25

Testing Readily Available Catchment-Scale Indicators as Measures of Catchment Salinity Status

**Joe Walker,[*] Trevor I. Dowling,[*] Bruce K. Jones,[†]
D. Peter Richardson,[*] Kurt H. Riitters[‡] and
James D. Wickham[§]**

Abstract

This study compares a biophysical index of catchment salinity status based on readily available indicators with field measures of stream salinity. It also looks at the time required to compile a data set from readily available data, and whether meaningful results can be obtained from averaged data for third-order catchments. The catchments studied form the entire Upper Murrumbidgee catchment (approximately 12,000 km^2).

The study outlines a systematic approach to selecting relevant, appropriate and readily available indicators. The indicators selected were per cent forest cover, forested areas greater than 50 ha, road density per unit area, per cent agriculture on slopes greater than 5%, number of roads crossing streams/rivers per unit area and the hypsometric integral per catchment. The indicators were compiled and collated in 10 days. The field data comprised stream salt concentration, salt load and two measures of macroinvertebrate group richness—the number of families of macroinvertebrates and the number of families observed compared to the number expected (O/E). The field work required nine months to complete. The biophysical and field indexes were calculated using a simple additive model. The data were placed in three classes using threshold values equivalent to best, intermediate and worst, weighted as 3, 2 and 1 respectively.

Significant relationships were detected between stream salinity and the biophysical index, and between the biophysical and field indexes. A lesser but significant relationship was detected between O/E biota and the biophysical index. These relationships suggest that the readily available data ranked the salinity status of the catchment in a credible way. We suggest that coarse-scale data are grossly undervalued in developing comparative scenarios; indicators carefully selected from readily available data can be used to quickly derive big picture scenarios.

---

[*] CSIRO Land and Water, PO Box 1666, Canberra, ACT 2601, Australia. Email: joe.walker@csiro.au

[†] Environmental Sciences Division, US Environmental Protection Agency, EMSL, Las Vegas, Nevada, United States.

[‡] Biological Resources Division, US Geological Survey, Knoxville, Tennessee, United States.

[§] Environmental Research Center, Tennessee Valley Authority, Historic Forestry Building, Norris, Tennessee, United States.

Walker, J., Dowling, T.I., Jones, B.K., Richardson, D.P., Riitters, K.H. and Wickham, J.D. 2002. Testing readily available catchment-scale indicators as measures of catchment salinity status. In: McVicar, T.R., Li Rui, Walker, J., Fitzpatrick, R.W. and Liu Changming (eds), *Regional Water and Soil Assessment for Managing Sustainable Agriculture in China and Australia*, ACIAR Monograph No. 84, 333–341.

本文对比了反映流域盐化状况的生物物理指标和反映河流盐分状况的野外量测指标，前者基于从现有资料中选择出来的环境指标，后者由野外测量得到。也讨论了从现有资料中收集整理出一套指标数据所用的时间，以及平均数据能否得到对第三级流域有用的结果。此项研究覆盖了整个默如比基流域的上游地区（约一万两千平方公里）。

作者概述了从现有资料中选择相关、适当的诊断指标的一个系统化的方法。选择的指标有森林覆盖率，面积大于 50 公顷的林地，单位面积的道路密度，坡度大于 5％的农地比例，单位面积内跨越河流的道路数量，以及每个流域的高程积分。健康诊断指标数据在十天内完成编辑汇总。野外数据包括河流盐分浓度，排盐量和反映大型无脊椎动物群丰度的两个值－－大型无脊椎动物门数及其调察值与预期值的（O/E）的比值。野外作业需九个月完成。生物物理指标和野外量测指标由简单的加法模型计算得出。数据被分为三个等级，其阈值分别相当于好、中、差，权重分别是 3、2、1。

研究发现河流盐分和生物物理指标之间以及生物物理指标与野外量测指标之间有着明显关联。O/E 和生物物理指标间的关联比它们稍弱但仍很明显。这些联系表明简单易得的诊断指标对流域盐分状况的反映可信度很高。我们认为写意式粗线条数据的价值总的来说被低估，在作对比项目中，采用认真挑选的诊断指标，能够快速反映总体轮廓特征。

THE PRIMARY purpose of this study was to investigate the credibility of a stream salinity index based on a small set of easily obtained landscape indicators, by comparing the index with independent measures of stream salinity. The study was also designed to look at the time needed to compile a data set from readily available data, and whether meaningful results could be obtained from averaged data for third-order catchments.

