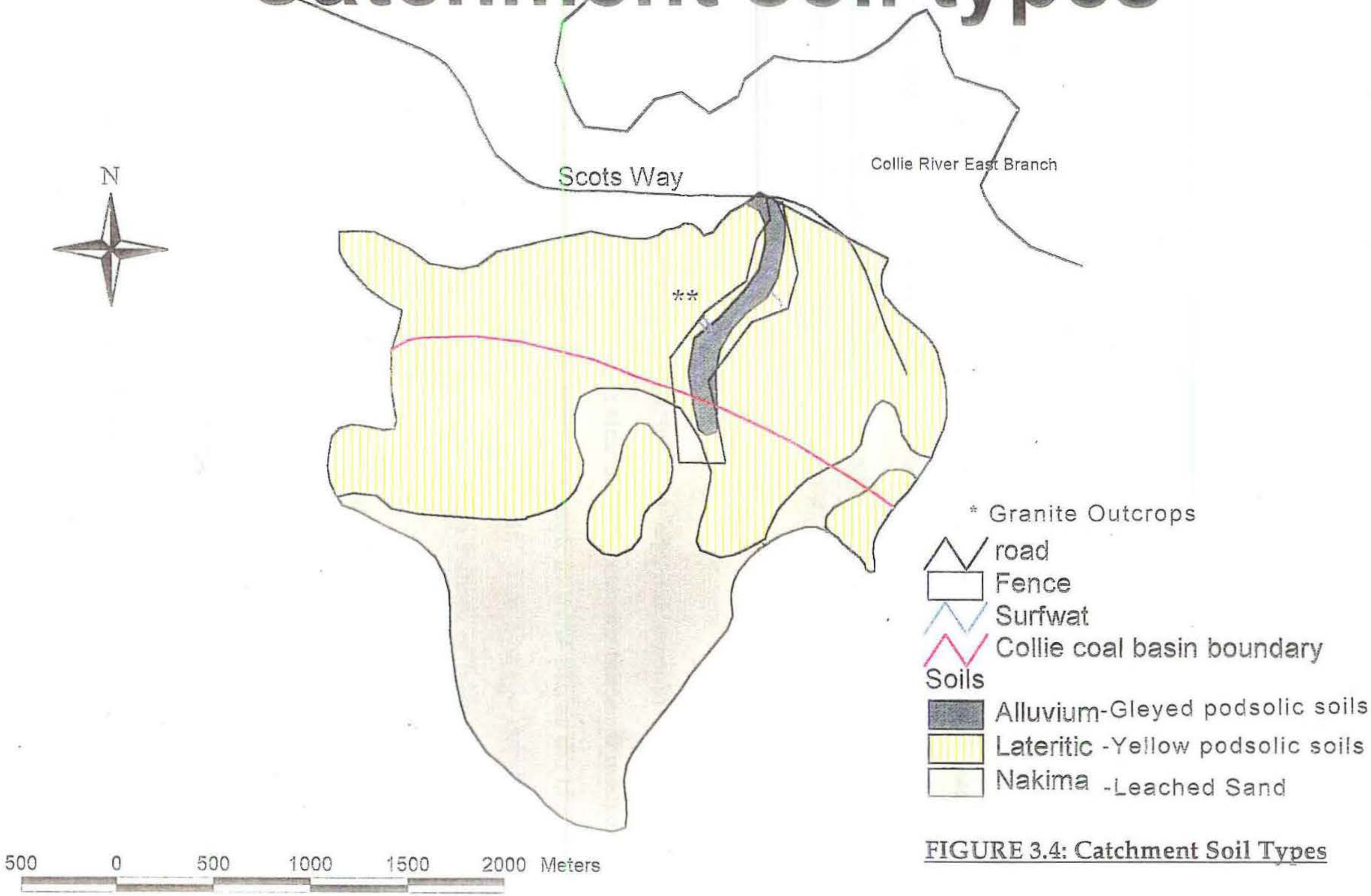


FIGURE 3.4: Catchment Soil Types

Moore, 1994). The size of the site which was fenced was restricted due to the location of the ash disposal sites. Therefore the wetland reserve is linear and problems have occurred due to the restrictions placed on the fence location.

The fenced reserve does not incorporate all of the land which becomes inundated. Mangement of wetland areas outside of the fenced area will be difficult due to land uses in these areas.

The fence construction altered the ground contours slightly and severely impeded the flow of runoff especially from the western side of the catchment. The fence had been buried by 300mm for feral proofing. Excess sand was piled at the base of the fence when the ditch was backfilled. The soil at the base of the fence had not been compacted. Runoff collected on the outside of the perimeter fence and channelled along it until the water could force an opening through the fenceline.

Between the July and August field trips to site, an erosion channel had developed along the external western side of the perimeter fence. It measured 160m long, was approximately 1m wide although in some places the channel was up to 3m wide with pedestal development. The average depth of the channel was 0.8m and it had eroded beneath the 300mm of buried feral proof fence in places and had exposed some of the concreted bases of fence posts. Anecdotal evidence estimated that the erosion channel occurred within approximately four days increasing by about 40m in length a day. The soil from the erosion channel washed down to the edge of the wetland stream channel near sampling site 7 and was up to 30cm deep in places.

The drainage of runoff from the western side of the catchment needs to be urgently addressed. The present farming lease is current for a further 2.5 years with an option for a further 5 years. Liaison with the lease holder is essential to develop engineering solutions to the problem. The potential for continued further erosion is seen as one of the main issues needed to addressed in the rehabilitation of this wetland.

A tranmission line and associated easement dissects the paperbark forest in the southern end of the wetland. Regrowth in the easement consists mainly of shrubs and would not pose future problems for the powerline. However tree species regeneration in this area is now probable due to exclusion of grazing and monitoring is recommended to identify such growth and selectively remove it. Mechanised clearing of the easement throughout its intersection within the wetland would be undesirable.

However, a pipeline is planned to be put through to wetland in the powerline easement. This pipeline will carry saline wastewater from the power station site to an ocean outfall. The pipeline is to be buried and at the completion of this work, the area should be replanted with appropriate species that now occur in the easement.

Hydrology

To investigate the quantity of water and salt entering the wetland system and its salinity, all incoming tributaries had to been identified and measured for flow rates and salinity levels. Sampling was done in autumn (19th April), mid winter (13th July) and late winter (11th September). Autumn sampling could only measure discharge (site 12) from the wetland as tributaries leading into the wetland did not have measureable flow rates in the beginning of the rain season. Two very small channels were evident and they were measured for conductivity only and could be compared to other studies that have measured

Horizontal soil salinity ECa (mS/m)

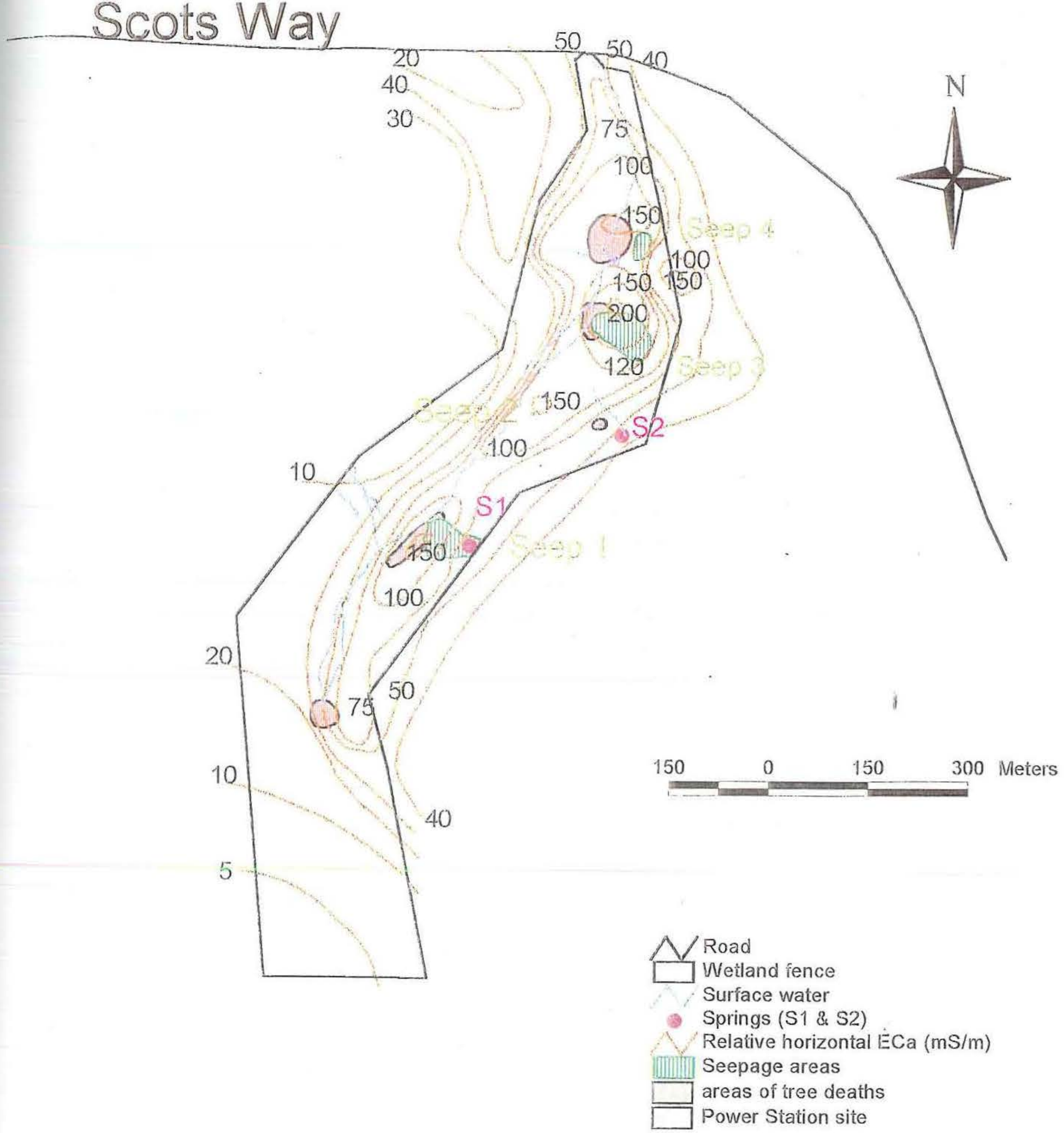


FIGURE 3.6: Horizontal Soil Salinity ECa(mS/m)

the salinity of these channels. These channels were at site 10 and 11 (see below).

