WETLANDS REHABILITATION FOLLOWING MINERAL SANDS MINING IN AUSTRALIA[1]

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Abstract.--The mineral sands industry has rehabilitated a variety of native ecosystems, including wetlands, on both the east and west coasts of Australia. On North Stradbroke Island in southern Queensland, wetland habitats have developed by natural succession in depressions formed within the frontal dune system. Rehabilitation was facilitated by planting a rhizomatous sedge as a primary colonizer. Subsequent vegetation distributions were closely related to soil water availability. On an extensive wet heath plain in northern New South Wales, techniques were developed to rehabilitate a range of wetlands ecosystems. It was essential to reestablish ground levels accurately and to drain surface water before and after mining. Topsoil techniques were developed to aid regeneration from vegetative propagules. The vegetation also responded to moderate fertilizer dressings. The site is now incorporated in a national park. At Capel in Western Australia, a series of lakes formed from volume loss during mining are being developed as wetlands for waterbirds. Baseline studies have identified the current limitations of the young habitats whilst highlighting their potential for further development. A five-year programme has commenced involving site development works and an integrated research programme on wetlands development and waterbird ecology, with particular emphasis on the food chain.

INTRODUCTION

Mining for the heavy mineral sands rutile, zircon, ilmenite and monazite commenced at Byron Bay on the north coast of New South Wales, Australia, in 1934 (Morley 1981). Two factors enabled the industry to develop to the extent that Australia has dominated world markets for these products. First, certain geological processes placed deposits with the world's richest grades of rutile and zircon in coastal sand masses on Australia's east coast (Shepherd 1986). These rich ore bodies were formed in coastal dunes extending from north of Sydney in New South Wales to Rockhampton in Queensland (fig. 1). In Western Australia, major deposts were also formed on the coastal plain both south and north of Perth, although these deposits were more varied in their mineral assemblage. Second, the technology for the efficient mining and separation of the

[1]Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and the US Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA.

Proceedings America Society of Mining and Reclamation, 1988 pp 146-153
DOI: 10.21000/JASMR88020146

