

Salt cycling in bottom sediments of a salt disposal basin, Loveday Lagoon, South Australia: implications for management under drought or a changing climate

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Introduction

The Murray Darling Basin is Australia's most important land and water resource. However, extensive landuse changes since European settlement have been associated with the mobilisation of salts in the regolith, and their transport via fluvial networks down catchment. This broadscale salinisation of the region has created the need to dispose of saline waters to maintain both agricultural productivity and environmental functionality. Salt disposal basins, using either wetlands, natural depressions or specifically constructed storages, are one approach to saline water disposal. Water within these basins is lost either via evaporation, or, seepage to groundwater. These processes generate hypersaline surface water bodies, and high concentrations of salts within the basin sediments. Seepage losses also create the additional risk of salt accessions to groundwater.

A decommissioned disposal basin at Loveday Lagoon, South Australia, is the focus of studies that are examining salt storage and cycling in the bed sediments (Lamontagne et al, 2004, Beavis et al, 2006). Loveday Basin is located within a natural meander cutoff and wetland immediately adjacent to the Murray River, near Berri, South Australia (Figure 1). Modification of the site commenced in the 1930s when the construction of Loch 3 on the Murray River would have permanently flooded the site. In 1972, engineering control structures were put in place to isolate the wetland from the river and the site was converted into a saline disposal basin for excess irrigation waters (Walter, 2005), thus creating a terminal system. These irrigation waters were too saline to be discharged directly into the river. As a consequence of limited flushing events and high evaporation, the surface water of Loveday basin is hypersaline (~69mS/cm). Shallow groundwater, within the bed sediments of the basin, has a salinity of up to ~113mS/cm, whilst deeper groundwater is relatively less saline (~50- 55mS/cm). These results indicate that the basin sediments are a significant store and source of salts.

At this site, the bottom sediments comprise strongly aggregated clays with a high shrink-swell potential. Wetting and drying cycles, imposed by seasonal fluctuations in water level or managed inflows from the adjacent Murray River, have generated polygonal pedal structures on the basin floor, dissected and separated by extensive, deep, crack systems. The greatest development of pedal structures correlates with the highest frequency of wetting-drying cycles within the basin, which vary spatially as a function of bed elevation. Clay mineralogy and physical properties of the sediments control the storage of salts and their movement within, through and between pedal structures. Stored salts can be released to the water column when the system is inundated (due to rainfall or controlled inflows). In addition, the cracks provide conduits for flow and salt accessions to the underlying groundwater, with possible implications for the discharge of saline groundwater to the Murray River, which is immediately adjacent to the site. Effective management of this, and other similar sites, is emerging as an increasingly important issue for a number of reasons. Firstly, salt disposal basins represent a form of water interception where poor quality water should be prevented from discharging to streams. Secondly, processes which cause this, and similar, systems to dry out, will be associated with increased risks of crack development and subsequent high salt fluxes on inundation. Such events will increase as wetlands are dislocated from the river system due to river regulation and climate change.

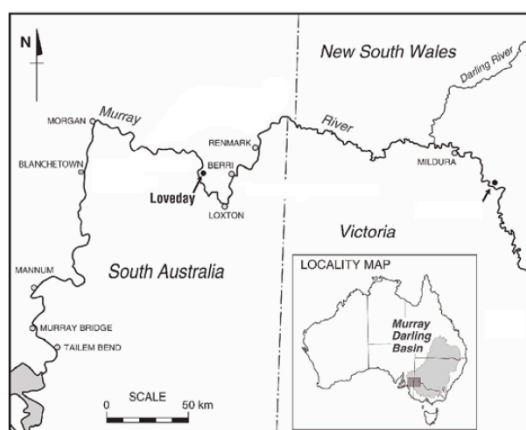


Figure 1 Location of study site (modified from Lamontaigne et al, 2004)

Materials and methods

Sampling of basin sediments included: surface salty crust; the material within the cracks that separate the pedal structures; the pedal material; and the sediment below the pedal structure/crack network. Analyses of sediments used X ray diffraction (XRD) and X-ray fluorescence (XRF), whilst 1:5 water:soil extracts were analysed by inductively coupled plasma atomic emission spectrometry (ICPAES), ion chromatography and a portable Orion conductivity meter. Infiltration of the sediments was measured using a disc permeameter (Perroux and White, 1988). Linear shrinkage was measured in the laboratory using AS1289.3.4.1 (Standards Australia, 1995). Microfabric and sediment mineralogy of resin impregnated, undisturbed sediment samples were examined by light microscopy.

Sediment characteristics

Cycles of wetting and drying generate cracking of the sediments, which imposes a distinctive microrelief of columnar pedal structures on areas of the basin bed. The spatial distribution of the pedal structures, and the degree of development, are a function of both mineralogy and hydrology. Since decommissioning, the volume of water in the basin has fluctuated, generating a zonation of pedal structures as follows:

- Near shore dry zone – pedal structures absent
- Wet-dry zone where cycles of wetting and drying have been the most frequent – optimal development of pedal structures
- Wet zone - pedal structures range from deteriorated remnants along water's edge to absent in subaqueous environment.

