RIVER SEDIMENT LOAD DYNAMICS INFLUENCE PARTICULATE MATTER CONCENTRATIONS IN WESTERN PORT, VICTORIA

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Sediment yields from terrestrial catchments impact the water quality and ecosystem condition of receiving water bodies but the extent of impact can be unclear due to coincident processes, such as tidal or wind driven resuspension of benthic sediments. Understanding the magnitude and dynamics of catchment impacts on coastal water quality is vital to help inform catchment management priorities, and to assess potential responses including potential time lags. We used 14 years of turbidity monitoring in rivers draining to Western Port to estimate suspended sediment load time-series. We investigated the magnitude and timescales of linkage between river loads and a remote sensing record of coastal water quality. Results were evaluated in the context of knowledge about long-term sediment sources to, and storage volumes within, the bay. The findings will help to guide priorities for protecting bay ecosystems and for managing erosion in the catchments and within the bay. The efficiency of sediment delivery to the bay, historical changes in seagrass extent within the bay, and conceptual modelling of seagrass responses to sediment inputs are considered in companion papers.

1 INTRODUCTION

Coastal water quality and ecosystem condition are impaired by catchment runoff and associated constituents in many parts of Australia and globally. Western Port, Victoria, Australia is an embayment (area 270 km^2) connected to the ocean by two channels around two islands allowing for tidal exchange flows. It includes large inter-tidal and shallow areas with important saltmarsh, mangrove and seagrass communities. Western Port experienced progressive loss of seagrass coverage between the 1970s and 2000 [1, 2]. Today much of the upper north arm and the eastern Rhyll and Corinella segments of the bay (Figure 1) are chronically turbid. However, significant natural values persist and the bay is of international significance as a Ramsar listed wetland. The extent to which catchment sediment inputs impact bay water quality and ecosystem condition, and therefore the potential for management interventions to improve the health of the bay, is unclear.

It is well-known that seagrass can be affected by coastal water quality [3], as a result of their sensitivity to light availability [4]. The causes of Western Port seagrass loss have not been conclusively identified, although deposition of sediments from catchment inputs since the Koo Wee Rup Swamp wetland and floodplain to the north was progressively drained during 1880–1950 is one plausible explanation [5]. Cardinia Creek, Bunyip River and Lang Lang River today pass through channels constructed across the former swamp to the upper north arm (Figure 1). Bass River is a large agricultural catchment which delivers to the Rhyll segment. Together these four catchments comprise more than two-thirds of the total catchment area draining to the bay. Approximately two-thirds of the fine sediment in the north of Western Port is derived from these river catchments, with the remaining one-third derived from coastal bank erosion along the north-eastern coastline near Lang Lang [6, 7]. The shape and location of Western Port also promotes strong currents driven by tidal and wind action, which resuspend and transport sediment in a clockwise direction around French Island (Figure 1). Thus, bay water quality may not respond to catchment erosion management in a straightforward manner.

This study developed time-series of fine sediment loads for the four large streams delivering sediment to Western Port. We compared the stream loads with bay non-algal particulate concentrations derived from Landsat data to investigate the degree to which river runoff events drive bay turbidity. We also investigated how current total suspended solids (TSS) loads compare with previous estimates from earlier decades.