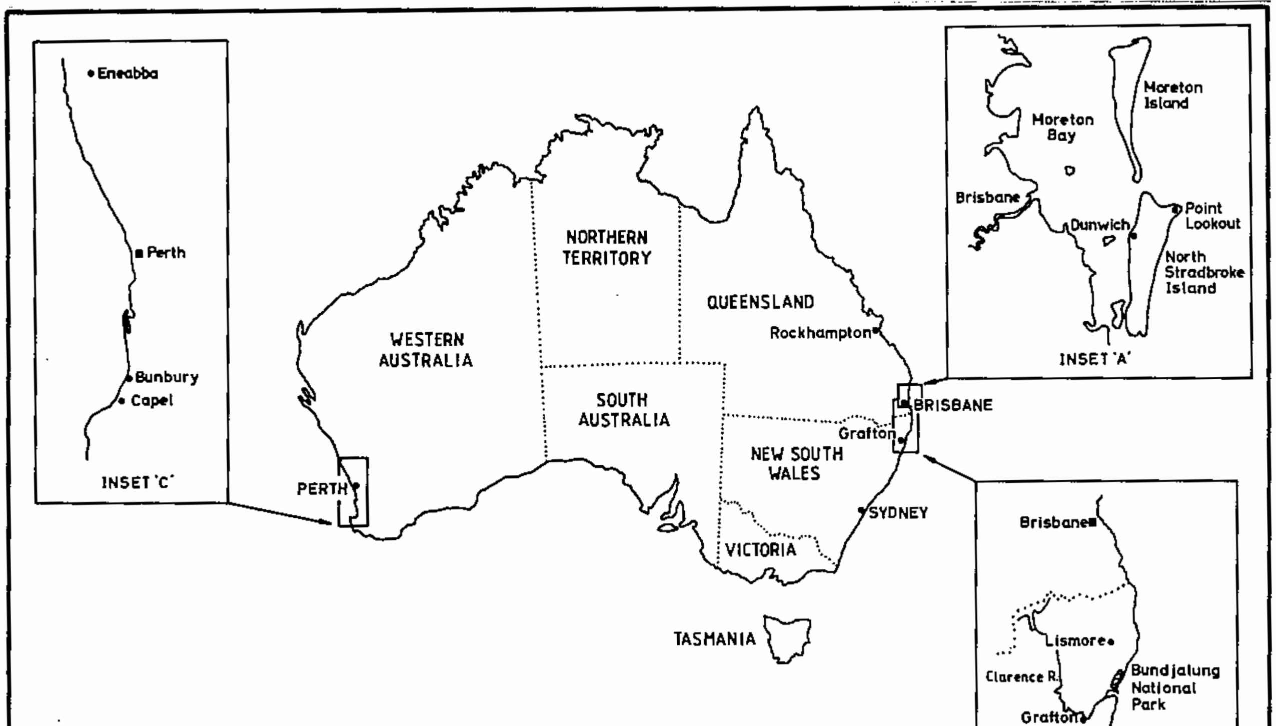

Figure 1--Location of mineral sands deposits along the eastern and western coasts of Australia.

heavy minerals was developed in Australia (Morley 1981). As a consequence of its development, Australia's mineral sands industry has mined over many landforms, vegetation types, and climates, and developed its technology for rehabilitation of native ecosystems accordingly (Brooks 1987).

On the east coast, the major landforms mined were frontal dunes of Holocene age, coastal lowlands containing strand lines of late Pleistocene age, and aeolian high dunes ranging in age from Holocene to Pleistocene. Vegetation types included sand spinifex grasslands of the frontal dunes, closed scrubs, sclerophyll forests, heaths, wetlands, and littoral rainforests. The climate varies from temperate in the south to subtropical in the north, with annual average rainfall in the range of 1,100-1,600mm (43-63 inches).

On the west coast, the landform consists of extensive sand plains with subdued topography, possibly of late Tertiary or Pleistocene age. Considerable mining has taken place on agricultural land, particularly in the southwest, although some low quality forests have also been encountered. In the Eneabba area, north of Perth, low complex heathlands cover much of the mineralized areas. The climate is Mediterranean, with rainfall varying from about 530mm (21 inches) in the north to 830mm (33 inches) in the south.

In this paper, the author will discuss rehabilitation of wetlands carried out by Associated Minerals Consolidated Limited (AMC), the world's largest mineral sands producer, in three states of Australia.

NORTH STRADBROKE ISLAND

North Stradbroke Island is a large sand mass lying 40km (25 miles) offshore from Brisbane in southeast Queensland (fig. 1). Together with Moreton Island immediately to its north, it encompasses Moreton Bay. The island has an area of 27,520ha (68,000 acres) and is approximately 37km (23 miles) long and 11km (7 miles) across its widest point.

The climate of North Stradbroke Island is subtropical. Mean maximum temperatures range from 19.4°C in July to 28.0°C in January, whilst mean minimum temperatures range from 11.5°C in July to 19.9°C in January. The mean annual rainfall is 1,645mm (65 inches), with the heaviest falls occurring in the January-March period.

Whilst aeolian high dunes of Pleistocene and Recent times occupy the bulk of the island, frontal dunes formed in the Holocene extend the full length of the island's east coast. Behind the frontal dunes and at the foot of the high dunes lies an extensive freshwater swamp (Eighteen Mile Swamp) at about R.L. 4.5m, which is a window of the hydrological gradient from the high dunes to the sea. The frontal dunes have experienced long periods of instability. Wartime aerial photography indicates numerous large blowouts, both active and inactive, encroaching into the swamp behind (Brooks 1980). Indeed, the northern part of the swamp had been overrun by sand drift from the unstable dunes. Prior to mining, the frontal dunes were mostly bare drifting sand with only a few remnant vegetated dunes occurring just above high water mark.

