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Research papers

Characterising alluvial aquifers in a remote ephemeral catchment (Flinders River, Queensland) using a direct push tracer approach

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ABSTRACT

The availability of reliable water supplies is a key factor limiting development in northern Australia. However, characterising groundwater resources in this remote part of Australia is challenging due to a lack of existing infrastructure and data. Here, direct push technology (DPT) was used to characterise shallow alluvial aquifers at two locations in the semiarid Flinders River catchment. DPT was used to evaluate the saturated thickness of the aquifer and estimate recharge rates by sampling for environmental tracers in groundwater (major ions, ^{2}H, ^{18}O, ^{3}H and ^{14}C). The alluvium at Fifteen Mile Reserve and Glendalough Station consisted of a mixture of permeable coarse sandy and gravely sediments and less permeable clays and silts. The alluvium was relatively thin (i.e. < 20 m) and, at the time of the investigation, was only partially saturated. Tritium (^{3}H) concentrations in groundwater was $\sim$1 Tritium Unit (TU), corresponding to a mean residence time for groundwater of about 12 years. The lack of an evaporation signal for the ^{2}H and ^{18}O of groundwater suggests rapid localised recharge from overbank flood events as the primary recharge mechanism. Using the chloride mass balance technique (CMB) and lumped parameter models to interpret patterns in ^{3}H in the aquifer, the mean annual recharge rate varied between 21 and 240 mm/yr. Whilst this recharge rate is relatively high for a semiarid climate, the alluvium is thin and heterogeneous hosting numerous alluvial aquifers with varied connectivity and limited storage capacity. Combining DPT and environmental tracers is a cost-effective strategy to characterise shallow groundwater resources in unconsolidated sedimentary aquifers in remote data sparse areas.

1. Introduction

Sustainable regional development globally requires understanding the water balance of catchments, the location and amount of land suitable for agriculture, the viability of different crop and livestock farming systems, as well as the potential constraints to individual development scenarios. However, the remote nature of many locations makes characterising groundwater resources challenging due to a lack of existing infrastructure and data. Mobilisation costs can be high (tens of thousands of dollars) and inefficiencies associated with conventional drilling can be expensive and time consuming when conducting preliminary or exploratory investigations. Where hydrogeological investigations are shallow (up to 30 m depth) and sediments predominantly unconsolidated, direct push technology (DPT) is a cost effective approach adopted widely internationally (Butler et al., 2007, 2002; Charette and Allen, 2006; Dietrich et al., 2008; Schulmeister et al., 2003; Sellwood et al., 2005; Vienken et al., 2012), but is seldom used in Australia for water resource assessments.

Direct push technology (Fig. 1) is the driving, hammering, pushing and/or vibrating of small-diameter hollow steel rods with attached tools or probes into the ground. These can be used to: i) collect soil, soil-gas and groundwater samples, ii) measure the physical and geochemical properties of the subsurface and iii) install temporary or permanent monitoring equipment (US EPA, 2005). This technology is particularly suited for investigations where infrastructure (that is, wells and piezometers) is sparse or lacking, where a high spatial density of measurements is required, or when leaving permanent instrumentation is logistically or culturally undesirable.

The aim of this study was to demonstrate the use of DPT to characterise shallow alluvial aquifers in a remote data sparse region, the semiarid Flinders River catchment. The Flinders catchment, the subject of a recent comprehensive agricultural resource assessment has both the capacity to supply surface water, as well as portions of suitable land to support some future irrigated agricultural development (Petheram et al., 2013). Groundwater investigations by Jolly et al. (2013) were part of the recent study by

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Fig. 1. Direct push drilling of the alluvial aquifer on the floodplain of the Flinders River using a Geoprobe Systems 7822DT rig.

Petheram et al. (2013) but focused mainly on characterising the nature of groundwater – surface water interactions at the regional scale. Nevertheless, the knowledge acquired by Jolly et al. (2013) as well as from the study's regional airborne geophysical survey (Munday et al., 2013) suggested that alluvial groundwater may also support economic development, particularly during extended dry seasons and prolonged periods of drought where ephemeral river flows are absent. Despite several previous investigations (Cochrane, 1967; Jolly et al., 2013; Laycock, 1973; Lloyd, 1970; QIWSC, 1973), whether the Flinders Alluvium and the alluvial aquifers it hosts is a reliable water supply was unclear, as their spatial extent and water balance is yet to be determined.

