*WETLANDS*, Vol. 15, No. 3, September 1995, pp. 247–257


# DESCRIPTION, HISTORY, AND WATER CHEMISTRY OF THE RECENTLY RESTORED WATERVALLEY WETLANDS IN THE SOUTHEAST OF SOUTH AUSTRALIA

Janice M. White and Lynn A. Brake
*Centre for Environmental and Recreation Management*
*University of South Australia*
*Salisbury Campus, Smith Road*
*Salisbury East, South Australia, 5109*

*Abstract:* The southeast of South Australia has a history of drainage of wetlands to increase the amount of land available for agriculture. Recently, some landholders have reversed this trend by restoring the wetlands on their land to provide habitat for wildlife. The Watervalley Wetlands are the most extensive of these restored wetlands. The water is high in nutrients, hard, alkaline, and variably saline. The salinity of these wetlands varies in both time and space. Seasonal variations in salinity within the wetlands are conducive to high productivity, and the variation between wetlands ensures diversity of habitat. However, careful monitoring is required to determine whether the observed seasonal cycles of rising and falling salinities will continue or whether salinity will increase to undesirable levels at some time in the future. Long-term monitoring is also necessary to determine whether the present high productivity will continue under the prevailing water regime or whether that productivity is an artifact of the recent restoration.

*Key Words:* wetlands, restoration, water chemistry, salinity

## INTRODUCTION

The southeast of the state of South Australia contains some of its most valuable agricultural land. However, much of that land is low-lying and prone to flooding and became suitable for agriculture only after extensive drainage systems were constructed. Since the early 1980s, some of the landholders in the upper southeast have restored the wetlands on their properties with the goal of encouraging the return of wildlife, particularly waterbirds. This study focuses on one such area: the Watervalley Wetlands. The nature of the Watervalley Wetlands is controlled by natural landscape features and the use of the land since European settlement in the 1840s.

The topography of the upper southeast of South Australia is characterized by a series of low, relict beach dunes, locally referred to as "ranges," although most are less than 35m above sea level. Broad swales three to ten kilometres wide separate the ranges (Blackburn 1964). This series of dune ranges and swales runs roughly parallel to the present coastline and was formed by the action of waves as sea levels rose and fell over the last 400,000 years (Schwebel 1983). The Coorong (Figure 1), a long, narrow, almost land-locked lagoon separated from the sea by beach dunes is the current expression of the formation of these features. There are no defined streams in these swales, but in the past, they tended to flood annually during winter rains and are often referred to as "watercourses." The water was shallow, spreading over much of the width of the swales and flow was slow. The overall topographic gradient in the direction of flow (northwest) is 1:5000 (EWS 1991). Large areas of seasonal swamp and even some small permanent lakes formed in the lowest areas of the swales. Although evidence is sparse, in many years, water made its way along the full length of swales and drained into the southern lagoon of the Coorong at Salt Creek (Figure 1) or, especially in the east, discharged underground through sink-holes (Blackburn 1964).

Since settlement by Europeans, the low-lying land has been progessively drained by the construction of a 1467-km network of generally shallow drains (SEWC 1991) and the higher ground cleared of native vegetation. The soil in the swales is relatively fertile, but that on the higher ground is sandy and of low fertility (Blackburn 1964). This process of drainage and clearing has had economic benefits but has led to enormous loss of wildlife habitat over very large areas of the southeast of South Australia. It is estimated that the area of permanent wetlands in the region is now 8% of the original (Jones 1978). Seasonal and ephemeral wetlands have also been reduced in area by an unstated amount. Recently, the loss of native vegetation has

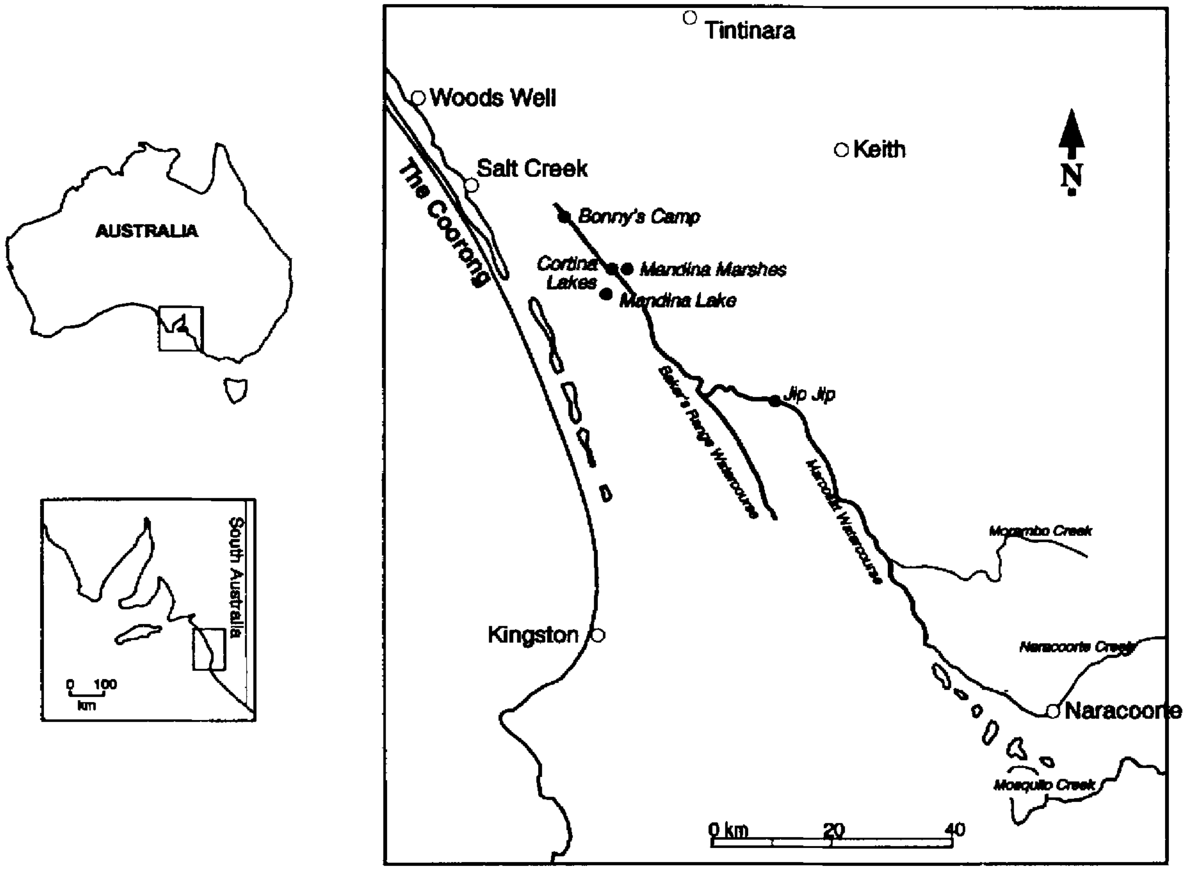


Figure 1. The upper south east of South Australia showing the location of those of the Watervalley Wetlands described in this paper.