During 2003, when the basin completely dried out, pedal structures were evident across all areas characterised by clay rich bed sediments.

The pedal structures comprise 3-5 prismatic macropeds (~10cm wide and 25cm long). These macropeds, in turn, are composed of strongly aggregated blocky peds of ~0.5-2cm diameter). Thin section analysis shows that these peds are made up of micropeds with a diameter <1mm. The boundaries between these fabric elements, together with macropores associated with root channels, are characterised by manganese and iron oxide staining and, at a microscopic scale, abundant framboidal pyrite. These indicate oxidising conditions at the interface between the cracks and soil material at a range of scales. Under wet conditions, the spaces between the pedal structures are infilled by an organic rich, hypersaline slurry, with a high proportion of monosulfidic black ooze (MBO), in which reducing conditions occur.

Shrink-swell behaviour of the bed sediments varies at a range of scales. Firstly, shrinkage of the sediments increases from the edges to the centre of the pedal structures and, generally, down profile. This suggests that differential shrinkage in the centre of pedal structures will impose shear stresses along vertical axes, and that this will generate heave and the extension

of cracks. This is demonstrated by the occurrence of pressure faces and slickensides on the vertical surfaces of the macropeds. It also suggests that, when the system continues to dry out, cracking networks will extend and expand at depth, despite any constraints imposed by overburden pressures. Secondly, shrink swell behaviour is highest in the clay rich sediments of the wet-dry zone and lowest in the sandier dry zone.

XRD analysis indicates that the dominant clays in the bed sediments are kaolinite, illite/mica and smectite. However, the pedal structures and underlying sediments are more abundant in clay minerals relative to the surface and crack materials. In particular, there is a greater abundance of smectite clays, which explains the shrink swell behaviour of the pedal structures, and the propensity for cracking. Measurement of infiltration indicates that the highest rates of influx occur in the sandier sediments of the dry zone near the basin perimeters but, significantly, also in the region of the wet-dry zone. In this latter region, the pedal structures are the most well developed and are dissected by extensive, permanent crack systems.

Geochemistry of sediments

Geochemistry of the sediments provides information on the type of salts present, their spatial distribution within the pedal structures, and how they respond to wetting episodes. This in turn allows inferences to be made about the storage of salts within the sediments and fluxes between the sediments, surface and ground waters. Gypsum, halite and calcite are the principal salts present, with halite being dominant in the pedal structures and underlying sediment. By contrast, gypsum is dominant in the crack infill and surface sediments. This variability in the spatial distribution of the different salts is explained by the greater solubility and mobility of halite.

The major factors affecting the composition and concentration of salts within the sediments have evolved over time as a result of management practices and drought conditions. When the basin was first used as a disposal basin, the concentration of salts in the sediments would have largely been controlled by infiltration of saline surface water, and diffusion of ions into the sediments either from the surface water or from the groundwater. When the basin initially dried, there would have been a sharp increase in the surface sediment salinity due to the formation of evaporite minerals - calcite, gypsum and halite - as a surface crust-. The thickness and composition of this crust would have varied basin wide depending on elevation, reflecting the differences in solubility of these minerals.

Subsequent to this, once the sediments dried and the extensive ped-crack structure developed, the distribution of salts would have changed dramatically as a result of wetting and drying. Under wet conditions, salt ingress occurs from the top of the sediments, moving down profile and laterally through cracks and other macropores. Furthermore, as the large cracks surrounding the pedal structures are inundated, saline water will infiltrate the sediments along the crack margins by diffusion, leading to elevated concentrations of salts along the edges of the peds and a decrease in concentration inwards. There will also be a fractionation of the ions depending on their diffusivity. As the site dries and the pedal structures are exposed, salts will be mobilized towards their surfaces, by evapotranspiration.

Conclusion

Sediment fabric, clay mineralogy and the spatial distribution of salts all contribute to the transport of solutes at different rates and over varying spatial and temporal scales. This has important implications for management of this site. Firstly, during wetting cycles, solute transport will occur as a multi-phase process as water infiltrates and flows through cracks of varying geometry by the different processes of advection and diffusion. This means that whilst an initial pulse of salt may occur on flooding, there will also be a slow release of salts over a longer term. Secondly, diffusion of salts will progress down profile with the risk of increasing salinity of the deeper groundwater. Under certain hydraulic conditions, this will be associated with increased salt loads to the river system. Diffusion will also transport solutes

further into the pedal structures, increasing the storage of salts. Finally, the drying of the sediments will promote cracking and further contribute to the risks of increasing salt storage and transport in later wetting cycles. Desiccation will occur under conditions of prolonged drought or shifts in climate, when the delivery of water to this site will be reduced due to low rainfall and limited water allocations. This creates a management conundrum. Limited water availability means that the system cannot be permanently flooded. Periodic flooding of the site will mobilise salts. Drying the site will generate deeper cracking, adding to future risks of salt transport and reduced environmental health.

References

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