Lake Bonney

South East, South Australia

Past, Present and Possible Future

Government of South Australia

EPA South Australia

Foreword

For most of the past 150 years since European settlement, Lake Bonney SE has been the largest freshwater lake in South Australia. And yet I wonder how many people in the state are aware of its presence, or its location about 10 km south from Millicent in the South East of the state, let alone who visit the shores of this 23 km-long, shallow coastal lake.

It is clear that the lake was locally significant from the 1860s to the mid to late 1950s for a range of recreational uses that included boating, swimming, fishing and shooting, and that Picnic Point to the north of the lake was a popular meeting place. It seems that many of these uses stopped, once the lake was lowered in 1958 to appease the flooding concerns of local landowners. According to the Lake Bonney Oral History Project (1990), the Cellulose Mill (which closed in 1998) caused localised impacts in the north of the lake around the drain outfall as early as 1945, but it was only in the early 1970s that the lake was widely considered to have been badly polluted by discharges from the pulp mills.

Over the years the state government has funded a number of monitoring studies that have provided data on the water quality and ecological condition of the lake. More recently the present owner of the remaining mills, Kimberly-Clark Australia, has contributed funds for the Lake Bonney Scientific Advisory Group to continue to coordinate monitoring programs on the lake.

Rather than just continuing to monitor the lake, the state government and Kimberly-Clark Australia have decided to focus attention on identifying the causes of the low biodiversity in Lake Bonney SE, and to develop ways to improve its health in a three-stage project from 2003 to 2006. The project will move from a review stage, through a targeted monitoring stage, to an evaluation stage that will identify the actions needed to improve the environmental and recreational uses of the lake.

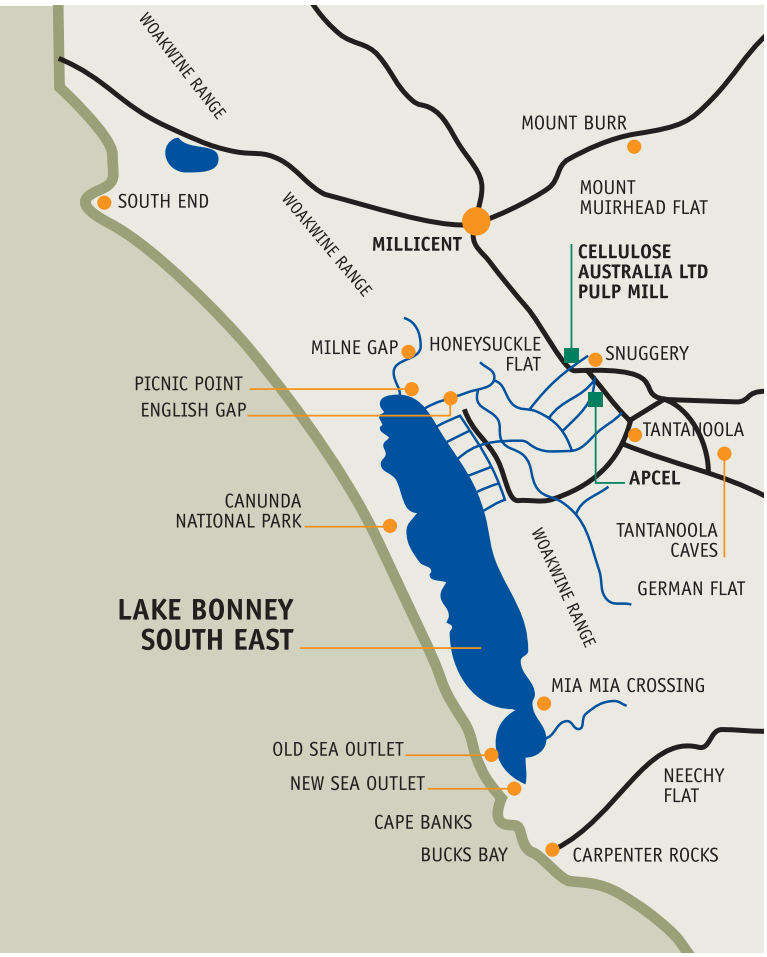
The project will contribute knowledge and understanding of the major processes and structural components of one of the state's major lakes, and begin its rehabilitation to an environmentally valuable lake for the benefit of future generations. It will also build on the directions outlined in the *Wetlands Strategy for South Australia (DEH 2003)* and the *State of the Environment Report for South Australia 2003* and focus on improving the environmental management and condition of a significant, degraded lake.

