
33rd WEDC International Conference, Accra, Ghana, 2008**ACCESS TO SANITATION AND SAFE WATER:
GLOBAL PARTNERSHIPS AND LOCAL ACTIONS****Natural clarification of potable water
in a semi-arid catchment**

T. Kuypers, M. P. Taylor & A. Mackay, Australia

This paper examines the efficacy of the natural clarification system developed for potable water treatment in the semi-arid Leichhardt River catchment of north-west Queensland, Australia. The system is examined through its various stages. Sediment and water analyses show progressive improvements to water quality parameters such as turbidity, colour and heavy metal concentrations to within Australian Drinking Water Quality Guidelines. Tracked improvements to microbial water quality indicators (faecal coliforms and enterococcus) before chlorination emphasise the critical role that natural processes and regulated intakes perform in the protection of the potable water supply. The success of the system over the past 24 years, combined with its low cost and minimal maintenance has seen the CWL system viewed as a reliable method for improving water quality that has the potential to be modelled in other water supply catchments.

Introduction

Clear Water Lagoon (CWL) is the only documented natural clarification system used for potable water treatment in Australia. Developed in the semi-arid Leichhardt River catchment, CWL provides an affordable, low maintenance method by which to manage turbid river flows through the monsoonal wet season. For 24 years the mining city of Mount Isa has relied on the system to treat surface water to within Australian Drinking Water Quality Guidelines (ANZECC, 2000).

The success of natural filtration systems for the treatment of municipal and industrial wastewaters has led to a greater appreciation of their multiple values (Green *et al.*, 1997; Gschobl & Stuible, 2000; Goulet *et al.*, 2001; O'Hagain, 2003; Chen *et al.*, 2006). However, the transfer of this technology into community scale potable water treatment systems remains poorly tested. The development of Mount Isa's unique method of water quality treatment was a slow evolutionary process that today represents a proven and economically attractive method for improving water quality on a community scale. This method of filtration has the potential to be modelled for use by other townships in difficult environmental settings where more traditional mechanical methods of filtration are not financially feasible.

This paper explores the functionality of the CWL system, building on previous research (Finlayson, 1980; Farrell, 1989. Griffiths and Farrell, 1991; Wrigley *et al.*, 1991; Kuypers *et al.*, 2006) to describe how each of the systems components contribute to water quality improvement. In addition, microbial water quality indicators are tracked in the supply catchment to examine the effect that flow regulations and natural processes have on microbial water quality before chlorination.

Site description

Mount Isa is the largest inland city in Queensland, Australia (population 20,695: ABS census 2006). The city sprawls along the banks of the upper Leichhardt River in the tropical continental region of north-west Queensland. Seventy five percent of the annual rainfall (480-1,250 mm: Taylor & Hudson-Edwards, 2005) is delivered during the humid wet season months from December to March. Intense and localised thunderstorms are generated by the passage of the inland trough system and intermittently by the southern extension of ex-tropical cyclones. The Leichhardt River flows only during and shortly after such rainfall events, which occur on average 4 times each wet season. For the remainder of the year the riverbed is dry with the exception of a series of disconnected permanent and temporary pools. The catchment is characterised by a sparse coverage of spinifex grass and scattered eucalyptus trees, a condition in part due to climate but is also a result of extensive cattle grazing. Flows from the arid catchment are always very turbid.

In the late 1950's the Leichhardt River was dammed to create Lake Moondarra (20°34'S, 139°35'E) which captures runoff from the Selwyn Range to provide a dependable supply of water to Mount Isa and its industry. The lake is located some 12 km downstream of the city and has a maximum capacity of 106,830 ML (Finlayson, 1980), capturing runoff from the catchment with an approximate area of 1,113 km² (Figure 1). Inadequate groundwater supplies necessitate almost complete reliance on Lake Moondarra and support reservoirs (Lake Julius and Rifle Creek Dam).

