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Paired geochemical tracing and load monitoring analysis for identifying sediment sources in a large catchment draining into the Great Barrier Reef Lagoon

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ABSTRACT

While sediment tracing has been typically applied to identify sediment sources that are difficult to measure by gauging (monitoring), it can also be useful in estimating relative sediment yields from gauged river catchments. The major and trace element composition of river sediments from eleven locations in the 130000 km^2 Burdekin River catchment, northeastern Australia was analysed to examine relative contributions from upstream source areas in the 2011/12 water year. Sediment tracing results are compared against estimates derived from sediment load monitoring at three locations. Comparisons show that there is good agreement between tracing results and monitoring data at one of the tributary confluences. At the second site, notable contrasts were found between the load estimates from the monitoring and tracing data. At this site a large impoundment occurs between the upstream sampling/gauging sites for source sediments and the downstream sampling/gauging sites for target sediments. The contrast is likely caused by temporal variations in particle size distributions of suspended sediment from each river and differential trapping efficiencies in the impoundment for sediment derived from the different tributaries. In the absence of the detailed particle size data and trapping efficiency estimates, sediment tracing provides the unique opportunity to elucidate source contributions of the finer fractions of suspended sediment. At a third site, where there were recognised measurement gaps in the monitoring data during large discharge events, the relative load estimates from the tracing data provided a means of constraining the recognized uncertainty of monitored load estimates. We conclude that sediment tracing can be used as a valuable adjunct to monitoring data particularly in remote, large and data-sparse catchments. Both tracing results and monitoring data show that the Upper Burdekin River and Bowen-Bogie Rivers were the dominant source of the <10 μm sediments being delivered to the GBR lagoon from the Burdekin River catchment in the 2011/12 water year. More substantial contribution from the Belyando-Suttor Rivers indicated by the tracing results than the monitoring data is attributed to preferential delivery of the 1–10 μm sediments through the impoundment and has uncovered a knowledge gap in sediment budgets in the catchment.

1. Introduction

Sediment tracing is a method to identify provenance (sources) of sediment based on comparison of sediment properties between sources and a sourcing-target location (Klages and Hsieh, 1975; Oldfield et al., 1979; Walling et al., 1979). This method allows an estimate of relative sediment contributions from upstream sources, which is an important factor when investigating catchment-scale sediment movement. Sediment budgets can be developed using load measurement and geomorphic analysis to link transported sediment with its sources (Dietrich and Dunne, 1978; Swanson et al., 1982; Trimble, 1983; Phillips, 1991; Sutherland and Bryan, 1991; Loughran et al., 1992; Page et al., 1994; Oguchi, 1997). Sediment budgets can be also constructed using sediment tracing results (Hill et al., 1998; Walling et al., 2001; Wasson et al., 2002). Sediment tracing is typically applied when sediment contributions from particular source types are difficult to estimate by monitoring (Walling, 2013). Such source types include surface soil and subsoil (or sheet wash and gully/bank erosion) (Peart and Walling, 1986; Wasson et al., 1987; Burch et al., 1988; Walling and Woodward, 1992; Olley et al., 1993; Wallbrink and Murray, 1993; Hancock et al., 2014; Wilkinson et al., 2015), different land-uses within catchments (Collins et al., 1997; Kurashige and Fusejima, 1997; Foster et al., 1998; Owens et al., 2000; Russell et al., 2001; Motha et al., 2003; Blake et al., 2012) and different lithologies (Walling and Woodward, 1995; Collins

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et al., 1998; Owens et al., 2000; Mizugaki et al., 2012). Ungauged catchments are another source type of interest for sediment tracing (Collins et al., 1996; Gingele and De Deckker, 2005).

Sediment load estimates using sediment rating curves with infrequent monitoring/measurement can involve significant uncertainties (Walling and Webb, 1988; Rustomji and Wilkinson, 2008; Kuhnert et al., 2012). Even in the case that event-based intensive monitoring is attempted, logistical problems, such as difficult access to sampling sites during storm events and insufficient capacity of automated samplers to record continuous information, may limit collection of suspended sediment concentration (*SSC*) data at relevant intervals (Collins and Walling, 2004). These logistical problems may be overcome by use of turbidity sensors, but the sensors must be operated with supportive procedures including regular calibration, lens cleaning and the development of a rating relationship between turbidity (nephelometric turbidity units: NTU) and *SSC* (mg L^{-1}) (Collins and Walling, 2004), which can limit their application.

It is generally accepted that sediment load monitoring data are practical and reliable quantitative accounts of river sediment transport (Rustomji and Wilkinson, 2008; Kuhnert et al., 2012), but given the problems and limitations, sediment tracing can provide complementary and independent information on catchment-scale sediment movement. In particular, while sediment load monitoring can provide valuable information on sediment delivery through impoundments (Lewis et al., 2013), sediment tracing can potentially be used to investigate differences in delivery efficiency between sources. In data-sparse environments sediment tracing can also reveal spatial patterns in sources within ungauged catchments; for instance, Rustomji et al. (2008) used both sediment load monitoring data and sediment tracing data to constrain a sediment budgeting model. When sediment load monitoring and sediment tracing are undertaken in the same catchment an opportunity for mutual evaluation of the techniques is provided. To date this endeavour has received little attention in the literature (Collins and Walling, 2004). Other examples include a study by Collins et al. (1998) which compared tracing results on catchment geological sub-areas with sediment yield data from sub-catchments in the River Exe basin, UK, although the geological sub-areas and the sub-catchments did not conform perfectly. Furuichi et al. (2013) showed results of sediment tracing applied in the Ayeyarwady River basin, Myanmar, and found they were consistent with suspended sediment load monitoring data.