Mining for mineral sands commenced about 1950 as a scraping operation centred on high grade beach placers (Morley 1981). In 1956, small-scale dredging commenced on the frontal dunes, with operations concentrated on the northern half of the dune system. In 1970, the Company moved a large dredge and concentrator unit onto the southern end of the frontal dune system. From there, the plant moved northwards along the dunes, through both virgin and previously mined ground, and mining was completed in this system in 1977.

Rehabilitation of these frontal dunes after mining aimed at recreating a diverse, though stable, landscape so as to allow a number of plant communities to develop in the various habitats formed (Brooks and Bell 1984). The dunes were revegetated with sand spinifex grass (Spinifex sericeus) and other herbs, together with native tree and shrub species adapted to this habitat.

With the methods used, a number of depressions were formed in the dune system, some deliberately, some by natural means. Many of them intersected the ground water table, and wetlands vegetation began to colonize them. It soon became apparent that successional development of new ecosystems was occurring, and this attracted the interest of research students of Queensland Institute of Technology and the University of Queensland.

The main depression studied dates back to 1974, when it was a deflation zone behind a broken line of remnant dunes. The mining plant passed by on the western side during January, 1974, whilst high winds and heavy rains associated with cyclonic conditions prevailed in the area. Heavy seas washed into the depression at that time. Later in the year, the remnant dune was repaired with levees across the washouts, dune-building fences, and fertilizer to encourage the growth of spinifex. The adjacent mined area was rehabilitated in the usual way (Brooks 1980).

Initially, the water trapped in the depression was saline, but as the ground level was below the natural ground water gradient, the salt water was quickly flushed out. In September, 1974, shoots of the small rhizomatous sedge Carex pumila were planted around the banks of the resulting waterhole to provide stability. Within three months, the Carex pumila had formed a complete ground cover, there were algae and invertebrates in the pond, and birdlife was attracted to the area.

By February 1975 a total of 12 native plant species had colonized the pond and its immediate environs, although only one of these (Carex pumila) had been planted. In May of that year, seedlings of Banksia integrifolia, Casuarina equisetifolia, Cupaniopsis anacardioides, and Pandanus pedunculatus were planted around the banks as part of the tree planting programme for the surrounding area.

In November 1977, studies of various aspects of the developing ecosystem were initiated. In February 1978, the depression was approximately 40m wide, and the pond 140m long, up to 30m wide and 1.25m deep. At this stage movement of sand into the depression from the beach had been halted by spinifex on the rehabilitated foredune.

In May 1978, 40 species were recorded for the site not including the tree seedlings planted in 1975 (College 1978). In August 1979, the count was 43 including 7 which were not recorded in 1978, while 4 species recorded in 1978 appeared to have died out (Connell 1979).

All of the species which colonized the site had seed or other propagules which would allow either wind or bird dispersal. As the prevailing wind was from the sea, it would appear that birds and perhaps other animals were the prime source of propagules in the area.

More than half of the species recorded in 1979 were common with a group of similar undisturbed "seepage areas" on Moreton Island to the North (Durrington 1977). Observations on other similar ponds on Stradbroke Island indicate that, with age, such sites become more similar to undisturbed sites when considered on the basis of species composition (Connell 1979).

The very rapid increase in both standing biomass, particularly in Typha and Scirpus communities, and the accumulation of organic matter in and around the pond has provided food and protection for a variety of fauna including birds, reptiles, mammals, amphibians, and invertebrates. Fish occur in the pond, but their origin is uncertain.

In an attempt to define those factors determining the distribution of the major plant species around the pond it became apparent that the distributions were closely related to the level of available soil water. As might be expected in such well-drained sands, total standing biomass was correlated with water availability, and generally decreased with vertical distance from the pond.