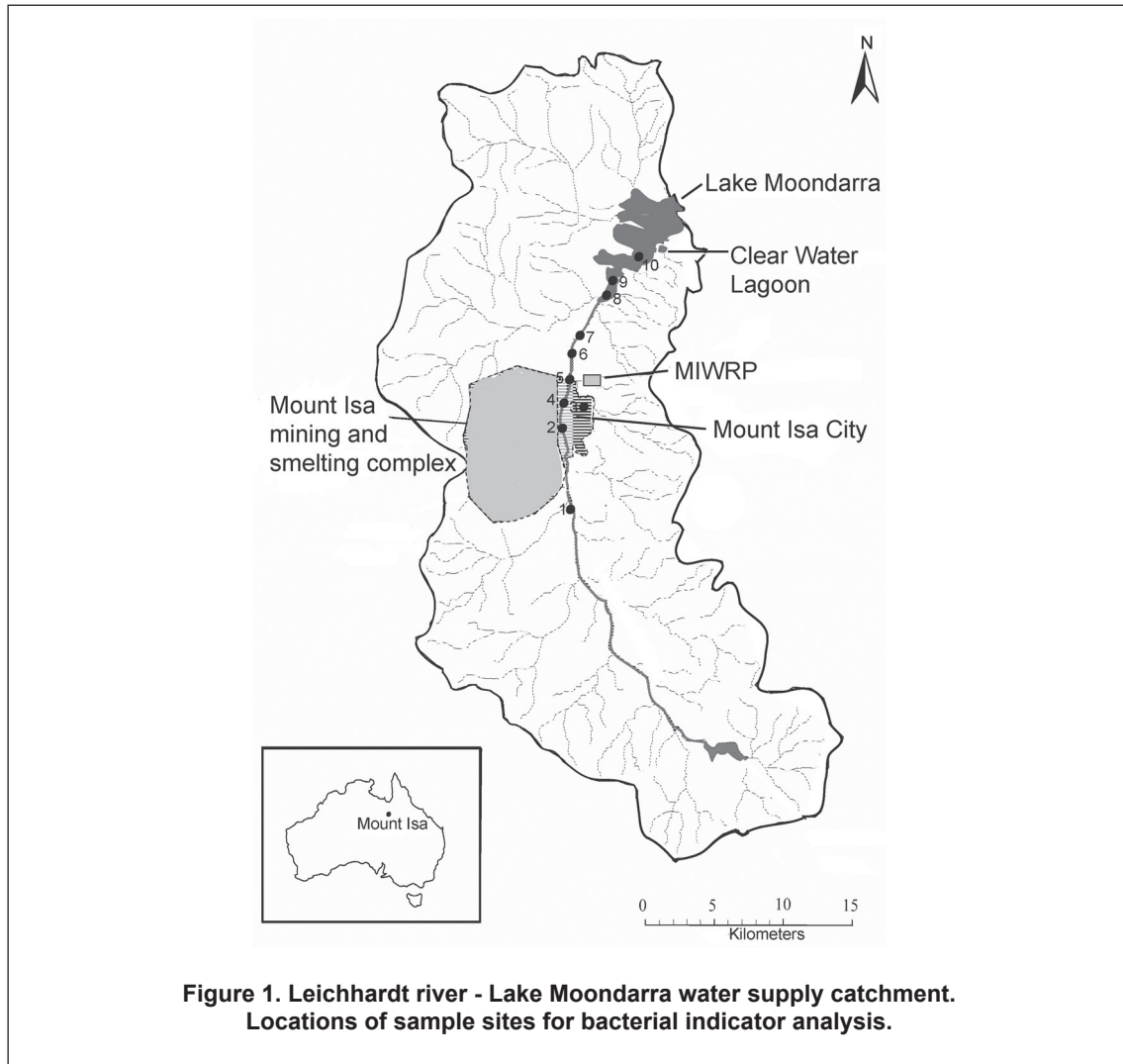


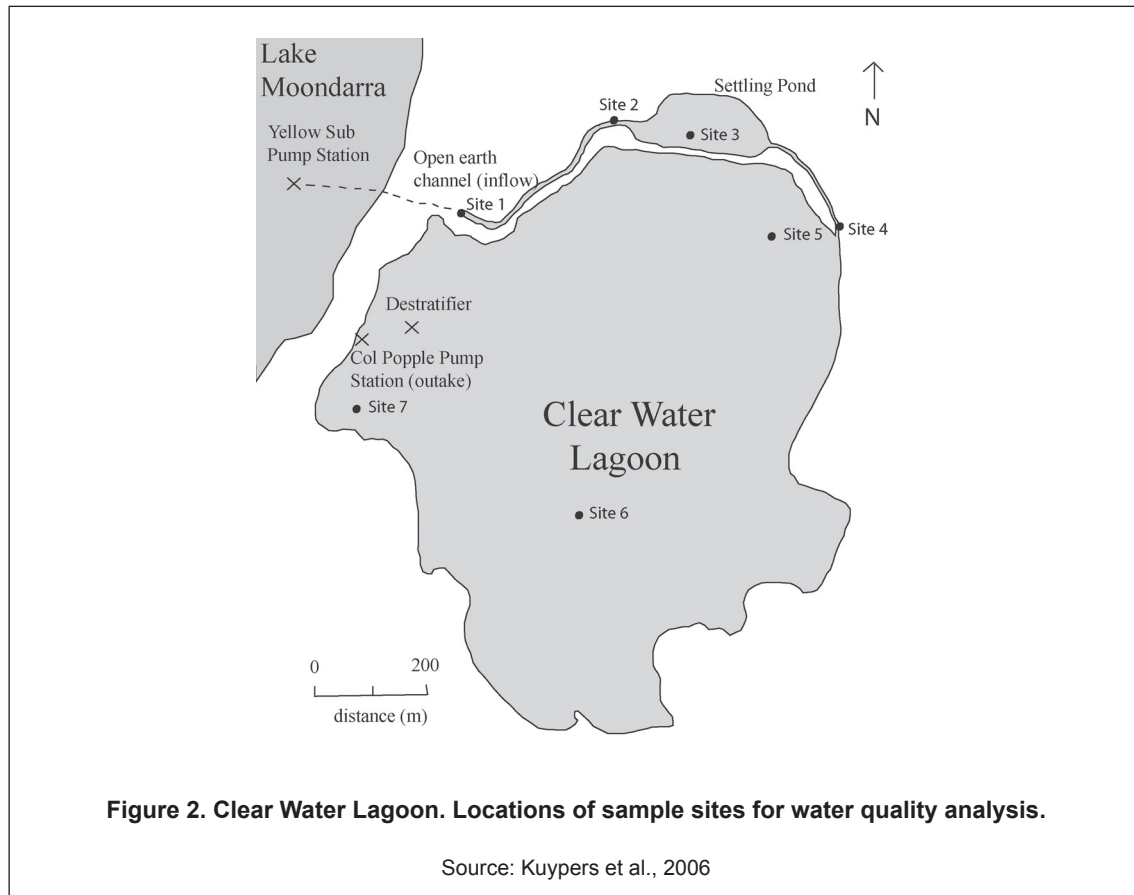
Figure 1. Leichhardt river - Lake Moondarra water supply catchment. Locations of sample sites for bacterial indicator analysis.