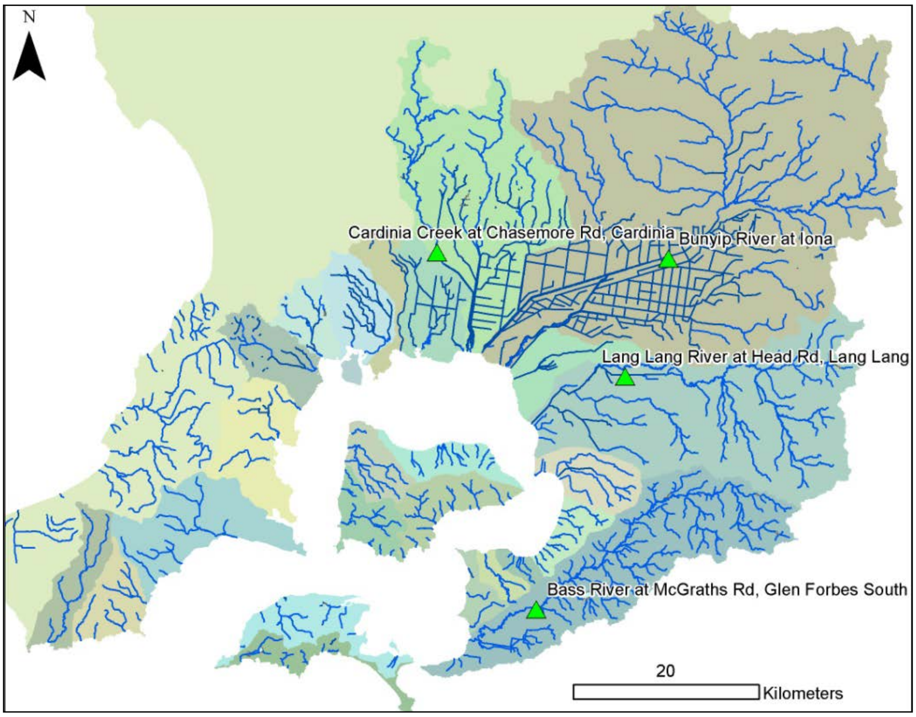

Figure 1. Location of stream gauges for which total suspended solids (TSS) loads were estimated (green triangles). The Western Port catchments (shaded) are derived from a digital elevation model [8]. French Island is in the north of the bay.

2 METHODS

Time-series of river TSS loads were estimated at downstream river stations on Cardinia Creek and the Bunyip, Lang Lang and Bass Rivers (Figure 1). Measurements of TSS were available from monthly manual water samples from 1990 onwards. During 2000–2014 (or 2006–2014 for Bass River), these were augmented by automatic water samplers and high-frequency observations of turbidity run by the Melbourne Water Loads Monitoring Program.

TSS concentration co-varies with and is dependent on turbidity [9]. Rapid variations in TSS concentration during runoff events were represented by site-specific regression relationships between the measured concentrations of water samples, and the turbidity recorded at the stream gauge closest to the time each sample was collected. Linear regressions were fitted for each river station (regressions to transformed data were also trialled but had poorer coefficient of determination (R^2). Data points for which concentration and turbidity measurement times differed by more than one hour, and which were outliers to the regressions, were omitted.

TSS concentration was predicted continuously through time by linear interpolation between adjacent turbidity observations. Load was calculated in SI units for each period as the product of mean discharge and concentration (trapezoid method). The concentration regression confidence intervals were used to calculate upper and lower bounds of concentration and load.

A time-series of non-algal particulate matter (NAP) concentration of surface water was estimated in the Rhyll segment of Western Port from Landsat imagery using the SAMBUCA model [10].

3 RESULTS

The degree to which TSS was explained by turbidity (R^2 values for TSS-turbidity regressions) for the 2001–2014 period ranged between 0.47–0.86 for most streams, although it was much lower for Lang Lang River (0.19) fow which fewer TSS samples were available. The R^2 values could have been improved by more sampling at higher turbidity values.

The sum total of mean-annual loads across the 4 river stations for the period 2001–2014 was 13 kt yr^{-1}. Annual TSS loads varied by more than 20 times, with the highest monthly loads occurring in 2011 and 2012 (Figure 2). The Lang Lang River station had the largest mean load (45% of the total across the four streams), followed by Bunyip and Bass Rivers (30% and 20%, respectively). The dependence of TSS on discharge for the period 2001–2014 was much lower than dependence on turbidity at all river stations, demonstrating the benefit of turbidity monitoring for concentration and load prediction through events relative to traditional sediment rating curves against discharge.

The non-algal particulate matter (NAP) concentration displayed large variations between adjacent Landsat image dates (Figure 2). However, NAP was more chronically turbid during the same periods that large river TSS loads occurred, with higher annual minimum values. This indicates that catchment runoff events do have a significant impact on bay turbidity which may impact ecosystem condition.

