Using concreted stormwater channels to determine 'worse case scenarios' for grading the relative condition of urban waterways

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Key points

- Using Report Card grades to communicate waterway condition is becoming increasingly common, because such grades are easily understood by general audiences. The condition of sites can be graded in comparison to those prevailing in minimally disturbed reference sites (graded A+) and severely degraded 'worst case scenario' (WCS) sites (graded F). Given that they are used to delineate the upper and lower limits of the grading scale, it is important to select appropriate sites for determining reference and WCS conditions.
- The ecological WCS in urban areas likely occurs when streams are engineered and concreted, with concomitant alteration of hydrology, habitat and water quality. But, most monitoring programs focus on 'natural' waterways, whilst overlooking or actively avoiding using concrete channels in waterway assessments.
- Using concrete channels to determine WCS, rather than 'natural' streams, did not markedly shift grades assigned to urban streams in the Georges River catchment of southern Sydney. But, using concrete channels for WCS determination could aid in using Report Card grades to communicate the severe degradation and loss of multiple functions in all urban streams.

Abstract

Derivation of Report Card grades from complex datasets aids communication of stream condition to diverse stakeholders. Upper and lower limits of ecosystem condition grading scales are often delineated using data from minimally disturbed reference sites and 'worst case scenario' (WCS) sites, respectively. In urbanised catchments, the WCS may occur in concrete channels. However, monitoring programs usually don't include concrete channels, even for calculating WCS, with reporting focused on 'natural' waterways. The objective of this study was to determine the effect that the selection of sites used to calculate WCS had upon ecosystem condition grading. We compared potential WCS values calculated from concrete reaches and 'natural' reaches for a suite of environmental variables monitored in waterways across the Georges River catchment, located in southern Sydney. Unexpectedly, few of the WCS values measured in concrete reaches were worse than the WCS from 'natural' reaches. Overall, the inclusion of concreted reaches rather than exclusively using 'natural' reaches to determine WCS had little effect on waterway grading. However, using concrete reaches in WCS determination aided interpretation of grades and highlighted the severe degradation of urban streams, as 'natural' streams graded E or F had an ecological condition 'as degraded as a concrete channel'.

Keywords: Report Card, Ecosystem condition grading, Stream monitoring, Biomonitoring, Bioassessment, Urban, Concrete

Introduction

Effective communication of environmental monitoring results to a diverse range of stakeholders is a key component of an adaptive management framework (Bunn et al. 2010; Connolly et al. 2013). Whereas it can be difficult to succinctly explain the multi-faceted consequences of altered habitat, elevated concentrations of pollutants, declining biodiversity and/or lost aesthetic appeal along waterways to a general audience, most people immediately understand the implications of grades along a traditional A to F scale. Thus, using Report Card grading as a tool for timely communication about the relative condition of waterways to the general public and decision makers is becoming increasingly popular around the world (Costanzo et al. 2017). The communication of grades facilitates the development of a shared understanding of the condition of waterways, leading to increased engagement by all stakeholders and informed allocation of appropriate management resources to facilitate maintaining or improving the capacity of waterways to perform multiple valuable functions. Guidance for organisations wanting to use Report Card grading for reporting on waterways is provided in the recently released *Practitioner's Guide to Developing River Basin Report Cards* (Costanzo et al. 2017). In Australia, the National Waterway Report Card Network is a growing group which includes representatives from research, government and non-government organisations, with links to over 20 Report Cards produced across the nation (see https://riverhealth.org.au/national-report-card-network/).

Whilst the rationale for Report Card grading is simplification to facilitate communication, it is crucial that determination of grades is objective and underpinned by rigorous science. Thus, grading requires integrating and synthesising information from complex scientific datasets. The suite of variables used to inform grading typically include quantifiable ecological, social and/or economic indicators useful for the evaluation of maintenance of values and/or amelioration of threats to those values (Costanzo et al. 2017). For each indicator, the range of values within which each grade that could be allocated can be guided by professional judgements, national guidelines, local guidelines or biological effects data (listed from least to most preferred option) (ANZECC 2000; Connolly et al. 2013).