Water quality hazards in the catchment

Despite the relative lack of agricultural activity and the consolidated nature of the urban area, the microbial quality of water entering Lake Moondarra from the Leichhardt River is predicted to present a risk to the potable water supply. Most notably, the Mount Isa Wastewater Reclamation Plant (MIWRP) is at times unable to adequately treat and distribute effluent water via the associated irrigation scheme, particularly during times of heavy rain, resulting in direct releases into the river. Damage to the sewerage infrastructure from underground mine blasting, runoff from the urban catchment and unrestricted cattle grazing present an additional risk to microbial water quality. The mineralised nature of the catchment also has the potential to affect water quality. Xstrata Mount Isa Mines, the largest lead-copper-zinc mine in Australia, is the most prominent feature in the water supply catchment. While current mining operations occur underground, in previous decades open cut surface mining operated under relaxed environmental regulation resulting in mine waste regularly flushing into the Leichhardt River (Taylor et al., 2007). In addition to hazards from upstream, Lake Moondarra is also used recreationally by the public, with swimming and boating regular activities. The nature of the treatment process demands knowledge of the hazards within the supply catchment in order to assess the risks to water quality.

Clear water lagoon

In 1968 a shallow depression next to Lake Moondarra was dammed to create CWL in response to high turbidity and contamination concerns in Lake Moondarra during wet season flows. It was initially constructed as a temporary storage lagoon into which water was pumped from Lake Moondarra during periods of low turbidity to provide a 30 day supply of clear water during wet season flows. However, since its inception, CWL has been extensively modified to form an indispensable part of the Mount Isa water treatment system which is now used throughout the year. Water from Lake Moondarra is pumped into the CWL system via an open-earth flume which directs flow via a settling pond, through reeds and other macrophytes, and finally into the primary holding lagoon (Figure 2).



The open earth flume was constructed around the northern edge of the lagoon as a means of distancing the inlet as far as possible away from the off-take pump. The flume was designed so that during periods of high turbidity poly aluminum chloride would be used to dose incoming water. A tank and dosing pump located at the main pump station distributed the chemical solution through a spray bar at the end of a turbulent section of the flume. The settling pond at the end of the flume collected the floc obtained from dosing before the water entered the main body of the lagoon. However it was realised within just a few wet seasons that PAC wasn't necessary if intake timing was carefully considered. After flows from the Leichhardt River the turbidity in Lake Moondarra always improves markedly within a week. If pumping is avoided during turbid conditions the CWL supply can be protected.

The dominant macrophytes in the lower flume, settling pond and main lagoon include *Hydrilla verticillata*¹, *Potamogeton tricarinatus*², *Typha orientalis*³ and *Vallisneria spiralis*⁴. Approximately 82% of the surface area of the lagoon has vegetation cover (extending from the shoreline to a depth of approximately 5 m). There are three major habitat types, each with a characteristic pattern of vegetation reflecting the texture and slope of the substrate and exposure to wind/wave energy. Maintenance of a constant water level in CWL is critical to the survival of rooted water plants, particularly the typha reeds that inhabit the perimeter of the main lagoon.

The macrophytes throughout the system perform an integral role in the filtration process. A positive linear relationship was found between the 'standing stock' of *Hydrilla verticillata*, the most abundant macrophyte, and the volume of captured suspended particles (Farrell, 1989). Entrapment of particles on *Hydrilla* occurred through two mechanisms:

- Lodgement of particles against plant surfaces at the leading edge;
- Entrainment into localized swirling vortices resulting from the drag force downstream of the plant body causing the particles to spiral downwards to the nearest substrate.

Individual plants periodically slump to the substratum carrying with them their silt loading thus facilitating downward transport of the particulate matter and its incorporation and stabilization within the sediment. A gradual build-up of sediment is expected with the slow migration of the front of the delta into the lagoon and a gradual reduction in the depth of the lagoon basin.

The main lagoon covers an area of 0.67 km² and has an average depth of 6 meters. Water is pumped into the open earth channel at a maximum rate of 70 000m³ day⁻¹ to maintain a lagoon volume of 2.19 x 10m³. This is equivalent to around 400ML of accessible water or 8 days supply at current average usage rates (MIWB, personal communication). A compressed air destratifier located close to the off-take operates in automatic mode throughout the year to ensure good mixing through the water column in order to avoid lake turnover. Once pumped out of the main lagoon at Col Popple Pump Station, the water undergoes chlorination before being pumped to Mount Isa Terminal Reservoir for distribution.