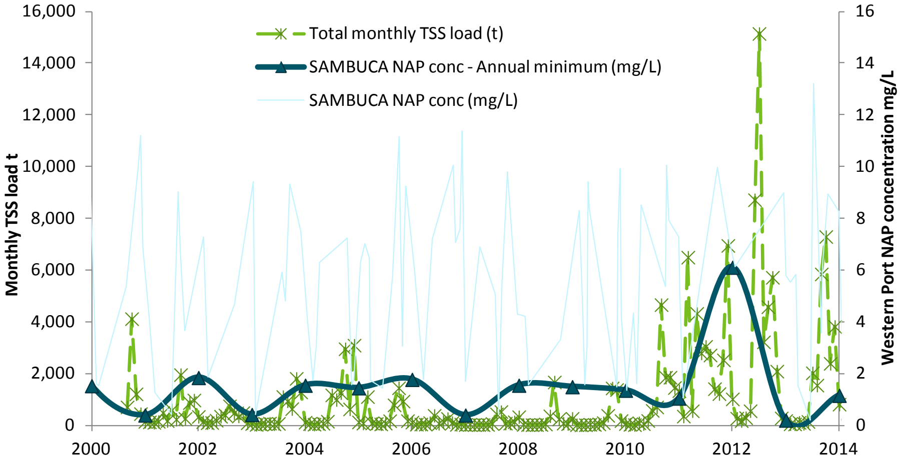

Figure 2. Monthly total suspended sediment loads across the four monitored rivers from monitoring data, and the non-algal particulate (NAP) concentration in Western Port derived from Landsat imagery [10].

4 DISCUSSION

Time lags between catchment management and water quality improvement can be significant [11]. We have shown that water quality remote sensing and river load monitoring are valuable methods for defining the nature and time scales of linkages between catchment fine sediment loads and coastal water quality in Western Port, to help inform catchment management priorities. Resuspension of fine sediment delivered in previous decades by wind and tidal currents results in fluctuations in the turbidity of eastern Western Port. Catchment sediment delivery in large runoff events appears to cause Western Port to become more chronically turbid for up to one year. Similar behavior has been observed in coastal water quality in the Great Barrier Reef lagoon offshore from the Burdekin River, where catchment runoff causes chronic reductions in water clarity for several months to one year after large runoff events independent of variations in wave-driven resuspension [12]. After that time, the chronic effect on coastal water clarity apparently decays, which suggests that reducing catchment erosion can provide a water quality response within the time-scales of climatic drought-flood cycles.

The total load estimate presented here is some 60% larger than a recent estimate based on rainfall-runoff modelling [8], but 75% smaller than the estimate made by erosion process modeling for the period prior to 2000 [13]. However, given that only 58% of the area of the four catchments is upstream of the gauges (Figure 1), the load estimates presented here are preliminary, and the nature of their timing and variability is more reliable than the absolute magnitudes. In further work, we will scale the river station load estimates to estimate delivery to Western Port, based on modelling of the erosion and sediment transport capacity of the constructed channels in floodplain reaches downstream of the stream gauges on Cardinia Ck and Bunyip River [14]. Sediment aggradation rates in the Upper North Arm in recent decades appear to have been much lower than in the Corinella and Rhyll segments [15], suggesting that previously-delivered sediment may be redistributed into more stable storage areas and that water quality may improve at some time in the future. However, future sea level rise may exacerbate ongoing coastal erosion.

The load estimates indicate that catchment management to reduce sediment delivery to Western Port should focus in the northern and eastern catchments. Managing erosion of coastal clay banks near Lang Lang should also be considered. Our catchment load estimates indicate that Bass River made a larger relative contribution to Western Port sediment loads in recent years than in earlier estimates by catchment models based on conceptual erosion process modelling [13] and on rainfall-runoff modelling [8], and by sediment source tracing [7], which all estimated that Bass River contributed <10% of total load. Sediment source tracing based on fallout radionuclides previously identified gully and river bank erosion of subsoil as the dominant catchment sediment sources [7]. Catchment erosion control should therefore focus on riparian management including revegetation and controlling stock access. Revegetating river banks can increase erosion resistance during floods relative to non-vegetated river banks exposed to comparable stream power [16].

5 ACKNOWLEDGMENTS

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