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Adaptive management for mitigating *Cryptosporidium* risk in source water: A case study in an agricultural catchment in South Australia

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ABSTRACT

Water-borne pathogens such as *Cryptosporidium* pose a significant human health risk and catchments provide the first critical pollution 'barrier' in mitigating risk in drinking water supply. In this paper we apply an adaptive management framework to mitigating *Cryptosporidium* risk in source water using a case study of the Myponga catchment in South Australia. Firstly, we evaluated the effectiveness of past water quality management programs in relation to the adoption of practices by landholders using a socio-economic survey of land use and management in the catchment. The impact of past management on the mitigation of *Cryptosporidium* risk in source water was also evaluated based on analysis of water quality monitoring data. Quantitative risk assessment was used in planning the next round of management in the adaptive cycle. Specifically, a pathogen budget model was used to identify the major remaining sources of *Cryptosporidium* in the catchment and estimate the mitigation impact of 30 alternative catchment management scenarios. Survey results show that earlier programs have resulted in the comprehensive adoption of best management practices by dairy farmers including exclusion of stock from watercourses and effluent management from 2000 to 2007. Whilst median *Cryptosporidium* concentrations in source water have decreased since 2004 they remain above target levels and put pressure on other barriers to mitigate risk, particularly the treatment plant. Non-dairy calves were identified as the major remaining source of *Cryptosporidium* in the Myponga catchment. The restriction of watercourse access of non-dairy calves could achieve a further reduction in *Cryptosporidium* export to the Myponga reservoir of around 90% from current levels. The adaptive management framework applied in this study was useful in guiding learning from past management, and in analysing, planning and refocussing the next round of catchment management strategies to achieve water quality targets.

1. Introduction

Traditional management of environmental issues involves the recognition of the problem and setting goals, analysing the problem and planning for management, developing a management strategy to fix the problem, implementing the management strategy, monitoring and evaluating to determine whether goals have been achieved (Linkov et al., 2006). The adaptive management framework (Holling, 1978; Walters, 1986) includes an explicit learning and adaptation phase which is used to iteratively inform planning of the next round of management. Adaptive management provides a way of managing environmental systems despite the inherent uncertainty and in doing so, learning from the outcomes of management intervention in a systematic process of 'learning while doing' (Lee, 1999; Walters and Holling, 1990; Linkov et al., 2006).

Adaptive management is often delineated into *passive* or *active* based on differences in the approach to learning (Walters and Holling, 1990; McCarthy and Possingham, 2007). Passive adaptive management implements a single preferred course of action based on the best available modelling and planning. Active adaptive management goes further in implementing a range of competing alternative courses of action framed as formal experimental treatments subject to rigorous (often

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statistical) evaluation. Passive adaptive management tends to be much simpler and less expensive than the active variant (Wilhere, 2002). However, learning is more limited under passive adaptive management because cause and effect relationships cannot be reliably established (Wilhere, 2002; Gregory et al., 2006b).

Recent reviews identify many theoretical studies that have developed the adaptive management framework for ecosystem management (NRC, 2004; Satterstrom et al., 2005; Gregory et al., 2006a; Linkov et al., 2006; McCarthy and Possingham, 2007). Many regulatory agencies have included adaptive management principles in their efforts to manage the interaction between human activity and ecosystems (WWF, 2001; USEPA, 2000, 2007; NOAA, 2008). Adaptive management principles have been invoked at the strategic planning stage in many environmental management domains including habitat restoration (Doyle and Drew, 2008), fisheries management (Rudd, 2004), species conservation (Wilhere, 2002), pest control (Shea et al., 2002) and water quality and quantity (Prato, 2003; Gregory et al., 2006b; Broderick, 2008). However, despite the attractiveness of adaptive management and its learning by doing approach, there have been few successful practical applications of the adaptive management framework (Walters, 1997; Satterstrom et al., 2005; Gregory et al., 2006a; Linkov et al., 2006). Critiques have identified many potential problems with implementation of adaptive management primarily related to the capacity and conflicting priorities of stakeholders, including scientists and policymakers, in complex jurisdictional and ecological settings (Gregory et al., 2006a). As a result of the difficulties associated with successful implementation, many well intentioned environmental management projects and programs have done little more than use adaptive management in name only (Gregory et al., 2006a). However, some studies are beginning to address these challenges (Broderick, 2008).