The approach with DPT was twofold, i) to determine the saturated thickness and lithology of the alluvium and ii) to collect vertical profiles through the saturated zone of the alluvium for several environmental tracers in groundwater (that is, compounds dissolved in groundwater giving indications of its 'mean residence time' and origin); (Clark and Fritz, 1997; Cook and Herczeg, 2000). Here, vertical profiles for major ions and the stable isotopes of water (deuterium (^{2}H) and oxygen-18 (^{18}O)) were used to evaluate the origin of the alluvial groundwater, and tritium (^{3}H) and carbon-14 (^{14}C) were used to evaluate its 'mean residence time' (Cook and Herczeg, 2000). The sources of water to an alluvial aquifer typically include rainfall recharge, bank infiltration during low flow periods, flood recharge during overbank flow events and regional groundwater discharge (Lamontagne et al., 2005; Lamontagne et al., 2015). These different sources frequently have characteristic signatures in environmental tracers that can be used to evaluate their relative contribution to aquifer recharge.

Tritium and ^{14}C are two radionuclides with half-lives of 12.32 and 5730 years, respectively (Godwin, 1962; Lucas and Unterweger, 2000). They are both naturally produced in the upper atmosphere by cosmic rays but were also released in large quantities in the 1950s and 1960s by atmospheric thermonuclear weapon testing (Fox and Parker, 1968). In the Southern Hemisphere, the ^{3}H bomb peak has now largely decayed or dispersed, so most of the ^{3}H now found in aquifers is from natural sources (Morgenstern et al., 2010; Stewart et al., 2012). The current ^{3}H activity in Southern Hemisphere rainfall is approximately 2 tritium units (TU; (Tadros et al., 2014)). The activity of ^{14}C in the atmosphere was 100 percent modern carbon (pmC) prior to 1890 (Clark and Fritz, 1997), it increased to near 200 pmC at the peak of the thermonuclear weapon testing in the late 1960s and is currently ~104 pmC (Hua et al., 2013). Tritium and ^{14}C can be used to estimate and evaluate the recharge rate to an aquifer (Cook and Böhlke, 2000).

In the following, the information collected by DPT is used to evaluate the recharge rate and the recharge source for the Flinders Alluvium at two locations. Also discussed, is the potential of the alluvial aquifers for development as a water resource, as well as the applicability of DPT sampling to further characterising the Flinders Alluvium at other locations.

2. Study area

The Flinders catchment encompasses a total area of approximately 109,000 km^{2} in north Queensland (Fig. 2). The Flinders River is the primary river in the catchment and, with an overall length 1004 km, is the longest river in Queensland (Petheram et al., 2013). The catchment has a hot dry semiarid climate, which is highly seasonal, including an extended dry season. The climate as reported in Hughenden (Hughenden Post Office) has mean annual minimum and maximum temperatures of 16.6 °C and 31.6 °C, respectively. Mean annual rainfall is 492 mm with the majority of precipitation occurring in December–February (1884–2001; BOM, 2015). Mean annual potential evaporation is 2467 mm and mean annual FAO56 Penman-Monteith reference evapotranspiration is 1935 mm (1970–2015; DSITIA, 2015) emphasising a large rainfall deficit and the semiarid nature of the catchment. The river is ephemeral with measurable discharge for approximately 7 months of the year (1972–2012; Flinders River at Glendower). The geometric mean annual discharge is 78 GL (1972–2012; Flinders River at Glendower) (Fig. 3) and large events (>267 GL/yr; exceed the mean by one standard deviation) occur approximately every seven years (DNRM, 2015).

Aquifers of the Flinders catchment include the regionally extensive and consolidated Mesozoic sedimentary aquifers of the Carpentaria Basin (Great Artesian Basin (GAB)), the Cainozoic and Palaeozoic fractured rock aquifers and shallow unconsolidated alluvial aquifers. The main aquifers utilised for water supply in the area include the Mesozoic Gilbert River Formation aquifer and to a lesser extent the alluvial aquifers. The Gilbert River Formation aquifer, is a regionally extensive quartzose sandstone that unconformably overlies the basement rock of the Etheridge Province in the east of the catchment (Fig. 2). The aquifer is unconfined in and near the outcrop zone where it receives recharge via infiltration of intense wet season rainfall and some infiltration of streamflow where steams traverse the outcrop zone. West of the outcrop zone the aquifer becomes confined and artesian as it dips steeply in the subsurface (Horn et al., 1995; Smerdon and Welsh, 2012). Groundwater flow is generally from east to west based on regional hydraulic head data for the entire Carpentaria region of the GAB (Smerdon and Welsh, 2012).

The alluvial aquifers are typically shallow (<20 m) sequences of sand, silt, gravel and clay, and are entrenched with bed sands associated with the streambed of current and previous rivers and their tributaries (Fig. 2). The alluvial sediments overly and are incised into the Lower Cretaceous Rolling Downs Group, which includes the Allaru Mudstone, Toolebuc Limestone and the Wallumbilla Formation. Very little information currently exists on groundwater flow processes in the alluvial aquifers other than historical baseline water level, water quality and lithological information. Initial hydrogeological work on the shallow alluvial aquifers by Cochrane (1967), Lloyd (1970) and QIWSC (1973) concluded the