This brochure details the findings from stage 1 of the project, which reviewed all available information and data on the water quality, hydrology, sediments and ecology of the lake. Also included are brief descriptions of some of the knowledge gaps that will be answered over the next 18 months.

I encourage all South Australians to protect and enhance our environment and to ensure that we are continually guided by the principles of ecologically sustainable development in the management of our resources. This project will build on the findings from a number of excellent studies undertaken by others over many years, and help identify management options to achieve a healthy and sustainable future for one of the state's major wetlands.

Dr Paul Vogel
Chief Executive, Environment Protection Authority

Lake Bonney SE Problems and steps to a solution



Above: Lake Bonney SE and surrounding environs (Map: from Kinhill 1990)

Lake Bonney SE—a large coastal lake about 10 km south of Millicent in the South East of South Australia—has, like most of the South East region, been extensively altered since European settlement, particularly by the effects of drainage schemes and various land use impacts.

Large volumes of wastewater from pulp and paper mills have, for over 60 years, also adversely affected the health of the lake. In recent times technological upgrades and modifications to the mills have significantly improved the quality of wastewater discharged to the lake. Water quality in the lake has thus improved, but remains highly coloured, turbid (cloudy), eutrophic (high in nutrients) and contains high concentrations of organic matter and elevated levels of organochlorine compounds.

Lake Bonney SE is characterised by poor biological diversity in phytoplankton, zooplankton, macroinvertebrates, fish and aquatic plants. However, the causal factor(s) of the poor condition of the lake is unclear. It may be the toxicants and highly coloured components in the wastewater from the pulp and paper mills in the past. High turbidity and strong winds in the area may also result in poor light penetration in the water and shoreward erosion, which thereby limit opportunities for diverse communities of plants and animals to thrive in the lake. The past decade was also very dry in the South East, resulting in low lake levels and higher than usual salinity concentrations, factors that may also contribute to the current low biological diversity of the lake.

The Environment Protection Authority, Office of Economic Development and Kimberly-Clark Australia are funding a project over 2003–06 to assess the current state of Lake Bonney SE and identify actions that can be taken to improve the health of the lake.

The first stage of the project has been completed and this brochure outlines its major

Above: Near Picnic Point at the north end of Lake Bonney in April 1991, just prior to re-opening of 1958 outlet. (Photo: Andrew Emmett, April 1991)

Above: Sailing on Lake Bonney SE (Photo: from Carthew 1991)

findings. Stage 2 is a monitoring program to address knowledge gaps listed in this brochure, and stage 3 will evaluate the findings and assess options to rehabilitate Lake Bonney SE for future recreational use.

History of Lake Bonney SE

Before European settlement, the Booandik people lived on the land around Lake Bonney SE, and early records indicated that it was 'a happy hunting ground for its aboriginal inhabitants' (District Council of Millicent 1956-59). Lake Bonney SE and nearby Lake Frome provided the Booandiks with permanent fresh water, fish and abundant waterfowl (Carthew 1991).

The earliest references to Europeans in the region were in 1822, when the first ship was seen in Rivoli Bay to the north west of the lake (Carthew 1991). Charles Bonney discovered the lake in 1839, and it was named after him by Governor George Grey who led an expedition to the area in 1844. George French Angas, an artist in the governor's party, recorded the earliest colonists' view of the area including sketches of Lake Bonney SE in May 1844 (see front and back covers). His sketches indicate a fairly full lake and the word 'brackish' is written in an annotation.

Colonists saw the enormous agricultural potential of the area and quickly squatted there. But too much water on the land during wet winters limited cropping and people's movements. Proposals to drain much of the region soon followed. Large drain excavations began in the Lake Frome area in 1863, and the formation of the Muirhead Drainage Board in 1867 led to the start of the Milne's Gap, English's Gap and German Creek excavations. These large drains carried freshwater runoff into Lake Bonney SE. Drain excavations continued into the mid 20th century, eventually draining 125,000 acres. In 1915, the 1.3 km Lake Bonney outlet to the sea was completed as a national drain to reduce the effects of severe flooding in the local area (South Eastern Drainage Board 1980).

