

**Sediment resuspension and water
quality during declining water levels in
a shallow lake: a case study of Lake
Alexandrina, South Australia**

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Abstract

Shallow lakes have a tendency to be present in one of two broad alternative states: clear or turbid. Increased demand for water by humans, drought and climatic shifts may reduce water availability and increase the frequency or magnitude of lake water-level drawdown. However, there is conflicting evidence as to how shallow lakes respond to water level decline. Many lakes become clearer due to reduced nutrient inputs from inflowing rivers. Alternatively, internal processes, such as the resuspension of sediments, can exacerbate the turbid state as lower water levels attenuate less wind-induced turbulence before it reaches the sediment surface. A better understanding of responses of lake water quality to drawdown will greatly improve the ability of water managers to maximise the ecological benefits of drawdowns, while minimising the adverse consequences.

Severe drought in the Murray-Darling Basin, Australia's largest river system, resulted in extreme water level decline in the two end of system lakes, Lake Alexandrina and Lake Albert (the Lower Lakes). Water depth in Lake Alexandrina dropped from a mean of 2.9 metres in summer 2006/07 to 1.3 metres two years later, where water levels remained until April 2010 when floods refilled the lakes. This provided a unique opportunity to assess the influence of water level decline on lake characteristics. The aims of this work were to firstly elucidate the effects of water level decline on sediment resuspension and redistribution, accompanying nutrient changes and light availability. Secondly, the study sought to understand the interactions between water level decline and sediment resuspension in the context of alternative stable states during periods of drought.

As water level fell in the Lower Lakes, the water quality became increasingly brackish as mean salinity rose from 0.6 g L^{-1} to 3.7 g L^{-1} . The concentration of suspended particulate matter (SPM) and associated nitrogen and phosphorus concentrations increased as water levels declined, whereas soluble phosphorus did not. A mass

balance showed that month to month variation in SPM could not be explained by the sum of inputs and outputs, suggesting that sediment resuspension was an important process in Lake Alexandrina at all water levels. Surveys of the size distribution of surface sediments suggested that focusing of fine sediments was more prevalent when water levels were higher. Analysis of gross sedimentation using sediment traps supported the hypothesis that the resuspension and redistribution of sediments had become spatially homogeneous as water levels declined.

High-resolution data collected from the centre of Lake Alexandrina suggested that sediment resuspension frequently occurred below even the deepest water. At bed shear stresses greater than 0.031 N m^{-2} particles with a nominal diameter of $26 \mu\text{m}$ were resuspended. Under low water levels, sediment resuspension strongly influenced the depth of light penetration into the water column (euphotic depth ranged between 0.68 and 0.91 metres). However, lower water levels led to an increase in the average irradiance through the water column compared with previous studies at higher water levels.

Hydrodynamic modeling was used to quantify the influence of wind speed on sediment resuspension. This showed that wind speeds of 7.7 m s^{-1} were required to resuspend particles with a nominal diameter of $26 \mu\text{m}$ when water levels were high. However, at low water levels, the wind speed imparting critical shear velocity at the lake-bed decreased to 2.4 m s^{-1} . The frequency distribution of wind speed suggested that sediments were being resuspended only 27% of the time when water levels were high, but over 87% of the time at the lowest water levels studied.

The shallow morphology of Lake Alexandrina, as well as the high wind-induced turbulent energy at the sediment surface due to its large surface area, increased the resuspension and redistribution of fine sediments during water level drawdown. For Lake Alexandrina, the internal process of sediment resuspension overcame the drought-induced reduction in nutrient inputs to result in an increasingly turbid system. These results imply that lake management should centre on the reduction of external nutrients, as well as biomanipulation of the food webs to increase the water clarity of Lake Alexandrina and improve conditions for macrophyte development.

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Declaration

I, Dominic Skinner certify that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Dominic Skinner 18/11/2011

