Environment Protection Authority

The South Australian monitoring, evaluation and reporting program for aquatic ecosystems

Rationale and method for the assessment of inland waters (rivers and creeks)

EPA
South Australia

The South Australian monitoring, evaluation and reporting program for aquatic ecosystems: Rationale and method for the assessment of inland waters (rivers and creeks)

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Summary

The Environment Protection Authority (EPA) has managed a water monitoring, evaluation and reporting (MER) program since 1995. This program was historically focused on assessing ambient water quality by comparing water chemistry measurements to the environmental values listed in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ 2000). Complementary biological assessments of river health were also carried out and reported separately but the objectives and scope of this work were not integrated with the water quality program.

In 2007, a new approach was developed that provided a more integrative and direct assessment of the condition or health of aquatic environments by focusing on biological indicators, while still including major water chemistry and physical habitat measurements. *The South Australian monitoring, evaluation and reporting program for aquatic ecosystems: context and overview*[1] describes the rationale behind redesigning the statewide MER program for inland surface waters and nearshore marine, using multiple lines of evidence to investigate and report on ecological condition, rather than to continue to rely on the indirect evidence provided by water chemistry data alone.

This report summarises the method used by the EPA to assess the broad condition of South Australian rivers and creeks (the Inland Waters MER program) and describes the Aquatic Ecosystem Condition Reports (AECR) that are published each year to provide the general public and key stakeholders with information about the state of the environment.

The MER program uses a risk-based, two-tiered structure for assessing condition according to a generalised ecological condition gradient. The Tier 1 assessment is a desk-top evaluation of the 'expected' condition of selected sites based on the upstream catchment and near-site pressures and threats that are evident from map-based land-use variables and metrics (modified from Bryce *et al* 2007).

The Tier 2 assessment is based on a field assessment of biological indicators, focused on aquatic macroinvertebrates and supplemented with information on aquatic, riparian and terrestrial vegetation, sediments and water quality data, which is used to develop descriptive biological condition gradient models for each sampled natural resource management region (based on Davies and Jackson 2006). This data is assessed each year by an expert panel using the regionally developed conceptual models to provide 'observed' Tier 2 condition ratings for each assessed site.

Both the Tier 1 and Tier 2 ratings are incorporated into the Aquatic Ecosystem Condition Reports for the sites sampled each year, along with relevant regional summary reports that describe the overall patterns observed from sites sampled in a NRM region in a particular year. The conceptual models and a description of the expert panel process and results are also published in a separate report each year.

It is important to note that more focused studies that typically address question-based pollution source identification, pathway and effects are carried out as finer-scaled Tier 3 projects, and they are published separately to the MER program on either the EPA website or as journal articles. Such studies are sometimes carried out to confirm unusual Tier 2 findings or to provide supplementary information about a stream, catchment or contaminant issue.

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1 https://www.epa.sa.gov.au/files/477486_aquatic_merp.pdf

1 Introduction

The Environment Protection Authority (EPA) coordinates a monitoring, evaluation and reporting (MER) program on the aquatic ecosystem condition of South Australian creeks and rivers. This MER program fulfils several objectives:

- Provides a statewide monitoring framework for creeks and rivers in each relevant natural resource management (NRM) region with sufficient frequency to allow for state of the environment reporting purposes.
- Describes aquatic ecosystem condition for broad government and general public understanding.
- Identifies the key pressures likely to be affecting aquatic condition and the management responses to address the most significant pressures.
- Provides up-to-date knowledge of the biology, chemistry and physical properties of our inland waters, and helps to maintain the inhouse expertise of professional staff relating to sampling, assessing and interpreting complex data to a range of applications and audiences.
- Contributes baselines for multiple uses, including the identification of reference conditions that can be used as management goals for remediation efforts or to assist with understanding the risks and likely effects from licensed discharges and unauthorised spills and discharges.
- Provides a useful reporting format that can support environmental decision making by government, the community and industry.

This program historically focused on assessing ambient water quality by comparing water chemistry measurements to the environmental trigger values listed in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC/ARMCANZ 2000). Complementary biological assessments of river health were also carried out using reference-based models based on aquatic macroinvertebrate data, and reported separately, but the objectives and scope of this work was not integrated into the wider water quality program.

In 2007, a new approach was developed, tested and implemented which provided a more integrative and direct assessment of the condition or health of aquatic environments. The *South Australian monitoring, evaluation and reporting rrogram for aquatic ecosystems: context and overview*[2] describes the rationale behind redesigning the statewide MER program for both inland surface waters and nearshore marine waters. The main difference with the new program was an increased focus on using multiple lines of biological, habitat and chemical evidence to report broad ecological condition, rather than continue to rely on the indirect evidence provided by water chemistry data alone.

2 http://www.epa.sa.gov.au/files/477486_aquatic_merp.pdf

2 Inland Waters MER Framework

A two-tier assessment of the biological condition of stream sites was tested and implemented after a comprehensive review of the methods used in Australia and overseas indicated that:

1. Map-based criteria could provide a coarse preliminary Tier 1 predictive assessment of 'expected' stream health (see Bryce *et al* 2007)
2. Field-derived biological (mostly aquatic macroinvertebrate) data from sampled streams could be converted into more detailed Tier 2 actual 'observed' condition ratings, based on a modified descriptive biological disturbance model (see Davies and Jackson 2006).

2.1 Sampling design

Approximately 30–70 sites have been sampled each year since 2008, in autumn and spring, with each major natural resource management board region that contain stream habitats sampled at least once every five years. Funding support from the Adelaide and Mount Lofty Ranges NRM has enabled more regular sampling every two years, which was supported because this region has the highest density of people and mixture of land uses, so disturbances from human activities were expected to be significant in the Adelaide Plains and Hills.

Sites comprise a 100-m section of stream selected to represent the typical physical conditions present in the stream to be assessed. Site coordinates are generally taken from the middle of each site.