The locations of the sampling sites for flow rate and salinity measurements are shown on Figure 3.5 Site 1 was located at the southern end of the lake. Water was flowing very slowly in a northerly direction from the forested area south of site 1. Site 2 was in the lake, 15m from the southern end of the lake edge. Samples were taken at this site for nutrient analysis only (see Chapter 5) as flow rates were insufficient to be measured at this site. Site 3 was in the main stream channel, 7m from the northern end of the lake. Measurements taken here reflect the rates of drainage from the lake rather than a water source into the system. Sites 4, 5 and 6 were gullies which drained runoff from adjacent farmland on the western side of the study area. Water in these channels flowed eastwards towards the main stream channel. Site 7 was located in the main stream channel just south of the main stand of emergent vegetation. The flow rate from this site included diffuse runoff and stream flow that orginated upstream.

Site 8 was across an erosion channel that flowed from the eastern side of the study area north-west towards the main stand of emergents. The channel began near the perimeter fence where there was a waterlogged area which supplied the channel with subsurface flow. Site 9 and 10 were drainage channels from groundwater seeps that orginated in stands of emergent vegetation on the eastern side of the wetland. Although this seepage was mainly diffuse, these two sites were found to have discrete channels where flow could be measured to indicate the quantity of water supplied from this area. Site 11 was a small channel of water that originated from a leaking monitoring bore on the eastern side of the wetland which flowed westward to the main wetland channel. Site 12 was approximately 26m south of the culvert and the northern edge of the wetland perimeter fence. This is the outflow of the wetland where water passes through the culvert and into the Collie River East Branch.

Site 13 was a runoff channel that was situated approximately 160m south of site 4. This site was not formed on 13th July, 1996 so measurements at this site were only taken on 11th September, 1996. Between the two sampling times, there was increased ponding on the western side of the perimeter fence outside of the study site. This ponding flowed in various streamlets through the fence until the majority of the water collected into the newly formed channel about 40m east of the fenceline where site 13 was located.

Springs 1 and 2 are also shown on Figure 3.5 were areas of ponded water which bubbled up groundwater, they had been modified possibly for stock water as they did not dry in summer . The salinity levels where taken here to compare with other studies done on the site. Spring 1 was approximately 20m upstream of site 8 while spring 2 had no associated channel but there was evident vegetation growth downslope which indicated drainage from the soil.

The velocity of the sampling sites were measured with a current flow meter, Model CMC 20 manufactured by Hydrological Services. As flow rates vary across a perpendicular section of a stream, velocity readings at different places along the cross-section were taken (Black, 1996). Black (1996) and Hudson (1993) recommend establishing regular width vertical sections across the stream channel where the velocity readings are taken. However, due to the relative narrowness of the measured streams and the variable flows, regular vertical sections could not be established. Instead, irregular vertical sections that had uniform velocity were established and the width and profiles of sections were recorded. Two readings were then taken in each vertical section and then the arithmetic mean found to give an average velocity for each vertical section, V_1 to V_n.

The cross-sectional area (A m^2) of the vertical sections of the stream channels were calculated from the recorded width and channel proflies, A_1 to A_n. Then the rate of flow or stream discharge, Q, was determined by the formula;

$$Q_n\,(m^3) = V_n\,(ms^{-1}) \times A_n\,(m^2) \qquad (1)$$

All of the discharge rates of the vertical sections were then added together to produce a total rate of flow, Q_s, across the width of the channel.

$$Q_s = Q_1 + Q_2 + \ldots Q_n \qquad (2)$$

A preliminary site visit (19th April 1996) coincided with a flushing of the wetland by a rain event early in the rain season. An opportunistic flow measurement was taken of outflow through the Scots Rd culvert, flow was estimated using the Chezy method (Newbury, 1995). As velocity is faster at the surface, the measured velocity was multiplied by a correction coefficient of 0.8 to give the average stream velocity (Hudson, 1993).

The current meter velocity method is considered reliable and accurate and is used by the main streamflow monitoring agency in the U.S., the U.S Geological Survey (Black, 1996). There are other methods of velocity/area calculations of flow rates which were found too time consuming for this study. Dye methods and dilution methods of chemicals or radio-isotopes are also not as accurate at determining the velocity as current meters (Hudson, 1993). The Chezy method was only used for opportunistic sampling and is not a accurate as current meter measurements. Velocities and therefore rates of flow, can be determined using empirical formulas (Hudson, 1993). Also sampling sites were not suitable for empirical estimation due to the required determination of roughness and slope of channels. A constructed gauging station could accurately measure annual discharges however this study also required inflow measurements. A gauging station is recommended if an accurate annual water budget for the site is needed. This project used fluctuations between inflows and outflows of water to discern trends in the winter water balance.

At each site where flow rates were measured, the conductivity of the water was also measured. A WTW (Wissenschaftlich-Technische-Werkstatten) meter was used to take measurements in microSiemans per cm (uS cm^{-1}). This figure is converted to milligrams of total dissolved solids per litre (TDS mg/L) by multiplying the uS cm^{-1} results by 0.6 co-efficient (Williams, 1966).

Soil salinity

The salinity of the soil of a site can be estimated from the electrical conductivity of the soils. This assists with determining the location of high salt concentrations in the soil and can aid in interpretation of groundwater salinity sources. Soil salinity was determined by electromagnetic induction using a Geonics EM38 according to methods in Geonics (1992). This gives an apparent electrical conductivity measurement (ECa) in mS/m by creating a primary EM wave that reflects a secondary eddy current produced by the conductive salinity levels in the soil (Williams, 1988).

The EM38 has two modes of measurement - 1) horizontal which gives a salinity reading to a soil depth of 1m, and 2) vertical which measures salinity to a depth of 1.5m.

The methods used were based on Williams (1988) and Bennett *et al* (1995), however the grid size that was used in this study differed. Measurements were taken on a grid of approximately 50m by 100m over the fenced site and the surrounding land with more intensive sampling in areas of high ECa measurements. A total of 114 sites were sampled, the results were plotted on a map and readings of common ECa were joined in contours.

The EM38 was chosen to assess soil salinity due its relative accuracy and availability. Although other EM instruments can test greater soil depths than the EM38, near surface soil salinity levels were all that are required for the assessment suitable rehabiliation strategies (Williams, 1988; Bennett *et al*, 1995).

Results

Hydrology

Flow rate and salinity are used to determine the salt load carried by the system in kg/day. The results are displayed in Table 3.1. Salinity levels are classified as 0 - 500mg/L is fresh, 500 - 1000mg/L is mildly saline, 1000- 3000mg/L is brackish and over 3000mg/L is considered saline (Davis *et al*, 1991; Williams, 1980).

Sites 1 and 3 are at either end of the lake. The salinities of both sites are considered very fresh. A slight increase in salinity levels (20.1mg/L at site 1 and 7mg/L at site 3) suggests that the area surrounding the lake appears to be gaining salt through winter. This is further dicussed in the following section in regards to soil salinity.

Sites 4, 5, 6 and 8 are also classified as fresh. These sites all had reduced salinity levels in August compared to July due to the dilution of fresh surface and subsurface runoff. Site 7 was fresh and also had reduced salinity later in winter which reflects this dilution.

site	19/04/96 Q (flow rate) m3/day	salinity mg/L	salt load kg/d	13/07/96 Q m3/day	salinity mg/L	salt load kg/d	11/08/96 Q m3/day	salinity mg/L	salt load kg/d
1				369.8	25.4	9.4	565.0	45.5	25.7
3				1095.4	85.2	93.3	3615.8	92.2	333.4
4				710.3	107.3	76.2	666.8	46.2	30.8
5				1188.4	56.7	67.4	786.8	46.3	36.4
6				1193.8	71.8	85.7	887.1	54.2	48.1
7				2023.0	199.8	404.2	2975.3	104.6	311.2
8				1256.9	57.9	72.8	1082.8	53.7	58.1
9				97.6	3384.0	330.4	53.0	528.0	28.0
10		13980.0		51.7	913.8	47.3	30.5	909.0	27.7
11		6720.0		38.2	1350.0	51.6	46.6	1368.0	63.8
12	823.1	18900.0	15556.6	3133.9	193.8	607.3	14742.4	136.8	2016.8
13					0.0		939.0	38.2	35.8
spring 1		4920.0			309.0			280.0	
spring 2		600.0			730.2			197.0	

Table 3.1 : Flow rates, salinity and salt load from April, July and August sampling. No inflow tributaries were measured in April, therefore only discharge was obtained as indication of salt load leaving wetland in autumn. Site 2 was situated in the lake so flow readings were irrelevant from this site. Salinity levels were determined at springs 1 and 2 for comparative purposes.

Site 9 had the highest salinity level in July of 3384 mg/L and was classed as saline. In August, the salinity was only 528 mg/L and classed as fresh. This area obviously takes in recharge from fresh surface and subsurface flow. Site 10 is approximately 50m north of site 9 and originated from a seepage area similar to site 9. Its salinity was measured in April as 13,980mg/L (saline) and had been diluted to 913mg/L (mildly saline) by July with a similar reading of 909mg/L in August. The differences between sites 9 and 10 could be due to either 1) an earlier inflow of fresh water entering the area around site 10 than what occurred at site 9, or 2) site 9 has a higher autumn salinity that was not able to be measured due to the lack of flow.

Site 11 was the leaking monitoring bore located 70m north of site 10. The measurements taken here can be assumed to be reflective of the groundwater. The trends shown at site 11 is similar to site 10 which suggests that they may originate from the same groundwater source. However, site 11 is less affected by fresh water flush, as the water being sampled was orginating from deeper within the profile due to the bore. The salinity level at site 11 went from saline quality in April (6720mg/L) to brackish in July and August (1350 and 1368mg/L respectively).