Why use a set of landscape metrics to rate relative salinity risk across a group of catchments when the measurement of salt concentrations in streams is relatively simple? The answer is that there is a major dilemma with salt measurements from streams. The problem is illustrated by Figure 1, in which stream salinity — electrical conductivity (EC) in microSiemens per cm — is plotted against sample time. Figure 1 shows that EC is extremely variable and is related to stream flows: high flows tend to have low salt concentrations and vice versa. The range in salt concentrations can be important; for example, for stream biota and for livestock drinking the water. Given that most streams lack sample points, establishing catchment stream salinity status would require regular sampling over years or even decades.

An alternative measure of salinity risk is salt loads in streams (concentration × volume). In Australian streams, water volumes can vary quickly following rainfall, often in a timespan of hours; stream volume is therefore much more difficult to measure than EC. Sampling across a region can take several days, so it is difficult to sample similar parts of the stream hydrograph (plot of volume against time).

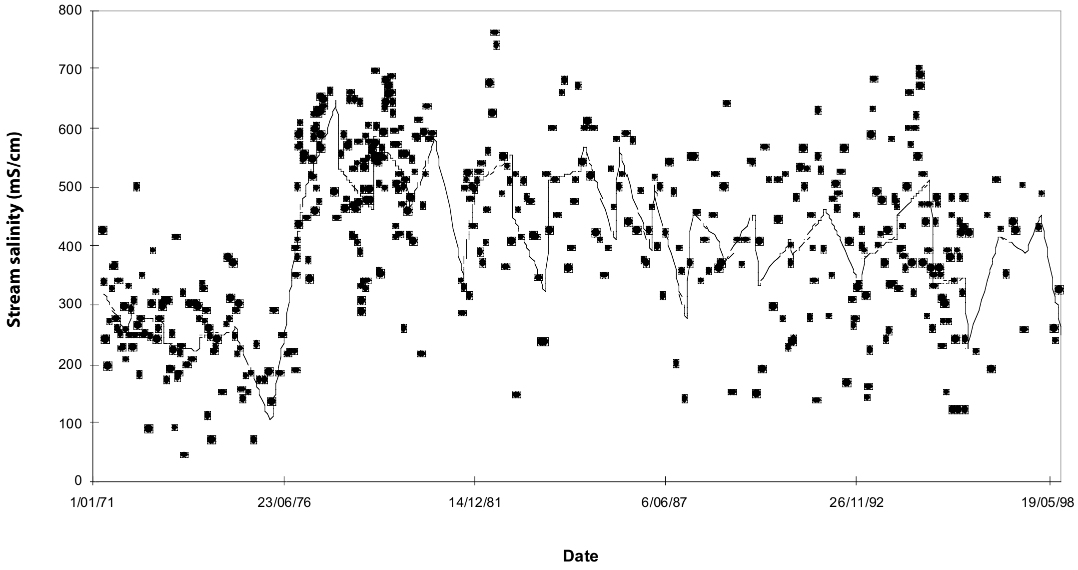

Figure 1. Stream salinity (electrical conductivity, EC) plotted with time for a stream in the Gininderra catchment, Australian Capital Territory (data from Environment ACT).

Accurate measuring of stream EC and volume requires permanent sampling stations and frequent (at least every hour) sampling. Such stations occur primarily on research sites or at the outlets of very large catchments, providing sparse but high-quality data. Dividing a large catchment into contributions from subcatchments can be a problem in the absence of sampling sites in the subcatchments.

We believe that stream salinity status can be assessed with appropriate landscape indicators. In this way, sparse, high-quality data can be complemented by poorer-quality, dense sampling. If the measures selected are the main drivers of the systems, the values obtained can act as benchmarks for further monitoring.

Study Area, Data Collection and Indicators

Figure 2 of the Overview shows the location of the Upper Murrumbidgee catchment. The catchment has a total area of approximately 12,000 km^2 and includes the national capital, Canberra (population 300,000), and the rural centres of Yass and Cooma, each with a population of less than 10,000. Land uses include cropping, extensive livestock grazing, forestry, viticulture, water catchments for the supply of town drinking water, national parks and many small hobby farms. Many areas have been cleared of native forest and woodland vegetation, and this contrasts with other areas that are in pristine condition. Issues identified by local Landcare groups and the Upper Murrumbidgee Catchment Committee include weeds, feral animals, waterlogging, salinity, stream turbidity, soil erosion and water quality.