In this study, we provide a practical application of the evaluation stage of a recently completed environmental management program and use this information in the planning stage of the second iteration of the adaptive management cycle to ultimately refocus and refine the management of significant residual issues. We present a case study of the management of the pathogen *Cryptosporidium* in source water entering a drinking water supply in the Myponga catchment in South Australia. *Cryptosporidium* is a parasitic protozoon that can potentially cause gastrointestinal illness in a wide host range including humans, cattle, and sheep is an issue of major importance in catchments supplying water for human needs (Baron et al., 2002; NHMRC, 2004). Several species of *Cryptosporidium* have been identified many of which are not harmful to humans. The most significant sources of human-infectious *Cryptosporidium* (most commonly *Cryptosporidium parvum* or *Cryptosporidium hominis*, hereafter simply *Cryptosporidium*) in source water include livestock such as cattle and sheep, especially young stock (Santin et al., 2004; Fayer et al., 2006), and human sources such as failing wastewater systems (Dechesne and Soyeux, 2007; McDonald et al., 2008). *Cryptosporidium* shed by wildlife such as kangaroos is typically of a non-human-infectious genotype (Power et al., 2005).

We evaluate the effectiveness of a recently completed water quality management program in motivating activities such as riparian fencing and livestock management using a survey of current land use and management practices in the catchment. The impact of these actions in mitigating *Cryptosporidium* in source water entering the reservoir is assessed using water quality monitoring data. Survey data is then used to populate a pathogen budget model in a quantitative risk assessment of the remaining sources of *Cryptosporidium* in the catchment following the first round of management. Finally, a range of catchment management scenarios are assessed for their potential to mitigate *Cryptosporidium* export. The study provides a practical assessment of the utility of the adaptive management framework in structuring the formal evaluation and refocussing of management priorities in addressing a high priority environmental issue with potentially significant human health and economic implications.

2. The Myponga study area

The Myponga River catchment covers an area of approximately 123 sq km, situated 50 km south of Adelaide, South Australia (Fig. 1). The Myponga reservoir in South Australia is the main source of filtered drinking water for more than 50,000 people in the southern coast area from McLaren Vale to Victor Harbor and provides about 5% of the fresh water supply to the city of Adelaide with a population of over 1.1 million (Fig. 1).

The Myponga catchment has an average annual rainfall of approximately 724 mm. Average yield in the Myponga River is 7507 ML/yr and flows are highly seasonal (Thomas et al., 1999). The Myponga reservoir has a capacity of nearly 28 GL and is entirely catchment fed. Hence, the quality of the source water entering the reservoir is largely influenced by the land use and land management practices in the catchment.

The upper catchment area consists of steep hills along the western boundary, changing to rolling hills on the eastern side of the Myponga River (Thomas et al., 1999). Topography in the mid-catchment area is predominantly undulating, with some lower lying marsh areas existing along the banks of the Myponga River. Thomas et al. (1999) document the disturbance of 90% the original riparian vegetation in the Myponga catchment and the subsequent impact on ecological health and water quality of watercourses.

Broad scale grazing (mainly beef cattle and sheep, with some horses and deer) is the dominant land use in the Myponga catchment (61%). Most of these properties are hobby farms with a few larger commercial landholders. Native vegetation (13%) and dairying (13%) are also significant land uses by area (Fig. 2). Recent trends in land use change include the conversion of significant areas of dairy farms to broad scale grazing (from 30% in 1998 (Thomas et al., 1999) to the 13% today).

Management of wastewater in the catchment is a critical issue affecting the quality of source water entering the Myponga reservoir. For most dwellings wastewater is managed largely by on-site sewage management systems (OSMS). A small (0.3 ML/day) wastewater treatment plant (WWTP) services the Myponga township (including 4 lagoons) and located only a few hundred metres from the Myponga creek. Wastewater from this plant is used for irrigating an adjoining livestock grazing pasture.

SA Water (the South Australian government water utility) is responsible for the quality of potable water provided to the majority of consumers in South Australia. For *Cryptosporidium*, SA Water has an aspirational goal of 0 oocyst/L with an intermediate target level of 1 oocyst/L. SA Water has adopted the *multi-barrier* approach to achieve this water quality target in accordance with the Australian Drinking Water Guidelines (NHMRC, 2004). The *multi-barrier* approach is widely accepted for managing water quality and recommends the provision of water quality protection mechanisms at multiple points from the *catchment* (where raw water is harvested) to the *tap* (or end consumer; Deere et al., 2001; NHMRC, 2004).

SA Water uses as a guide the USEPA LT2 rule which requires a minimum of 99% removal efficiency of *Cryptosporidium* from raw water to create 'safe' drinking water. The Myponga Water