Aquatic macroinvertebrates have been sampled using the same basic strategy that was developed as part of the National River Health Program in 1994. This involved using a 250-µm meshed triangular dip-net to sample non-flowing edge and fast-flowing riffle habitats, whenever they extend over at least 10 metres within the site to be sampled. The majority of South Australian streams had edge or pool habitats present during either the autumn or spring period but some also maintained sufficient riffle habitat to enable an additional sample to be taken of the organisms favouring flowing waters. In cases where the available habitat did not meet the 10 m distance threshold, no sample was formally taken at the site. However, notes were invariably made of the animals identified in the field with the naked eye from whatever habitat was able to be inspected[3].

Sample processing has been modified over time to meet differing objectives. Work carried out as part of the National River Health and Australian River Assessment Scheme (AUSRIVAS) from 1994–99 focused on obtaining the highest quality data possible, whereby samples were preserved in the field and sorted in the laboratory at a later time using microscopes. At least 10% of each sample was processed using a standardised subsampling method, with the residue scanned for the presence of rare taxa.

Specimens were identified to the lowest level possible using available keys, and counts made of the abundance of each sorted taxon. Separate entries were retained, on an Excel spreadsheet, for each habitat sorted from each sampling site, so permanently flowing sites had data for edge and riffle habitats sampled in autumn and spring (maximum of four samples in any one year), while less permanent sites obviously had less samples taken.

The same processing strategy was maintained by the EPA during a more limited ambient monitoring program from 2000–06. However, concerns about the lack of integration of indicators, limited use of the data and findings from the EPA funded water programs, and delays in processing samples (usually involved reporting results that were 12+ months old) resulted in a review of the inland waters program. This led to a number of changes being implemented in terms of the data collected, how it was analysed and assessed, and the manner in which the results were reported to the general

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3 https://ausrivas.ewater.org.au/index.php/resources2/category/19-manuals?download=28:sa-sampling-and-processing-manual-04mb

public. In terms of sample processing, a field processing method was adopted to ensure all results were capable of being reported soon after the completion of any sampling campaign. The field method involved scanning each habitat sample for at least 30 minutes, with taxa identified and an estimate of total abundance of each made at the conclusion of processing. If a new taxon was recorded within the last 5-minute period, then an additional 5-minutes would be used to continue to scan for new species. Representative specimens of each taxon were preserved in a labelled container for later verification of identifications using microscopes in the laboratory.

The period from 2008–11 involved testing the new MER approach to as many sites as resources allowed but subsequent work since 2012 has led to a reduction in site coverage and the inclusion of new biological indicator data (ie benthic diatoms). The latter was included because many streams in South Australia show evidence of nutrient enrichment, so incorporating diatoms, a group of algae that are well known to respond to nutrient availability and other water quality stressors (Chessman *et al* 2007, Tang *et al* 2016, Tibby *et al* in press), was expected to strengthen the assessment of stream condition by including data from a primary producer (diatoms) and the main consumer (aquatic macroinvertebrates) present in our rivers and creeks.

Sites have been selected each year from a list of previously sampled sites (often from gauging stations or sites sampled as part of the National River Health Program from 1994–99[4]) to complement other monitoring priorities or needs of the Department for Environment and Water (DEW), NRM boards, other agencies or local government. The distribution of selected sites each year has ensured that the spatial extent of the stream network that can easily be accessed from the existing sealed and unsealed road network (ie within 500 m from roads) in each region is sampled. This strategy aims to minimise the likelihood that sampling teams will disrupt farming activities, or cause erosion or fire hazards when accessing sites using vehicles.

This sampling design provides targeted information about the fixed sites that are sampled and enables the results to be used to report on the general condition of waters in each region. However, the lack of randomly selected sites using this approach limits the ability to provide a statistically valid assessment of all waters in a region with a known degree of error (Dobbie *et al* 2008).

The EPA has in fact developed a stream reach database linked to the road network that can be used to select random sites, using an unequal probability of selection criterion to ensure a similar number of sites can be generated for each stream order (Catchment Simulations Solution 2011). This enables a statistically valid assessment to be made of the km or % of streams with different condition ratings, presence of sensitive or flow dependent taxa, enriched with nutrients or dominated by fine sediments to be made for each region.

However, in consultation with staff from each respective NRM region, DEW, and SARDI, the decision in most cases has been to continue to build on what is considered to be a spatially limited information base from previously sampled fixed sites, and to use the results to promote a general understanding of the condition of waters in each region.

A large number of random sites was incorporated into the sampling design from the Western Mount Lofty Ranges in 2013, and the results showed for the first time the significance of some first and second order tributary streams as sources of fine sediments and nutrients to downstream waters. The option remains for future assessments to incorporate a mixture of random and fixed sites, which is considered the preferred design for MER programs, particularly where reporting on broad regional trends is desirable (Urquhart *et al* 1998).

4 https://www.epa.sa.gov.au/files/4771460_soe_inland.pdf

3 Conceptual models and assessment of ecological condition

3.1 The assessment

The descriptive model for interpreting change in aquatic ecosystems in relation to increasing levels of disturbance published by Davies and Jackson (2006) is the basis for the assessment approach used to report the condition of inland waters. The main assumption of the model is that biological (ecological) condition deteriorates as the degree of human disturbance in the upstream and adjacent catchment increases, and conversely, the best condition occurs where there is little to no human disturbance of the environment (Figure 1).