been implicated in the increasing incidence of soil salinization through rising ground water (EWS 1991).

The Watervalley Wetlands are a series of complexes of wetlands covering a total of 5600ha—individual wetlands range from 13ha to 1865ha—along the Marcollat and Bakers Range Watercourses (Figure 1). In this paper the term "wetlands" is used in its local sense as a general term covering any inland water body, natural or constructed, permananent, seasonal or ephemeral and includes lakes (Paijmans et al. 1985). The Watervalley Wetlands constitute one of the largest projects for the conservation of wetlands for wildlife undertaken in Australia by private enterprise. Each of the wetland complexes is made up of one or more seasonal and/or permanent swamps, with or without associated shallow (< 2 metres deep) lakes as defined by Paijmans et al. (1985). Waters within the Watervalley Wetlands vary from fresh to saline in both time and space.

The Marcollat and Bakers Range Watercourses were originally fed by several ephemeral streams (Figure 1) that carried water from western Victoria and the lower southeast of South Australia in a generally northwesterly direction, flooding the lower-lying areas in all but exceptionally dry years. These streams now discharge into a series of constructed drains, some of which divert water southwest to the sea and some of which flow in the direction of the original water courses towards the northwest. These constructed drains are the major source of water for the Watervalley Wetlands. Local precipitation events produce low runoff volumes because of the extremely sandy soil that covers most of the region (Blackburn 1964). Most of the region is used for agriculture and grazing by sheep and cattle, although 68km$^2$ are declared as reserves under the National Parks and Wildlife Act (Jones 1978).

In 1992, we began a long-term project monitoring water chemistry, invertebrates, and vegetation on six of the Watervalley Wetlands. The purpose of the project is to develop guidelines for the management of the Watervalley Wetlands to maintain and enhance their value as wildlife habitat, especially for waterbirds. As a first step, we set out to determine the chemical characteristics of the water in some of the wetlands and to monitor seasonal changes in water chemistry.

In this paper, we give a brief history of the wetlands and identify the principal ions constituting the salinity of the waters in the wetlands, changes in pH and salinity, and the nutrient status of the waters at each study site. We offer explanations for the high levels of nutrients frequently observed in the water and comment on the observed variations in salinity and the consequences of altered drainage patterns. The data presented in this paper are preliminary results of the monitoring program on the Watervalley Wetlands.

Prior work in the region focused on the more undisturbed water bodies in the region, particularly the volcanic lakes further south (Bayly and Williams 1964, 1966), the shallow, saline coastal lakes to the southwest (De Deckker and Geddes 1980, Brock 1981), and the freshwater lakes near the mouth of the Murray River to the north (Geddes 1984). Some earlier studies include descriptions of some of the Watervalley Wetlands (Jones 1978, Atkins 1988), but these are based on inadequate data, often collected during a single visit to a site. Therefore, before plans for the long-term management of these and similar wetlands in the region can be completed, further data are needed (NRCSA 1993). Where management plans are already written, monitoring programs are needed (Harper and Weinert 1992, NRCSA 1993).

## HISTORY OF THE WATERVALLEY WETLANDS

The land immediately surrounding the study area was only sparsely settled before 1945 (EWS 1991), and native vegetation, especially on the dunes, was substantially intact until then. Prior to this time, landholders further east held grazing leases over large tracts of this land, and sheep were grazed on low lying areas vegetated with native grasses and herbs that grew on these wetter areas (Brinkworth pers. comm.). Large-scale clearing of native vegetation did not take place until the 1960s, and 6000ha of land surrounding Bonneys Camp (Figure 1) have never been cleared. However, from 1960 until 1983, when the South Australian government effectively banned the clearing of native vegetation, both the swales and many of the relict dunes were cleared and pastures of introduced species were established over most of the region (EWS 1991). Watervalley is one of the extensive pastoral properties that were set up during this period of agricultural expansion. Both sheep and cattle are grazed on Watervalley, as is the case on most of the properties. Peak regional stocking rates were reached in 1976 when the 617,000ha of grazing land supported 3.25 million dry sheep equivalents (DSE—a measure of grazing capacity e.g. a cow and calf to weaning = 12 to 15 DSE); by 1990, stock numbers were reduced to 2.71 million DSE as a result not only of vagaries of the weather and market prices but also of deteriorating pastures due to soil salinization (EWS 1991).

Each of the Watervalley Wetlands was affected by the regional drainage scheme that began in the 1860s, with the greater impact occurring after the 1960s. In 1964, a major drain was constructed that was estimated to reduce the flow of water to the study area by 50% (EWS 1991). Private local drainage works continued in the region through the 1980s, which continued to reduce the amount of water reaching the wetlands. In spite of this, all of the wetlands continued to be subject to at least partial seasonal flooding in most years, and two deep waterholes at Jip Jip and the deeper parts of Cortina Lakes and Bonneys Camp retained small areas of permanent water.

The Watervalley Wetlands were restored progressively from 1984 to 1991 by constructing levees and controlled inlet points that intercepted and directed water into the wetlands through the system of constructed drains. This had the effect of turning some pasture into seasonal swamps, some seasonal swamps into semi-permanent swamps, and restoring permanent swamps and lakes to an approximation of their pre-drainage depths. Herbaceous vegetation in some parts of the wetland basins was plowed before flooding to provide a mosaic of open water and vegetated areas.