Walker et al. (2001) and Jones et al. (1997) have suggested a series of steps in developing an indicator approach to resource assessment. These are:

- first identify *societal values*;
- then identify the *specific issue* to examine;
- frame an *assessment question* to address the issue; and
- select *indicators* that address the assessment question.

In this study of the Upper Murrumbidgee catchment, the societal value was good-quality water; the issue was the risk of increasing stream salinity; and the assessment question was 'What is the relative salinity status of catchments in the Upper Murrumbidgee?'

In order to gain an indication of how long it would take to complete a national assessment, a time limit for the study was set at 10 days. Another aim of the study was to determine whether a catchment size of about 500 km^2 could be used to assess catchment condition. The size is typical of catchments used by Landcare groups and as management units for regional planning and management. At an Australia-wide scale, catchments approximately 500–1000 km^2 in area are often third-order catchments and can be explicitly defined from appropriate digital elevation models (DEMs).

The strategy adopted to address the assessment question was as follows:

- identify and collate readily available spatial environmental attributes for the region;
- select indicators from the available attributes according to the criteria (reliability, interpretability, data availability, known thresholds and links to biophysical processes);
- use a simple additive model to calculate an index of salinity status for each catchment (a relative ranking from best to worst (good to bad)); and
- collect independent data on stream salinity and examine the relationship with the catchment condition values (the expectation is that a relationship should exist).

Figure 2 shows the subcatchments used in the study. The Upper Murrumbidgee region was divided into 13 third-order stream catchments defined by the New South Wales Department of Land and Water Conservation from previous and current gauging stations. Catchment No. 8 was larger than the others and subdivision would be desirable. However, only 13 catchments were gauged.

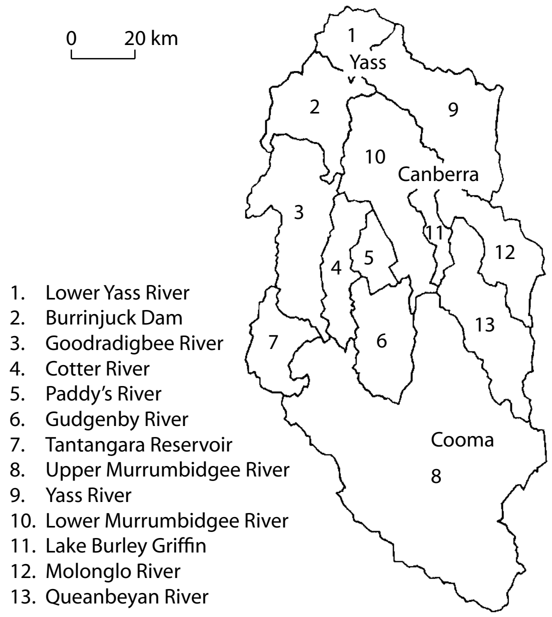

Figure 2. Subcatchments in the Upper Murrumbidgee Region of New South Wales.

Indicators of Catchment Condition

The processes driving salinisation in this region are well understood; they include urban development, tree removal for agriculture, destruction of the riparian buffer and shallow, salty groundwaters. We selected indicators that were linked with these processes and were readily available. The data sources were Thematic mapper satellite imagery,[1] a DEM at 250 m resolution (AUSLIG 1994), and cadastral and land-use information (AUSLIG 1996). The imagery enabled us to identify the major vegetation/land-use types — treed areas (woodland and forest with a projected cover of more than 20%), improved pastures, cropping areas and urban areas. The DEM allowed slope classes and catchment areas to be derived. From the DEM data we calculated two landscape indexes — catchment area and a hypsometric integral. Strahler (1952) defined a hypsometric integral as an area–altitude curve that relates horizontal cross-sectional area of

---

[1] Provided by Dr Tim McVicar and Lingtao Li, CSIRO Land and Water. See Chapter 16 for specifications of Landsat Thematic mapper.

a drainage basin to relative elevation about the basin mouth. The measure was considered to be related to several catchment processes, including hydrological regime, soil erosion, landscape age and sedimentation. It has seldom been applied or used to interpret catchment processes.