List of abbreviations

AHD:	Australian Height Datum, where zero equals the mean sea level recorded between 1966 and 1968
ANCOVA:	Analysis of Covariance
ANOVA:	Analysis of Variance
ASS:	Acid sulfate soils
Chl a :	Chlorophyll a
CSIRO:	Commonwealth Scientific and Industrial Research Organisation
DOC:	Dissolved organic carbon
DWLBC:	Department for Water, Land and Biodiversity Conservation
EC:	Electrical conductivity
FRP:	Filterable reactive phosphorus
GDP:	Gross Domestic Product
Gt:	Gigatonne (equal to 1000 Megatonnes)
IC:	Inorganic carbon
ICP-AES:	Inductively coupled plasma atomic emission spectrophotometry
ICP-OES:	Inductively coupled plasma optical emission spectrophotometry
IG $_0$:	Loss-on-ignition (reported as a percentage of fresh weight)
LISST:	Laser <i>in-situ</i> scattering and transmissometry
LOI:	Loss-on-ignition (reported as a percentage of dry weight)
MDBA:	Murray Darling Basin Authority
ML:	Megalitre (equal to 1 000 000 litres)
Mt:	Megatonne (equal to 1 000 000 tonnes)
NATA:	National Association of Testing Authorities
OC:	Organic carbon
pCO $_2$:	Partial pressure of carbon dioxide
PSD:	Particle size distribution
PVC:	Poly-vinyl chloride

RMSE:	Root mean square error
SIPM:	Suspended inorganic particulate matter
SOPM:	Suspended organic particulate matter
SPM:	Suspended particulate matter
TC:	Total carbon
TIPM:	Trapped inorganic particulate matter
TN:	Total nitrogen
TOPM:	Trapped organic particulate matter
TP:	Total phosphorus
TPM:	Trapped particulate matter
WC:	Water content
Z_{mean} :	Mean depth (metres)
Z_{max} :	Maximum depth (metres)

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Preface

Ecosystem management in the twenty-first century is facing multiple, compounding crises that threaten to undermine the social fabric upon which Western civilisation has been founded (Foley *et al.* 2005; Annan *et al.* 2009; Rockström *et al.* 2009). These crises arise from a fundamental philosophical inconsistency with how we perceive ourselves, the environment and our place within it (see for example Aarons 1972; Capra 1982; Medlin 1992; Wetzel 1992; Norgaard 1995; Skinner 2007; Beddoe *et al.* 2009). It is not difficult to find examples of the pervasive extent to which human action has impacted ecosystems (the current geological era has even been called the anthropocene Vitousek *et al.* 1997; Steffen *et al.* 2007). Some notable figures of the anthropogenic impact on natural resources follow:

- Water impoundments retain over 10 800 cubic kilometers of water, reducing global sea levels by 3 cm (Chao 2008). Shifting this hydrological mass has had an observable influence on Earth's polar drift and its rotational velocity (Chao 1995).
- Of the easily accessible freshwater runoff, 54% is impacted through consumption or pollution by agriculture, industry or urban use (Postel *et al.* 1996).
- An additional 4.5 – 14.5 Mt/year of phosphorus is estimated to be accumulating in agricultural lands and aquatic systems compared with pre-industrial times (Bennett *et al.* 2001).
- Globally, 96-98% of mammalian biomass is directly associated with human activity (i.e. humans, domesticated animals, pets etc. Smil 2002).
- Over 1 000 barrels of crude oil are consumed globally every second (International Energy Agency 2010).

The general problem was succinctly stated in the Millennium Ecosystem Assessment (MEA 2005), where it was written that

“human activity is putting such strain on the natural functions of the Earth that the ability of the planet’s natural ecosystems to sustain future generations can no longer be taken for granted” (p.5).

Moreover, what were previously perceived as sufficient management responses to mitigate these human impacts on ecosystems, have often included unintended consequences. For example, Likens *et al.* (2009) contend that “knowledge about aquatic ecosystems required to support water-resource management lags behind the increasing problems caused by past, often piecemeal, management approaches” (p.271). To ameliorate these shortcomings, the use of ‘best available science’ to inform policy is widely advocated in aquatic ecosystem management (ARMCANZ/ANZECC 1996; Sutherland *et al.* 2004; Moss 2008; Ryder *et al.* 2010). The contention is that applying the most coherent, consistent and detailed scientific knowledge presently available, while accepting that uncertainty is inescapable, will prevent piecemeal, and therefore problematic, management solutions. There remains an imperative to correctly define the scope of management, the scale of intervention and the levers available to achieve certain outcomes. If this is not done, the efforts of aquatic ecosystem managers can be poorly targeted (Pullin *et al.* 2009; Vörösmarty *et al.* 2010).

To meet the objective of contributing to the best available science, while preventing any conclusions from being misconstrued as solutions in their own right, this thesis starts (and ends) with a broad and inclusive definition of the problems it is addressing.

The chapters in this thesis have been prepared in a format suitable for later publication in scientific journals. This has inevitably led to some repetition between chapters.