Wetland drainage and the use of superphosphate and trace minerals to treat nutrient deficient soils allowed and promoted intensive agriculture in the region. However, although wetland drainage and agriculture must have had an impact on Lake Bonney SE, it continued to be used as a recreational waterway until around the late 1950s.

Picnic Point was a popular place for swimming, boating and recreation, and many used the lake for shooting and fishing (Carthew 1991). The Pompoon school sports days were always held at Picnic Point, and some claimed water from the lake made the best cup of tea! Clearly, the early settlers in the Canunda region used and valued the lake for its appearance—'sparkling like diamonds in the sun' (Woods 1862)—and recreational uses.

Mill operations and wastewater discharge into Lake Bonney SE

In 1942, the first pulp and paper mill at Snuggery started to send large quantities of solid and dissolved waste into the lake.

The 'Cellulose' and 'Apcel' pulp and paper mills near Millicent were established under state government Indenture Acts, at a time when the government of the day promoted this development to economically use the forest resources in the region. Importantly, the indentures allowed the mills to discharge wastewater into drains that flow into Lake Bonney SE, as the government accepted legal responsibility for the waste mill effluent being released into the environment.

Above: English Gap Drain discharging paper mill wastewater into Lake Bonney SE, April 2003 (Photo: Skyring Environment Enterprises)

Kimberly-Clark Australia, current owner of the Millicent and Tantanoola mills, has indemnity for the paper mill at Millicent to discharge into Lake Bonney SE until 2014.

Major production changes at the mills over the last 15 years have followed global trends in efficiencies, and environmental initiatives have improved wastewater quality.

> October 1991: Replacement of chlorine bleaching with peroxide bleaching significantly reduced chlorinated organic compounds—measured as adsorbable organic halides (AOX)—discharged to the lake.

> February 1992: Installation of an additional clarifier reduced suspended solids in the wastewater discharge.

> October 1992: A technical initiative diverted spent sulfite liquor (and lignosulfonates) from the effluent.

> August 1993: Installation of aeration ponds reduced the biochemical oxygen demand in the effluent.

> September 2003: Closure of the eucalypt pulp mill reduced the colour of the effluent.

Treated wastewater from the pulp and paper mills contains a wide range of organic contaminants, including coloured compounds and AOX. It also contains appreciable quantities of suspended solids, nutrients (nitrogen and phosphorus) and heavy metals (chromium, copper and zinc).

Lake Bonney SE Some physical facts

- **Dimensions:** length 23 km; width 4 km; average depth along the centre of the lake 3 m; area 6400–7900 ha, depending on the depth.
- **Catchment area:** about 43,000 ha, from the north to Lake Frome, east to the Woakwine Range and south to the area drained by Benara Creek and Bucks Game Reserve.
- Woods (1862) noted that much of the lake had dried up around 1850; in the 1860s the lake was 40 km long (presumably quite full).
- **Overflow:** from European colonisation to 1958: natural overflow of Lake Bonney SE to the ocean only when level of the lake greater than 2.34 m; 1958 to 1993 (the most recent): around 22 managed discharges to release water from the lake into the sea and prevent flooding of pastures around margins of the lake.
- **Depth variation** since 1972: 0.4 m to 2.1 m; 1994 to present: drier than average conditions are keeping the volume of water in the lake at consistently low levels.
- **Water inputs** to the lake: directly from rainfall and the inflow of groundwater, by discharge of effluent from the pulp and paper mill into English Gap Drain, and natural runoff from other drains that flow into the lake. **Major losses** from the lake's water budget: evaporation, and seepage into the sea.
- **Water column:** generally well mixed vertically and horizontally due to the shallowness of the lake and frequent strong winds in the area. There are small salinity differences between the northern part and the rest of the lake because of the constant paper mill discharge via English Gap Drain. However, measurements of surface and bottom waters from 1972 to 1989 showed that the lake is often stratified with respect to temperature, conductivity, dissolved oxygen, ammonia and AOX. This can influence the release of nutrients, heavy metals and toxicants from sediments, and may impact on the biological health of the lake.
- **Submerged pine logs:** the possible presence of submerged logs in the lake has caused the

Above: Woods and Forests log storage, July 1985. (Photo: Andrew Emmett, July 1985)

ongoing closure of the lake to boating. The logs were stored in the lake to preserve the wood following the Ash Wednesday (February 1983) fires but an unknown number escaped from an impoundment during a storm in mid 1983.