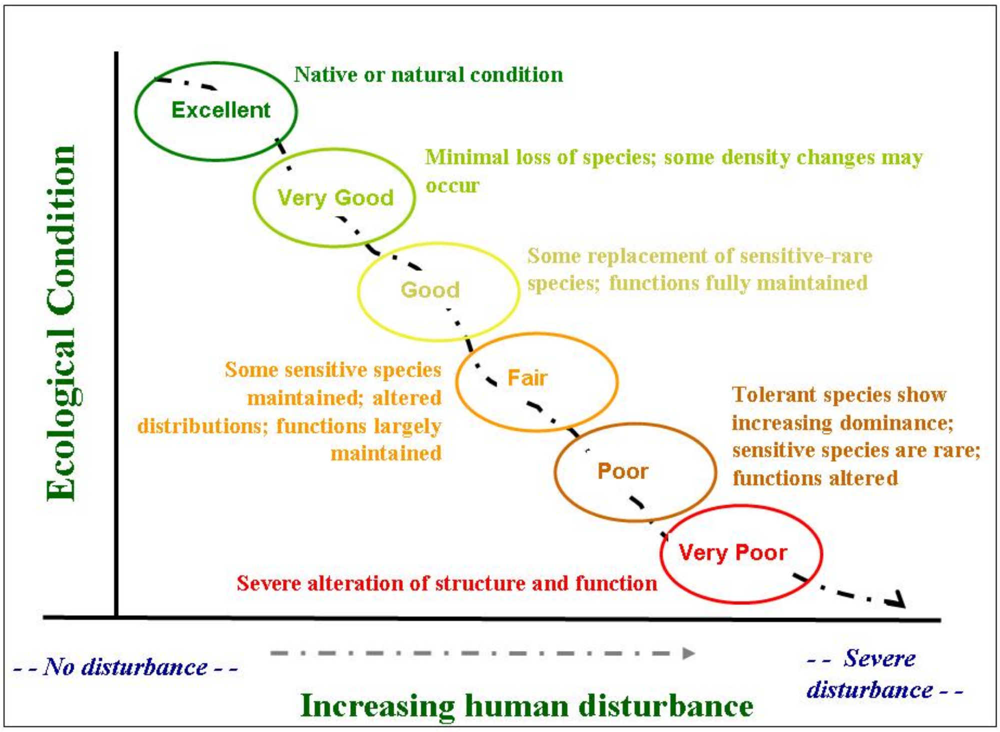

Figure 1 **Human disturbance gradient showing the six different ecological condition grades or ratings ranging from Excellent (best) to Very Poor (worst) with a brief definition of each condition**

The model describes how 10 different biological attributes respond to the generalised disturbance gradient, which is divided into six condition tiers or grades that range from pristine, with no or negligible human disturbance, through to the most degraded condition, with evidence of severe disturbance. The attributes include many of the widely published responses to disturbance (eg loss of sensitive species and habitats specialists, and increase in tolerant and introduced species with increasing disturbance).

Most biological monitoring programs collate data that can readily be used to describe attributes 1–6, since they relate to measures of taxonomic composition and community structure. The remaining attributes are, however, rarely comprehensively assessed, including organism condition and system performance measures (eg fish condition, evidence of production and respiration), and spatial and temporal measures of physical habitat and biotic interactions (eg filamentous algal cover and extent, habitat connectivity). The rarely assessed attributes describe important functional and process measurements of ecosystems, so they continue to be included in any application of this modelling approach despite the lack of good supporting data to contribute to any condition assessments (Davies and Jackson 2006, US EPA 2016).

3.2 Tier 1 expected condition using map-based variables

Details of the approach used to predict the expected condition of stream sites are outlined in Appendix 1. This method, modified from the published study (Bryce *et al* 2007), provides a broad indication of the likely condition of sites based on the location, available map-based data and satellite images of the upstream and adjacent catchment.

Comparisons between the Tier 1 and 2 assessments over time indicate that for heavily modified areas like the South East, more than 80% of sites show similar condition scores using the map and field-based methods. In contrast, areas such as the Mount Lofty Ranges that support a more diverse mix of land-use activities provide more variable results, with some years recording comparable results in less than 50% of sampled sites.

3.3 Tier 2 Expert panel assessment of actual condition

The process that has been used in South Australia to grade or rate the condition of sampled sites involves the following steps, carried out by a panel of expert biologists who each have more than 15 years' experience in sampling streams and knowledge of the presence and distribution of aquatic macroinvertebrates in South Australia.

Firstly, a conceptual model describing the ecological responses to the general disturbance gradient is developed, reviewed and updated by the panel; separate models are developed for each NRM region each year they are monitored to represent the different stream types that occur throughout the regions in the state (Appendix 2, Table 1).

Secondly, species lists are compiled for each model from the data collected in each year that are used to describe the expected biotic assemblage for each of the possible condition ratings (Appendix 2, Table 2).

Thirdly, each panel member independently assigns a condition rating based on the macroinvertebrate communities and vegetation assemblages that have been recorded during the sampling period. The sediment, water quality and habitat data provide information about the pressures and degree of human disturbance at the site scale to confirm if the biology is consistent with the conceptual models for each region. For sites that are consistently dry, only the vegetation and habitat data are used to provide an interim rating; during wetter periods, many of these sites would probably rate differently but the assessment is always based on the conditions that occurred during each site visit in the year they are sampled.

Lastly, the individual ratings derived by the panel members are reviewed, enabling each expert to change any of their assigned ratings if appropriate, and then the results are combined to produce an overall or final rating for each site (Appendix 2, Table 3).

The final reported ratings are based on the mode (most common rating from the panel members for each site). The panel report that describes the models and assessments in each year, also includes the ratings from each panel member, thereby providing a clear record of the consistency or variation in rating sites using the expert panel approach.

The six ratings or tiers in the model range have been assigned the following textual descriptions: Excellent, Very Good, Good, Fair, Poor and Very Poor. However, not all ratings are considered possible in each NRM region due to the extent of land-use change and habitat disturbance, so some models highlight where the Excellent and Very Good or Very Poor ratings are unlikely to occur.

3.4 Reporting

Since 2008, the results have been published on the EPA website as individual site reports under the Aquatic Ecosystem Condition Reports (AECR). Also included is the above-mentioned panel report and regional summary reports that highlight the range of stream conditions assessed in each sampled NRM region each year[5].

The inland waters MER program aims to build on historical data, and add new data and knowledge about the current condition of sampled sites using multiple lines of evidence to highlight the most likely reasons or factors affecting condition scores. Management responses expected to mitigate sources of degradation are included. If they prove successful then we would expect future stream condition to improve, or at least be maintained at present levels as evidenced by the indicators and measurements included in this assessment.