Since 2009, Georges Riverkeeper has produced River Health Report Cards (available via www.georgesriver.org.au), with grading based on the relative ecological condition of sites within the Georges River catchment in southern Sydney. Indicators include structure of riparian vegetation, a suite of water quality parameters and metrics for macroinvertebrate communities. Across the catchment, expanding urbanisation is known to be associated with ecological degradation (Tippler et al. 2012a). But, using biological effects data to guide grading is not possible, given that there is not adequate knowledge of biological effects across taxonomic groups or an agreed understanding of the appropriate level of protection to maintain or improve the ecological integrity of urbanised streams (see ANZECC 2000). Macroinvertebrate communities are commonly used in monitoring programs and used as proxy indicators of biological effects. Guideline (or trigger) values for each indicator are derived from local waterways, as recommended in ANZECC (2000) guidelines (see Tippler et al. 2012b).

Calculating grades relies upon combining values of indicators with disparate scales, which is accomplished by using an equation to standardise all indicator scores on a 0 to 1 scale (Connolly et al. 2013):

$$\text{Standardised Score} = 1 - \frac{x - \text{G}}{\text{WCS} - \text{G}}$$

Where, x = the value of the indicator measured at the site
G = guideline value for indicator
WCS = worst case scenario value for the indicator

This enables averaging of standardised scores across all indicators, with that average score then converted to an overall grade for each site. In the present study, the range of standardised scores corresponding to each grade were: >0.95 (A+), >0.85 to 0.95 (A), >0.70 to 0.85 (B), >0.55 to 0.70 (C), >0.40 to 0.55 (D), >0.25 to 0.40 (E) or ≤0.25 (F).

For each indicator contributing to River Health grades, guideline values (G) are calculated from minimally disturbed reference site data; as the 80th percentile for variables that cause problems at high concentrations (e.g. nutrients), or the 20th percentile for variables that cause problems at low concentrations (e.g. dissolved oxygen). Such guideline formulation is as suggested within the ANZECC (2000) guidelines and commonly used for Australian Report Cards (Connolly et al. 2013). River Health sites where the values of all variables comply with guidelines are graded A+, reflecting that they maintain high ecological integrity. Conversely, 'worst case scenarios' (WCS) represent the most degraded conditions for waterways within the Georges River catchment. Traditionally, WCS for indicators were calculated from all data collected across all monitoring sites; as the 90th percentile (e.g. for nutrients) or 10th percentile (e.g. for dissolved oxygen). River Health sites where the values of most variables are similar to WCS values are graded F, reflecting severe degradation.

Although they are ubiquitous in urban landscapes, there is a reluctance to include concrete channels in waterway monitoring programs, presumably because they are thought to have minimal ecological integrity. But, such reasoning makes them potentially useful for determining ecological WCS. In urban catchments, the common practice of excluding concrete channels from WCS determination implies that the WCS occurs amongst waterways with natural substrates that are in the bottom 10th percentile for each parameter or metric. However, in such catchments even worse values may persist in concrete channels, given that they are specifically designed for efficient drainage of stormwater, with no consideration of maintaining pre-urbanisation flow regimes, connection to groundwater, filtration capacity or habitat heterogeneity (Gurnell et al. 2007).

The objective of the present study was to determine whether waterway grades were markedly shifted by inclusion of concrete channels in the determination of WCS values, compared to the traditional use of only reaches with natural substrates in grading calculations. It was predicted that using concrete channels would result in the lowering of WCS values for most variables, with a concomitant increase in grades for urban streams with natural substrates.

Methods

Surveys were conducted in the Georges River catchment, in southern Sydney. This catchment was chosen due to its usefulness in comparing the condition of streams flowing through different land uses, as much of the north and west of the catchment is highly urbanised, but the central and southern catchment is mostly minimally disturbed forest contained within National Parks and water catchment areas.