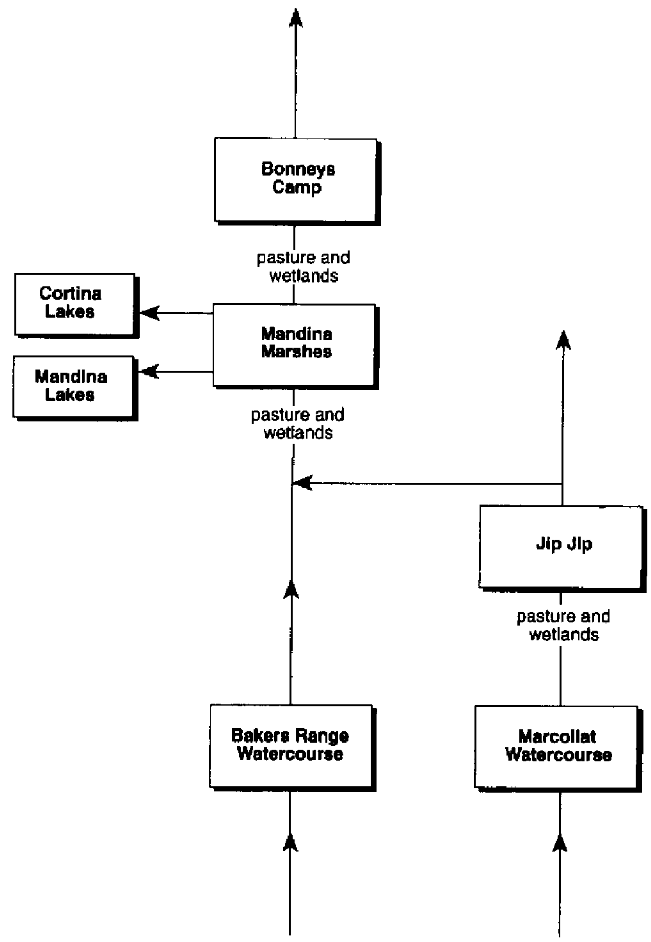


Figure 2. Schematic diagram of flow through the Watervalley Wetlands from Jip Jip to Bonneys Camp.

Figure 3. Mandina Lakes. The sampling site is at the bottom left of the photograph and Mandina Marshes lie between the hills in the middle distance and those on the far horizon.

The amount of water flowing into the wetlands can be controlled, but it is not possible in all cases to drain the basins; some can only be dried by stopping inflow and allowing the remaining water to evaporate. Sheep and cattle are now excluded from most of the wetlands and their margins.

All the wetlands are linked by the constructed drains that flow through pastoral land between Jip Jip in the south and the interconnected Mandina-Cortina complex and thence to Bonneys Camp in the north (Figure 2).

The wetlands were restored initially to provide increased opportunities for duck hunting, but that aim was soon extended to conserve increased areas of habitat for all wildlife associated with the wetlands. The whole wetlands enterprise is now vested in the Wetlands and Wildlife Trust, a non-profit oranization dedicated to the conservation of wildlife. The uncleared native terrestrial vegetation at Bonneys Camp is also conserved in perpetuity under a Heritage Agreement with the State Government of South Australia.

## STUDY SITES

Six of the Watervalley Wetlands are the focus of this study. The sites were chosen in order to cover a range of waters from fresh (Jip Jip) to saline (Mandina Lake) and to include examples from longer established wetlands (Jip Jip) to the most recently restored ones (Bonneys Camp). All figures for surface area when full, water depth, and vegetation cover are from Harper and Weinert (1992) and dates of restoration are from T. K. Brinkworth (pers. com.). Definitions of classes of salinity are those of Halse et al. (1993).

*Site 1:* Mandina Lake (area 480ha; mean water depth 100cm; brackish to hypersaline; date of restoration 1989). This shallow lake is largely surrounded by cleared grazing land (Figure 3). The sampling site supports dense areas of *Ruppia* sp., but there is virtually no emergent vegetation. At the sampling site, the bottom is fine mud over sand, and during the study period, the depth of water varied from 30 to 100 cm but began drying back rapidly in the summer of 1993–94. In

February 1994, the sample site was moved 20m further towards the center of the lake in an attempt to remain in the water. Although the water level in the lake varies seasonally (maximum September to January; minimum May to July), it does not dry completely. Substantial isolated hypersaline pools remain in the deeper areas even in years of below mean rainfall. However, because of the shallowness of the lake, small changes in depth produce large changes in the area under water.

*Site 2:* Mandina Marshes (area 1865ha; mean water depth50 cm; fresh to saline; date of restoration 1989). Mandina Marshes are bordered by grazing land to the west and native vegetation to the east, but a belt of native terrestrial vegetation is being allowed to regenerate along much of the western fringe. The marshes include large areas dominated by the shrub *Melaleuca halmaturorum* F. von Meuller and others with dense stands of mixed *Baumea* spp.. Harper and Wienert (1992) state that the area of open water is 1% but observations suggest this is an underestimate. The bottom is similar to that of Mandina Lake. The sampling site supported little aquatic vegetation and dried completely for part of the study period. In years of low rainfall when there is no flow of water through the constructed drains, the whole area dries out during the summer. Water levels in this system can be manipulated to some extent.

*Site 3:* Cortina Lakes (area 350ha; mean water depth 250cm; fresh to marginally saline; near-permanent shallow lake with deeper permanent waterholes fringed by swamps). Cortina Lakes are bordered in part by grazing land but also by substantial patches of native woodland. This water body is about 50% open water, and the rest is dominated by emergent *Baumea* spp. with submerged charophytes. There is a small patch of *Phragmites australis* (Cav.) Trin. ex Steudel in this system. The sampling site had 30% basal area cover of two species of *Baumea* with submerged charophytes; the bottom is sandy. Throughout the study period, the sampling site retained water that varied in depth from 50 to >100cm.