5 https://www.epa.sa.gov.au/data_and_publications/water_quality_monitoring/aquatic_ecosystem_monitoring_evaluation_and_reporting

4 Refinements and future directions

The major refinement for this MER program will involve the future use of supporting analytical models to provide interim Tier 1 and 2 assessments, which will then be reviewed and amended by the expert panel, as needed, to decide on any final condition ratings. Otherwise, it is expected that the program will continue to focus on the collection of aquatic macroinvertebrate and diatom data as the main datasets, although it is possible that selected fish survey data from other sources (eg SARDI, Aquasave) may also be able to be included as a third biotic dataset in future Tier 2 assessments in some NRM regions (eg Mathwin *et al* 2014).

Many states in the USA have already applied a wide range of analyses and models in an attempt to automate assigning waterbodies to different biological condition gradient levels (US EPA 2016). They include multiple attribute decision models (mostly based on mathematical fuzzy logic to mimic human reasoning), multivariate discriminant models, and the identification of dose-response thresholds for commonly used biological indices (eg multimetric indices, predictive model indices, Ephemeroptera/Plecoptera/Trichoptera (EPT) indices). This has invariably been done to help standardise assessments using quantitative decision rules identified or used by the expert panel to distinguish the different condition levels, and to also avoid having to reconvene the panel each year (Gerritsen *et al* 2017).

In South Australia, from 2008–17 each NRM region has been sampled and assessed at least twice using the expert panel approach. This has provided the opportunity to refine the conceptual models and any biotic patterns that the panel consider significant enough to separate sites into different condition classes for each region that support stream habitats. Future work will determine if these Tier 1 and Tier 2 condition scores can be used to identify the main environmental drivers likely to contribute to stream condition.

A relatively new machine learning technique called boosted regression trees (BRT) has been able to identify significant environmental variables using map and field-based data, with the aim of being able to predict the condition of unsampled stream reaches (eg Waite and Van Metre 2017). BRTs differ from traditional regression methods that produce a single ‘best’ model by using two algorithms, regression trees and boosting, to build and combine a collection of models which optimises predictive performance (Elith *et al* 2008).

BRTs are being internally developed by the EPA at both the state and NRM regional level, using the stream condition as the response variable and a wide range of explanatory variables, to identify which environmental variables are significant for the Tier 1 and Tier 2 assessments at different spatial scales. Future reporting will incorporate the modelled Tier 1 and 2 assessments and be used by an expert panel to confirm if the modelled expected (map-based only) and actual (combined map and field data) provide agreed condition ratings, or outline why adjustments to any ratings are warranted.

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Appendix 1 Tier 1 broad-scale assessment of relative condition of rivers and creeks in South Australia

Introduction

The activities and actions of humans have altered the structure and function of most aquatic ecosystems in many different ways but particularly through land-use changes to the natural environment. Assessing the ecological condition of waters is a complex task and invariably involves an evaluation of the biota and environmental factors that have direct and indirect effects on biota (eg Fleeger *et al* 2003) at a scale relevant for the living organisms inhabiting waters and for people to be able to use for water management purposes.

In the past, most studies have generally focused on assessing the condition of the biota (eg Karr 1981, Karr and Chu 1997) while others have assessed individual stressors (eg nutrients cited in numerous publications by the US Geological Survey and US EPA since the 1990s onwards) or issues [eg cattle impacts by Silla (2005) or wider land-use impacts by Sponseller *et al* (2001)]. Integrative methods that provide an indication of the general condition of streams have not been widely used despite the obvious value in providing a rapid assessment of large numbers of stream reaches or catchments in a region or state.

Bryce *et al* (1999) proposed a process to provide a simple assessment of numerous catchments and classify them along a human disturbance gradient using coarse-scale data from a range of geographic information systems layers, topographic maps, aerial photographs and previous data collected during site-based studies in the past. The results can be summarised into risk ratings that describe the likely type and degree of disturbance from human activities in the catchment area upstream from specific reaches and sites.

This approach assumes that stream biota in a catchment with few disturbances is considered at low risk of impairment whereas biota in a watershed subject to multiple disturbances over larger areas is considered to be at high risk. Implicit in this assumption is that the lower-risk sites have few signs of human use and occupation, changes subject to agriculture and pastoral grazing cause an intermediate level of disturbance (Miserendino *et al* 2011) and that high-risk sites occur in urbanised streams or streams receiving point-source discharges from industry.

Using a modified version of Bryce *et al* (1999), a broad-scale Tier 1 assessment of the likely expected condition of sampled sites was trialled and incorporated into the Aquatic Ecosystem Condition Reports. This assessment was included because historical and current land-use modifications and practices have caused some degradation of urban and rural streams, and it would be unrealistic to expect many of them to rate well using any condition assessment process, given the scale and type of disturbances that are likely to continue to affect such streams in the future.

Methods

Sites and their watersheds covering the entire catchment upstream from the GPS sampling point on each waterway were delineated using GIS. A range of data was then compiled for each site using topographic maps, satellite and aerial photograph images available on Google maps, and land-use data summarised into areal estimates for each upstream catchment to confirm the probable presence of major human stressors (eg houses, roads and mines) relating to catchment land uses. Some disturbance measures such as road density and land-use statistics were based on quantitative data whereas others such as the presence of houses and mines were visually estimated from either satellite, topographic maps or based on previous field studies and experience from sampling in each region.

The approach of Bryce *et al* (1999) was modified to include the major risk attributes relevant to the South Australian landscape and focused on rating those activities that influenced or altered natural vegetative cover, channel morphology, sedimentation and chemical loading of streams found in each respective region.

For the southern part of the state (eg Mount Lofty Ranges, Murraylands, Fleurieu Peninsula, Kangaroo Island, South East and Eyre Peninsula) the major human land uses include large areas of agricultural cropping and grazing, residential development in rural and urban settings, vineyards, irrigated crops, and some native and pine plantation forestry. Many streams in these areas have been incised and channelised due to historical vegetation clearance and the effects from urbanisation and stormwater flows and only a few retain more than 50% of the original native vegetative cover (in conservation parks or largely inaccessible coastal areas that were unsuitable for clearing and subsequent cropping or grazing uses).

The South East is unusual because there are naturally only a few streams that occur in a region that has been artificially dried by a large network of drains that have been installed in the past. The few natural streams include four that originate in western Victoria and discharge to swamps and drains in the Bordertown to Naracoorte area, and a few coastal streams in the Port MacDonnell to Glenelg River area that have also been subjected to variable degrees of channelisation and modification to help support largely dairy grazing practices in the local area.