It would appear that the choice of C. pumila for early planting around the pond was a good one. Although it originally formed quite thick pure stands, it has given way to many other native species, particularly Phyla nodiflora and Bacopa monniera. Toward the end of 1978 about equal biomass contributions were made by these three species, but C. pumila spanned a wider range of environmental conditions (including soil water and nutrient availability) than the other two, or indeed any species present (College 1978). Although the pond was entirely surrounded by S. sericeus, virtually none of it has grown into the pond or its margins. This suggests that planting of species such as C. pumila can be valuable in stabilizing and revegetating wet depressions. The presence of readily available water is the greatest difference between such a depression and its surrounding dunes. The resulting plant community apparently progressed very much further along its successional path than its surroundings, and in so doing provided a significant degree of shelter for further plant and animal "colonizers".

Following the promising early development of the vegetation in this depression, a similar approach was adopted at other sites in the dune system. In particular, a number of lagoons had been created during and at the completion of mining, and their banks were planted with C. pumila in the same way. Similar successional development occurred, although it appears that their rate of development may have been influenced by such factors as site exposure and water depth.

It was concluded that the techniques employed enabled habitat diversity to be increased in the newly stabilized dune system. Success resulted from creating suitable conditions for plant colonization to follow natural successional trends.

JERUSALEM CREEK

Many mineral sands ore bodies on the east coast occur as ancient strand lines underlying extensive heath plains referred to as coastal lowlands. The topography of these lowlands is subdued with complex drainage patterns giving rise to a mosaic of dryland and wetland vegetation associations. Typical vegetation types include low dry open forests and shrublands, dry heaths, wet heaths, sedgelands, and swamp woodlands.

One such area occurs on the north coast of New South Wales at a location known as Jerusalem Creek, north of the Clarence River (fig. 1). Mining commenced here in 1890, when prospectors discovered gold in the ancient strand lines, and small-scale gold mining continued spasmodically for many years (Morley 1981). Following World War II, a number of small mineral sands operations were carried out, however, they failed to survive various market pressures. Subsequently, AMC commenced large-scale operations in 1969, and continued through to 1982 when it was forced to close by government restrictions. Mining was conducted by bucketwheel excavator followed by a concentrator unit floating in a pond created by levees built across the pit. The mining plant followed the strand lines on a series of narrow, more or less parallel, mine paths over an area of about $13 km^2$ ($5 mi^2$).

For the first four years, the mining plant followed a low sand ridge supporting dry heath vegetation. Rehabilitation of this landform followed principles developed elsewhere (Brooks 1987). In 1974, the mining plant moved onto the lower lying country supporting wetlands vegetation associations. On this landform, the water table was typically at or above the ground surface for 4-6 months of the year, falling below ground level during the drier late winter-early spring months. The vegetation type was governed by moisture relationships, with wet heaths being slightly higher and inundated for shorter periods than sedgelands. Swamp woodlands carried surface water at all times except droughts.

Techniques for rehabilitating these wetlands were developed from hard experience. Early attempts were thwarted by a series of flood events. Vegetation attempted to regenerate from rootstock and seed in the replaced topsoil a number of times. On each occasion, the young vegetation was killed by scalding from the shallow surface water following heavy rains. Finally, about two years after the initial topsoil return, a short-term drought allowed the water table to fall below the surface and enabled freshly regenerated vegetation to develop above the height of normal water levels. The vegetation has since continued to develop satisfactorily.

From this experience, three important interrelated principles for the rehabilitation of wetlands were developed. Subsequent experience proved they were equally applicable to all wetlands vegetation types encountered.

First, it is essential to reestablish ground levels accurately. In this type of country, variations in contour are subtle, and changes in ground level of as little as 15cm (6 inches) can have a profound effect on drainage patterns and, hence, vegetation recovery. Therefore, control of tailings placement by operations personnel is critical and needs to be carefully planned.

Second, drainage of the area before and after mining is essential. Small drains were installed prior to mining to remove surface water, enabling the topsoil to be removed in moist though not sloppy condition. Otherwise, saturated topsoil would cause a loss of viability of propagules following disturbance. After mining the drains were reinstated so as to keep the water levels at or below the ground surface whilst the vegetation reestablished. The drains were removed when the vegetation had gained sufficient height and maturity to cope with inundation.