*Site 4:* Jip Jip (area 56ha; mean water depth 100cm but deliberately lowered to 80cm from 1992; fresh to marginally brackish; date of restoration 1984). This site is surrounded by 164 ha of native woodland and contains small areas of both *Melaleuca halmaturorum* and *Eucalyptus camaldulensis* Dehnnardt swamp. Emergent vegetation covers only 10% of the surface. This wetland was drained to complete the work necessary to lower the water depth in early 1992, and water levels were not restored until September 1992. It was drained again for maintenance in autumn of 1993 and remained dry from June 1993 until the end of the study period. The sampling site supported no emergent or submergent vegetation, and the bottom is clayey sand.

*Site 5:* Bonneys Camp South Lagoon (area 620ha; mean water depth 120cm; fresh to brackish; date of restoration 1991). This site is separated from Bonneys Camp North Lagoon by a narrow spit of land bisected by a natural channel that connects the two lagoons when water levels are high.

*Site 6:* Bonneys Camp North Lagoon (area 360ha; mean water depth 80cm; fresh to brackish; date of restoration 1991). The north and south lagoons together are surrounded by 6,112 ha of native woodland and heath. About 70% of the south lagoon and 40% of the north lagoon is open water. The rest is covered with sedges. Both lagoons are on sand.

### Climate

The region has a typical Mediterranean climate with cool, wet winters and warm, dry summers. Precise rainfall data are not available; the two nearest rainfall stations are at Kingston (mean annual rainfall 595mm) and at Tintinara (mean annual rainfall 472mm). The Watervalley Wetlands lie between these two stations (Figure 1). Evaporation exceeds rainfall in all months except May to August (figures provided by Bureau of Meteorology, Adelaide).

## METHODS

We established permanent sampling points in the six wetlands described above between April and July 1992. In December 1992, high water levels made access to the site at Bonneys Camp North difficult, so this sampling point was moved about 400 m south until lower levels again allowed access in February 1993. At the other five sites, all samples were taken from these fixed points. Water was sampled at four- to six-weekly intervals between July 1992 and April 1994. Seven major ions that contribute to salinity (sodium, potassium, calcium, magnesium, chloride, sulphate, bicarbonate) and nitrate, nitrite, phosphate, dissolved oxygen, surface temperature, pH, and conductivity were measured. Water samples were collected from 10 to 30cm below the water surface adjacent to 20-m transects established for invertebrate studies. The water samples used to test for nitrate and nitrite were collected in plastic bottles previously washed in hydrochloric acid and those for all other ions and nutrients in bottles washed in nitric acid. Water to be analyzed for dissolved oxygen was collected in a glass, stoppered bottle with the bottle submerged for at least two minutes.

Except for sodium, all analyses were conducted on

Table 1. Summary of chemical and physical characteristics of the Watervalley Wetlands.

| Site (N) | Conductivity $mScm^{-1}$ Mean (SD) Range | pH Mean (SD) Range | Surface Temp °C Mean (SD) Range | Turbidity FTU Mean (SD) Range | Dissolved $O_2$ $mgL^{-1}$ Mean (SD) Range | Alkalinity $mgL^{-1}$ Mean (SD) Range |
|---|---|---|---|---|---|---|
| Mandina Lake (17) | 18.9 (14.9) | 8.9 (0.4) | 18 (5) | 61 (39) | 8.2 (2.3) | 787 (431) |
| | 6.6–69.3 | 8.4–9.5 | 10–24 | 30–175 | 4.9–12.5 | 470–2130 |
| Mandina Marsh (14) | 7.4 (3.5) | 8.4 (0.3) | 16 (6) | 31 (9) | 8.3 (2.3) | 522 (113) |
| | 2.4–16.8 | 8.0–8.9 | 7–25 | 20–51 | 5.8–12.0 | 296–762 |
| Cortina Lake (18) | 9.3 (3.1) | 8.5 (0.3) | 18 (4) | 9 (4) | 8.6 (2.0) | 553 (135) |
| | 5.6–16.1 | 8.1–8.9 | 10–25 | 3–17 | 6.3–13.6 | 248–868 |
| Jip Jip (7) | 3.8 (1.4) | 8.9 (1.0) | 19 (7) | 18 (5) | 9.2 (1.2) | 259 (47) |
| | 2.1–5.6 | 7.6–10.1 | 9–26 | 13–29 | 8.1–11.8 | 156–280 |
| B's Camp South (17) | 6.1 (1.4) | 8.6 (0.4) | 18 (6) | 6 (2) | 9.3 (1.8) | 485 (55) |
| | 4.2–9.3 | 7.8–9.1 | 10–27 | 1–9 | 6.8–13.9 | 424–596 |
| B's Camp North (18) | 6.7 (1.6) | 8.3 (0.6) | 19 (6) | 14 (5) | 7.1 (2.1) | 583 (174) |
| | 4.3–11.2 | 6.5–8.9 | 9–27 | 3–20 | 4.4–10.1 | 188–910 |

site and completed less than two hours after collection using a Hach DREL/2000 portable analysis kit. Nitrate, nitrite, phosphate, sulphate, potassium, and turbidity were determined by spectrophotometry, and calcium, magnesium, chloride, bicarbonate/alkilinity, and dissolved oxygen were determined by titration. Temperature was measured initially with a mercury thermometer and later by TPS probe. Conductivity was measured by a Hanna Instruments probe and pH by either a TPS probe or an ICI probe—the two were calibrated against each other. Sodium was determined from stored samples by flame photometry in the laboratory using a Corning Clinical Flame Photometer.

The choice of field analytical methods was a trade-off between loss of accuracy during storage and transport from the study area, which is remote from the laboratory, and the (possibly) greater accuracy that might be obtained by use of laboratory instruments (Briggs et al. 1985, Tominaga et al. 1987).

## RESULTS

All sampling sites except Jip Jip (which had been drained) had been flooded at least since the date of their restoration. Winter rainfall, which contributes most to the flow of water through the drainage system, had been above average since 1988. Over the 22 months of the study, we experienced two extreme seasons. Rainfall was about 120% of the annual mean in 1992 and about 75% in 1993. The total for the first three months of 1994 was again below average with February receiving less than 40% of the monthly mean and no rain at all fell in March.