Spring 1 is upstream from the runoff channel where site 8 was located. Its April measurement was classed as saline (4920mg/L) and this was diluted throughout winter and classified as fresh in July and August. This site has been measured in other previous studies and the results are shown in Table 3.2. Evans (1996) measured the salinity on 16th February, 1996 at 6190 uS/cm (3714mg/L). So spring 1 had an increase in salinity from February to April, which could be due in part to evapo-concentrative effects or salt flushing into the spring in the early rain events of the season. The dilution of salinity measured for this study is also reflected in Western Power analysis of this site (Table 3.2).

salinity mg/L	spring 1	spring 2	site 11	site 12
Reeves (1996)				
19/04/96	4920	600	6720	18900
13/07/96	309	730.2	1350	193.8
11/08/96	280	197	1368	136.8
Evans (1996)				
15/02/96	3714	660.6	9990	5172
Western Power monitoring				
16/08/95	194			882
15/02/95				12700
18/08/94	398			794

Table 3.2: Salinity results (mg/L) from this and previous studies taken at same sites.

The salinity level at spring 2 ranged from 309mg/L in July to 280mg/L in August and is classified as fresh throughout winter sampling. Spring 2 was classed as mildly saline when measured by Evans (1996) in February. Due to the mildly saline conditions in summer, it appears that this spring is being fed from groundwater.

The water discharging from the wetland at site 12 is saline in summer. The highest salinity (18900mg/L) was recorded by this study during an early flushing in April. The discharge salinity levels was diluted considerably in winter (193.8mg/L in July and 136.3mg/L in August) and was classified as fresh. The wetland discharge salinity levels recorded in winter 1995 and 1994 were mildly saline (882mg/L and 794mg/L respectively). The improvement seen by this study in winter may be the result of a much higher rainfall recorded in 1996 (1076.7mm to 16th October) compared to 1995 (866.7mm/yr)

The results shown in Table 3.1 are combined to give a comparison of the overall input of streamflows and salinity levels to the discharge at site 12. The wetland becomes dry in summer with only a small amount of water being supplied from sites 10 and 11. The rainfall event that resulted in the streamflow measurement on the 19th April was primarily direct runoff as there had not been enough rain to initiate subsurface discharge, and groundwater baseflow had already been established to be extremely low. The salt load recorded in this sampling was extremely high, over 1.5 tonnes, and reflects the flushing of precipitated surface salts that had accumulated during summer.

Soil salinity

The results of the EM38 testing are shown in Figures 3.6 (horizontal) and 3.7 (vertical mode).

There is a high salinity level area through the centre of the wetland. The ECa levels were higher in the horizontal (surface) than vertical (1.5m depth) mode. This area extends south past the lake and it could be supplying the lake and surrounds with salt that is concentrated at the soil surface. This would account for the increased salinity levels of site 1 and 3 from July to August.

The highest readings of ECa were in excess of 150mS/m and they coincided with areas of groundwater seepage as is shown in Figures 3.2 and 3.3. The seepage site associated with spring 2 had an ECa reading of >150mS/m(H) and >100mS/m(V) at its downslope end, however the spring was supplying fresh to mildly saline water. Spring 2 appears to be fed from a freshwater aquifer that

FIGURE 3.7: Vertical Soil Salinity ECa(mS/m)

is perched above a more saline aquifer which has influenced the ECa reading at the base of this seepage area.

Seepage 2 was a very small area of *Isolepis prolifera* and some stands of *Juncus pallidus* surrounded by pasture. This site had ECa readings of >150mS/m for both horizontal and vertical modes. Seepage 3 had the highest ECa of >200mS/m (H) on the northern edge of the seep close to site 10. (The ECa (V) reading was highest on the southern side of the seep near site 9. So it appears that the salinity concentration increases south to north of the seep area from 1.5m depth to the surface.)(unclear) Therefore, the saline groundwater is closer to the surface at site 10 which recieves an earlier winter dilution of fresh water than site 9. The saline groundwater at site 9 is therefore probably deeper from the surface than site 10 and takes longer to recieve freshwater dilution in winter.

Seepage 4 was associated with an area of *Typha domingensis* and *Bolboschoenus caldwellii* north of the leaking monitoring bore, site 11. The majority of the stand of *B. caldwellii* had died, probably killed by the saline seepage from this area. The ECa readings (both H and V) were much higher downstream (east) of the seepage than around the seepage area. The saline seepage from this site concentrates in this area. There was also a pocket of higher salinity concentrations east of seepage 4 with an ECa of >150mS/m (H) which did not have a corresponding high ECa (V) reading. The soil salinity at this site appeared to be the concentration of surface runoff originating from seepage 3.

Salt scalds are evident surrounding the high ECa levels associated with seepages 3 and 4. The subsoil is exposed, hard and most impermeable. There were decaying tree skeletons scattered through this area, other dead vegetation, and soil precipitates on the surface in summer.

However the high ECa readings associated with seepages 1 and 2 did not have such evidence of salinisation. This area supported pasture with scattered trees, with no bare areas or salt precipitation, although a few dead trees were noticed in the lower reaches of seepage 1. The ECa results and the dead trees showed that this area is saline and might degrade to resemble the scalds of the northern section of the wetland without intervention.

Discussion

Hydrology

The results from the three sampling periods can be used to understand the hydrology of the site. In summer, the wetland becomes dry except for a very small amount of water supplied by a leaking monitoring bore and seepage 3. The April reading shows that initial rains of the season contribute to streamflow as surface runoff, carrying with it the surface soil salts that have precipitated over summer.

To compare the inflow and discharge of water and salts, the results from Table 3.1 were combined. The results are shown in Table 3.3. The daily volume of water flowing (Ri) into the wetland was calculated from all the tributaries measured. Sites 3 and 7 were excluded as they measured the main stream channel flow rather than inflow from tributaries and runoff channels. The total inflow of water on the 13th July was 4906.68 m^3/day and on the 11th August it had increased slightly to 5057.61m^3/day.

The area of the catchment was determined by geographical information systems (GIS) using Microstation and ArcView software. The spatial coverage of the two main vegetation types (jarrah forest and agricultural pasture) of the catchment and the surface area of the waterbodies were also calculated from GIS. Using evaporation data and water-use coefficients of the two vegetation communities, the total evapo-transpiration (ET) on the days of sampling were estimated. Appendix 3.1 contains the details of the calculation.(based on whose figures)

Total supply into the wetland (R_t) was found by formula (1)

$$R_t = R_i - ET \qquad (1)$$

As no rainfall was recorded on the two days of winter streamflow sampling, this extra input of water to this system did not have to be included in the calculations.

Total discharge (D_t) from the wetland was measured at site 12 and subtracted from R_t to give a value of the hydrologic difference (Hd).

$$Hd = D_t - R_t \qquad (2)$$

parameter	19/04/96	13/07/96	11/06/96
Ri (m3/day)		4906.7	5057.6
ET (m3/day)		584	539
Rt (m3/day)		4322.7	4518.6
Dt (m3/day)	823	3134	14742
Hd (m3/day)		1685	7623.4
Cs (m3)		2487	2600
salt load input (kg/d)		741	319
salt load output (kg/d)	15551	607	2017
salinity (mg/L)	18900	194	136

Table 3.3. : Results of hydrological assessment (derived from Table 4.1). Comparison can be made between the flow of water in July compared to August. R_i is total runoff input, sites 3 and 7 where excluded as they were along main channel rather than inflow to system. ET = evapotranspiration for day, R_t = total runoff, Dt = total discharge, Hd = hydrological difference, Cs = channel storage. Details of calculations in Appendix 3.1.

A negative value for Hd indicates water lost into the wetland and groundwater system. A positive Hd value shows the amount of water being gained from groundwater and wetland drainage. Positive Hd values need to be subtracted from channel storage (Cs), which gives the volume of discharged water gained (Dg) from the system.

$$Dg = Hd - Cs \qquad (3)$$

Channel storage was computed from spatial information data and details are shown in Appendix 3.1.

The results in Table 3.3 show that the wetland gained 1189 m^3 of water per day at the time of the July sampling. On the day of August sampling, the wetland and groundwater system discharged 7623.4 m^3 of water per day. Therefore, the wetland and perched seasonal aquifer beneath were accumulating water in July, and groundwater was contributing to discharge in August. This trend is common in wetlands throughout the region (Loh and Stokes, 1981).

The changes in salinity and salt load are also shown in Table 4.2. The very saline waters measured in April are diluted in July and August. This trend has also been reported in wetland systems in the region (Schofield *et al*, 1988). The difference in input and output salt loads showed that the wetland was a sink for salt in July and a net export of salt load in August. The total salt load carried in August was higher than in July, even though the salinity was lower, which is a function of the greater discharge of water from the system.

It should be noted that if rehabilitation or site engineering works reduces discharge at a faster rate than the salt load is reduced, then increasingly salinised waters may be discharged from the wetland. This is not a recommended practise for water resource catchments (Schofield *et al*, 1989).

Groundwater greatly influences the hydrology of the wetland. It appears a perched seasonal aquifer forms beneath the wetland. Seasonal aquifers are most likely to be fresh throughflow which comes into contact with saline groundwater (Schofield *et al*, 1988). These shallow groundwaters allow capillary flow of water to the surface where evapoconcentration occurs and salt crystals have been recorded on site in summer (Evans, 1996). The hydrology of the site reflects studies in region (Loh and Stokes 1981).

Salinity sources are often evident in summer. Less evident sources can be evident during winter. These areas need to be idenitified for management.

Chapter 4 Assessment of nutrient sources

Introduction

Nutrient levels in the water is a factor which can influence the restoration of a wetland (Cooke *et al*, 1993; Hammer, 1992). Nutrient levels can be used to indicate the condition of the wetland (OECD, 1982). In previous studies on the site, excessive nutrients have been shown not to be a problem, particularly as it is a seasonal wetland (Dames and Moore, 1994; Evans, 1996). Due to land use in catchment, nutrient levels should be monitored regularly to examine changes that may influence the wetland.