Third, topsoil handling procedures are critical because a high proportion of this vegetation can recover from vegetative propagules in the soil. Not only is moisture content important, but the topsoil needs to be handled carefully by the bulldozer operators. At Jerusalem Creek, a double stripping method was developed in order to minimise disturbance to the soil and damage to the plant propagules. The top 20-25cm was removed in slices by the bulldozer so as to retain the soil and plants in large lumps, and stored to one side of the mine path. A further 10-15cm was then stripped and stored on the opposite side. Immediately after the mining plant had returned the tailings to the mine path, the topsoil layers were returned to their respective positions. The topsoil storage time was governed by the rate of forward progress of the mining plant, but was of the order of 1-3 months.

Regeneration of the vegetation was further enhanced by the application of a moderate dose of mixed fertilizer following topsoil return. In an experiment conducted in 1976, a mixed fertilizer (10.0N:3.9P:6.1K) was applied to large plots (50m by 100m) at the rate of 500kg/ha (4 cwt./acre). At age 16 months, the regenerating wet heath had a higher species number, percent cover and abundance with fertilizer compared with no fertilizer (table 1). In fact, the area with fertilizer treatment had a higher species number than before mining, even though the soil had been retained within the boundaries of the vegetation association. The topsoil disturbance had stimulated species lying dormant in the soil. These species were usually relatively short-lived.

A common feature of the heath vegetation on the sand plains of the eastern Australian coastline is the widespread distribution of Xanthorrhoea spp. At Jerusalem Creek, X. resinosa subsp. fulva is a dominant or subdominant species, with cover values ranging from 6% to 28%, and densities from 5 to more than 10 "crowns"/m^2 (up to 105,000/ha). In the wet heath habitat, this species adopts an acauline habit, and many plants are multi-crowned. They rarely flower except after fire, and it is probable that the species is part of a fire-induced climax and an important component of the vegetation.

Whilst it is generally believed that the species will not survive topsoil storage, it was observed that at least some of the original plants survived the handling procedures used. Topsoil storage time and stripping method were two potential factors. To quantify these effects plant counts were carried out at five sites within the same plant community. All live crowns were counted at each site in 10 quadrats, each 10m by 10m, laid out in a line transect.

Table 1.--Response of rehabilitated wet heath at Jerusalem Creek to fertilizer at age 16 months (Brooks unpublished data).

	FERTILIZER	
	-	+
SPECIES NUMBER	25	39
PERCENT COVER	1.2	34.9
ABUNDANCE	1.15	5.27
SPECIES NUMBER PRE-MINING	34	

When topsoil was single stripped, there was no positive response to reduction of storage time on survival and regeneration within the time scale measured (table 2). However, at age 2 years, there was a large response to double stripping compared with single stripping. This response was further illustrated by the high level of regeneration at the site of age 1 year, after topsoil handling procedures had been further refined. Although the percentage survival of the plants is low, the level of regeneration is high relative to alternative methods available. As opportunities to collect seed of this species were very rare, it was not possible to reestablish it by direct seeding. Even if sufficient seed was available to raise nursery stock, it would not be economically feasible to plant out such stock at the densities shown. Hence, the additional care required in topsoil handling for the level of regeneration achieved was fully justified.

During the study it was also observed that the disturbance encouraged the plants to flower subsequently. This occurred at about age 3 years, when 20-30% of the plants were recorded in flower. Thus, although the population of X. resinosa subsp. fulva was reduced, significant numbers of plants survived with the potential to increase the population further in future years.

The adoption of the rehabilitation techniques described enabled the various vegetation associations, including swamp woodlands, to recover rapidly and successfully. The mined area is now incorporated in the Bundjalung National Park, and listed on the Register of the National Estate. In considering the registration, the Australian Heritage Commission formally acknowledged the success demonstrated in reestablishing the native ecosystems.