For the more arid parts of northern South Australia which include the Flinders Ranges and Lake Eyre Basin, the extent of human uses of the landscape are more diffuse, and most towns and settlements are located on major road networks well away from streams. A range of cropping activities occurs in the southern Flinders Ranges, largely in the Willochra catchment but elsewhere the major land use involves grazing natural vegetation. Sheep and cattle grazing dominates in the Flinders Ranges (along with feral goats in places) with pastoral cattle grazing dominating in the Far North around the Lake Eyre Basin. The most notable towns or settlements situated near named creeks in the Far North include Crystal Brook, Gladstone, Melrose, Pekina, Quorn, Wilpena, Leigh Creek and Arkaroola in the Flinders Ranges, Oodnadatta from the Western Lake Eyre Basin and Innamincka from the Eastern Lake Eyre Basin. A number of abandoned mines occur in the region, particularly throughout the Flinders Ranges, but the most significant active mines that are located near regularly flowing streams occur in the vicinity of Leigh Creek. Otherwise, numerous rural houses are widely distributed across the region from the limited road network that occurs within the Flinders Ranges and both sides of the Lake Eyre Basin. The western part of the state lacks surface streams and only a few intermittent streams are located in the Mann and Musgrave ranges in the northwest of South Australia.

Scoring the stream sites

The information and data collected from each site in each sampled region was used to assign a risk index score that ranged from Excellent to Very Poor, which corresponded to the gradient from minimal to highest risk of disturbance or impairment. Each score was an integration of information from the regional, catchment and reach scales that summarised the type and degree of disturbance upstream from the sample sites that were subsequently evaluated in the field as part of the Tier 2 actual condition assessment.

Climate, geological, geomorphic and soil features were included where appropriate, to provide a broad characterisation of the effects of temperature, rainfall, flow and sediment properties on the stream network present in the region of interest. Particular attention was placed on the climatic patterns when sampling occurred, to allow some consideration of average, below or above average rainfall and subsequent flow patterns on stream sites to be assessed in any particular year. The number and intensity of upstream and streamside land uses were then considered relative to the expected conditions in each region. The expectation was that aquatic biota in catchments with few disturbances were likely to be at a low risk of impairment whereas biota in catchments subjected to many disturbances over large areas were considered to be at a high risk.

The stressor matrix (Table 1) derived for each year, over the period from 2008–17, shows how the criteria were used to assign scores to sample sites and their catchments. It was expected that due to the large spatial scale sampled, the full disturbance gradient was probably sampled from each region. The risk attributes were aligned in rows on the left side of the matrix and were ranked in order from the lowest to the most severe level of disturbance when moving from the top to the bottom of the matrix.

The process of deriving the Tier 1 risk ratings involved assessing the presence of positive (+) risk attributes (naturalness features, limited human disturbance), zero (0) attributes for ‘swing’ features that can alter a score from an Excellent to a

Very Good condition or Poor to a Fair condition, and minus (–) attributes that indicate significant human activities in a catchment.

Consequently, sites located in protected areas with no human disturbance and only + attributes were rated Excellent; sites with mostly + and a few 0 scores were rated Very Good; those with mostly + and 0 scores and perhaps a – score were rated Good; sites with mostly 0 and a few – scores were rated Fair; sites with mostly – and a few 0 scores rated Poor; and the worst rating of Very Poor was given to highly disturbed sites with only – scores. Not all attribute categories were relevant to all sites, so only those that related to each specific site and its catchment were considered.

Table 1 Stressor matrix showing criteria and broad Tier 1 condition classes for stream sites based on the presence of risk factors in their catchments

Stressor	Rating	Rocky River (KI)	Cygnet River (KI)
Protected area present in or adjacent to catchment eg national and conservation parks (>1% catchment)	+	+	
Native vegetation cover extensive and dominates >90% of the catchment	+	+	
Only a few minor unsealed roads in the catchment and possibly one sealed access road	+	+	
No obvious point or diffuse pollution in catchment (ie historical mining or cropping)	+	+	
Few to no residences in the catchment	+	+	
Mostly comprising native vegetation or plantation forests (>50% cover)	0		
Minor levels of agricultural development (<50% cover)	0		
Few small farm dams present (at least some drainage lines without dams)	0		
Low density of minor sealed/major unsealed roads present	0		0
Low density of rural residences present (<5% catchment)	0		0
High % of the catchment cleared or modified (>50%) and agricultural land uses dominate	–		–
Many small dams or 1–2 large dams or reservoirs present in catchment (often >0.1% catchment area)	–		–
Major road network of sealed roads and/or unsealed roads and tracks (>1% catchment)	–		
Inter-basin water transfers or large reservoirs present	–		

Stressor	Rating	Rocky River (KI)	Cygnet River (KI)
High % of the catchment cleared (>60%) and urban land uses extending over 20% catchment	–		
High streamside urban development or in local vicinity (within 5 km upstream)	–		
Channelisation, dredging and urban stormwater inflows present	–		
Potential point source pollution from industry, mines, or agricultural feedlots	–		
Expected grade (Tier 1)		Excellent	Fair

Results and summary

This coarse assessment can be made from any site where a field sampling Tier 2 assessment has been carried out, and is designed to provide a pragmatic first-cut assessment of the likely condition of a stream given the land-use modifications that have occurred over the last 170 years since European settlement. The expectation is that much of the landscape has been changed over time due to the extent of agricultural development in an essentially flat and undulating terrain, so few streams would retain their completely original natural characteristics.

Indeed, given the extent of cropping and grazing land uses throughout much of South Australia, few streams would be expected to be assigned to the Excellent and Very Good ratings and most would show variable evidence of nutrient enrichment and fine sediment impacts which would place them in the Good to Poor ratings on the six-scale condition rating system used in the biological condition gradient model (Davies and Jackson 2006). Only the most heavily polluted and disturbed streams should be assigned to the worst Very Poor rating, and would generally be expected to occur in major urban streams or downstream from an industrial point-source discharge.