On 16 September 1992, water flowed from the drains into Jip Jip, the southern-most of the wetlands, and flowed through to the northern-most site at Bonneys Camp (50km north north west) less than one month later. Water ceased flowing along the drainage system in late January or early February 1993. The water level at all sites peaked in December 1992. No water entered the wetlands from the drains after February 1993. Any recharge to the wetlands after January 1993 was the result of local rainfall. The structures controlling the water level in Mandina Marshes were left open after the flush of water went through in the summer of 1992–93 to permit the marshes to dry out in January 1994 (this is a routine procedure necessary every three years to maintain the health of *Melaleuca halmaturorum*). Jip Jip was drained for maintenance of the outlet control in June 1993 and was dry for the remainder of the study.

Table 1 summarizes the range of salinity (measured indirectly as conductivity), pH, surface temperature, turbidity, alkalinity, and dissolved oxygen at each of the sampling sites.

The salinity of these alkaline waters ranged from fresh through brackish to, in the case of Mandina Lake, hypersaline. Salinity at all sites varied seasonally, with lowest levels experienced in spring and summer and highest levels in autumn and winter (Figure 4). Ions contributing to salinity were strongly dominated by sodium and chloride, with the cations generally in the order $Na^+ >> Mg^{++} > Ca^{++} > K^+$ and anions $Cl^- >> HCO_3^- > SO_4^{2-}$. However, in the saline Mandina Lake, $K^+$ exceeded $Ca^{++}$ and $SO_4^{2-}$ exceeded $HCO_3^-$ at most times except when salinity was reduced by inputs of freshwater. In Mandina Marshes, Jip Jip, and Bonneys Camp South, the three freshest of the wetlands, $Ca^{++}$ concentrations always exceeded $K^+$, and at Cortina Lake and Bonneys Camp North $K^+$ exceeded $Ca^{++}$ only in the last months of the study. As the water bodies dried back to varying degrees towards

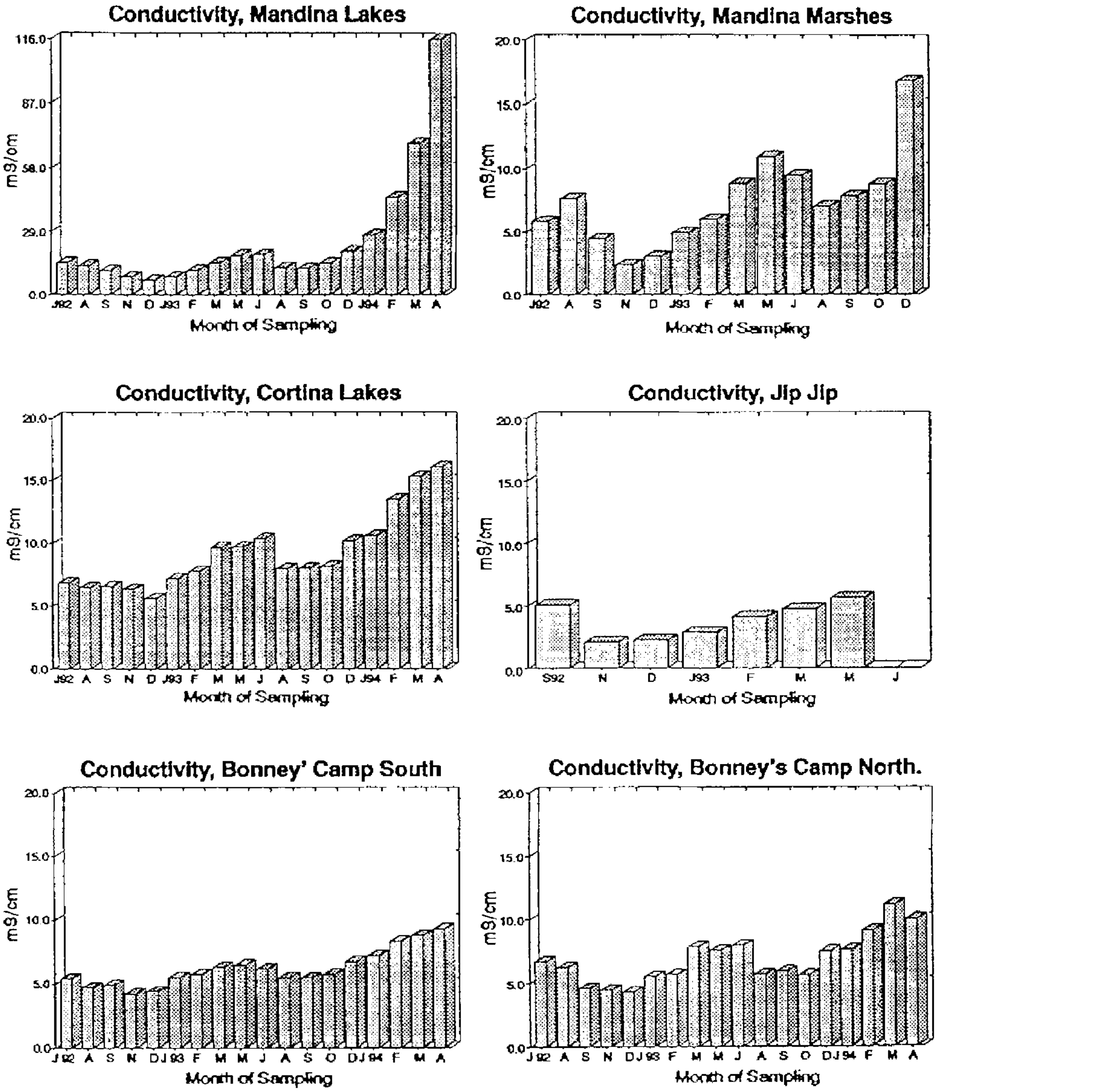


Figure 4. Changes in salinity measured as conductivity from July 1992 to April 1994. Note different scale on y axis for Mandina Lakes.

the end of the summer of 1993–94, $SO_4^{2-}$ concentrations exceeded $HCO_3^-$ at all sites except for Bonneys Camp North.

The variation in the proportion of monovalent to divalent cations (M:D) was greatest in Cortina Lake, with a range of 2 to 6. The range within all other wetlands was similar, and there was no apparent difference between the more saline wetlands and the fresher ones.

All of the sites had relatively high, but variable, levels of nutrients (Table 2). There was no apparent seasonal trend in the variation of nutrients. None of the wetlands was recorded as being in oxygen deficit at any time.