This study uses geochemical sediment tracing to determine the source of fine sediment exported from the Burdekin River catchment, a large sub-tropical catchment of northeastern Australia. In particular the delivery of sediment from each of the multiple tributary sources upstream of the large Burdekin Falls Dam is investigated. The source contribution is compared with existing measurements of the suspended sediment load monitoring for the 2011/12 water year. Results of this study will provide information for managing sediment delivery to the Great Barrier Reef (GBR) lagoon.

2. The Burdekin catchment

2.1. Physiography

The Burdekin River catchment drains into the middle coastal region of the GBR lagoon (Fig. 1) and has an area of 130000 km^2 (Table 1), the second largest basin draining into the GBR lagoon. The catchment area contains seven sub-catchments (Fig. 1). There are distinct contrasts in physiography and river forms between Sub-catchments A (Belyando), B (Suttor) and C (Cape), and Sub-catchments D (Upper Burdekin), E (Lower Burdekin), F (Bowen) and G (Bogie) (Table 1). The former three sub-catchments are dominated by lower gradients except at their fringes (mean gradients from 2.0% to 2.4%; Table 1), while the latter four sub-catchments contain steeper slopes (mean 4.8% to 10.3%; Table 1). Rivers in the former three sub-catchments are anastomosing, whereas rivers in the latter four sub-catchments are primarily incised, single channel systems (Fielding and Alexander, 1996).

2.2. Geology and soils

The Sub-catchments A, B and C are dominated by sedimentary rocks (Fergusson and Henderson, 2013) and cracking clay soils with grey/brown clays and red/yellow earths (Roth et al., 2002). Soils with dispersive properties due to high sodium contents as a result of past salinization and leaching occur in areas in the Sub-catchment B (Roth et al., 2002). Surface materials of these sub-catchments have felsic compositions. The metamorphic rocks and batholith are partially exposed at the fringe of the Sub-catchments A and B (Fergusson et al., 2013). Exposure of these rocks provides surface materials that are alkali-rich but the influence to geochemical composition of river sediment appears limited. The Sub-catchment D comprises mixtures of various igneous, metamorphic and sedimentary rocks (Fergusson and Henderson, 2013; Henderson and Withnall, 2013) which generate diverse geochemical compositions in surface materials. Accordingly, soil types vary considerably and include erodible red duplex soils, black and red basaltic soils, and sodic duplex soils (Roth et al., 2002). The middle to upstream areas of the Sub-catchment F generally consist of acidic sedimentary rocks (Draper, 2013) and the remaining lower section of Sub-catchment G are comprised of various types of intrusive, extrusive and metamorphosed rocks (Withnall, 2013) which often include mafic materials. Red-brown earths, yellow soils, gravely/sandy soils, and black earths cover largely from east to west of the Sub-catchment F (Roth et al., 2002).

2.3. Rainfall

Spatial rainfall patterns also display considerable contrast across the sub-catchments (Table 1; Fig. 2). On average, <600 mm yr^{-1} of rain occurs in the Sub-catchments A and B, and >2000 mm yr^{-1} of rain falls in areas along the coastal mountains. During the 2011/12 water year, approximately 700–1000 mm of rain occurred across the Sub-catchments A, B and C, compared to the long-term annual mean of <600 mm yr^{-1}.

2.4. Land-use

Cattle grazing is the dominant land-use in all sub-catchment areas: 93% of the Sub-catchments A and B, 81% of the Sub-catchment C, 88% of the Sub-catchment D, 73% of the Sub-catchments F and G and 73% of the Sub-catchment E (Dight, 2009). Grazing land occurs largely on native pastures within open woodland communities (Bartley et al., 2014).

2.5. Sediment delivery, sources and budgets

Catchment-scale modelling indicates that the Burdekin catchment is the largest single source of sediment to the GBR lagoon, exporting >25% of the total average annual load (~4×10^6 t $year^{-1}$) (Kroon et al., 2012). Bainbridge et al. (2012) showed that suspended sediment exported to the marine environment from the Burdekin River during flood events is dominated by clay and silt size fractions. Sources of sediment in the Burdekin catchment have been studied through sediment load monitoring at the whole-catchment and sub-catchment scales (Bartley et al., 2007; Turner et al., 2012, 2013; Bainbridge et al. 2014; Wallace et al., 2014). Catchment modelling also provided estimates of contributions from sources at the whole-catchment scale (Prosser et al., 2002; McKergow et al., 2005; Post et al., 2006; Kinsey-Henderson et al., 2007; Wilkinson et al., 2014; Dougall, et al., 2014). Croke et al. (2015) analysed cosmogenic radionuclide concentrations in river sediments and revealed long-term denudation patterns. Collectively, the results of these studies at the whole-catchment scale have indicated that the