These broad patterns are able to be captured by the Tier 1 assessment and represent the expected condition based only on remotely collected data. The results can then be compared against the actual Tier 2 ratings from detailed sampling of the biology, chemistry and physical properties of stream sites to confirm whether the observed condition matches the expected condition, or is markedly different and subsequently requires further work to understand why any discrepancy exists. Both the condition ratings from the expected (Tier 1) and observed (Tier 2) assessments are reported in the AECR, and more detailed studies of specific catchments with unexpected results or specific water quality issues are reported separately as part of a Tier 3 program.

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Appendix 2 Examples from the latest AECRs assessments of sites sampled from the Flinders Ranges in 2017

Table 2 Conceptual model describing the general biological responses to the human disturbance gradient in the Flinders Ranges

Rating	Excellent	Very good	Good	Fair	Poor	Very poor
Stressor description	As naturally occurs with native vegetation and no pest or introduced species present. Given the historical sheep and cattle stocking practices in region from the 1800s-mid-1900s, ongoing damage caused by pest species (eg goats, donkeys rabbits, and mosquitofish in some catchments), occasional grazing of refuge springs and waterholes by stock and feral animals and presence of weeds across much of the Flinders Ranges, this rating may no longer exist in the region.	Least disturbed assemblages. Vegetation largely native trees over predominantly native understorey but typically includes some introduced species. Aquatic macroinvertebrate assemblages typically with high richness; intolerants and specialist taxa often dominate abundances but more ephemeral habitats include rich insect fauna; may include some introduced species present in low abundances.	Slightly modified and likely to be showing initial signs of enrichment and some modification of natural habitat features. Likely to occur in springs and streams with large areas of natural vegetation remaining. Generally only applies for well-vegetated, permanent or near permanent freshwater habitats but may also include more ephemeral waters with only minor habitat changes and evidence of slight addition of nutrient and fine sediment from the surrounding land uses.	Moderate changes to native vegetation and habitats but retains major natural features present in watercourses from the region. Some localised nutrient enrichment and fine sediment additions likely to occur due to the extent of stock and feral animals accessing the site.	Substantially modified and likely to retain only limited areas of native vegetation and show evidence of clearly altered habitats. Damage from stock and feral animal grazing of riparian habitats likely to be widespread and evidence of large amounts of nutrients and possibly fine sediment being added to sites from local sources. May occur near urban centres, mines or major roads, areas where historical damage to springs and creeks may have occurred in the past and contributed to the poor condition of individual reaches or springs. May also	Severely altered and likely to only occur in the region in urban stream reaches. Sites assigned to this rating will typically be affected by a toxicant or other disturbance that significantly limits the diversity and abundance of aquatic life present in a stream. Past work focused on current and disused mines in the region, failed to show any evidence of significant sediment or contaminant damage of streams but it is possible that localised reaches or future tailings dam failures could result in major environmental damage. However, given the existing land

Rating	Excellent	Very good	Good	Fair	Poor	Very poor
					occur at springs and waterholes damaged by leaking septics from nearby rural homesteads or where stock concentrate near waters due to local farming practices.	uses in the Flinders Ranges, this rating is unlikely to occur in the region.
Biological assemblages	Native assemblages of plants and animals, as naturally occurs for the landscape. Typically native gum tree overstorey with range of native understorey plants, including different age classes but no introduced species. More saline landscapes may lack gum trees and often comprise paperbarks or acacia overstorey species. Aquatic macroinvertebrate assemblages usually comprise some flow dependent species and non-insect groups, and a wide range of insect species. No obvious symptoms of stress or presence of any	Least disturbed with high proportion of natural features. Water likely to be naturally fresh (salinity <3,000 mg/L) apart from the Willochra catchment and some low-lying streams along the eastern side of Lake Eyre that are possibly naturally saline. Streams are also typically well oxygenated and show no evidence of significant eutrophication effects (eg large algal or plant growths, blackened sediments due to organic enrichment).	Good richness; generalist assemblage that includes at least some non-insect species for the permanent springs and creeks but more ephemeral habitats may only support aerially dispersed insects such as beetles, waterbugs and dipterans; emerging symptoms of stress in relation to nutrient enrichment evident due to the dominance by organic feeders; vegetation is slightly altered from the natural assemblage expected for the landscape, comprising predominantly native trees with a few weeds	Impaired assemblages; generalists and tolerant taxa dominate numbers which usually includes some very abundant taxa; more sensitive and rare taxa, if present, only occur in very low numbers; absence of some taxa expected for the available habitats present; vegetation showing obvious change from natural assemblages in the landscape, comprising at least some trees present in or near the riparian zone that is dominated by introduced plants; extent of the moderately	Degraded assemblages; tolerant and generalist insect taxa dominate but numbers usually reduced, although 1–2 generalist taxa may be present in high abundances; only 1–2 rare or non-insect species present in low abundances or absent; often few or only 1–2 scattered trees occur as small patches over an understorey dominated by introduced plants; extent of the poorly bank vegetative cover typically <25% cover.	Severely degraded assemblages with few taxa and generally low abundances; may have large numbers of one or two tolerant taxa such as oligochaetes, mosquito larvae or midges (eg Chironomus, Procladius and Tanytarsus); vegetation typically expected to comprise introduced species with little to no remnant native vegetation.