Methods

Progressive analyses were undertaken through the filtration system to ascertain the presence of any functional relationships between vegetation coverage, sediment deposition and water quality. Water and sediment samples were taken from CWL during the wettest months of January and February 2006. Water quality parameters (colour, turbidity, metals, nutrients, pH and dissolved oxygen) were measured at seven sites throughout the lagoon system (Figure 2) using a YSI 556 Handheld Monitoring System and a Palintest Photometer. Preliminary samples were also transported to Simmonds and Bristow in nitric acid washed bottles for heavy metal testing (NATA accredited laboratory). Measurements from the Photometer were found to be within ±10% variability of the laboratory results. Sediment samples were collected from Sites 1, 3, 5 and 7 and analysed for their total extractable As, Cd, Cu, Fe, Mn, Ni and Pb concentrations. Samples were analysed by Inductively Coupled Plasma Spectroscopy at Simmonds and Bristow (NATA approved laboratory). Duplicate samples were found to be within 15% variability.

Raw water samples were collected from upstream of Lake Moondarra for the analysis of faecal coliforms and enterococci. Samples were collected during the 2006-2007 wet season from 10 locations (Figure 1). Sites were selected to test presumed point sources of microbial contamination (e.g. MIWRP, effluent reuse scheme) and to provide a catchment snapshot of microbial water quality. Samples were collected during 6 different flow conditions in detergent washed brown glass bottles and stored on ice (4°C) prior to analysis. Analyses were conducted at Mount Isa Council Laboratory using the membrane filtration method. The results were interpreted alongside records from Mount Isa Water Board on faecal coliform counts collected weekly from site 7 in CWL (1995-present). This provides an indication of how well flow regulation and natural processes work to protect microbial water quality before chlorination.

Results and discussion

Progressive improvements to water quality are observed from the intake through to the main lagoon (Table 1). Turbidity values decline throughout the system until reaching ADWG (NHMRC, 2004) compliant levels at Site 5. Values average less than 5 NTU at the final sample site adjacent to Col Popple Pump Station. Regression analysis of the relationship between turbidity and colour showed that 84% of the variation in colour can be explained by the variation in turbidity. A marked improvement in heavy metal concentrations (Al, Cu, Fe) occurs between Site 2 (entrance to the settling pond) and Site 4 (reed beds). Since samples are unfiltered, the peak values of Al, Cu, and Fe recorded at Sites 2 and 3 may be explained by the relative high turbidity values recorded at these locations. Within the main lagoon (Sites 5 to 7) there is very little variation in these measured heavy metals, providing evidence that the destratifier is working to mix water in the main lagoon.

Site	Turbidity (NTU)			Colour (PCU)			Aluminium (µg/L)			Iron (µg/L)			Copper (µg/L)		
	Min	max	Mean	min	Max	mean	min	max	mean	min	max	mean	min	Max	mean
1	6	150*	22	20	320	92	0	60	19	40	1100	300	20	180	81
2	6	26	16	25	95	56	0	30	8.1	50	600	270	16	170	64
3	-	-	-	25	85	45	0	30	5.5	30	720	230	0	20	8
4	0	16	8	20	70	38	0	0	0	0	340	150	0	60	15
5	0	8	4	0	20	12	0	10	7	0	120	46	0	20	2.5
6	0	8	5	0	30	13	0	50	13	0	80	28	0	0	0
7	0	8	4	0	45	16	0	0	0	0	70	37	0	40	9
	ADWG** = <5 NTU			ADWG** = ≤15 PCU			ADWG** = 200 µg/L			ADWG** = 300 µg/L			ADWG* = 1000 µg/L ADWG*** = 2000 µg/L		
<p>* = High turbidity reading was the result of pump failure (1 day) and use of deeper drawing back-up pump ADWG** = Australian Drinking Water Guidelines, Aesthetic guideline value ADWG*** = Australian Drinking Water Guidelines, Health guideline value (NHMRC, 2004).</p>															

Measurements of sediment distribution and thickness reveal that the majority of sediment deposition occurs within 40 m from the entrance to the settling pond (Sites 2 to 3, Figure 2). This is attributed to influent flow velocity reduction aided by the energy dissipaters (riffles) at the end of the open channel, channel widening at the entrance to the settling pond, and filtration through the dense bed of submerged macrophytes. Sediment laden *Hydrilla* within the flume and settling pond suggest that the physical filtration is primarily occurring as water passes through this part of the system.