Some water and sediment chemistry facts

> **Salinity:** this slightly saline lake becomes freshwater following very wet winters; since 1971, usually 3000-4000 mg/L (upper limit for freshwater: 3000 mg/L; seawater salinity: 35,000 mg/L).

> The **past decade** of very dry weather in the region decreased lake water levels and increased salt concentrations to more than 6000 mg/L.

Above: Some remnant pine logs of the breakaway in 1983 on the shore of Lake Bonney SE (Photo: Skyring Environment Enterprises)

> **Past salinity:** presence of saline tolerant species such as swamp paper-bark (*Melaleuca halmaturorum*) along an old shoreline and shells of a salt lake snail (*Coxiella*) in the sediments indicate higher salinity in the past.

> **Total organic carbon** (TOC): 200–500 mg/L (high compared to other Australian coastal lakes); SA Environment Protection (Water Quality) Policy (WQP) sets maximum TOC at 15 mg/L for protection of inland aquatic ecosystems (EPA 2003).

Above: Lake Bonney SE remains closed to boating activities (Photo: KCA, November 2003)

> **Total nitrogen (**TN): 2–5 mg/L (high compared to many Australian coastal lakes and equivalent to around 800 tonnes of nitrogen (N) for a lake volume of 200,000 ML); mill discharges around 130 tonnes of N/year (2002 estimate); WQP sets maximum TN at 5 mg/L for protection of inland aquatic ecosystems (EPA 2003).

> **Total phosphorus** (TP): 1991–95 concentrations ranged from 0.06–0.35 mg/L, indicating the lake contained around 8 tonnes of phosphorus (P); the mill discharges about 20 tonnes of P/year (2002 estimate), so nutrient loads must be deposited along the 11 km drain and/or into the lake's sediments; concentrations exceed National Water Quality Guidelines value of 0.025 mg/L (ANZECC/ ARMCANZ 2000) but fall below WQP 0.5 mg/L threshold for the protection of aquatic ecosystems (EPA 2003).

> **Heavy metals** chromium (Cr) and zinc (Zn): increased in the lake from 1993 to 1996 (Cr 0.02 mg/L and Zn 0.25 mg/L); WQP sets Cr at 0.001 mg/L and Zn at 0.05 mg/L for the protection of inland aquatic ecosystems (EPA 2003).

> **Colour:** peaked at 1400 HU in 1992, decreased to around 100 HU in 2000; coloured organic substances were (and still are) discharged from the pulp and paper mills into lake; the high colour probably affects algal and plant growth; WQP sets colour at

Above: Lake Bonney SE water in April 2003; both turbid and yellow in colour (Photo: Skyring Environment Enterprises)

30 HU for the protection of inland aquatic ecosystems (EPA 2003).

> **Turbidity:** there is a range of anecdotal reports on the clarity of the lake before 1940 but it has been persistently turbid since 1972; wind action disturbing sediments often assumed to be cause of high turbidity (currently 100–300 NTU) in the lake; strong winds have presumably always prevailed, therefore unlikely to be the primary cause of turbid lake; WQP sets turbidity at 20 NTU for the protection of inland aquatic ecosystems (EPA 2003).

> **Adsorbable organic halides** (AOX): originated predominantly from the chlorine and calcium hypochlorite pulp bleaching process in the paper mill; peak concentration around 1300 µg/L in 1990, falling to around 500 µg/L in 1993 and constant to 2000. The mill's current discharge is less than 130 µg AOX/L. The presence of chlorinated phenols and other chlorinated organic compounds in the lake will require further work to assess human health risks for recreational contact.

> **Sediments:** likely to be a major sink (e.g. reservoir) for removal of organic matter, nutrients, heavy metals and AOX that enter the lake from various drains (English Gap and Milne Gap) and creeks (Stony and Benara).

Some biology and ecology facts

> **Bacteria:** number of faecal coliforms in the lake decreased by about one order of magnitude after clarification procedures improved at paper mill in 1992–93; now below the national water quality guideline for recreational waters of 150 organisms per 100 mL; bacterial contribution from local dairy farms to the lake not measured but expected to be only locally significant.

> **Phytoplankton:** low diversity and abundance of most species; eutrophic lake (green plant pigment chlorophyll at concentrations greater than guideline levels of 5 µg/L, typically 60–80 µg/L); high density of mostly two types of green algae (*Crucigenia* and *Planctonema*), which have dominated the algal community in the lake from 1972 to 2001.