Six indicators collected were used in the analysis. Indicators used were per cent forest cover, per cent forested areas of more than 50 ha, road density per unit area, per cent agriculture on steep slopes (slopes of more than 5%), number of roads crossing streams per unit area and the hypsometric integral. Table 1 shows values for the biophysical indicators.

Classification

The individual indicator values were placed into three classes (thresholds), representing poor, medium and good (red, yellow and green), as illustrated in the example shown in Table 2. For four of the six indicators, the range in values was simply divided into three equal parts. For per cent forest cover, evidence from other studies suggested that classes at < 20%, 20–60% and > 60% were correlated with stream salinity (high to low). The three classes for the hypsometric integral were determined as equal areas under the frequency/value curve obtained from a more extensive study in the region. This classification gave approximately equal numbers of catchments in each class for each indicator (more by chance than design). Maps of classes for individual indicators were drawn using individual indicator values but are not presented here.

Class weightings

Weightings can be carried out in several different ways; similarly, the means to recognise class boundaries and to develop an index can have several variants. Weightings were applied to each of the classes as 1, 2 or 3 (poor, medium or good) and summed for each catchment to give an aggregated

Table 1. Biophysical attributes (indicators) for the catchments.

Catchment number	Road density per unit area	% Forest cover	% Forested > 50 ha	Roads crossing streams	% Agriculture on steep slopes	Hypsometric integral	Biophysical index
1	0.0165	2.99	0.00	0.3181	38.07	0.3787	7
2	0.0136	21.51	1.53	0.1443	46.64	0.2393	9
3	0.0137	72.41	32.20	0.1890	23.46	0.3995	14
4	0.0174	81.75	46.16	0.2695	16.05	0.4312	14
5	0.0169	54.79	17.68	0.1793	37.18	0.3836	12
6	0.0100	61.55	20.58	0.1780	33.41	0.4495	16
7	0.0108	60.99	8.12	0.2059	21.57	0.2916	12
8	0.0156	46.15	14.26	0.1449	28.81	0.3200	12
9	0.0152	13.63	0.17	0.0442	37.13	0.3578	8
10	0.0210	14.91	0.39	0.0598	46.02	0.3028	8
11	0.0282	17.89	0.26	0.0514	34.87	0.2195	9
12	0.0157	35.35	7.45	0.1130	27.96	0.3342	11
13	0.0144	48.57	15.04	0.1618	34.47	0.3853	13

value for its condition, as illustrated in Table 2. Thus, values for catchment biophysical condition ranged from 6 (all indicators poor) to 18 (all indicators good). These catchment ratings were then compared with independent field measures of stream salinity.

Table 1 shows the biophysical index values for the catchments using these threshold values and weightings.

Field Sampling for Stream Salinity and the Biotic Response

We selected four independent measures (termed field indicators) to reflect changes in stream salinity:

- salt concentration (measured as EC at base flow/ discharge);
- salt load (salt concentration × stream base flow); and
- two measures of macroinvertebrate group richness (number of families of macroinvertebrates, and observed over expected number of families).

The measures were for an autumn sample and were taken at the exits of the 13 catchments during a period of base flow some 10 days after a rainfall event. The assessment team collected the data for EC. The Co-operative Research Centre for Freshwater Ecology (University of Canberra) and Environment ACT supplied the data for macroinvertebrates. These data are part of a national study that defined expected values and determined methods for sampling and analysis. One field site was omitted from the analyses (site 2 was sampled at the outlet rather than the inlet of Lake Burley Griffin), because the lake acted as a salt buffer.

The field sampling had to be deferred several times because of variable stream base flows across the catchments, and the need to coincide with the macroinvertebrate sampling. Sampling for EC required two field days, so we had to wait for the right conditions. Table 3 gives the values for the field measures and the field index.

Table 2. Classification of indicators using threshold values. Green indicates good; yellow indicates medium; and red indicates poor. Classes are weighted 1, 2 and 3, respectively (good to poor) and the weightings added to give an index score. The minimum score is 6 (all poor); the maximum is 18 (all good). Three examples are shown to introduce the working.

