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Supplementary Material

Hydrology and runoff water quality from three improved pastures compared with virgin brigalow (*Acacia harpophylla*) woodland over 8 years in semiarid Australia

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SUPPLEMENTARY MATERIAL: Comparison of four methods for calculating a site event mean concentration

Hydrology and runoff water quality from three improved pastures compared with virgin brigalow (*Acacia harpophylla*) woodland over 8 years in semi-arid Australia

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Introduction

An event mean concentration (EMC) is defined as total load discharged during a runoff event divided by total flow discharged during the same event (Bartley and Speirs 2010). Based on first principles, a site EMC could be calculated as total load for all monitored events divided by total flow for the same events (Method 1). However, international literature on urban stormwater refines the calculation of a site EMC to the arithmetic mean of multiple event-based EMCs (Method 2) (Erickson *et al.* 2013; Maniquiz *et al.* 2010; Mitchell 2005). The long-term Brigalow Catchment Study has historically added a further step in this process by calculating a site EMC as the arithmetic mean of all annual EMCs, where each annual EMC was calculated as the arithmetic mean of all event-based EMCs in a year (Method 3).

Comments received during an independent review of the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program in 2015, and also during the review process for Elledge and Thornton (2017), indicated that Method 3 may be mathematically invalid. Validation of the applicability of this method was required, as site EMC data from the Brigalow Catchment Study have been used in APSIM, HowLeaky, Universal Soil Loss Equation (ULSE) and Dynamic SedNet catchment models that all underpin the Paddock to Reef Integrated Monitoring, Modelling and Reporting Program (The State of Queensland 2018; The State of Queensland 2019). Thus, 8 years of water quality data from four land uses during the adaptive land management phase (Stage IV) of the Brigalow Catchment Study were used to address this concern.

Methods

Observed water quality data from the corresponding journal paper were used to calculate a long-term site EMC for each of the 11 runoff pollutants from each of the four catchments based on the following methods:

(1) Total load for all events divided by total flow for all events.

(2) Arithmetic mean of all event-based EMCs, where each EMC was calculated as total load for each event divided by its total flow.

(3) Arithmetic mean of all annual EMCs, where each annual EMC was calculated as the arithmetic mean of all event-based EMCs in a year.

(4) Arithmetic mean of all annual mean concentrations (AMCs), where each AMC was calculated as total load in a year divided by total flow in a year.

The EMCs for Methods 2 to 4 were plotted against that for Method 1, and Methods 2 and 3 were also plotted against each other. Regression analyses were performed to determine the correlation of these pairwise comparisons.

Results

Regression analyses of the linear models for all four methods were well correlated, explaining 92% to 99% of the variability (Fig. S1). While Methods 2 and 3 had good correlation with Method 1, their correlation with each other was stronger. Method 4 was the least correlated with Method 1. Data points for total dissolved nitrogen and phosphorus plotted further from the 1 to 1 line, especially when the pairwise comparisons involved Method 1. Analyses of these two parameters only commenced in 2012; hence, there were fewer data points than other parameters due to the absence of results from the two wettest years of the study.