Rating	Excellent	Very good	Good	Fair	Poor	Very poor
	introduced aquatic species. Include a range of short and long-lived life history strategies, and wide range of traits which confer local ecosystem resilience to disturbance. More permanent habitats likely to provide a significant refuge but more ephemeral and naturally saline waters will typically be dominated by a range of generalist insects. Abundances of all aquatic species generally low.		and introduced species present; extent of the well vegetated bank cover typically >50%.	well vegetated bank cover typically <50%.		
Water chemistry conditions	As naturally occurs; no human contaminants present and stock or pest species elsewhere in the catchment not impacting on the local water quality (eg nutrients, hormones).	Near natural habitat and flow regimes; mostly well vegetated catchments with few dams present; range of sediment types present and not always anaerobic.	Largely unremarkable water quality but with at least some nutrients present at higher than expected concentrations, coupled with at least one plant indicator showing emerging signs of enrichment effects eg either chlorophyll a >10 ug/L, macrophyte extent >35% cover and/or filamentous	Fair water quality with generally saturated dissolved oxygen (when sampled during the day), nutrients present at high concentrations and corresponding high levels of algal and plant growths eg chlorophyll a >10 ug/L, macrophyte extent >35% cover and/or filamentous algae >10% cover) evident on occasions.	Poor water quality with generally saturated dissolved oxygen (when sampled during the day), nutrients present at very high concentrations and high plant productivity evident throughout the site eg chlorophyll a >>10 ug/L, macrophyte extent >35% cover and filamentous algae >10% cover most of the time).	Very poor water quality with at least one parameter at a toxicant concentration that limits aquatic diversity; often very low dissolved oxygen and may be saline and enriched in nutrients but algal and plant growth limited.

Rating	Excellent	Very good	Good	Fair	Poor	Very poor
			algae >10% cover) but site not overwhelmed.			
Physical habitat and flow patterns	Natural habitat and flow patterns; no dams or abstractions present; range of sediment types typically present and not always anaerobic.		Good habitat structure and flow patterns; extent of dam development has not caused an obvious loss of riffle habitats; range of sediment types present and not always anaerobic.	Fair habitat structure and flow patterns; many small dams may be present in the catchment; anaerobic fine sediments usually present, except for coarse sandy sediments or when large algal growths oxygenate the sediments.	Poor habitat structure and flow patterns; may have many dams present in the catchment; anaerobic fine sediments usually present except when large algal growths are present and aerate the sediments.	Severe modifications to physical habitat and flow patterns; may have many dams present in the catchment; generally cleared agricultural or urban sites; anaerobic fine sediments often dominate.

Table 3 List of biota expected to occur for each rating in the Flinders Ranges in autumn and spring 2017

Note that streams in an Excellent condition probably no longer occur in the region and would be expected to support some sensitive and rare species, similar to sites in Very Good condition, but have no introduced species present. Similarly, streams in Very Poor condition would not be expected to occur due to the absence of large cropping or irrigated agricultural disturbance or urban centres; although may occur if a major contaminant spill occurred from a tailings dam from a mine or accident involving a tanker. Very Poor sites would be expected to only include a few tolerant species and have water quality too poor to support fish.

Rating	Very Good	Good	Fair	Poor
Attribute 1 – Rare and/or regionally endemic	**Acarina** several families may be present in low numbers (including *Limnesiidae, Unionicolidae, Pionidae, Oxidae*); **Mollusca** *Isidorella*; **Crustacea** Melitidae;	**Acarina** several families may be present in low numbers (including *Limnesiidae, Unionicolidae, Pionidae, Oxidae*); **Mollusca** *Isidorella*; **Crustacea** Melitidae	**Acarina** more than one family may be present (including *Limnesiidae, Unionicolidae, Pionidae, Oxidae*); **Mollusca** *Isidorella*; **Crustacea** Melitidae	None present
Attribute 2 – Sensitive, rare or vulnerable specialist taxa with narrow environmental requirements	Wide range of beetles present in low numbers, including some rarely collected species (eg Anacaena (formerly *Paranacaena*), *Necterosoma dispar, Hyphydrus)*; several flow dependent species may be present, sometimes in large numbers (including the beetle *Platynectes,* biting midge *Forcipomyia*, blackfly *Simulium ornatipes*, fly family Dolichopodidae, and caddisfly *Cheumatopsyche*); **Ephemeroptera** *Thraulophlebia inconspicua* (southern region, freshwater streams only), *Offadens congruens*	Wide range of beetles present in low to moderate numbers, including some rarely collected species (eg Anacaena (formerly *Paranacaena*), *Necterosoma dispar, Hyphydrus*); several flow dependent species may be present in generally low to moderate numbers (including the beetle *Platynectes,* biting midge *Forcipomyia*, blackfly *Simulium ornatipes*, fly family Dolichopodidae, and caddisfly *Cheumatopsyche*); **Ephemeroptera** *Thraulophlebia inconspicua* (southern region, freshwater streams only), *Offadens congruens*	Wide range of beetles present, including some rarely collected species (eg Anacaena (formerly *Paranacaena*), *Necterosoma dispar, Hyphydrus*); several flow dependent species may be present (including the beetle *Platynectes,* biting midge *Forcipomyia*, blackfly *Simulium ornatipes*, fly family Dolichopodidae, and caddisfly *Cheumatopsyche*); **Ephemeroptera** *Thraulophlebia inconspicua* (southern region, freshwater streams only)	Saline tolerant beetles with limited distribution in region may be present (eg *Necterosoma penicillatus, Limnoxenus zealandicus*); and at least one flow dependent species may be present in low numbers (eg *Simulium ornatipes*)