This study determines concentrations of nutrients and chlorophyll *a* to be able to assess the quality of the wetland. This information can be used to determine sources of nutrients if they exist.

Methods

On the 13-7-96, water samples were taken for laboratory analysis at Edith Cowan University, Joondalup. The samples were taken from the same 12 sites where flow readings where taken and are shown on Figure 3.5 (see previous chapter). A sample of water was collected, filtered through glass fibre filter paper and stored in three separate 50ml containers. Two 100ml samples of unfiltered water were also collected. All water samples were placed into a car freezer and kept frozen to preserve their integrity. Frozen samples were defrosted in a water bath and shaken vigorously prior to analysising.

Determination of concentrations of nutrients in the water samples were carried out on a Skaler Autoanalyser using methods outlined by APHA (1989) and Skaler (1993). The filtered water samples were used to determine nitrite/nitrate, ammonia, and orthophosphate concentrations, and the unfiltered samples were used to analyse total kjelkahl nitrogen (TKN) and total phosphorous. Two samples from each site were analysed to serve as replicates to ensure tha. the differences between the replicate results were not too large as to indicate a problem with analysis.

Phosphorus

Phosphorus predominantly occurs in water as three forms of phosphates; orthophophates, condensed phosphates and organically bound phosphates. Orthophosphate is an important form of phosphorus in water and reflects the amount of breakdown of organic material as well as the presence of agricultural fertiliser (APHA, 1989; Davis, 1993).

Filtering a water sample largely removes suspended forms of phosphorus so that reactive phosphorus can be analysed. Reactive phosphorus is primarily the dissloved orthophosphate, although small amounts of other forms of phosphates may be included in the reading (APHA, 1989). The reactive phosphorus shall be termed orthophosphate and was autoanalysed from filtered water samples using the ascorbic acid colourimetric method following the procedures outlined by APHA (1989) and Skaler (1993). The ascorbic acid method was chosen as it is recommended for analysis using the Skaler autoanalyser with expected phosphorus levels lower than 6 mg/L.

Total phosphorus

Condensed phosphates and phosphorus held in organic matter can be read in combination with orthophosphate as a measure of total phosphorus in water. An unfiltered sample from each site was treated with a perchloric acid digestion procedure to oxidise phosphorus from organic matter into the form of orthophosphate. This proceedure mineralises organic phosphorus in concentrate perchloric acid at the boiling temperature perchloric acid of 265 degrees C (APHA, 1989).

Although this method is more involved than other techniques, the organic phosphorus is more successfully recovered to orthophosphate with this digestion procedure (APHA, 1989; Davis, 1993). As the total phosphorus contained within the water samples had been converted into orthophosphate by the digestion, total phosphorus was then determined using the same ascorbic acid technique used to determine orthophosphate.

Nitrite and nitrate

Nitrogen is a macronutrient required for protein production in all organisms. Plants can only assimilate nitrogen as nitrate and ammonia. In biogeochemical processes nitrogen is cycled from atmospheric nitrogen by fixation, nitrification and ammonification and denitrification back to nitrogenous gas. Nitrite is converted to nitrate by nitrification which is the form required for assimliation. Along with ammonia, these three forms of nitrogen are an indication of how much nitrogen is available for plants.

Nitrite and nitrate were analysed using the cadium reduction method where the water sample passes through a glass column of copper-cadmium so that the nitrate is reduced to nitrite. This method without the cadium reduction is used to determine concentrations of nitrite without nitrate, however nitrate is difficult to determine as an individual species due to the complex procedure and possibility of interference (APHA, 1989). Therefore, nitrate was reduced so that a combined reading of the nitrate and nitrite could be obtained.

Ammonia

The Skaler autoanalyser determines levels of ammonia in the water samples by the modified Berthelot reaction method (Skaler, 1993). All methods that determine ammonia levels, analyse ammonia and ammonium (NH_4^+) levels together. Often, natural water sources contain mostly ammonium (Davies, 1993).

Filtered water samples were used to determine ammonia levels. As ammonia can be absorbed into the water sample from the air, care was taken with the collection and storage of the water samples. The samples were taken from the freezer 30 minutes prior to analysing, to allow minimum time to defrost to restrict aerial ammonia absorption. Water samples were put into the Skaler* autoanalyser tray in replicate pairs as they were required, in order to limit exposure. Samples that were waiting to be analysed were kept in sealed containers.

Total nitrogen

Total nitrogen includes the ammonia, nitrite and nitrate, and organic nitrogen components in the water. It is difficult to obtain measurement of total nitrogen directly and therefore the method 'kjeldahal' nitrogen determination is used. Unfiltered water samples were subjected to a 'kjeldahal nitrogen' digestion to convert organic nitrogen into ammonium ion (NH_4^+) by digestion with sulphuric acid in a mecury catalyst at 360 degrees C (just below the boiling temperature of sulphuric acid) (APHA, 1989). The determined values of kjeldahal nitrogen and nitrite/nitrate can be combined to give total nitrogen (APHA, 1989). The ammonia results can be subracted from kjeldahal nitrogen to give an estimated amount of organic nitrogen (APHA, 1989).

Chlorophyll a

A further indicator of water quality used was the assessment of the algal biomass within water samples. An index of phytoplankton productivity can be indirectly assessed by analysis of chlorophyll *a*, which is a less complex procedure than phytoplankton counts or other productivity methods (APHA, 1989).

Samples for chlorophyll *a* analysis were taken on 11-8-96. Sampling for chloropyll *a* was done later than nutrient sampling, results then could be used to determine the effect of the early winter addition of nutrients from runoff in stimulating algal biomass growth in the wetland system. Sampling for chlorophyll *a* was collected from the same sites used for nutrient sampling except a sample was not collected from Site 2 as it was too difficult to access.

The methods used for the collection of samples followed the principles in APHA (1989) although with some modifications. A sample of 1000mls of water from each site was filtered through a filter-tower fitted with a manual vacuum pump. Glass fibre filter papers (Whatman GF/C) were used as recommended by APHA and each one was folded, placed in a labelled plastic bag and frozen for laboratory analysis.

The procedure used to determine chlorophyll *a* concentrations was the spectrophotometric determination as described by APHA (1989). It is a commonly used technique (Davis *et al*, 1991) and therefore was chosen to facilitate comparisons with chlorophyll *a* results from other studies.

Results

Nutrient analysis

The results from nutrient analysis can be seen in Table 4.1. Total nitrogen was estimated by the sum of nitrite/nitrate concentrations with TKN (APHA, 1989). The ratio of TN:TP was also determined so the value could be used as a further indicator of the nutrient status of the wetland waters. Due to interference encountered four samples were not able to be analysed. These were samples from sites 4, 9, 10 and 11.

Orthophosphate levels were relatively low with a mean of 15.29ug/L and a range from 10.9 to 36.4ug/L. The highest reading came from site 5 which was the stream with the highest runoff flow from the adjacent farmland on the western side of the wetland. Total phosphorus levels had a mean of 21.91ug/L with a range from 11.35 to 64.4ug/L with site 5 having the highest level of concentration.

Nitrite/nitrate concentrations were exceedingly high with a mean of 5260.63ug/L and a range of 5.6 to 13,451.7ug/L. The highest reading was from the main lake, site 2 which reflects the accumulation of nitrite/nitrate from the upstream and adjacent areas that drain into the lake. The lowest reading came from site 11 which was the leaking monitoring bore and it can be presumed that this represents the nitrite/nitrate level of the groundwater.

site	P04 3- ug/L	TP ug/L	NO2-/NO3- ug/L	NH4 ug/L	TKN ug/L	TN ug/L	TN:TP RATIO
1	13.3	13.0	6447.7	56.3	2459.8	8907.5	685.2
2	13.0	18.6	13451.7	351.4	2377.6	15829.3	851.0
3	13.3	16.3	5273.3	63.2	1786.9	7060.2	433.1
4	17.1	25.5	4928.5	49.5	na	na	
5	36.4	64.4	3656.5	45.7	843.6	4500.1	69.9
6	11.2	13.9	9414.6	38.9	1637.4	11052.0	795.1
7	11.6	19.8	4840.6	50.1	1811.8	6652.4	336.0
8	11.2	11.4	6818.5	22.7	1749.5	8568.0	754.9
9	16.1	23.6	1864	53.8	na	na	
10	13.7	20.8	658.7	44.5	na	na	
11	15.7	22.5	5.6	104.3	na	na	
12	10.9	13.2	5767.8	40.7	1525.2	7293.0	552.5
mean	15.3	21.9	5260.6	76.8	1774.0	5821.9	494.0

Table 4.1 : Results of nutrient analysis.

Nutrient analysis was preformed on Skaler autoanalyser according to methods of APHA (1989) and Skaler (1993). TN is sum of NO^{2-}/NO^{3-} and TKN. TN/TP was used to determine their ratio.

Ammonia levels had a range from 22.7 to 351.4ug/L with a mean of 76.76ug/L. The highest level of ammonia was from site 2 (the lake). Kjeldahal nitrogen (TKN) concentrations is a measure of ammonia/ammonium and organic nitrogen. The TKN levels had a mean of 1773.98ug/L with a range from 843.6 to 2459.8ug/L. The lowest concentration was recorded from site 5, the major runoff tributary from adjacent farmland. This site had the concentration of 3656.5ug/L nitrite/nitrate and therefore appears to contain its nitrogen load in this compound rather than TKN. The highest level came from site 1 which was upstream from the lake adjacent to the relatively undisturbed forested area. Its nitrite/nitrate levels were above the mean and must also be a sink for adjacent farmland runoff.

Total nitrogen, as previously discussed is the sum of TKN and nitrite/nitrate. The average total N was 5821.87ug/L with a range from 4500.1 to 15829.3ug/L. The highest level was from the lake which reflects its high nitrite/nitrate and TKN concentrations. The lowest total N concentration found at site 5 is a result of the low ammonia levels found in this water course.

Total nitrogen to total phosphorus ratios have been used to determine if the levels of one nutrient limits the affect on productivity of the nutrient (Davis, 1991). The average TN:TP ratio is 494.03 with the highest ratio in the lake (851.04) and the lowest was recorded at site 5 (69.88).