Table 2.--Recovery of crowns of <u>Xanthorrhoea resinosa</u> subsp. <u>fulva</u> from different topsoil handling regimes at Jerusalem Creek (Brooks unpublished data).

	SITE				
	1	2	3	4	5
Density (crowns per hectare)	430	670	110	1,970	6,540
Age (year)	3	3	2	2	1
Topsoil Storage Time (month)	1-2	3	1-2	1	1-2
Stripping Method	Single	Single	Single	Double	Double

CAPEL

In Western Australia, continuous mining for mineral sands commenced near Capel, 200km (125 miles) south of Perth, in 1956 (Baxter 1977). Mining in this area was based on the lower value mineral ilmenite, although very high grades have been mined at some sites resulting in significant volume loss. Whilst the contours of surrounding areas have been restored, the volume loss has been accounted for by creating lakes where the pits have intersected the water table.

Because more than three-quarters of the wetlands on the Swan Coastal Plain have been destroyed through various forms of development, these newly created lakes are showing potential for development as valuable waterbird habitats. Permanent freshwater bodies are particularly scarce, as in this Mediterranean climate (AAR 830mm, 32.5 inches) many wetlands dry up during the summer months.

The Company's minesite just south of Capel contains a series of such lakes. The main lake system was formed during mining between 1975 and 1979. There are eight lakes in the system with a total water surface of about 56ha (140 acres). Most of them are interconnected, as they receive effluent from the mineral processing plants and serve as the mine water supply. Some of the lakes occur on private land, although the majority of them are in a State Forest.

Initially, rehabilitation of the area mined was concentrated on reestablishing pastures on the surrounding land and on planting trees and shrubs around the banks of the lakes for aesthetics and to attract birdlife. Most of this work took place between 1977 and 1983. Meanwhile, the lakes became partially colonized with wetlands flora, and waterbirds were frequently observed to visit them.

In 1984, the Company commissioned the Royal Australasian Ornithologist's Union (RAOU) to advise on the potential of the lakes for development of self-sustaining wetlands ecosystems for the benefit of waterbird conservation.

Jaensch (1985) reported that, with a number of development techniques, the lakes had considerable potential to achieve the stated objective, as well as providing considerable opportunities for research, education and passive public recreation. On this basis the Company initiated its Wetlands Project in 1986.

A management committee for the project was established to advise the Company on objectives and priorities, management and research proposals, and budgets, and to review progress. Through its membership the committee taps the main expertise and responsibilities for wetlands and waterbird conservation in the state, thereby forging links with appropriate Government authorities, and research and conservation institutions. There is representation from the Company, RAOU, Department of Conservation and Land Management, University of Western Australia, and Curtin University of Technology.

One of the first steps in the project was to initiate a series of multi-disciplinary baseline studies to determine the current ecological status of the lakes and to indicate priorities for future research and development. Nearby natural wetlands were used as control sites. These studies were completed during 1987 and planning for a habitat enhancement programme and an ongoing research programme was commenced.

A preliminary survey of waterbird usage of the lakes, using volunteer observers once a month, was conducted from November 1984 to November 1986. A total of 24 species of waterbirds was recorded on the lakes system during the survey period (Jaensch 1986, Bamford and Jaensch 1987). Whilst the lake system supports an appreciable number of species and individuals, it is not as valuable as other natural wetlands in the district. Limitations of the habitat in supplying food and shelter were reported as being the main probable factors. This conclusion was supported by the observation that the older lakes were more heavily utilized by the waterbirds. Seasonal patterns of usage revealed that the system was of greatest value as a refuge in the dry season (late spring to late autumn) when seasonal waterbodies in the district dried up. Two species, Pacific Black Duck and Black-fronted Plover, were observed breeding on the lakes during the survey.