## DISCUSSION

This paper was intended to set the scene for further papers that will arise out of the long-term monitoring program commenced in 1992. In it, we have placed those restored wetlands in historical and social context and have described the chemical characteristics of the water—a necessary first step towards management. We do not yet have sufficient data on which to base definitive plans for management, but even these preliminary results allow us to make some recommendations. These will be discussed below.

It should be noted that because each of the water bodies is so large, it would be unwise to consider that

Table 2. Summary of nutrient levels.

| Site | Nitrate $mgL^{-1}$ Mean (SD) (N) Range | Nitrite $mgL^{-1}$ Mean (SD) (N) Range | Phosphate $mgL^{-1}$ Mean (SD) (N) Range |
|---|---|---|---|
| Mandina Lake | 1.0 (0.9) | 0.033 (0.025) | 0.14 (0.28) |
| | (17) 0–3.7 | (13) 0–0.063 | (17) 0–0.94 |
| Mandina Marsh | 0.2 (0.1) | 0.077 (0.113) | 0.05 (0.04) |
| | (14) 0–0.6 | (7) 0.015–0.330 | (14) 0–0.15 |
| Cortina Lake | 0.8 (0.3) | 0.028 (0.023) | 0.09 (0.18) |
| | (18) 0.2–1.4 | (13) 0–0.082 | (18) 0.01–0.78 |
| Jip Jip | 1.4 (2.0) | 0.004 (0.006) | 0.08 (0.10) |
| | (7) 0.1–5.3 | (6) 0.001–0.016 | (7) 0–0.25 |
| B's Camp Sth | 0.8 (0.3) | 0.019 (0.016) | 0.07 (0.06) |
| | (17) 0.2–1.4 | (16) 0.001–0.059 | (16) 0–0.24 |
| B's Camp Nth | 0.9 (0.3) | 0.030 (0.020) | 0.19 (0.03) |
| | (18) 0.2–1.4 | (13) 0.001–0.079 | (18) 0.01–0.88 |

the sampling sites are necessarily representative of the whole. For example, because the sampling sites are near the shore, the levels of nutrients are likely to be higher than would be measured further out. Likewise, conductivity is probably higher than would have been the case had the sampling sites been closer to parts of the wetlands where flow is greater. We are nonetheless confident that the observed results do give a reasonable picture of the order of changes that would have occurred in each of the water bodies as a whole.

Generally speaking, the waters of the Watervalley Wetlands are typical of those found in dryer inland regions of Australia. All sites, except Jip Jip, had a wide range of salinities, wider than those given by Harper and Weinert (1992) for the same wetlands. Mandina Lake showed by far the greatest variation. In that lake, conductivity increased by an order of magnitude in fifteen months. Increases of this order are not unusual in Australian inland waters, and many organisms are adapted to extremes greater than those found within the Watervalley Wetlands (Brock 1985, Williams 1985, Timms 1987, 1993). However, as Mandina Lake continued to dry back during the autumn of 1994, conductivity rose to 116.0mS/cm in a large, isolated pool less than 50m from the sampling site. When the lake next fills, it is possible that the water retained in such remaining hypersaline pools will not mix with the incoming fresh water, although this is unlikely in such a shallow body of water that frequently experiences strong winds. However, if mixing does not occur, each time the lake dries back, these pools will become increasingly hypersaline at the bottom and maintain areas in the lake where the growth of rooted macrophytes will be impossible. The high levels of salinity in Mandina Lake in comparison with the other Watervalley Wetlands result from its limited outflow coupled with the very high rate of evaporation from such a large body of very shallow water devoid of emergent vegetation. Without careful management, this waterbody could become permanently hypersaline and lose its value as wildlife habitat. Continued monitoring of this site is crucial.

Before Mandina Marsh dried, salinity rose to levels one and a half times those previously recorded. The vegetation on this wetland is such that drying is necessary once every three years to maintain the health of the melaleucas, which provide valuable breeding habitat for colonial nesting waterbirds (Harper and Weinert 1992). As mentioned earlier, this wetland presently can only be dried by evaporation. The feasibility of providing a means of draining this wetland more quickly should be investigated. If this is not done, the base level of salinity is likely to rise each time it is dried out.

The ionic dominance of the wetlands is typical of Australian inland waters (Williams and Buckney 1976, Geddes et al. 1981, De Decker 1983, Hart and McKelvie 1986), and the excess of bicarbonate over sulphate agrees with Williams' (1981) generalizations for waters of the range of salinity found at Watervalley. The degree of dominance by sodium and chloride reflects both the proximity to the coast (less than 60 km) and the marine origin of the soils on which the wetlands lie. The perhaps unexpected pattern of lower salinity in summer (Figure 4) in this area of predominantly winter rainfall is related to the dependence of the wetlands more on water coming through the drainage system than on winter rainfall. However, this pattern of low salinity in the spring and summer might be skewed because the winter rains began later than usual in both years of the study. Even in the wet year of 1992, rainfall in May, June, and July was below average. In years of rainfall closer to mean conditions, the period of lowest salinity might occur earlier. Only continuing monitoring over many years will determine this. However, the study does show that, even with no fresh water entering the wetlands from the drains, local rainfall alone is sufficient to depress the salinity of the water from the autumn and winter highs in all of the wetlands. However, it is reasonable to assume that if fresher water does not flow through the system in most years, the wetlands will gradually become more saline. Indeed, past interference to the natural patterns of flow by draining may be contributing as much to the problem of increasing soil-salinity in the region as the oft-cited rise in ground water resulting from the clearance of native vegetation.

Williams (1981) suggests that with increasing salinity, the proportion of monovalent to divalent cations also increases. This was not noticed on these wetlands, with the proportions being similar throughout (M:D = 2 to 6), and the range of the proportions experienced in one wetland, Cortina, which is intermediate in salinity, was greater than the range between all the other wetlands. Ratios of monovalent to divalent cations of 1 to 14 support the growth of algae (Reynolds 1984).