Rating	Very Good	Good	Fair	Poor
Attribute 3 – Sensitive, ubiquitous taxa	**Ephemeroptera** *Cloeon* and (often in large numbers), *Tasmanocoenis tillyardi*	**Ephemeroptera** *Cloeon* and *Tasmanocoenis* (indicator permanent, freshwater with salinity <3,000 mg/L)	**Ephemeroptera** *Cloeon* and *Tasmanocoenis* (indicator permanent, freshwater with salinity <3,000 mg/L)	None present (too salty, lacks coarse sediments or too ephemeral)
Attribute 4 – Opportunistic or generalist taxa	**Mollusca** several types of non-operculate molluscs (eg *Ferrissia, Glyptophysa, Bullastra (formerly Austropeplea*) from permanent springs; **Diptera** wide range families present; **Trichoptera** several genera including *Hellyethira*, *Hydroptila*, *Ecnomus* often present at same sites	**Mollusca** several types of non-operculate molluscs (eg *Ferrissia, Glyptophysa, Bullastra (formerly Austropeplea*) from permanent springs; **Diptera** wide range families present; **Trichoptera** several genera including *Hellyethira*, *Hydroptila*, *Ecnomus* often present at same sites	**Mollusca** several types of non-operculate molluscs (eg *Ferrissia, Glyptophysa, Bullastra (formerly Austropeplea*) from permanent springs; **Diptera** few families present often in large numbers; **Trichoptera** *Ecnomus* (often lowland streams)	**Mollusca** none present; **Diptera** Few families present, occasionally in large numbers; **Coleoptera** Few genera typically present, sometimes present in large numbers
Attribute 5 – Tolerant taxa	**Turbellaria; Crustacea** *Austrochiltonia* (few at fresh sites, large numbers at saline sites), *Cherax destructor;* **Coleoptera** *Scirtidae* (often large numbers at upwelling zones), low numbers more saline tolerant beetles at freshwater sites such as *Limnoxenus zealandicus, Laccobius zietzi, Necterosoma penicillatus*; **Hemiptera** often several genera present including *Micronecta, Agraptocorixa, Anisops, Microvelia;* **Diptera** *Stratiomyidae, Tabanidae;*	**Turbellaria; Crustacea** *Austrochiltonia* (few at fresh sites, large numbers at saline sites), *Cherax destructor;* **Coleoptera** Scirtidae (often large numbers at upwelling zones), low numbers more saline tolerant beetles at freshwater sites such as *Limnoxenus zealandicus, Laccobius zietzi, Necterosoma penicillatus*; **Hemiptera** often several genera present including *Micronecta, Agraptocorixa, Anisops, Microvelia;* **Diptera** Stratiomyidae, Tabanidae;	**Turbellaria; Crustacea** *Austrochiltonia* (few at fresh sites, large numbers at saline sites), *Cherax destructor;* **Coleoptera** Scirtidae (often large numbers at upwelling zones), low numbers more saline tolerant beetles at freshwater sites such as *Limnoxenus zealandicus, Laccobius zietzi, Necterosoma penicillatus,* **Hemiptera** *Micronecta, Agraptocorixa, Anisops;* **Diptera** Stratiomyidae, Tabanidae, Culicidae *Anopheles;* Ceratopogonidae	**Turbellaria; Mites** Arrenuridae and Unionicolidae (Koenikea);**Crustacea** *Austrochiltonia* (few at fresh sites, large numbers at saline sites), *Cherax destructor;* **Coleoptera** *Limnoxenus zealandicus, Laccobius zietzi, Necterosoma penicillatus,* **Hemiptera** *Micronecta,Agraptocorixa, Anisops;* **Diptera** Stratiomyidae; *Ephydridae* (saline waters), Culicidae *Anopheles;* Ceratopogonidae (large numbers at saline sites with large algal

Rating	Very Good	Good	Fair	Poor
	Culicidae *Anopheles;* Ceratopogonidae (eg *Dasyhelea*); Chironomidae (*Procladius, Paramerina, Cricotopus, Tanytarsus, Chironomus*); **Odonata** *Hemianax papuensis, Diplacodes, Orthetrum,, Hemicordulia tau;* **Trichoptera** *Triplectides australis*	Culicidae *Anopheles;* Ceratopogonidae (eg *Dasyhelea*); Chironomidae (*Procladius, Paramerina, Cricotopus, Tanytarsus, Chironomus*); **Odonata** *Hemianax papuensis, Diplacodes, Orthetrum, Hemicordulia tau;* **Trichoptera** *Triplectides australis*	(large numbers at saline sites with large algal growths); Chironomidae (*Procladius, Paramerina, Cricotopus, Tanytarsus Chironomus*); **Odonata** *Hemianax papuensis, Diplacodes, Orthetrum, Hemicordulia tau;* **Trichoptera** *Triplectides australis*	growths); Chironomidae (*Procladius, Tanytarsus, Chironomus*); **Odonata** *Hemianax papuensis, Hemicordulia tau;* **Trichoptera** *Triplectides australis*
Attribute 6 – Non-endemic or introduced taxa	**Fish** None present	**Fish** Gambusia (low numbers). Note also that the yabby may not naturally occur in the region but has been included in the table above as a tolerant taxon.	**Fish** Gambusia (possibly many). Note also that the yabby may not naturally occur in the region but has been included in the table above as a tolerant taxon.	**Fish** Gambusia (possibly many. Note also that the yabby may not naturally occur in the region but has been included in the table above as a tolerant taxon.

Table 4 Condition ratings given by each panel member and final overall rating for selected sites assessed from the Flinders Ranges during 2017 (part published table only included)

Note: Site codes indicate the year sampled. NRM region followed by the site number for that year sampled. Refer to the EPA website for the site map coordinates and the aquatic ecosystem condition regional reports.

[1] denotes the habitats at each site (eg dry sites, or if edge (E) or both edge and riffle (ER) aquatic habitats were present; results for each autumn and spring sampling period were separated by comma, so E, ER means edge was sampled in autumn and both edge and riffle were sampled in spring). NS indicates not sampled in spring for Lake Eyre sites.

Site code	Site name	Habitats[1]	Very Good	Good	Fair	Poor	Very Poor	Final Rating
2017.SAAL01	Italowie Creek, Italowie Gap	E, E	–	1	2	–	–	Fair
2017.SAAL02	Artimore Creek, Nildottie Spring	E, E	–	2	1	–	–	Good
2017.SAAL03	Mount Chambers Creek, Mt Chambers Gorge	E, E	–	–	3	–	–	Fair
2017.SAAL04	Wilpena Creek, Wilpena Pound	Dry, Dry	–	3	–	–	–	Good
2017.SAAL05	Paralana Creek, Paralana Hot Springs	ER, ER	–	2	1	–	–	Good
2017.SAAL06	Balcanoona Creek, Weetootla Campground	Dry, Dry	1	2	–	–	–	Good
2017.SAAL07	Baratta Creek, Baratta Springs	E, E	–	–	–	3	–	Poor
2017.SAAL08	Reedy Creek, Reedy Springs	E, E	–	2	1	–	–	Good
2017.SAAL09	Eregunda Creek, Eregunda Spring	ER, ER	1	2	–	–	–	Good
2017.SAAL10	Wirrealpa Creek, Wirrealpa Spring	E, E	–	–	3	–	–	Fair