Chlorophyll a

The absorbance readings of chlorophyll *a* treated filtrate was analysed according to APHA (1989) methods. The results are shown in Table 4.2. The results were low, all being below 3.5ug/L of chlorophyll except sites 1 and 11. These two sites had obvious fixed algae within their water courses and therefore do not reflect a measure of phytoplankton alone but include macroalgae and are therefore disregarded in the chlorophyll *a* assessment.

site	Chl a ug/L
1	17.3
3	1.3
4	1.7
5	3.5
6	0.8
7	2.7
8	0.4
9	1.5
10	3.4
11	11.4
12	2.2

Table 4.2 : Results from chlorophyll *a* analysis

Chlorophyll *a* was analysed according to APHA (1989) methods. Sites 1 and 11 had evident fixed algae and therefore are disregarded in assessment of indirect measurement of phytoplankton.

Discussion

Nutrient sources

Nutrient levels give an indication of the trophic condition of aquatic systems. (defintion on trophic conditions) Standard classification of trophic status according to nutrients concentrations in lakes have been developed by the OECD (1982) and the ANZECC (1992) recommend nutrient level ranges for aquatic systems. It should be noted that the ANZECC recommended limits are for rivers and streams while OECD limits are for lakes. It is difficult to specifiy limits in nutrient concentrations in flowing systems due to other factors that limit productivity such as sunlight, grazing and velocity. Moving waters can have higher nutrient concentrations than lakes without exhibiting deteriorating trophic status due to flushing of nutrients and algal biomass prevents build-up to high levels. (ANZECC, 1992). However, ANZECC recommends limits that have known to cause problems if exceeded. OECD classification is used to assess what effect the nutrient concentrations may have on the wetland as it stagnates and dries in summer.

Total phophorus levels in the wetland are in the range from oligotrophic to mesotrophic except for site 5 which falls into the range of eutrophic classification (OECD, 1982). The total phosphorus concentrations fall within the recommended range of the ANZECC (1992) for rivers and streams. As the OECD levels specifically refer to lakes and the concentrations fall within the ANZECC recommendations, phosphorus is considered to be within accepable limits. Although evapoconcentrative effects in spring and summer along with stagnant conditions prior to drying may give higher phosphorus concentrations which may contribute to developing trophic status in spring and summer. The drying of the wetland in summer to autumn will assist in eliminating any algal growth that may occur.

Total nitogen levels from the site are at the upper limit of eutrophic status according to the OECD (1982). The recommended range of total nitrogen from the ANZECC (1992) is exceeded in the wetland by ninefold (lowest level at site 7) to 21 times in the lake, site 2. Therefore the nitrogen levels in the system are extremely high and suggest that eutrophic conditions may develop as the wetland stagnates.

To further analyse the condition of the wetland, TN:TP ratios were compared with other studies. Research on Perth wetlands have shown that detrimental water quality does not usually occur until TN:TP is less than 30ug/L (Davis, 1991). Therefore, the low phosphorus levels in the wetland waters may limit excessive algal production. Davis and Rolls (1987) have shown that TN:TP ratios can change in spring and if the ratio approaches ~30, eutrophic conditions may occur.

The nutrient results are reflective of the adjacent farm management. Two to twelve years previously, the farm manager had not added any fertilisers due to the uncertainty of the development of the Western Power site. The current manager, in the last two years, has applied superphosphate to increase productivity. This year urea fertiliser (46% nitrogen) was also applied in early winter to the oats crop sown as cattle feed. Many previous water quality studies on the site have shown no problems with nutrient levels but the new management regime may alter the trophic condition of the wetland.

Chloropyll a

Chlorophyll *a* levels are classified as oligotrophic by both OECD (1982) and ANZECC (1992). Algal biomass reflected by chlorophyll *a* concentrations are not likely to be able to build to nuisance levels in the short resident time of the moving waters of this wetland. However as the system becomes stagnant in summer prior to drying out, the high N levels may promote algal growth.

Chlorophyll *a* is often measured throughout the year particularly in summer to obtain a peak level that can be compared with the mean level (Davis, 1991; Davis and Rolls, 1987). This project was not able to sample the site more that once and future monitoring is recommended. A chlorophyll *a* measurement from site 2 would have been useful in assessing the eutrophic condition of the lake. This would aid in determining if the wetland was suffering from the high nitrogen levels.

Limitations

This nutrient study analysis involved one sampling round. Nutrient monitoring is recommended to monitor changes over seasons. The lack of chlorophyll *a* analysis from the lake (site 2) impeded the analysis that could be made regarding the trophic condition of the wetland. Being a relatively still body of water, chlorophyll *a* assessment of this site may have allowed interpretations that could not be gained from sites containing moving waters. Chlorophyll *a* analysis should also be performed in summer when primary productivity is optimal. This would give an indication of peak productivity. However the timing of this study limited such sampling.

General Discussion

Nutrient analysis of wetlands is important in determining the condition of the system (EPA, 1988). Nutrient assessment allows investigation of the sources of nutrients that may be entering the system. The results shown in this study reflect that the adjacent agricultural land use supplies nutrients into the system.

There is a need to address application of fertiliser, even though the wetland is mainly a flowing system. There are ponding areas which may be affected by eutrophic conditions particularly in summer. Liaison with the farm manager may help to address this issue through altering application techniques and timing of fertilising.

Understanding the nutient input into a wetland is vital information for the development of a rehabilitation. By being aware of the source of the nutrient supply, then the issue can be redressed. This is more difficult if the nutrient are being supplied from a non-point source. This study was able to determine the source of nutrient supply into the wetland. Due to altering management decisions in a catchment, nutrient analysis should be ongoing so that changes can be evaluated.

Chapter 5 Rehabilitation plan

Introduction

There are many established approaches to developing rehabilitation plans for lakes and bushland remnants (Cooke *et al*, 1993 and Tizard 1993). This study will combine elements from these approaches, supplemented with site specific requirements. This wetland site is damaged by various elements, including salinity; grazing; erosion and introduced flora and fauna species. A rehabilitation plan is required to be developed to improve these environmental conditions on the wetlands site.

Western Powers' objectives for the site include improving the quality of the water that goes into the Collie River East Branch, rehabilitating natural communitites and providing an educational and scientific resource.

The rehabilitation plan will address these issues based on the data collected in this study. It is important for rehabilitation plans to achieve the goals of the land owner. This helps insure implementation of the plan.

By having to achieve specified objectives, aspects of the management plan have to be modified.

Methods

The formula followed by other authors has been adapted for this study. Literature was consulted to determine existing strategies for rehabilitation of salt affected land and wetlands. To produce the plan, site assessment and research was carried out, as described above. Western Power reccommendations and objectives were also sought.

Classification of separate land management units were determined. The recommendations of the rehabilitation plan will be based on these land units. The land units have been modified and expanded from those described by Pettit and Froend (1992).

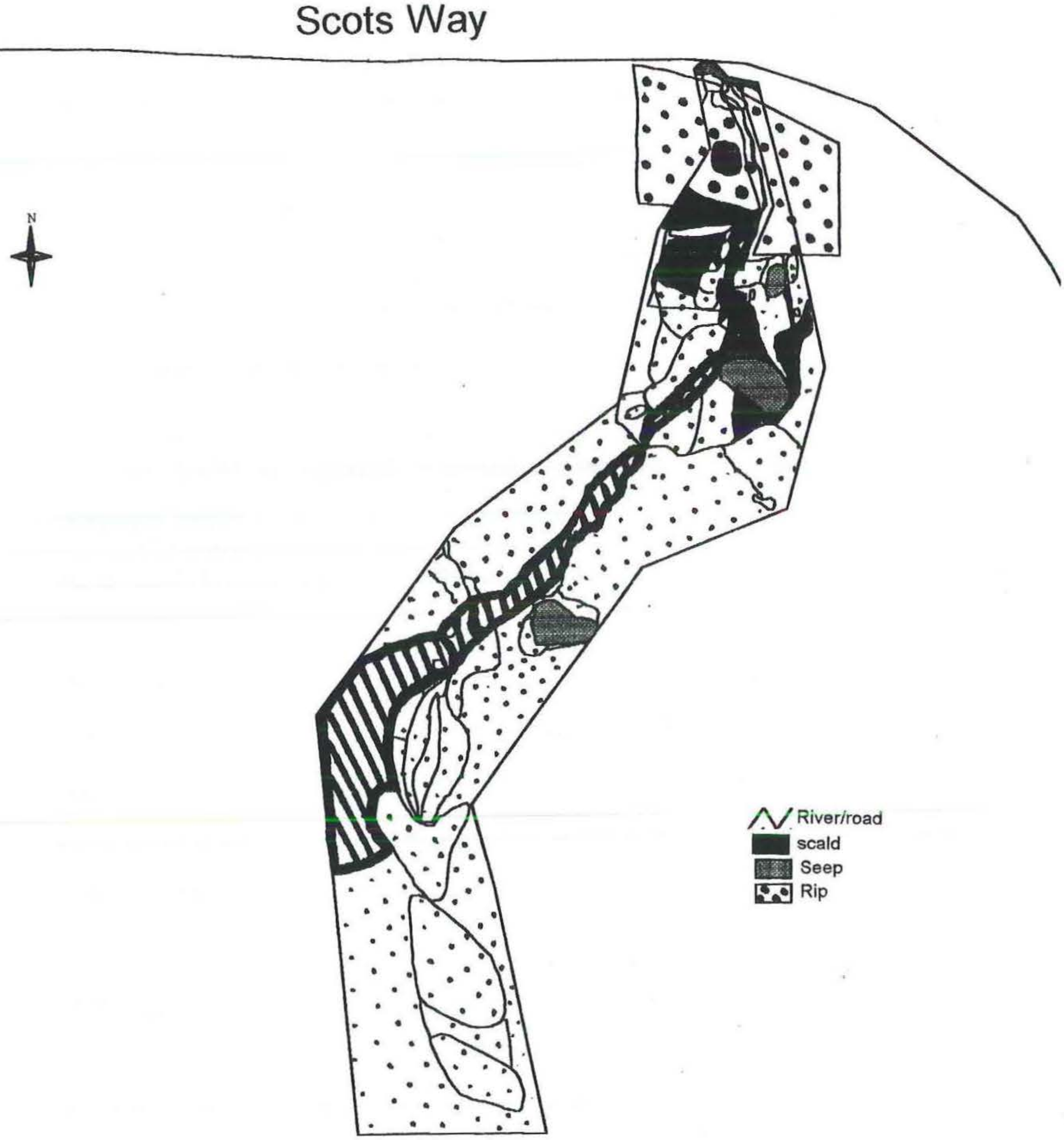
Results

The land management units are shown in figure 5.1 Salt affected areas are harsh and have special requirements for revegetation (Schofield *et al*, 1989). Areas not suffering from salinity will not be restricted by the special considerations required in the salt affected areas.