> **Macrophytes:** community of various fringing rushes, grasses and sedges but lake itself generally devoid of emergent and submerged

LANDSAT image 1980

Right: LANDSAT image of Lake Bonney SE in the 1980s, showing dark red colour of the lake due to the coloured organic discharge from the pulp and paper mill at Snuggery (Photo: ©Commonwealth of Australia—ACRES, Geoscience Australia)

species; this may have cascading impacts on the rest of the biota from lack of habitat and physical structure in the lake.

> **Zooplankton:** sparse community with low diversity of species, remarkable by absence of many species and families that frequent inland waters elsewhere in Australia. Dominant species are two calanoid crustaceans (*Gladioferens spinosus* and *Calamoecia gibbosa*) that are common in open water habitats of many Australian shallow coastal wetlands.

> **Macroinvertebrates:** community of lower diversity and abundance than expected for a lake in a cool, temperate region in the state; most common species include the amphipod *Austrochiltonia australis,* waterbug *Micronecta,* and occasionally the snails *Potamopyrgus* and *Physa acuta;* the cnidarian *Cordylophora,* freshwater crab *Amarinus lacustris* and waterbug *Anisops* also commonly recorded.

> **Fish:** commercial numbers of mullet recorded in the past when connection to the sea well established; in recent times, freshwater species such as common galaxias (*Galaxias maculatus*) in the 1970s appear to have been replaced with more saline tolerant small-mouthed hardyhead (*Atherinosoma microstoma*) and big-headed gudgeon (*Philopnodon grandiceps*) during the 1990s; interesting records include presence of the nationally vulnerable Yarra pygmy perch (*Nannoperca obscura*) in 1913, southern pygmy perch (*Nannoperca australis*) in 1974 and dwarf galaxias (*Galaxiella pusilla*) in 2001.

> **Birds:** general decline in aquatic bird breeding due to the loss of Ibis Island as a site for colonially nesting species, low lake levels and fox predation.

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Top Right:

1: The freshwater crab *Amarinus lacustris* commonly found under rocks at Lake Bonney SE and in the region (Photo: Australian Water Quality Centre, SA)

2: Numerous shells of the saline tolerant snail *Coxiella* species present in the sediments of Lake Bonney SE, indicating that the lake was salty in the past (Photo: Australian Water Quality Centre, SA)

3: Back-swimmers *Anisops* species commonly found in the lake in deeper, open water region (Photo: Australian Water Quality Centre, SA)

4: The freshwater snail *Physa acuta* commonly occurs in Lake Bonney SE and the region (Photo: Australian Water Quality Centre, SA)

LANDSAT image 2000

Left: LANDSAT image of Lake Bonney SE in 1999–2000, showing obvious improvement in lake colour (Photo: ©Commonwealth of Australia—ACRES, Geoscience Australia)

Summary What we know and don't know

Lake Bonney SE has:

- high colour, high turbidity, high suspended solids, high organic carbon, elevated AOX and high chemical oxygen demand in lake waters
- sediments of variable composition, possibly with high sulfide concentrations and possibly highly coloured pore waters
- water that varies from fresh to slightly saline (brackish)
- eutrophic water with high nutrients and high numbers of algae
- poor biodiversity.

Further work is needed on the lake's hydrology, physical and chemical properties, sediments and biology to help us understand why the lake is in such a poor condition. The knowledge gaps are summarised below.

Hydrology

- We need to collect reliable data on groundwater flows, seawater seepage, evaporation losses and lake bathymetry.
- Do we understand the salt balance in the lake? Is the effect of salinity underestimated? Lake salinity is at a level where a marked drop-off in biological diversity (in aquatic ecosystems generally) would be expected.
- What sort of conditions constitutes a healthy lake for Lake Bonney SE? Should it be managed as a brackish/saline or freshwater lake? This will impact on what can live in the lake and what indicators we use to assign health or condition in the lake.

Chemistry

- Groundwater inflows and all drain inputs are not fully understood nor characterised.
- Turbidity, colour and light attenuation are key controls on lake productivity. What is the nature and cause of the lake's high turbidity?
- The nature of the AOX is not known. What are the key AOX chemicals? Is the AOX at levels likely to be harmful to biota—either in sediments or the water above? Can the

Above: Shoreline vegetation at Mia Mia crossing, Lake Bonney SE, April 2003 (Photo: Skyring Environment Enterprises)

Above: Lake Bonney SE (Photo: KCA, November 2003)

AOX be characterised to assess possible biological impacts (i.e. distribution, chemical characteristics, and toxicity)? Are they soluble, colloidal or particulate? Is the chemical composition of the AOX still entering the lake via hypochlorite use at the mill the same as that in the lake?