Three reach types were surveyed: forested reference reaches (REF), urban streams with natural substrates which we refer to as non-engineered urban reaches (NEUR) and concrete channels which we refer to as engineered urban reaches (EUR). REF (7 sites) had minimal upstream human disturbance and less than 5% of their upstream catchment area was covered by impervious surfaces (Tippler et al. 2012a): all sites in the O'Hares Creek subcatchment, as well as sites labelled Georges River Upper and Woronora River on Report Cards. NEUR (16 sites) flowed through urban areas with high imperviousness (Tippler et al. 2012a), although the reaches themselves were not engineered and had natural substrates, including soft and hard sediments: all sites in the Bunbury Curran Creek, Cabramatta Creek, Prospect Creek and Lower Georges River Tributaries subcatchments on Report Cards. EUR (10 sites) were distributed across the urbanised subcatchments with high imperviousness, and were engineered concrete channels, which are not included on Report Cards. See River Health Report Cards (via www.georgesriver.org.au) for an overview of the relative condition of sites across the Georges River catchment and the location of REF and NEUR sites used in this study.

At each site, the condition of riparian vegetation and channel morphology was assessed using Rapid Riparian Assessment (RRA) (Findlay et al. 2011). For assessment of water quality, a TPS 90FLMV multi probe meter was used for spot measurements of dissolved oxygen, electrical conductivity, pH and turbidity; whilst concentrations of total nitrogen and total phosphorus were measured using standard methods (APHA 1998) by a National Associations of Testing Authorities accredited laboratory. Dissolved oxygen readings above 100% saturation were recorded as 100%, given that the meter was calibrated for readings between 0 and 100%.

Macroinvertebrate samples were collected following the Australian National River Health Program protocols (DEST et al. 1994). Samples were collected across 10 metres of edge habitat using a dip-net with 250 µm mesh and macroinvertebrates were live-picked by two people over 30 minutes. Macroinvertebrate samples were preserved in 70% ethanol prior to identification to family level using a microscope and appropriate guides (Hawking & Smith 1997; Gooderham & Tsyrlin 2002, plus keys listed within those publications). Taxon richness, SIGNAL-2 scores (Chessman, 2003) and Shannon-Weiner diversity were used as metrics for macroinvertebrate communities. Riparian assessments were done once at the beginning of the study in spring 2016, whilst water quality and macroinvertebrates were surveyed in spring 2016, autumn 2017 and spring 2017.

As explained in the introduction, guideline values for each parameter or metric that were used to inform the upper limits of grading scales were determined using data from REF. WCS that were used to inform the lower limits of grading scales were determined either using data from REF and NEUR and the traditional method explained in the introduction, or an alternative method where data from EUR were also considered.

Ensuring that grades were validly assigned and that the use of concrete channels in WCS determination is scientifically defensible requires clarifying the definition of WCS. The WCS values are intended to reflect those that commonly occur in the most degraded waterways, not the periodic and temporary ‘worst conditions in the most highly degraded waterways’. Traditionally, 10th percentiles or 90th percentiles of values recorded in sites with natural substrates were used as WCS. Those cut-offs require no *a priori* selection of group of sites that are likely to have the worst conditions. They provide an indication of highly degraded conditions in streams with natural substrates, but do not use outlier values from such streams as WCS that, if used, would skew grades towards providing a comparison to an unrepresentative and very low baseline. When considering EUR in WCS determination, median values were used rather than 10th percentiles or 90th percentiles of values. The justification was that an *a priori* decision was made to include only the most highly degraded reaches (presumed to be EUR) in WCS determination and the average of values from those reaches was most appropriate for consideration as alternative WCS. This was preferred over setting lower baselines based on calculating ‘worst conditions in most highly degraded reaches’, by including only highly degraded EUR and using the 10th percentiles or 90th percentiles of values. Medians were used in preference to means, to reduce the influence of outliers on calculation of alternative WCS values.

For the alternative method, if the alternative WCS value (i.e. median EUR values) departed from the regional guideline value more than the traditional WCS (i.e. 10th or 90th percentiles of REF and NEUR), the alternative was used as the WCS. Otherwise, the traditional WCS was retained for grading calculations. Grades calculated using the alternative WCS were compared to grades calculated using the traditional WCS.