The breeding success of waterbirds on the lakes was studied during the 1986/87 breeding season (Bamford 1987). Although 12 species bred on a nearby natural swamp, 5 species bred on the lake system with a poor success rate. Most losses occurred within the first two weeks from hatching, the major causes apparently being poor nutrition and predation. The Pacific Black Duck, which relies heavily on invertebrates as a protein source, fledged only 2 ducklings from a minimum of 22. On the other hand, the Purple Swamphen, which has a more varied diet, fledged 7 chicks out of a minimum of 10. Breeding success was highest on the oldest lakes with better developed emergent vegetation providing more breeding sites and improved nutrition. The species list was increased to 27 during this study, 25 of which could have bred on the lakes given suitable conditions. Thus, these results reflect the early development of habitats on the lake system.

Lack of invertebrate larvae as a protein source was confirmed as one of the major factors in the poor breeding success of the birds (Cale and Edward 1987). Whilst the lakes have a high invertebrate species richness, abundance is low compared with natural wetlands. Eighty-three invertebrate taxa were recorded, the most abundant being Coleoptera (18%), Chironomidae (17%) and Crustacea (10%). The oldest lake supported 57% of all identified taxa, and was best in all habitat components, i.e., benthic, macrophyte and plankton. This result correlates strongly with the level of macrophyte cover. The faunal studies confirm that the lakes have the potential for development as self-sustaining wetlands, although the need to increase their productivity through habitat development is highlighted.

Factors limiting the productivity of the lakes were found by Gordon and Chambers (1987) to include steep slopes, hard substrates, and poor water quality. The ponds are well oxygenated, have no temperature and oxygen stratification, and show small diurnal changes. Water quality limitations include low pH, extremely high ammonia levels, low phosphorus concentrations, and high iron and manganese levels which could give rise to phosphorus complexing. Sediments are also low in inorganic and organic phosphorus. These studies demonstrate the need for extensive landscaping of the existing system to provide shallow areas with wide flat banks of soft sandy substrate so as to encourage the development of vegetation. Water quality is improving as effluent treatment facilities of the processing plants are being upgraded.

Hydrology studies have revealed that water levels in the lakes are being maintained artificially high by 0.5-1.0m because of the effluent stream and management of the lake system for mine water supply (Nield and Townley 1987). It was concluded that water levels would fall back to the natural surficial aquifer level when operations ceased in the long term. However, as a water bore is now being installed to supply the mine with make-up water, water levels in the lake system will be adjusted to reflect natural ground water levels.

With the benefit of these studies, a long-term conceptual plan has been developed for the lakes. It is planned to create a variety of habitat types to provide refuge for a large range of waterbird species on these permanent freshwater bodies. The plans also involve the development of education and passive recreation facilities in keeping with a multiple-use concept for this zone of the State Forest integrating conservation, recreation, and education with nearby forestry. A visitor's centre is planned with parking and picnic facilities. A number of walking trails will be developed incorporating a series of hides and viewing towers at strategic locations.

Site development works have commménced during the 1987/88 summer to enhance the limited habitat range by providing feeding, breeding, and loafing sites for the birds. The work programme includes earthworks to create channels, moats and islands, landscaping of banks, mass plantings of wetlands trees, shrubs and emergent vegetation, construction of wave barriers and artificial floating islands, and installation of nestboxes. These works will continue over a five-year programme.

An ongoing research programme will be an integral component of the project. The programme will integrate studies of wetlands development and waterbird ecology, with particular emphasis on the food chain. There will be studies on sediment/water/nutrient interactions, vegetation and invertebrate recolonization, bird diets, breeding patterns, and the pattern of usage of the developing ecosystem by birds. The project will have obvious benefits in wetlands conservation, particularly in view of the dramatic loss of natural wetlands in southwest Western Australia. The multidisciplinary nature of the research programme, integrated by the Management Committee, is attracting considerable interest in the scientific fraternity. The project will increase understanding of wetlands, and will also help to develop and demonstrate the technology for the rehabilitation of wetlands. It is believed that the project is unique in Australia.

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