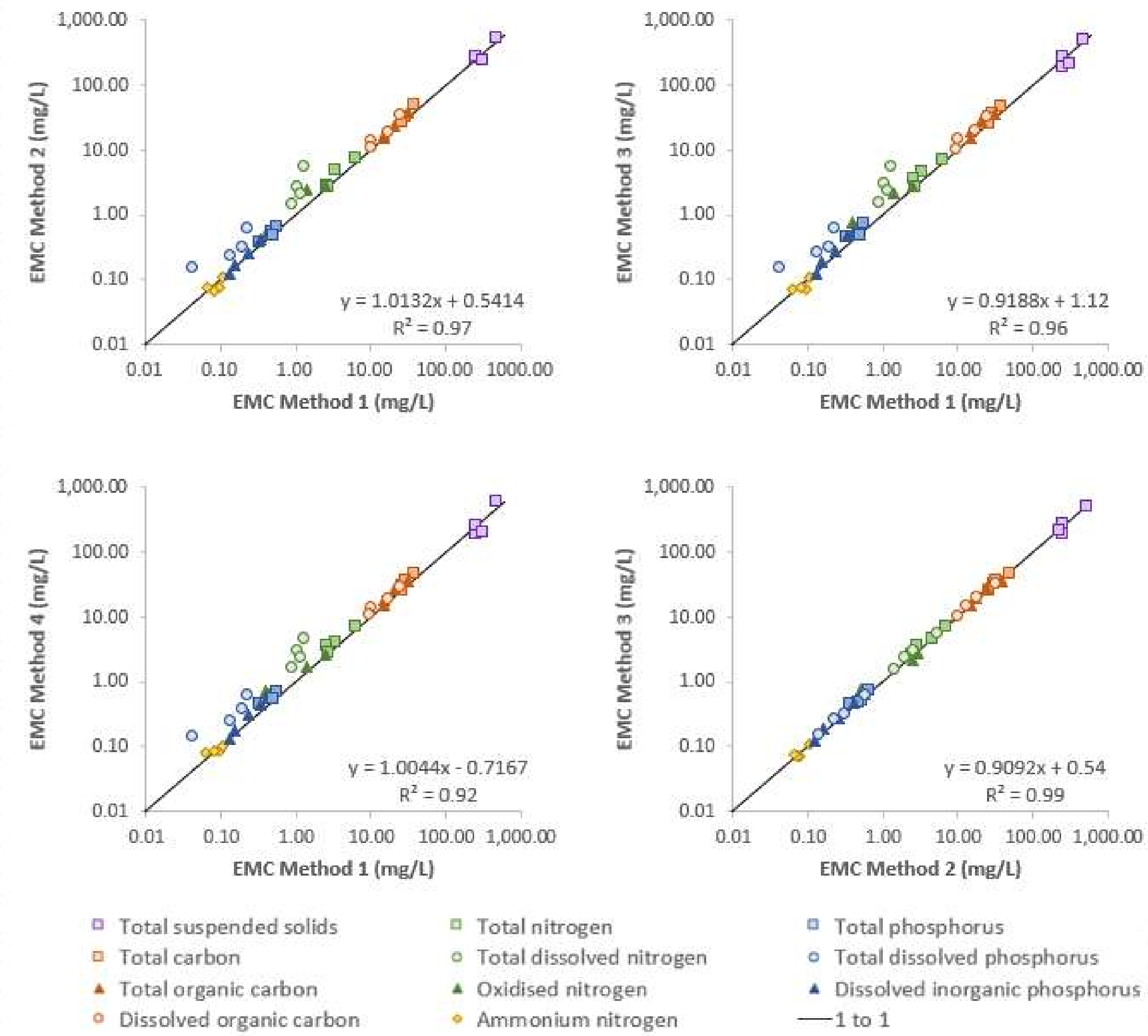

Fig. S1. Comparison of four methods for calculating a site event mean concentration (EMC) based on 8 years of water quality data from virgin brigalow woodland and three improved pastures; presented on a log scale.

Discussion

Regression analyses showed that Methods 2, 3 and 4 were well correlated with Method 1 (R^2 ranged from 0.92 to 0.97), the approach based on first principles. Method 3, the historical method used to calculate a site EMC for the Brigalow Catchment Study, was well correlated with Method 2, the international approach used for storm water (R^2 = 0.98). Thornton and Elledge (2018) reported a similar result ($R^2 \geq 0.95$) using 16 years of water quality data from five catchments of the Brigalow Catchment Study during parts of both the land use comparison (Stage III) and adaptive land management (Stage IV) phases. These results support the validity and ongoing use of Method 3 to calculate site EMCs for the Brigalow Catchment Study. Furthermore, a combination of Methods 1, 2 and 3 are often used to generate loads for validation purposes within the Paddock to Reef program catchment scale models (McCloskey, G. 2020 *Pers. Comm.*).

It is reasonable for a short-term study to calculate a site EMC based on the arithmetic mean of event EMCs (Method 2). However, sufficient long-term data to average event EMCs by year before calculating a site EMC (Method 3) allows climatic variation between hydrological years to be captured. For example, the five above average rainfall years followed by three below average rainfall years presented in the corresponding paper. It is important for a range of flows and concentrations to be captured to avoid bias (Quilbe *et al.* 2006), so the method applied to a dataset should consider the number and location of samples collected during each event (Bartley and Speirs 2010). That is, were the samples used for water quality analyses based on one composite sample or multiple discrete samples, and were the samples captured on both the rise and fall of the hydrograph? Bias is known to increase with the size of the averaging window; for example, an annual load based on four quarterly loads will be more biased than an annual load based on 12 monthly loads (Richards 1998). Thus, it is important to ensure that data are not bulked excessively before a site EMC is calculated. The authors were comfortable applying Method 3 to the long-term data in this paper based on the regression results and the number of events captured over the eight hydrological years monitored; that is, a total of 13 events from brigalow woodland and at least 29 events from each of the three improved pastures.

International urban stormwater literature widely reports that concentration data has a log-normal distribution, which indicates that a median or log-transformed mean is a better estimate of central tendency than an arithmetic or flow-weighted mean (Baldys *et al.* 1998; Quigley *et al.* 2009). Medians are an appropriate statistic when comparing site EMCs, as large outlier values have less influence on them. However, means are often reported as they account for these extreme values, which provides a more accurate estimate of pollutant loads. Arithmetic means tend to overestimate site EMCs but converge with flow-weighted and log-transformed means as sample size increases (Bartley and Speirs 2010; May and Sivakumar 2013; Mitchell 2001; Quigley *et al.* 2009). Although it is not stated what sample size is required to converge these values, the authors assume that the Brigalow Catchment Study dataset is large enough for its purpose without log transformation. That is, the long-term study uses a site EMC to interpolate missing water quality data when flow data from the same site was measured. In contrast, urban stormwater literature often extrapolates site EMCs to forecast loads at other sites (Baldys *et al.* 1998; United States Environmental Protection Agency 1992; von Guerard and Weisser 1995). Local data provides the best estimate, as the climate, physical environment, watershed size, land use and management practices are specific to that site (Charbeneau and Barrett 1998; Quilbe *et al.* 2006). Whereas grouping data by land use or geographic area greatly increases the variation of EMCs and doesn't reflect local impacts of dilution from changing flow and concentration values (Smullen *et al.* 1999; Tuomela *et al.* 2019; von Guerard and Weisser 1995).