The pH of the wetlands was alkaline throughout except one reading of 6.5 at Bonneys Camp North. In all cases, the lowest measurements of pH were recorded early in the study. This was most likely due to the influence of the incoming water carrying dissolved humic substances from vegetation that had decayed in the beds of the drains over summer. Soils in the region are generally alkaline (Blackburn 1964), being derived largely from marine sediments, particularly in the immediate region of the wetlands. This accounts for the pH readings generally being in the range of 8 to 9, similar to those reported by Williams (1981), Tominaga et al. (1987), and Timms (1987, 1993) for saline lakes in other inland areas of Australia. The pH in Jip Jip and to a lesser extent Mandina Lake reached very high levels as they dried back in the autumn of 1993. The extreme readings at both sites were made late in the afternoon on clear days. This is consistent with Timms' (1993) findings of daily fluctuations in pH in saline lakes in inland New South Wales.

All of the wetlands had relatively high levels of nutrients, well in excess of levels measured by Tominiga et al. (1987) in much more saline lakes on Yorke Peninsula, South Australia, but comparable with those found by Briggs et al. (1985) in wetlands in southwestern New South Wales and by Timms (1987) in Queensland. It is the practice of farmers and pastoralists in the region to apply phosphate fertilizers to the soils each year, usually in the autumn. Fertilizer on Watervalley is spread by a broadcaster on the ground, rather than from a light aircraft, but it is inevitable that this will have some effect on those wetlands adjacent to pastures. Nutrients levels at Jip Jip were initially very high. The first analyses were conducted within days of the swamp filling after a dry period and so releasing nutrients. Also, the water that flooded Jip Jip came from shallow drains that also had been dry. After these drains empty in summer, they provide one of the few sources of green feed for stock and so are heavily grazed. They must have carried very high nutrient loads. The level of nutrients quickly fell, indicating that when Jip Jip returns to its usual state of near permanent water, its nutrient levels are likely to be much lower.

The high levels of nutrients at other sites can be attributed to the activity of stock (Mandina Lake) or to the breakdown of recently flooded vegetation (Bonneys Camp). The depth of the Bonneys Camp lagoons means that they will become valuable refuges for waterbirds as some of the smaller and shallower wetlands dry out in drought years, and so it is desirable that they remain productive.

The high levels of sulphate present in all of these wetlands might ensure that phosphate in the systems remains available for growth of algae and plants rather than being locked up in the sediments (Caraco et al. 1989). This could lead to problems of cyanobacterial blooms (not yet observed on these wetlands but experienced in others [Harper and Weinert 1992]) associated with low N:P ratios, which are likely anyway from the source of the water (Downing and McCauley 1992). Although native terrestrial vegetation is being encouraged to regenerate around the perimeter of those wetlands where this is not already the case, this is likely to have little effect on the nutrient status of the more southerly wetlands where the influence of the input of nutrients from the drainage system is greatest. It might be advantageous to plant reed beds at the entry point to all of the wetlands if problems due to excessively high levels of nutrients become apparent.

The objective of the restoration of the Watervalley Wetlands was to provide habitat for wildlife; therefore, highly productive wetlands are desirable. Nonetheless, cyanobacterial blooms due to excessive levels of nutrients are undesirable in any system, and the nutrient status of the wetlands will continue to be monitored closely to ascertain whether their current nutrient status, and hence productivity, continues or is simply an artifact of their recent restoration.

## IMPLICATIONS FOR FURTHER RESTORATION OF WETLANDS

The deterioration of pastures in the upper southeast of South Australia due to increasing soil salinization was alluded to earlier in this paper. There has been a series of investigations into methods for alleviating the problem (NRCSA 1994). Many of the areas threatened by salinization are in the broad swales, which, before the constructed drains altered the natural hydrology, were subject to flooding with shallow water in most years during the winter rains. One solution to salinization includes plans to restore more of the former wetlands south of the Watervalley Wetlands as well as others in the watercourses that run parallel to the Bakers Range and Marcollat Watercourses. The success of the restoration of the Watervalley Wetlands indicates that such restored wetlands can rapidly provide highly productive areas for wildlife.

At present, there is not sufficient flow, even in the wettest years, for the water to reach its natural, predrainage, outlets. The engineering structures, that could increase the flow should the decision be made to do so, are in place. Both the Bakers Range and Marcollat Watercourses terminate in wetlands to the northwest of the Watervalley Wetlands. These will become increasingly hypersaline unless an outlet is provided. The observed fluctuations in salinity in Mandina Lake indicate that although flushing with fresher water can quickly depress salinity, without such flushing any restored waterbodies, especially those in areas already suffering salinization, are likely to reach a state of permanent hypersalinity in quite a short time. Guidelines for the management of these systems are yet to be finalized, but indications so far are that flows of water through the system as often as possible will be a crucial factor. Careful monitoring of the whole system is required to determine whether salinity will increase to undesirable levels at some time in the future.

The range of salinity currently experienced in the Watervalley Wetlands is conducive to high productivity and diversity of habitat. Within three years of restoration, the melaleuca swamps of Mandina Marshes supported over 2000 nests of egrets, ibis, spoonbills, and cormorants (Harper pers. comm.) and all the wetlands support a large and diverse community of waterbirds and other wildlife (Harper and Weinert 1992, our unpublished data). There are many areas in the region that are similar to the Watervalley Wetlands before they were restored. If those areas were similarly restored, they should provide equally diverse and productive wetlands and begin to redress the past destruction of wildlife habitat particularly during the last 30 to 40 years. The provision of additional wetland habitat is an important consideration in a state that is often quoted as being "the driest state in the driest continent." Also, wetlands in this area are of national importance in terms of the conservation of waterbirds (Harper and Weinert 1992). The wetlands of the ranges and adjacent coastal plains of the whole of southeastern Australia provide essential drought refuge for nomadic species of waterbirds that are largely dependent on the ephemeral wetland systems of inland Australia for breeding (White 1987). Wetlands in all these refuge regions have been severely depleted by urban and agricultural development and flood mitigation schemes. This part of South Australia does not have the pressure of human population that the wetland areas nearer the east coast have, so the opportunities for restoring large areas of wetland are greater. Land that might never again be productive in agricultural or other more conventional economic terms could become highly productive and valuable wildlife habitat.