Sediments

> Are the sediments a source of turbidity? What are the relative rates of sedimentation and sediment re-suspension?

> What is the distribution of sediment types (grain sizes; mineral and total organic matter content and type) in the lake?

> Are the sediments a source of contaminants (AOX, ammonia, sulfide or other chemicals) to the lake? What are the release rates?

> Is the composition of sediment pore waters likely to be harmful to biota?

Biology

> What is the toxicity of the current mill effluent and lake water to test organisms? We need chronic tests using appropriate sensitive species (for example, algal growth tests; 7-day daphnid reproduction tests) to establish whether toxicants in the lake contribute to its low diversity.

> What are the key stressors on the biology of the lake? Is it poor habitat, adverse sediment conditions, low light, high salinity, high AOX, colour, turbidity or organic matter, or strong-wind driven agitation?

> Would reference sites provide a comparative framework to understand the low diversity and abundance in the lake?

> Are there toxins from phytoplankton that may be a concern for recreational contact?

> Are animal-derived faecal bacteria (e.g. from dairy cows) an issue?

Rehabilitating the lake

The most obvious goal for Lake Bonney SE would be for it to be a healthy ecosystem that the community could use for recreation and tourism. But first some hazards must be removed.

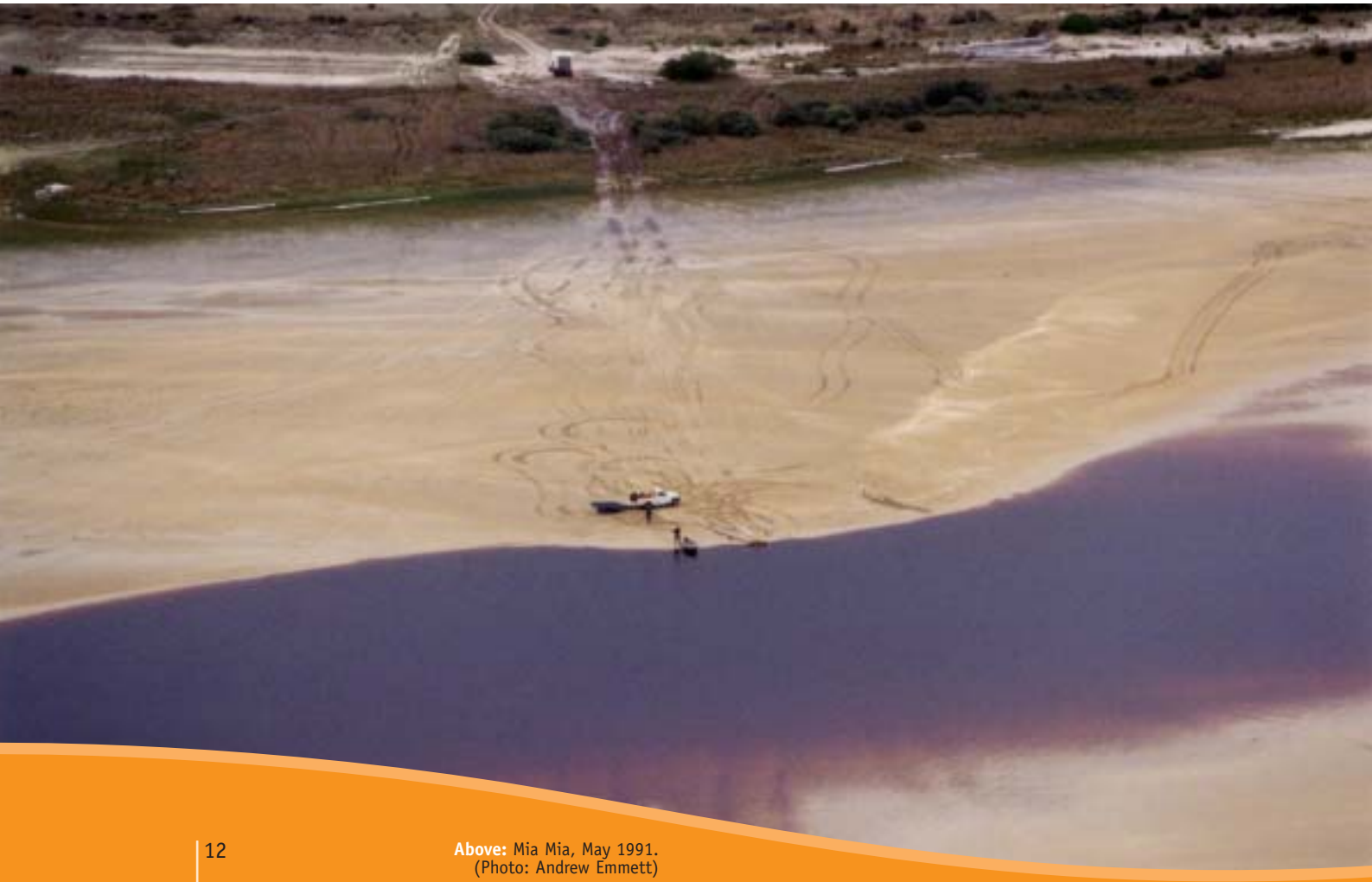
Boating on the lake (secondary contact recreation) is currently closed because of the physical hazard of submerged logs. Exposed and submerged rocky outcrops provide similar risks for boating that also need to be managed. Any rehabilitation plan that aims to allow secondary contact recreation on the lake would need to:

> improve the visual appearance of the lake by eliminating its high colour and turbidity

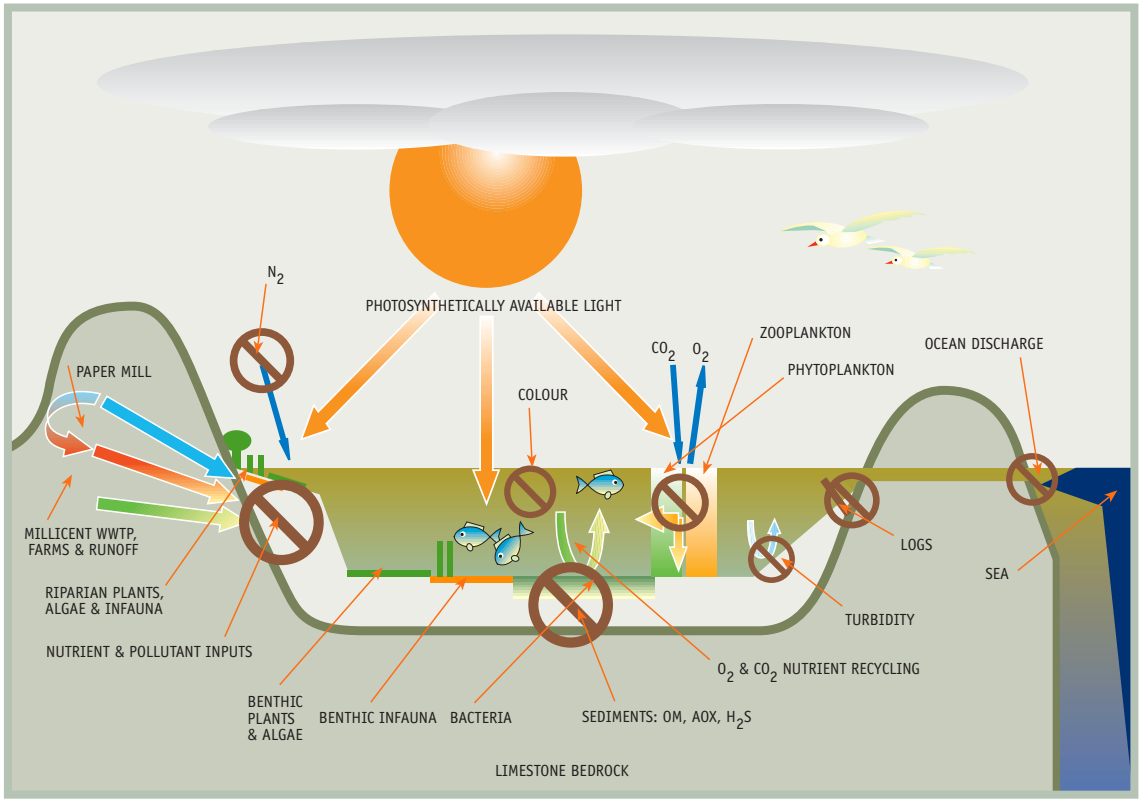
> remove all log hazards in the lake and mark or chart shallow rocky areas.