All sediment samples tested for heavy metals were well within the ANZECC/ARMCANZ (2000) guidelines for freshwater ecosystems, with the exception of sediment Pb concentrations at Site 1. The entrance to the settling pond holds the most contaminated sediments. A marked improvement to sediment quality occurs between sites 3 and 5 suggesting that the *Hydrilla* in the settling pond and the *Typha* reed beds across the entrance to the main lagoon work in tandem to filter suspended particulates. The associated physical parameters of turbidity, colour and heavy metal concentrations support this interpretation as they too significantly improve in the same locations.

Table 2 reports the results from raw water analyses conducted at 10 sites through the upper catchment and Lake Moondarra (Figure 1). Consistently elevated microbial indicator counts were recorded through the urban catchment (sites 2, 3, 4 & 5), results that were expected considering sample collection was conducted during and shortly after river flow. Site 5 recorded the highest counts after the first flush flow (Ent = 119,000 cfu/100 mL, faecal coliforms = 95,000 cfu/100 mL). This is thought to be the result of heavy runoff from the irrigated horse paddocks as well as overflow from the MIWRP. Dilution and mixing of river flows with water stored in Lake Moondarra result in microbial indicator counts suddenly declining at Sites 8, 9 & 10. However pump activation to draw water from Lake Moondarra to CWL must be carefully considered at this time of the year.

Site	Enterococci (cfu/100mL)			faecal coliforms (cfu/100mL)		
	Min	Max	mean	Min	max	Mean
1	200	4400	2292	110	5200	1652
2	1100	14300	7217	230	14500	5938
3	30	11000	2958	530	7500	3593
4	260	8500	4550	260	8500	3047
5	5500	119000	38333	3200	95000	31783
6	30	11000	2957	120	13500	3838
7	1100	10500	3690	150	17800	6270
8	15	450	147	2	2670	244
9	4	20	12.25	15	190	75
10	2	590	31.8	15	60	32

Results from the water quality monitoring program conducted by Mount Isa Water Board show that faecal coliform densities at Site 7 in CWL (Figure 2) have consistently read between <1-1 cfu/100mL since the beginning of monitoring in 1995. Therefore, despite water quality concerns in the supply catchment the combination of carefully regulated intakes from Lake Moondarra, system design and UV irradiation on the open waters of the main lagoon act to adequately protect the microbial quality of the water supply.

Conclusion

The incorporation of natural clarification processes into the treatment of potable water supplies has the potential to affordably improve water quality. Clear Water Lagoon provides an example of how careful flow regulation, system design and the use of aquatic macrophytes have overcome quality concerns in a difficult semi-arid water supply catchment. Sediment and water analyses have shown that the CWL system significantly improves influent water quality parameters such as heavy metal concentrations, turbidity and colour to within Australian Drinking Water Guidelines. Inflow regulation also protects the water supply from microbial water quality concerns during wet season flows. The concept of natural clarification has the potential to be applied to existing water treatment facilities, acting as an additional barrier to water quality protection. Remote communities where more traditional methods of water treatment are not economically viable should also consider the value that manipulation of natural processes can offer to the improvement of water quality.