## ACKNOWLEDGMENTS

This study was supported by grants from the University of South Australia and by the Wildlife Conservation Fund of South Australia. We thank Tom and Pat Brinkworth, who had the forsight to restore these wetlands, for unlimited access to their property, and for accommodation and their hospitality. Dr. Tom White made valuable comments on early drafts of the paper. Comments from anonymous referees helped improve the focus of this paper. We thank Tom White, Marcel Cardillo, Tamra Chapman, Andrew Pymm, Kevin Smith, Vivienne White, and Dereck Vodelsang for their assistance in the field and Katherine Bailey and Wayne Looker for assistance in the lab. Jeffrey Dunn assisted with the figures.

## LITERATURE CITED

Atkins, B. (ed.). 1988. Wetlands of the Bakers Range and Marcollat Watercourses: Environmental Characteristics. Report for the Dept. Environment and Planning of South Australia, Adelaide, Australia.

Bayly, I. A. E. and W. D. Williams. 1964. Chemical and biological observations on some volcanic lakes in the south east of South Australia. Australian Journal of Marine and Freshwater Research 15:123–132.

Bayly, I. A. E. and W. D. Williams. 1966. Further observations on some volcanic lakes in the south-east of South Australia. Australian Journal of Marine and Freshwater Research 17:229–237.

Blackburn, G. 1964. The soils of Counties Macdonnell and Robe, South Australia. Soils and Land Use Series No 45. CSIRO. Australia.

Briggs, S. V., M. T. Maher, and S. M. Carpenter. 1985. Limnological studies of waterfowl habitat in south-western New South Wales. I. Water Chemistry. Australian Journal of Marine and Freshwater Research 36:59–67.

Brock, M. A. 1981. The ecology of halophytes in the south-east of South Australia. Hydrobiologia 81:23–32.

Brock, M. A. 1985. Are Australian salt lake ecosystems different?—Evidence from the submerged aquatic plant communities. Proceedings of the Ecological Society of Australia 14:43–50.

Caraco, N. F., J. J. Cole, and G. E. Likens. 1989. Evidence for sulphate-controlled phosphorus release from sediments of aquatic systems. Nature 341:316–318.

De Deckker, P. 1983. Australian Salt Lakes: their history, chemistry, and biota—a review. Hydrobiologia 105:231–244.

De Deckker, P. and M. C. Geddes. 1980. Seasonal fauna of ephemeral saline lakes near the Coorong Lagoon, South Australia. Australian Journal of Marine and Freshwater Research 31:677:699.

Downing, J. A. and E. McCauley. 1992. The nitrogen: phosporus relationship in lakes. Limnology and Oceanography 37:936–945.

EWS (Engineering and Water Supply Department). 1991. Dryland salinity impacts and related groundwater and surface water management issues in Counties Cardwell and Macdonnell, South East South Australia. Final Report. Bakers Range/Marcollat Watercourses Working Group. Report No. EWS 7097/90.

Geddes, M. C. 1984. Seasonal studies on the zooplankton community of Lake Alexandrina, River Murray, South Australia, and the role of turbidity in determining zooplankton community structure. Australian Journal of Marine and Freshwater Research 35: 417–426.

Geddes, M. C., P. De Deckker, W. D. Williams, D. W. Morton, and M. Topping. 1981. On the chemistry and biota of some saline lakes in Western Australia. Hydrobiologia 82:201–111.

Halse, S. A., M. K. Williams, R. P. Jaensch, and J. A. K. Lane. 1993. Wetland characteristics & waterbird use of wetlands in south-western Australia. Wildlife Research 20:103–126.

Harper, M. and M. Weinert. 1992. Watervalley Wetlands Management Plan. National Parks and Wildlife Service. Department of Environment and Planning SA.

Hart, B. T. and I. D. McKelvie. 1886. Chemical Limnology in Australia. p. 3–31. In P. De Deckker and W. D. Williams (eds.) Limnology in Australia. CSIRO, Melbourne. Australia.

Jones, W. 1978. The Wetlands of the South-East of South Australia. Nature Conservation Society of South Australia, Adelaide, Australia.

NRCSA (Natural Resources Council of South Australia). 1993. Upper south east dryland salinity and flood management plan. Draft environmental impact statement. Department of Environment and Natural Resources, Adelaide, Australia.

NRCSA. 1994. Upper south east dryland salinity and flood management plan. Supplement. Department of Environment and Natural Resources, Adelaide, Australia.

Paijmans, K., R. W. Galloway, D. P. Faith, P. M. Fleming, H. A. Haantjens, P. C. Heylegers, J. D. Kalma, and E. Loffler. 1985. Aspects of Australian Wetlands. Division of Water and Land Resources Technical Paper No 44. CSIRO Australia.

Reynolds, C. S. 1984. The Ecology of Freshwater Phytoplankton. Cambridge University Press. Cambridge, UK.

Schwebel, D. A. 1983. Quaternary dune systems. p. 15–24. In M. J. Tyler, C. R. Twidale, J. K. Ling and J. W. Holmes (eds.) Natural History of the South East. Royal Society of South Australia.

SEWC (South East Wetlands Committee). 1991. Wetland resources of the south east of South Australia. SA Government Printer, Adelaide, Australia.

Timms, B.V. 1987. Limnology of Lake Buchanan, a tropical saline lake, and associated pools, of north Queensland. Australian Journal of Marine and Freshwater Research 38:877–884.

Timms, B.V. 1993. Saline lakes of the Paroo, inland New South Wales, Australia. Hydrobiologia 267:269–289.

Tominaga, H., N. Tominaga, and W. D. Williams. 1987. Concentration of some inorganic plant nutrients in saline lakes on the Yorke Peninsula, South Australia. Australian Journal of Marine and Freshwater Research 38:301–305.

White, J. M. 1987. The New England lagoons as drought refuges for waterbirds. Emu 87:253–255.

Williams, W. D. 1981. The limnology of some saline lakes in Western Victoria. A review of some recent studies. Hydrobiologia 82:233–259.

Williams, W. D. 1985 Biotic adaptations in temporary lentic water, with special reference to those in semi-arid and arid regions. Hydrobiologia 125:85–100.

Williams, W.D. and R. T. Buckney. 1976. Chemical composition of some inland surface waters in south, western and northern Australia. Australian Journal of Marine and Freshwater Research 27:379–397.

Manuscript received 13 June 1994; revision received 6 February 1995; accepted 18 May 1995.