To enable like-for-like comparison of NEUR and EUR values, median values from NEUR and 10th percentiles or 90th percentiles of values from EUR, plus the worst recorded values (i.e. those furthest from the guideline value for each indicator, recorded over the three seasons of surveys) were also calculated.

Results

As expected, comparison of median values indicated that EUR were more degraded than NEUR for most parameters and metrics, except dissolved oxygen, turbidity and SIGNAL scores (Table 1). A similar pattern occurred for the worst values recorded at any time over the three seasons of surveys: most of the worst values occurred in EUR, except dissolved oxygen, electrical conductivity, turbidity and SIGNAL score (Table 1). However, contrary to expectations, the ‘worst’ 10th percentile values recorded from REF and NEUR were usually ‘worse’ than the median values from EUR, except for RRA scores, pH and Shannon-Weiner diversity (Table 1). Therefore, when EUR were considered in alternative WCS calculations, only those three WCS values differed from the traditional WCS.

Standardised scores and corresponding grades for riparian vegetation were slightly higher using the alternative WCS for RRA scores (Figure *1*a), given that the alternative WCS was lower than the traditional WCS (Table 1). For determination of water quality grades, pH was excluded from calculations of standardised scores, because the regional guideline and WCS values were similar (Table 1). For all other water quality parameters, WCS values were the same for traditional and alternative calculation of standardised scores, so those scores and corresponding grades were also the same (Figure *1*b). For macroinvertebrates, using alternative rather than traditional WCS resulted in slightly higher standardised scores and corresponding grades, owing to a slightly lowered WCS for Shannon-Weiner diversity, although WCS for SIGNAL scores and taxon richness did not change (Figure *1*c). Overall, the standardised scores and corresponding grades were only slightly higher when EUR were considered in the alternative calculation of WCS, rather than when EUR were not considered using traditional calculation of WCS (Figure *1*d).

Whether traditional or alternative WCS were used in calculations of standardised scores, all REF had an overall grade of A+, whilst most NEUR had overall grades ranging from D to F, and most EUR had overall grades ranging from E to F (Figure *1*d). This was reflective of NEUR generally having highly degraded riparian vegetation (Figure *1*a) and macroinvertebrate communities (Figure *1*c), but some NEUR maintained relatively good water quality (Figure *1*b).

Conclusions

Historically, the lack of a common understanding across stakeholders about: the severity of urbanisation impacts on all receiving waterways, whether directly engineered or not; and, appropriate management of urban streams to maintain a range of ecological, social and economic values, have acted as major impediments to the development of water sensitive urban landscapes (e.g. Roy et al. 2008). Waterway scientists and managers are already well aware of the severe degradation of urban streams, including the multiple symptoms of the urban stream syndrome (Walsh et al. 2005). But, an important component of adaptive management of urban streams is providing accessible information about their condition to diverse stakeholders (Bunn et al. 2010), including those who do not necessarily read literature about stream ecology, but do make important decisions about how streams will be managed. Making information about stream condition more accessible can be aided by using Report Card grades. To determine grades, the selection of sites, indicators and algorithms is somewhat subjective, and needs to be scientifically defensible (Bunn et al. 2010; Connolly et al. 2013). Reducing subjectivity would be aided by adoption of a standardised approach, which could include using concrete channels in WCS determination in urban landscapes, given that such channels are ubiquitous in those landscapes.

For ecological condition assessments reported on River Health Report Cards for the Georges River catchment, lower limits of grading scales are determined using locally derived WCS data. Contrary to expectations, we found that River Health grades did not markedly improve when concrete channels were included in the determination of WCS, compared to the traditional use of only reaches with natural substrates in grading calculations. We acknowledge that there are limitations in using a suite of univariate indicators to assess ecological condition, given that stream ecosystems are complex and there are many potential stressors that could be quantified in urban streams, but we chose indicators that are most commonly used in stream monitoring programs. In an accompanying paper, we used multivariate analyses to show that the benthos of urban streams with natural substrates and concrete channels have similar diatom communities and only slightly different macroinvertebrate communities (Tippler and Reid 2018). For the present study, along with the lack of shift in grades, it was also surprising that many 'natural' reaches in urban areas had similar grades to nearby concrete channels. That is, although concrete channels are designed solely for efficient drainage of stormwater and commonly assumed to have minimal ecological value, the present study showed that concrete channels and urban streams with natural substrates received similar low ecological condition grades!