References

- Australian Bureau of Statistics (ABS) (2006): <http://www.abs.gov.au/AUSSTATS/abs@nsf-> Accessed April 3rd 2007.
- Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000): *National Water and Quality Management Strategy. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality*. Paper No. 4- Volume 1 Chapter 3. Department of the Environment and Heritage, Canberra, Australia, 3.5-4 pp.<http://www.deh.gov.au/water/quality/nwqms/volume1.html> - Accessed 20 April 2007.
- Chen, T. Y., Kao, C. M., Yeh, T. Y., Chien, H. Y. & Chao, A. C. 2006. Application of a constructed wetland for industrial wastewater treatment: A pilot-scale study. *Chemosphere* 64: 497-502.
- Farrell, P.D. (1989): Aspects of the hydrobiology of a natural water clarification system at Mount Isa, Queensland, with special reference to the role of aquatic macrophytes. Unpublished Masters Thesis. James Cook University of North Queensland, 243 pp.
- Finlayson, C.M. (1980): Aspects of the hydrobiology of the Lake Moondarra-Leichhardt River water supply system, Mount Isa, Queensland. Unpublished Doctoral Thesis. James Cook University of North Queensland, 448 pp.
- Goulet, R. R., Pick, F. R. & Droste, R. L. 2001. Test of the first-order removal model for metal retention in a young constructed wetland. *Ecological Engineering* 17: 357-371.
- Green, M. B., Griffin, P., Seabridge, J. K. & Dhoobie, D. 1997. Removal of bacteria in subsurface flow wetlands. *Water Science and Technology* 35: 109-116.
- Griffiths, D.J. & Farrell, P.D. (1991) Turbidity and water quality in tropical reservoirs in Northern Australia. *Verh. Internat. Verein. Limno.* 24: 1465-1470.
- Gschlobl, T. & Stuibler, H. 2000. Reed bed systems: design, performance and maintainability. *Water Science and Technology* 41: 73-76.
- Kuypers, T., Mackay, A., & Taylor M.P. (2006). Engineered reed beds for the treatment of potable water. *Water*, 33 (6), 52-57.
- Nanson, G., Tooth, S., & Knighton, D. (2002) "A global perspective on dryland rivers: perceptions, misconceptions and distinctions." *Dryland Rivers: Hydrology and Geomorphology of Semi-arid Channels*. Bull, L.J & Kirkby, M.J (ed.) John Wiley & Sons.
- O'Hagain, S. 2003. The design, operation and performance of a municipal hybrid reed bed treatment system. *Water Science and Technology* 48: 119-126.
- Taylor, M.P. and Hudson-Edwards, K.A. (2005): Dispersal and storage of sediment-associated zinc in the Leichhardt River, Mt Isa, Queensland. In: Roach, I.C. (Ed.) *Regolith 2005- Ten years of CRC LEME*, Cooperative Research Centre for Landscape Environments and Mineral Exploration, Canberra, Australia, p. 309-313.

Taylor, M.P. and Hudson-Edwards, K.A. (2007): The dispersal and storage of sediment-associated metals in an arid river system: the Leichhardt River, Mount Isa, Queensland, Australia. *Environmental Pollution*.

Wrigley, T.J., Farrell, P.D., Griffiths, D.J. (1991): Ecologically sustainable water clarification at the Clearwater Lagoon, Mt Isa. *Water*, 18: 32-34.

Note/s

¹ *Hydrilla spp* and ²*Potamogeton spp* are submerged pond weeds.

³ *Typha spp* are bullrush or Catails.

⁴ *Vallisneria spp* are eel grass or tape grasses.

Keywords

potable water, clarification, filtration, ephemeral river

Contact details

Tabitha Kuypers
Department of Physical Geography
Macquarie University, North Ryde, Sydney
Tel: 02 98506372
Email: tkuypers@els.mq.edu.au

Dr Mark P. Taylor
Department of Physical Geography
Macquarie University, North Ryde, Sydney
Tel: 02 9850 6319
Fax: 02 9850 8420
Email: mtaylor@mq.edu.au
www: <http://www.es.mq.edu.au/physgeog/staff/mt>