Conclusion

Using the arithmetic mean of annual EMCs (Method 3) to calculate site EMCs for runoff pollutants has been validated in this supplementary material and will continue to be used for Brigalow Catchment Study data.

References

Baldys, S., Raines, T.H., Mansfield, B.L., and Sandlin, J.T. (1998) Urban stormwater quality, event-mean concentrations, and estimates of stormwater pollutant loads, Dallas-Fort Worth area, Texas, 1992–93. Water resources investigations report 98–4158. United States Department of the Interior and United States Geological Survey, Texas.

Bartley, R., and Speirs, W. (2010) Review and summary of constituent concentration data from Australia for use in catchment water quality models. eWater Cooperative Research Centre, Indooroopilly.

Charbeneau, R.J., and Barrett, M.E. (1998) Evaluation of methods for estimating stormwater pollutant loads. *Water Environment Research* **70**(7), pp. 1295-1302.

Elledge, A., and Thornton, C. (2017) Effect of changing land use from virgin brigalow (*Acacia harpophylla*) woodland to a crop or pasture system on sediment, nitrogen and phosphorus in runoff over 25 years in subtropical Australia. *Agriculture, Ecosystems and Environment* **239**, pp. 119-131.

Erickson, A.J., Weiss, P.T., and Gulliver, J.S. (2013) 'Optimizing stormwater treatment practices: A handbook of assessment and maintenance'. Springer, New York.

Maniquiz, M.C., Choi, J., Lee, S., Cho, H.L., and Kim, L.-H. (2010) Appropriate methods in determining the event mean concentration and pollutant removal efficiency of a best management practice. *Environmental Engineering Research* **15**(4), pp. 215-223.

May, D., and Sivakumar, M. (2013) Prediction of long-term urban stormwater loads at single sites. *Water Management* **166**(2), pp. 81-92.

Mitchell, G. (2001) The quality of urban stormwater in Britain and Europe: Database and recommended values for strategic planning models. Report to the UK Engineering and Physical Sciences Research Council. The University of Leeds, United Kingdom.

Mitchell, G. (2005) Mapping hazard from urban non-point pollution: A screening model to support sustainable urban drainage planning. *Journal of Environmental Management* **74**, pp. 1-9.

Quigley, M., Clary, J., Earles, A., Poresky, A., Leisenring, M., Strecker, E., Jones, J., Miller, R., and O'Brien, J. (2009) Urban stormwater BMP performance monitoring. Geosyntec Consultants and Wright Water Engineers, United States.

Quilbe, R., Rousseau, A.N., Duchemin, M., Poulin, A., Gangbazo, G., and Villeneuve, J.-P. (2006) Selecting a calculation method to estimate sediment and nutrient loads in streams: Application to the Beaurivage River (Quebec, Canada). *Journal of Hydrology* **326**(1), pp. 295-310.

Richards, R.P. (1998) 'Estimation of pollutant loads in rivers and streams: A guidance document for NPS programs'. United States Environmental Protection Agency.

Smullen, J.T., Shallcross, A.L., and Cave, K.A. (1999) Updating the U.S. nationwide urban runoff quality database. *Water Science and Technology* **39**(12), pp. 9-16.

The State of Queensland (2018) Reef 2050 Water Quality Improvement Plan 2017-2022. Reef Water Quality Protection Plan Secretariat.

The State of Queensland (2019) Paddock to Reef. Available at www.reefplan.qld.gov.au/tracking-progress/paddock-to-reef [Accessed 05 December 2019].

Thornton, C.M., and Elledge, A.E. (2018) Paddock scale water quality monitoring of grazing management practices in the Fitzroy Basin: Technical report on the effect of grazing pressure on water quality for the 2015 to 2018 hydrological years. Report to the Paddock to Reef program. Department of Natural Resources, Mines and Energy, Rockhampton.

Tuomela, C., Sillanpaa, N., and Koivusalo, H. (2019) Assessment of stormwater pollutant loads and source area contributions with storm water management model (SWMM). *Journal of Environmental Management* **233**, pp. 719-727.

United States Environmental Protection Agency (1992) Guidance manual for the preparation of part 2 of the NPDES permit applications for discharges from municipal separate storm sewer systems (Report EPA 833-B-92-002). Office of Wastewater Enforcement and Compliance, Washington.

von Guerard, P., and Weisser, W.B. (1995) Water quality of storm runoff and comparison of procedures for estimating storm-runoff loads, volume, event-mean concentrations, and the mean load for a storm for selected properties and constituents for Colorado Springs, southeastern Colorado, 1992. Water resources investigations report 94-4194. United States Department of the Interior and United States Geological Survey, Colorado.