Even though their inclusion did not cause a shift in grades, including concrete channels in the determination of WCS may be useful for clarifying the dire state of all urban streams to managers, funding bodies and/or the general public. Results from the present study could be used as the basis for reframing of the message that urban streams are very severely degraded, given that being graded 'as bad as a concrete channel' is less abstract than being graded 'as bad as the worst 10th percentile of streams with natural substrates'. To clarify that the urban stream syndrome is not hopeless, such negative messaging should be presented along with solutions (Schultz et al. 2017), as we have put considerable resources into 'the search for a cure'. Our knowledge of water sensitive solutions is ever increasing (e.g. see https://watersensitivecities.org.au/), it is widespread implementation and government support of the solutions that is lagging, as most stakeholders in urban development do not prioritise directing adequate resources to the implementation of integrated water cycle management. Urban streams can be redesigned with an understanding that they will not maintain the full biodiversity and range of functions of undeveloped streams, but they can achieve multiple ecological, social and economic functions, rather than just being concreted and designed with the sole purpose of being conduits for efficient drainage of stormwater.

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Table 1: Guideline thresholds and potential WCS values for use in determining ecological condition grades for waterways in the Georges River catchment. Grades reported on River Health Report Cards (see www.georgesriver.org.au) were traditionally determined using the 10th percentiles or 90th percentiles from REF and NEUR as the WCS values. An alternative suggestion is to use the median from EUR as the WCS value, when that value is further from the regional guideline value than the traditional WCS value, for each parameter or metric. WCS values used for the alternative approach are shown in bold italic font.

Category	Parameter or metric (units)	ANZECC guideline thresholds*	Regional guideline thresholds: REF 20%ile or 80%ile	Potential 'worse case scenario' values				
				Traditional: REF and NEUR 10%ile or 90%ile	NEUR median	EUR 10%ile or 90%ile	EUR median	Worst recorded value**
Riparian	Rapid Riparian Assessment score	na	> 75	-21	-4	-47	***-26***	-48 EUR
Water quality	Dissolved oxygen (% saturation)	> 85	> 68	***26***	58	87	100	5 NEUR
	Electrical conductivity ($\mu S\ cm^{-1}$)	< 200	< 193	***1644***	619	2572	1059	3337 NEUR
	pH	< 9.0	< 7.73	7.71	6.81	9.94	8.81	10.06 EUR
	Turbidity (NTU)	< 6	< 4	***23***	7	51	6	97 NEUR
	Total nitrogen ($mg\ L^{-1}$)	< 0.350	< 0.352	***1.837***	0.945	5.841	1.570	26.000 EUR
	Total phosphorus ($mg\ L^{-1}$)	< 0.025	< 0.025	***0.269***	0.090	1.280	0.105	8.850 EUR
Macroinvertebrates	Taxon richness - family level	na	> 16	***7***	10	4	9	1 EUR
	SIGNAL-2 score	na	> 4.5	***2.4***	2.9	2.7	3.0	2.0 NEUR
	Shannon-Weiner diversity	na	> 2.0	0.8	1.1	0.05	***0.6***	0.0 EUR

* For lowland coastal rivers in NSW (ANZECC 2000). For pH, the upper limit is provided because pH is often naturally below the lower ANZECC limit of 6.5 in the Georges River catchment (Tippler et al. 2012b) and urbanisation is associated with an increase, rather than a decrease, in pH values. However, pH was not used in grading calculations, given that the guideline and traditional WCS values were very similar.

** These values are those furthest from the regional guideline values recorded over the three survey seasons (spring 2016, autumn 2017 or spring 2017). Superscripts indicate whether the values were recorded in a non-engineered urban reach (NEUR) or engineered urban reach (EUR).