	Threshold values for the 13 site analysis						
Weighting	Forest cover (%)	% Forested areas > 50 ha	Road density per unit area	% Agriculture on steep slopes	No. of roads crossing streams per unit area	Hypso-metric integral	
1 (poor) (red)	< 20	< 5	> 0.015	> 36.0	> 0.2	< 0.31	
2 (medium) (yellow)	20–60	5–10	0.015–0.010	22.0–36.0	0.1–0.2	0.31–0.4	
3 (good) (green)	> 60	> 10	< 0.010	< 22.0	< 0.1	> 0.4	
Catchment no.							Field index
1	2.9	0.00	0.0165	38.1	0.318	0.3787	7
2	21.5	1.5	0.0136	46.6	0.146	0.2393	9
3	72.4	32.2	0.0137	23.5	0.189	0.3995	14

Relationships Between Catchment Condition and Field Measures

The four field data sets and the field index were plotted against the catchment biophysical index. Figure 3 shows the plots that had a significant linear relationship (note that some points are plotted on top of each other, giving apparently different numbers of catchments). The relationship between stream salinity (measured as EC) and the biophysical index (Fig. 3a) was negative and the correlation strong ($r^2 = 0.75$, $P < 0.001$). This suggests that the index is predicting the salinity status of the streams very well.

The relationship between the biophysical index (based on indicators) and the field index (which includes biological and stream salt measures) (Fig. 3b) was likewise strong and positive ($r^2 = 0.74$, $P < 0.001$). The relationship between the macroinvertebrate data (observed number of macroinvertebrate families over expected number) and the biophysical index (Fig. 3c) was positive but weak ($r^2 = 0.34$ $P < 0.05$). This suggests that at the scale of catchments used in the study (500–1000 km^2), the influence of landscapes and changes in land use is reflected in the stream fauna. Although weak, this relationship is encouraging, given the limited nature of the field data and the potential for large variability. The relationship between salt load and the biophysical index (not shown) was very weak ($r^2 = 0.04$). An examination of the biophysical data set suggested that the measure dominating the results is per cent tree cover remaining in the catchment.

Discussion and Conclusion

This study set out to compare readily available landscape biophysical data, which can be collected quickly, with stream measurements, which take much longer to collect and also require specialist

Table 3. Field measurements of salinity and biota in the catchments.

Catchment Number	Conductivity (EC)	Salt load (concentration × flow)	Macro-invertebrates (observed mean)	Macro-invertebrates O/E	Field index
1	974	1.412	8.50	0.86	7
2	406	0.128	2.00	0.21	7
3	102	2.239	14.00	1.11	10
4	64	0.077	10.50	0.83	11
5	99	0.072	12.20	1.08	12
6	140	0.057	11.20	0.97	12
7	30	0.777	13.00	0.89	11
8	494	0.401	11.00	0.97	11
9	1081	0.954	8.00	0.79	6
10	970	0.085	5.15	0.57	6
11	456	0.133	5.33	0.55	7
12	505	0.504	8.20	0.88	9
13	314	0.412	7.80	0.78	9

O/E = number of families of macroinvertebrates observed compared to the number expected expertise. The strong correlation between the biophysical landscape data and the field data suggests that, at least for the area examined, the index performed very well.