Land Management Unit 1

These areas are affected by severe salinity and waterlogging. They can be identified by vegetation cover, supplemented with salinity assessment. The core area in this land unit is mostly bare with less than 20% vegetation cover, usually sea barley grass, but there may be other tolerant species. Research reviewed recommended treatments for these severly degraded sites.

Land management areas



200 0 200 400 600 Meters

FIGURE 5.1:

Land Management Units

- Unit 1 (scald)
- Unit 2 (seeps)
- Unit 3
- Unit 4

Rip = land already rip, mounded and planted

Recommendations;

Double ridge mounding (~50cm high) is considered essential to ensure seedling survival. Ripping (preferably 1m deep) is required to break down hardened soil, thus enabling seedling to establish their roots. Mulching has been found to improve seedling survival in these areas (Pettit and Ritson, 1991) and is therefore recommended to be applied after seedlings have been planted.

Ridge lines that are adjacent to the stream channel should be angled towards it, so that water can drain into the stream. These severe saline sites that are not away from the stream channel should be mounded on the land contour to prevent erosion caused by run-off.

Mounds should be prepared in autumn when the soil is easier to break up. Delaying planting of seedlings until late June to early August allows time for the mounds to settle and leach some of the soil salt.

Herbicide application in these previously pastured areas is essential. A combined knockdown and residual herbicide should be applied in May. This needs to be carried out when there is no predicted rain for at least 2 to 3 days after application. This ensures effective absorption, and minimises drainage into wetland.

Seedling stock should be robust to enable maximum survival. Species that are recommended for planting in this area are not indigenous to this site, as they are specifically salt tolerant. Due to the now saline conditions of the site, only salt tolerant species are recommended for planting in the short term. When salinity levels decrease in these areas, local species can be reintroduced.

Species recommended include:

C. obesa

M. cuticularis

Atriplex cinerea, A. amnicola, A. undulata

Acacia saligna

Mixed interplanting in ridge furrows is recommended to give a more natural appearance. Broadcast seeding of *Atriplex* species on to mounds in June, (2 years after the initial planting) can be done to establish a ground cover. The mounds need to have crevices for seed lodgement if broadcast seeding is going to be done. Raking is recommended.

Land Management Unit 2

This land unit deals with areas affected by mild salinity and waterlogging. These conditions may be found in an entire saline seep area, or in the area surrounding a severly affected site. These areas can be identified by 80% pasture cover which is mostly sea barley grass (Pettit and Froend, 1992).

Recommendations;

These conditions are treated much the same as a severly affected area, although mulching is not considered necessary.

Additional species that are suitable to this soil type are:

E. cornuta and *E. occidentalis*

E. rudis

Broadcast seeding of all species is recommended in June.

Land Management Unit 3

This unit looks at non saline or waterlogged areas, with no (or little) salinity or waterlogging problems. These areas are usually found outside saline seeps, and have a typical pasture cover.

Ripping and mounding is not required in this land management unit, as a part of revegetation strategies. This will retain the natural contours of the land, and provide a more natural appearance. Herbicide treatment described above is recommended i , these areas.

Research has shown that most species are suitable for planting in these areas (Pettit and Froend, 1992), therefore the species recommended will be those that occur naturally in the area.

Planting of seedlings in best in the early rain season, while broadcast seeding can be done in April/May.

Land Management Unit 4

My research has shown that an additional category is evident on this site, as areas of fresh waterlogging were identified, which have their own specific rehabilitation needs. This area is shown in Figure 5.3, and includes the low salinity area along the stream channel.

Freshwater emergents grow throughout this area, although it is only seasonally inundated. Revegetation in this land unit should include these emergent species. Transplanting and broadcast seeding of these species is recommended as per methods described by Chambers *et al*, 1995. Western Power have shown an interest in organising community transplanting days, to increase the distribution of these emergents throughout this land unit.

Ripping and mounding are not recommended in this land management unit, to protect natural seedling regeneration.

Other Management considerations

Natural Regeneration

Some native flora species have regenerated naturally on the site and the success of the seedlings have been observed since the exclusion of grazing stock. Areas of natural regeneration have been mapped and are shown in Figure 5.2. These areas must support suitable conditions for regeneration and should be protected from site disturbances. Manual planting around these areas is preferrable to any mechanised site works. These areas also appear to be suitable for broadcast seeding with appropriate species.

The seedlings are associated with mature remnants that still exist in the wetland. Predominantly, the regeneration is of *E. rudis* although other species deserve mention. Regeneration area 3 is close to a large isolated *E. calophylla* and the seedlings at this site includes this species with *E. rudis*. Regeneration area 7 is the existing paperbark forest within the wetland site. Seedlings of many species were observe throughout this area. The cleared transmission line easement supports shrub species which have regrown from clearing. Regeneration area 8 is close to a small seepage area with high salinity (seepage 2). Acacia saligna saplings was observed growing south of this seep. This confirms George's (unpublished) recommendations for planting A. saligna in areas with ECa higher than 150mS/m.

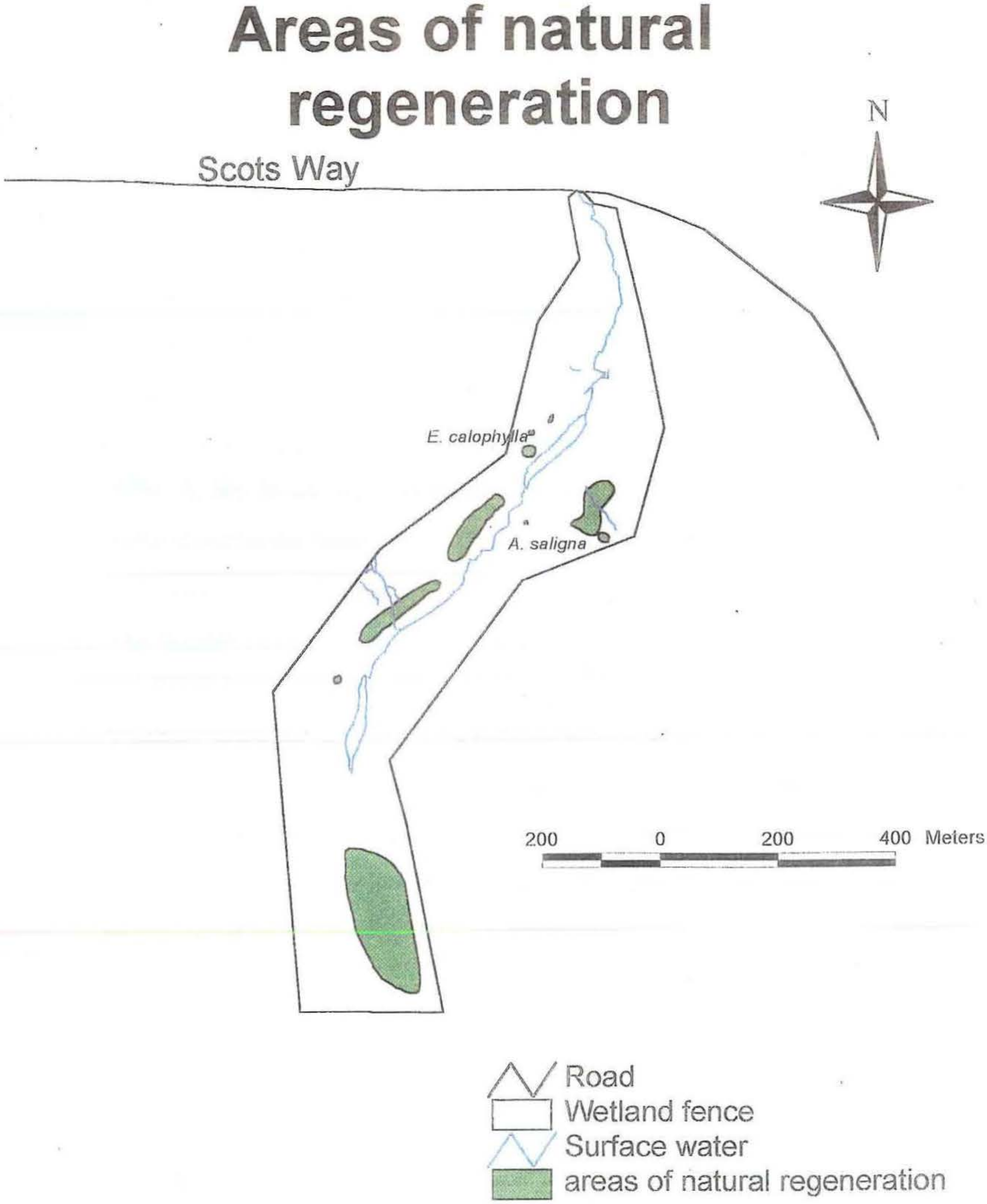


FIGURE 5.2: Areas of Natural Regeneration
All areas predominantly *Eucalyptus rudis* regeneration
Areas with *Acacia saligna, E. calophylla* are as marke

Fire

A fire hazard can develop with fencing previously grazed and pastured riparian vegetation. Pasture regrowth should be controlled by manual means, such as slashing, in preference to mechanised weed removal. Fire has a negative impact on the conservation and recreation values of bushland. If a fire occurs, rapid suppression is recommended to protect biodiversity (Kaeshagen, 1995). A fire break will be maintained by Western Power, adjacent to the wetland perimeter fence.