Before the lake can be used by the public for primary recreation contact (for example, swimming), other hazards must be assessed and, if practical and necessary, removed or mitigated. These include the risks posed by exposure to toxicants in the water and sediments.

The lake is also eutrophic (high in nutrients), and undesirable cyanobacterial blooms may pose public health risks in the future. Together with high phytoplankton numbers, they may make the lake too turbid for safe boating and swimming. The long-term plan for the lake could be to restore the water quality of the lake to make it safe for swimming and other forms of recreation such as boating and tourism.



Above: Mia Mia, May 1991.
(Photo: Andrew Emmett)



Above: A schematic diagram for the restoration of Lake Bonney SE (Skyring Environment Enterprises)
The stressors marked with a ⃠ should be moved or managed to restore the lake to an environment that is safe for indigenous riparian/aquatic flora, aquatic fauna including fish and birds, sediment infauna and humans.

Where to from here for a healthier Lake Bonney?

The following key steps need to be taken to ensure that the polluted waters of Lake Bonney SE are returned to a condition where it can be used and valued once again:

> Form a community consultative committee to provide input into plans to rehabilitate the lake.

> Determine what would be an acceptable condition and use for the lake. This needs to be discussed and agreed in consultation with the community.

> Continue to improve the quality of wastewater discharged from the pulp and paper mill and by other contributors to the lake.

> Evaluate management options needed to achieve the desired use for the lake.

> Identify and implement actions needed to most effectively deliver the desired outcomes for the lake.

> Monitor and assess measures of success that can be used to determine if the desired outcomes are being achieved.

Stage 2 of the project—the 2004–05 monitoring program—is addressing four initial critical knowledge gaps.

1. It is determining whether there are any suitable shallow, coastal lakes available to act as comparative references (for example,

Lake Frome to the north of Lake Bonney SE and Lake Wellington in Victoria). A reference lake could help clarify what is missing from Lake Bonney SE and, more importantly, allow us to identify when the lake reaches a healthy state.

2. Historically, the lake appears to have been alternately saline and fresh for extended periods. A study of fossil freshwater and saline species in the sediment profile (for example, diatoms) will clarify how lake levels and salinity have changed over time. Saline tolerant and freshwater species in the sediment profile should show how salinity in the lake changed before European settlement, and whether the current salinity of the lake is typical or due to the effects of drainage schemes over the past 150 years. This work will also help determine what we measure condition against, and contribute to the setting of management objectives for the lake.
3. The high colour in the lake may limit its biological diversity by preventing sufficient light penetration through the water column for most algae and other plants to thrive. A study will measure light penetration through the water column in the lake.
4. The high turbidity in the lake may also be a major factor affecting the biological health of the lake. A study will characterise the turbidity and suspended solids in the lake to determine if the high turbidity is due to inorganic sediments, organic compounds (e.g. tannins), dead organisms (e.g. algal cells) or live organisms (e.g. algae and zooplankton).

Further work will also be required on the toxicity of the lake water, sediment pore water and current mill discharges, as well as work on the release of contaminants from the sediments to the overlying water.

The results from this stage of the project will focus on answering whether improvements in the water quality are likely to have any effect in reversing the current status of the lake.

Lake Bonney SE is not included in tourist brochures for the South East of the state. This project could be the means to demonstrate its natural potential.

Above: Lake Bonney SE in April 2003
(Photo: Skyring Environment Enterprises)

Above Right: Re-opening the 1958 Outlet at Lake Bonney SE (Photo: Andrew Emmett, May 1991)

References

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Abbreviations

AOX	adsorbable organic halides
TOC	total organic carbon
TN	total nitrogen
TP	total phosphorus
EPA	Environment Protection Authority
SE	South East of South Australia
Cr	chromium
Zn	zinc
NTU	nephelometric turbidity unit
HU	Hazen unit
WQP	*Environment Protection (Water Quality) Policy 2003 (SA)*
L	litre
g	gram
mg/L	milligrams per litre
µg/L	micrograms per litre
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand

Sketches (both front & back covers) by George F Angus, 1844: courtesy National Library of Australia

KCA November 2003