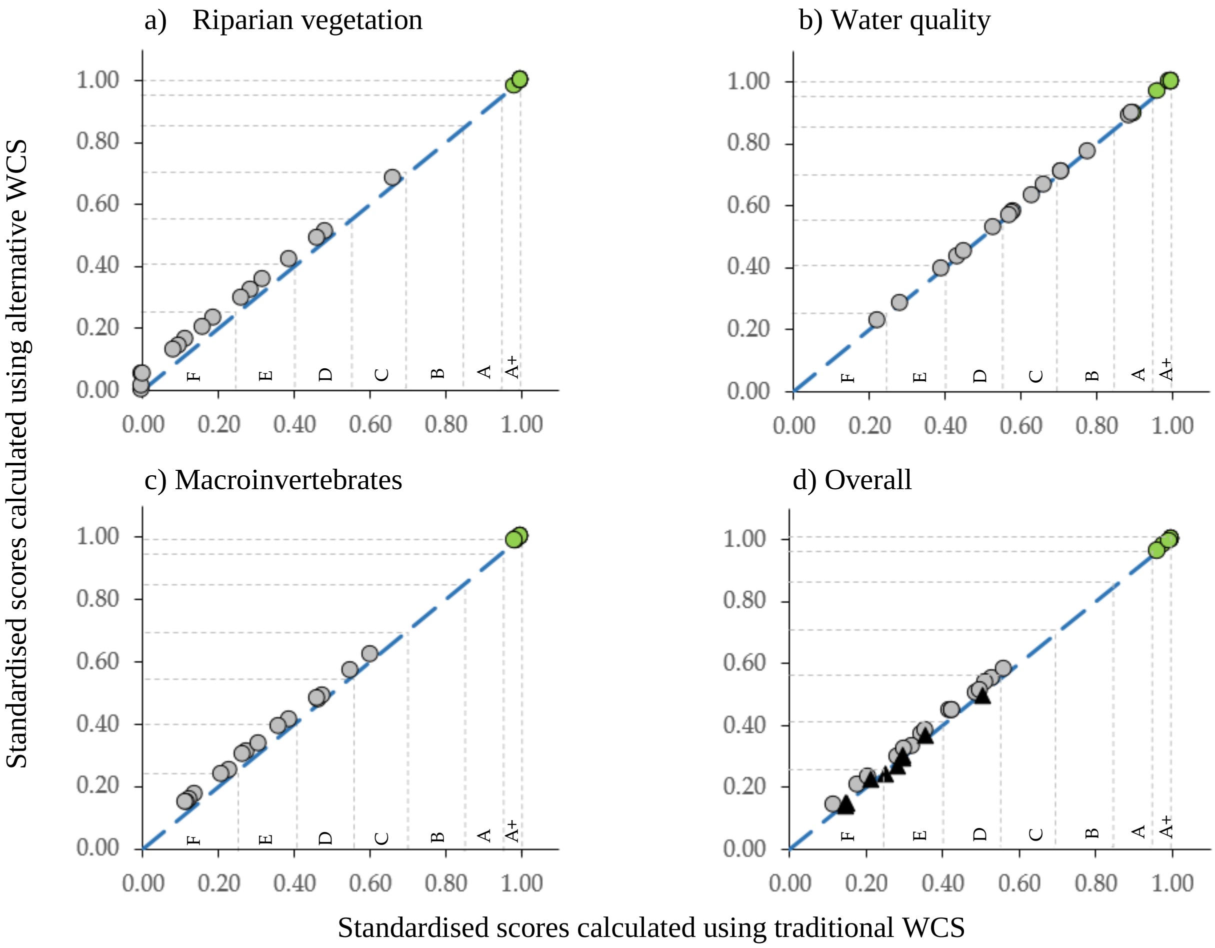

Figure 1: Comparison of standardised scores calculated for REF (circular symbols shaded green) and NEUR (circular symbols shaded grey) using traditional WCS and alternative WCS (see table 1 for explanation of calculation of WCS). EUR (black triangles) are included only for comparison of overall standardised scores and grades. The range of standardised scores corresponding to each grade are indicated by grey dashed lines and lettering along horizontal axes. Circular site symbols are intersected by blue dashed lines if x = y (i.e. no difference in standardised scores and corresponding site grades whether using traditional WCS or alternative WCS).