Feral animals

A baiting program has been initiated to eradicate introduced foxes and rabbits. Rabbits have caused considerable destruction in the paperbark forest in the southern area of the wetland. Foxes pose a threat to native fauna within the reserve. Western Power envisage a time when small native marsupials can be reintroduced to the area.

Surrounding catchment use

Surrounding catchment use can have an impact on the wetland. Management of these external issues is important to minimise impact on the wetlands. Farmland on the western side of the wetland is a source of nutrients. This may become detrimental to the water quality of the wetland. Liasion with the farm manager to improve fertiliser application may reduce the level of nutrients entering the wetland.

Discussion

Western Power objectives have limitations on the extent of rehabilitation, as complete site restoration cannot be carried out due to plans to provide infrastructure for educational and recreational utility. The fencing of the wetland was seen as a priority in previous studies on the site (Dames and Moore, 1994). However, the fence has created problems with water flow, which in turn has caused major erosion. The fence has prevented the use of the wetland as a corridor between Collie River and the State Forest.

Conclusion

Only a brief outline of the rehabilitation plan is presented here. A detailed plan has been prepared for Western Power, and is available from the author.

Chapter 6 General discussion

The method used by this study to develop a rehabilitation plan was restricted to a 6 month time period. Within this period, studies of the hydrology, salinity and nutrient levels of the site were completed. These aspects, combined with a review of rehabilitation practices, culminated in the development of the rehabilitation plan.

Other rehabilitation plans consulted, involved extensive long-term hydrology monitoring which were beyond the scope of this project. However the hydrology testing which was completed, gave a good indication of the groundwater inputs.

Within the time frame, the methods chosen were found to be suitable to provide enough information to formulate a workable plan. Any further information collected will complement the existing the plan. The success of the plan can only be determined with future monitoring. This will also recognise any alterations that may be required to the management plan.

The methods used in this study could be applied to formulate rehabilitation plans for similarly affected wetlands. However each site has its own unique problems and restrictions that need to be addressed.

Western Powers' desires to offer the site as a community resource limits the sites' potential to be restored. Rehabilitation needed to incorporate public access and interpretative infrastructure.

Unfortunately the potential for this wetland is secondary to the needs of Western Power to utilise the Coollangatta Farmland for the power station and associated by-products.

However, Western Power are very enthusiastic about the rehabilitation of the wetland. Site preparation and initial planting began in the winter of 1996 and there are plans to continue implementing the recommendations of the plan. Previous revegetation has involved the community and it is anticipated that this will continue in the future.

Achieving the objectives of this project provided enough understanding of the hydrology, salinity and external influences that have contributed to the degradation of the site. This understanding enabled the development of an appropriate rehabilitation plan, which could be utilised in other areas of the south west of Western Australia.

References

ANCA, 1996. *RAMSAR Sites*. Canberra: Australian Nature Conservation Agency.

Anon., 1994. *Toolibin Lake Recovery Plan and Recovery Action*. Perth: Department of Conservation and Land Management.

ANZECC, 1992. *Australian Water Quality Guidelines for Fresh and Marine Water*. Canberra: Australia and New Zealand Environment and Conservation Council.

APHA, 1989. *Standard Methods for the Examination of Water and Wasterwater* 17th Ed.). American Public Health Association, Washington D.C.

Aplin, G., Mitchell, P., Clough, H., Pitman, A., Rich, D., 1995. *Global Environmental Crisis: An Australian Perspective*. Melbourne, Oxford University Press

Bell D.T., and Froend R.H., 1990. Mortality and growth of tree species under stress at Lake Toolibin in the Western Australian Wheatbelt. In *Journal of the Royal Society of Western Australia* 73 (3) p63-66.

Bennett D., George R., and Ryder A., 1995. *Soil Salinity Assessment using the EM38: Field operating instructions and date interpretation*. Perth: Department of Agriculture, Western Australia. Misc. publication No. 4/95

Black, P.E., 1996. *Watershed Hydrology.* 2nd Edition. Michigan: Ann Arbor Press Inc.

Chambers, J.M., Fletcher, N.L., McComb, A.J. 1995. *A Guide to Emergent Wetland Plants of South Western Australia.* Murdoch Unversity W.A.

Conacher A., 1982. Dryland agriculture and dryland salinity. In *Man in the Australian Environment.* W.S. Hanley and M.J.M. Cooper (Eds.) Sydney: McGraw-Hill pp 113-125

Cooke G.D., Welch E.B., Peterson S.A., and Newroth P.R., 1993. *Restoration and Management of Lakes and Reservoirs* (2nd Ed.). Lewis Publishers, Florida, USA.

Dames and Moore, 1994. *Wetland Survey: Collie Power Station Project.* Report prepared for the State Energy Commission of Western Australia, Perth.

Davis, J.A., Rolls, S.W., and Wrigley, T.J., 1991. *A Survey of the Environmental Quality of Wetlands on the Gnangara Mound, Western Australia.* Perth: Water Authority of Western Australia in conjuction with the Environmental Protection Authority, Western Australia.

Davis J., 1993. *Management of Aquatic Systems: Practical exercises and manual of practical methods.* Reader for School of Biological and Environmental Sciences, Unit N311. Murdoch University, Perth, W.A.

Davis J., and Rolls, S., 1987. *A Baseline Biological Monitoring Programme for the Urban Wetland of the Swan Coastal Plain, Western Australia.* Perth: Environmental Protection Authority, Bulletin 265.

EPA, 1988. *The Lake and Reservoir Restoration Guidance Manual* (1st Ed.). Environmental Protection Agency, Washington D.C., U.S.A.

EPA, 1991. *Environmental Protection Policy: Swan Coastal Plain Wetlands.* Environmental Protection Authority, Perth.

Evans, S., 1996. *Baseline Monitoring of Western Wetland, Collie Power Station.* Unpublished report, Edith Cowan University, Perth.

ESRI, 1992. *Understanding GIS: The ARC/INFO method.* Rev. 6. Environmental System Research Institute Inc, USA.

ESRI, 1994. *ArcView : Introducing ArcView.* Environmental System Research Institute Inc, USA.

Froend R.H., Heddle E.M., Bell D.T., and McComb A.J., 1987. Effects of salinity and waterlogging on the vegetation of Lake Toolibin, Western Australia. In *Australian Journal of Ecology* **12:** (3) p281-298.

Froend R.H., and McComb A.J., 1991. An account of the decline of Lake Towerrinning, a wheatbelt wetland. In *Journal of the Royal Society of Western Australia.* **73** (4) p123-127.

Froend, R., and Davis, J., 1995. Disturbances affecting wetlands and how to manage them. In M. Scheltema and J. Harris (Eds.) *Managing Perth's Bushlands.* Greening Western Australia, Perth.

Froend R.H., Halse S.A., and Storey A.W., in press. *The Recovery of Lake Toolibin, Western Australia.*

Geonics, 1992. *EM38 Operating manual.* Ontario, Canada: Geonics Ltd.

George R.J., unpublished. *A selection of High Water Use species for Mid to Lower-slope and Discharge zone planting.*

George R.J., Cochrane D.L., and Bennett D.L., 1994. Groundwater systems responsible for dryland salinity in the Lake Towerrinning catchment, Western Australia. In *Proceedings of Water Down Under 94.* ACT: Australian Institute of Engineers. pp 355-360.

George R.J., McFarlane D.J., and Speed R.J., 1995. The consequences of a changing hydrologic environment for native vegetation in southwestern Australia. In D.A. Saunders, J.L. Craig, and E.M. Mattiske (Eds.) *Nature Conservation 4: The Role of Networks.* NSW: Surrey Beatty and Sons Pty Ltd. pp9-22.

Halse S.A., 1987. *Probable Effects of Increased Salinity on the Waterbirds of Lake Toolibin.* Perth: Department of Conservation and Land Management Technical Report No. 15.

Hammer, D.A., 1992. *Creating Freshwater Wetlands.* Lewis Publishers, USA.

Hearn S.J., 1988. *Soil Conservation and Management Strategies for the Toolibin Catchment.* Perth: Western Australian Department of Agriculture. Technical Report 75.

HGM, 1994. *Collie Power Station Conceptual Layout for Ash Disposal Sites and Water Storage Dams*; Report to SECWA. Perth: Halpern Glick Maunsell, Report No. PG3123A/1.

Hillman, R.M., 1981. Land and stream salinity in Western Australia. In *Land and Stream Salinity: Developments in Agricultural Engineering 2.* J.W. Holmes and T. Talsma (Eds.)pp 11-18. Amsterdam: Elsevier Scientific Publishing Co. An International Seminar and Workshop held in Nov 1980, Perth, Western Australia. Reprinted from Agricultural Water Management Journal 1981 Vol 4: No. 1, 2 and 3.

Hudson, N.W., 1993. *Feild measurement of soil erosion and runoff.* Rome: Food and Agriculture Organisation of the United Nations; Bulletin 68.

Kaeshagen, D. 1995. Intergrating Fire into Bushland Management.*IN* J. Harris (Ed). *Burning Our Bushland.* pp59-61 W.A. Urban Bushland Council Perth

Keighery, B., 1994. *Bushland Plant Survey: A guide to plant community survey for the community.* Wildflower Society of Western Australia, Perth.

Loh, I.C. and Stokes R.A., 1981. Predicting stream salinity changes in souther-western Australia. In *Land and Stream Salinity: Developments in Agricultural Engineering 2.* J.W. Holmes and T. Talsma (Eds.)pp 227-254. Amsterdam: Elsevier Scientific Publishing Co. An International Seminar and Workshop held in Nov 1980, Perth, Western Australia. Reprinted from Agricultural Water Management Journal 1981 Vol 4: No. 1, 2 and 3.

Microstation, 1995. *Microstation Reference Guide: Academic suite.* USA: Bentley Systems Inc.

Newbury, R.W., 1995. Rivers and the art of stream restoration. In *American Geophysical Union Monograph Series: M. Gordon Wolmon Volume.* June 1995.