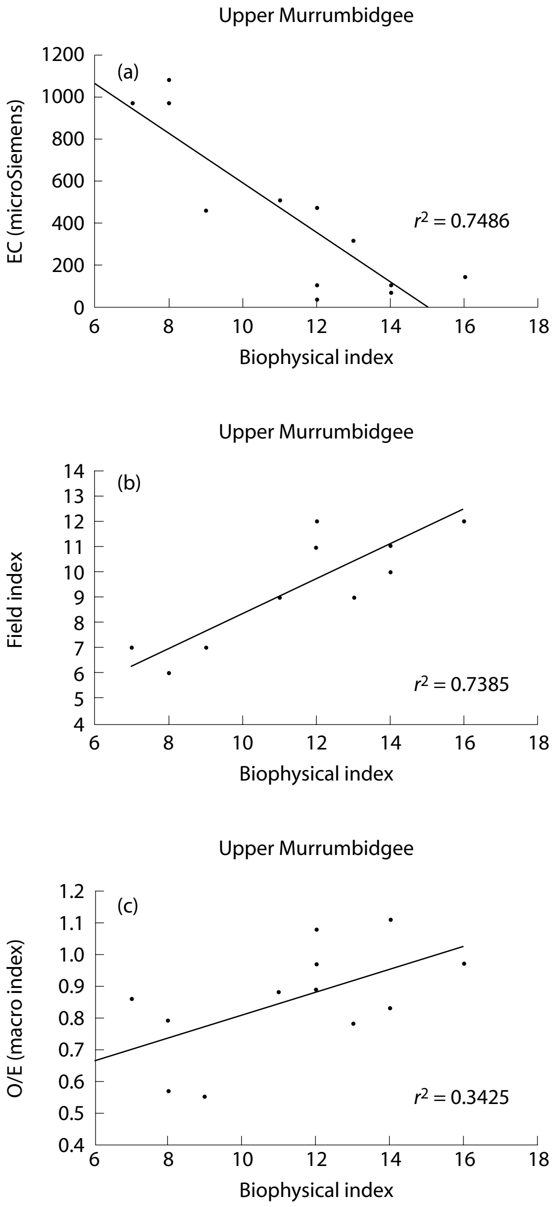

Figure 3. Relationships between catchment condition and stream measurements: (a) plot of stream salinity versus the catchment condition biophysical index; (b) plot of the biophysical versus field catchment condition indexes; and (c) plot of observed/expected macroinvertebrate groups versus the biophysical index of catchment condition.

The mechanisms controlling salinity in the study area were reasonably well known and the question arises as to whether the same indicators can be used in other areas to rate salinity status. Sufficient research has been carried out across Australia to suggest that different mechanisms are at work in different regions (e.g. seasonality of rainfall, magnitude and mobility of salt stores and different kinds of groundwater flow systems contributing to dryland salinity). Recent groundwater mapping as part of the National Land and Water Resources Audit (Coram et al. 2000) shows the areas with local, intermediate and regional groundwater flow systems. Inspection of the maps suggests that the indicator set could apply to the southeast temperate areas of Australia on the western side of the Great Dividing Range, mapped as local or intermediate groundwater flow systems.

The catchment size used approximated third-order catchments, with the majority ranging in size from 500 to 1000 km^2. Subsequent studies over smaller and larger areas suggest that size does influence the results, particularly threshold values, and the indicators that are appropriate (Walker et al. 2001). There could be many different reasons for this effect, but the most obvious with respect to stream salinity are that:

- as size increases, varying inputs of high-quality versus salty water along the length of the river will affect the relationships, and
- at smaller scales, the impacts of good management practices can reduce salt inputs from the land (e.g. repairs to the riparian zone can reduce overland flows).

Data for these parameters are generally not available at the broader scales. Therefore, it is advisable to use sizes of around 500 km^2. Nevertheless, the indicator approach described can be useful as context information at the more detailed scale, and detailed data can be added when available.

The collation of the data sets was carried out within a week, suggesting that application at a national level is possible within a realistic timeframe. Regional differences are important in such an exercise, and it would be advisable to identify the local mechanisms controlling salinity inputs.

Because the study was confined to 13 catchments it has statistical limitations. The next stage, before a national study, involved collecting data from 169 subcatchments in the Upper Murrumbidgee and more intensive field sampling. Some results of this work are reported in Chapter 26.

The results raise an interesting question about the use of coarse-scale data as opposed to detailed measurements to carry out 'big-picture' assessments. It may well be that detailed measurements will not perform any better, and past experience suggests that spatial density is a major consideration. Perhaps continental-scale data have been undervalued and a top-down approach will suffice for most applications relevant to planning or policy development.

References

AUSLIG (Australian Land Information Group) 1994. Topo 250k Series 1, 1:250,000 Digital Topographic map data of Australia. AUSLIG, Canberra (digital data).

AUSLIG 1996. Geodata 9 second DEM, Total Relief in 9 seconds, A national digital elevation model of Australia with a grid spacing of 9 seconds in latitude and longitude. AUSLIG, Canberra (digital data).

Jones, K.B., Ritters, K.H., Wickham, J.D., Tankersley Jr, R.D., O'Neill, R.V., Chaloud, D.J., Smith, E.R. and Neale, A.C. 1997. An ecological assessment of the United States mid Atlantic region: a landscape atlas. United States Environmental Protection Agency, EPA/600/R-97/130.

Strahler, A.N. 1952. Hypsometric analysis of erosional topography, Bulletin of the Geological Society of America, 63, 1117–1142.

Walker, J., Veitch, S., Braaten, R., Dowling, T., Guppy, L. and Herron, N. 2001. Catchment Condition in Australia: Final Report to the National Land and Water Resources Audit, November 2001.