OECD, 1982. *Eutrophication of Waters: Monitoring assessment and control.* OECD

Peck A.J., 1979. How saltland can be reclaimed. In *Western Australia Journal of Agriculture* **20:** 72-73

Pettit N.E., and Ritson P., 1991. *Preformance of Selected Tree and Shrub Species Grown for Stream Salinity Control in the Wellington Reservoir Catchment.* Perth: Water Authority of Western Australia Report No. WS 78.

Pettit, N.E. and Froend, R.H., 1992. *Research into Reforestation Techniques for Saline Groundwater Control.* Report No. WS 97. Water Authority of Western Australia, Perth.

Preston M., 1995. *Collie Power Station Ash Disposal Site: Groundwater monitoring programme inception report.* Report to Western Power. Perth: Ultramafics P/L.

Schofield N., and Scott P., 1991. Planting trees to control salinity. In *Western Australian Journal of Agriculture* **Vol 3:** 3-10

Schofield N.J., and Bar M.A., 1991. Valley reforestation to lower saline groundwater tables: Results from Stene's Farm, Western Australia. In *Australian Journal of Soil Research.* **29:** 635-50.

Schofield, N.J., Loh, I.C., Scott, P.R., Bartle, J.R., Ritson, P., Bell, R.W., Borg, H., Anson, B., and Moore R., 1989. *Vegeation Strategies to Reduce Stream Salinities of Water Resource Catchments in South-West Western Australia.* Perth: Water Authority of Western Australia,Water Resource Directorate Report No. WS 33.

Schofield N.J., Ruprecht J.K., and Loh I.C., 1988. *The Impact of Agricultural Development on the Salinity of Surface Water Resources of South-West Western Australia.* Perth: Water Authority of Western Australia, Water Resources Directorate. Report No. WS27.

SECWA, 1990. *Proposed Collie Power Station: Environmental review and management programme* Report No. BD 90/12. State Energy Commission, Western Australia.

Sharma M.L., Barron R.J.W., Williamson D.R., 1987. Soil water dynamics of lateritic catchments as affected by forest clearing for pasture. In *Journal of Hydrology*. **94:** 29-46

Skaler, 1993. *The SAN^TM Segmented Flow Analyser and its Application* (Publication N. 060993). Skaler Analytical B.V., Breda, Netherlands.

Steering Committee for Research on Land Use and Water Supply, 1989. *Stream Salinity and its Reclamation in South-west Western Australia.* Perth: Water Authority of Western Australia, Water Resources Directorate.

Stokes R.A., and Sheridan R.J., 1985. *Hydrology of Lake Toolibin*. Perth: Water Authority of Western Australia, Hydrology Branch, Report No. WH2.

SVAC, 1982. *Salting of Non-irrigated Land in Australia.* Melbourne: Soil Conservation Authority of Victoria.

Thompson, J.R., 1992. *Prairies, Forests and Wetlands: The Restoration of Natural Landscape Communities in Iowa.* University of Iowa Press, USA.

Tizard, B.K. 1993. *Reality, Dreams and Pathways: a manual for preparing and implimenting management plans.* Perth: Armadale Settlers Common Field Study Centre.

Western Australian Water Resources Council, 1986. *Water Resources and Water Use, Summary of Data for the 1985 National Survey.* Water Resource Perspectives Western Australia: Report No. 2. Perth: WAWRC Publ. No. WRC 7/86.

Williams B., 1988. Subsurface Investigations. In *Australian Soil and Land Survey Handbook: Guidelines for conducting surveys.* R.H. Gunn, J.A. Beattie, R.E. Reid, and R.H.M. van de Graaff (Eds.) Chap 11 pp 154-165. Sydney: Inkata Press.

Williams, B.G., and Bullock, P.R., 1989. *The Classification of Salt-affected Land in Australia.* Australia: CSIRO Division of Water Resources, Technical Memorandum 89/8.

Williams W.D., 1966. Conductivity and the concentration of total dissolved solids in Australia lakes. *Australian Journal of Marine and Freshwater Research.* **17**: 169-176.

Williams, W.D., 1980. *Australian Freshwater Life: The invertebrates of Australian inland waters.* Melbourne: Macmillan Company of Australia.

Appendix 1

Recommended species list

George, R., unpublished data, Agricultural Department of Western Australia, Bunbury.

Table 1. A Selection of High Water Use Species for Mid to Lower-slope and Discharge Zone Planting.

Note: * It is assumed that good site preparation is undertaken before planting.

This would include:

Ripping to 1 metre deep on clay soils, 0.5m on deep sands

Mounding and surface drainage on waterlogged sites. The idea here is to allow the trees to establish under drained conditions.

Weed control with a knockdown and residual herbicide. Weed control on saline sites may not be necessary but beware, improved soil conditions due to ripping and mounding often cause a flourish of weed growth.

Scalping works well in low rainfall areas as it provides rainfall catchment and weed control, however the site must not be subject to waterlogging or inundation.

* Growth rates of the species listed will generally be higher, at the lower salinities within each salinity range.

* In most cases, the species listed within a higher salinity class, will grow well in a lower soil salinity class.

HIGH RAINFALL (> 600mm)

i) **ECa = 0-50 mS/m** (EM38 in Horizontal Mode)

E. globulus (Tasmanian Blue Gum)
E. maculata (Spotted Gum)
E. grandis (Rose Gum) [rainfall > 800mm]
E. saligna (Sydney Blue Gum)
E. botryoides (False Mahogany)
E. sideroxylon subsp. tricarpa (Red Ironbark)

ii) **ECa = 50-150 mS/m** (EM38 in Horizontal Mode)

E. camaldulensis (River Red Gum or Saltdown Clones)
E. cladocalyx (Sugar Gum)
E. melliodora (Yellow Box)
E. microcarpa (Grey Box)
E. robusta (Swamp Mahogany)
E. rudis (Flooded Gum)

iii) **ECa = >150 mS/m** (EM38 in Horizontal Mode)

E. occidentalis (Flat Topped Yate)
Acacia saligna (Golden Wreath Wattle)
Casuarina obesa (Swamp Oak)
C. cunninghamiana (River Oak)
Atriplex amnicola, undulata, cinerea (Saltbush)

Appendix 1
George R, unpublished data. Dept Ag, Bunbury

Appendix 2: Species List for Salinity and Water Logging

Various authors have recommended a variety of species to be used in a wetland rehabilitation program. This is a list of recommended species with the author.

Species Name	Common Name	Author
Casuarina obesa (a)	swamp sheok	1,2,3,4
Eucalyptus camaldulensis (d)	red river gum	1,2,3,4
E. cornuta (a, b)	yate	4
E. loxopheba (a)	york gum	2
E. occidentalis (a)	swamp yate	1,2,3,4
E. platypus (c)	roundleafed moort	3
E. rudis (a)	flooded gum	2
E. sargentii (b)	salt river gum	1,2,3,4
E. spathulata (c)	swamp mallet	2,3
E. wandoo (a, b)	wandoo	4
Melaleuca cuticularis (a)	saltwater paperbark	4
M. lanceolata (a)	Rottnest teatree	3
M. rhaphiophylla (a)	freshwater paperbark	4
Tamerix aphylla (e)	Athel tree	3

1. Schofield, N.J., I.C. Loh, P.R. Scott, J.R. Bartle, P. Ritson, R.W. Bell, H. Borg, B. Anson & R. Moore (July 1989)

2. Schofield, N.J. & P.R. Scott (1991)

3. Pettit, N.E. & R.H. Froend (June 1992)

4. Pettit, N.E. & P. Ritson (Feb 1991)

Place of Origin: (a) south west Western Australia
(b) south east Western Australia
(c) Western Australia (unspecified)
(d) eastern Australia (unspecified)
(e) Africa

Appendix 3.1

Calculations for table 3.3

Evapotranspiration data from
Greenwood E., Klien L., Beresford J., and Watson G., 1985. Differences in annual evaporation between grazed pasture and *Eucalyptus* species in plantations on a saline farm catchment. In *Journal of Hydrology*. 78: 261-278

Attached table shows calculations for budget in table 3.3

site	surface area (m2)		13/07/96		
		width(m)	c-sect area (m2)	length (m)	storage (m3)
1	49	3.5	0.11	14	1.54
	0				
3	126	0.6	0.05	210	10.5
4	65	1.25	0.04	52	2.08
5	172.7	1.1	0.09	157	14.13
6	259	3.7	0.13	70	9.1
7	409.5	1.95	0.17	210	35.7
8	5.355	0.51	0.05	10.5	0.525
9	8.19	0.18	0.007	45.5	0.3185
10	12.25	0.25	0.008	49	0.392
11	7.35	0.21	0.006	35	0.21
12	635.25	1.05	0.1	605	60.5
13	0			0	0
total					
surface area (m2)	1749.595				
	1750				
2 area*depth	2437		2437	0.5	1218.5
lake 2	2268		2268	0.5	1134
area*depth					
total					
surface area (m2)	6455				
channel storage					2487.4955
ET		13/07/96	11/08/96		
EO (m)		0.0022	0.002		
ET(jarrah/winter)	1.15EO	0.00253	0.0023		
ET (pasture/winter)	.5EO	0.0011	0.001		
ET (bare soil)	0EO	0	0		
surface water	.7EO	0.00154	0.0014		
area (m2) in wetland		ET(m3)			
jarrah	157693	398.96329	362.6939		
pasture	159831	175.8141	159.831		
bare ground	50	0	0		
surface water july	6455	9.9407	8.6968		
surface water aug	6212		8.6968		
total ET		584.71809	539.9185		

		11/08/96		
surface area (m2)	width (m)	c-sect area (m2)	length (m)	storage(m3)
78.4	5.6	0.09	14	1.26
0				
378	1.8	0.13	210	27.3
36.4	0.7	0.02	52	1.04
157	1	0.06	157	9.42
45.5	0.65	0.04	70	2.8
323.4	1.54	0.22	210	46.2
4.41	0.42	0.04	10.5	0.42
11.375	0.25	0.005	45.5	0.2275
14.7	0.3	0.006	49	0.294
7	0.2	0.004	35	0.14
399.3	0.66	0.26	605	157.3
51.8	0.7	0.02	74	1.48
1507.285				
1507				
2437		2437	0.5	1218.5
2268		2268	0.5	1134
6212				
				2600.3815