Australian Government
National Water Commission

Australian Water Resources 2005

A baseline assessment of water resources for the National Water Initiative

Level 2 Assessment

River and Wetland Health Theme

Assessment of River and Wetland Health: Testing the Framework

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Executive Summary

The National Framework for the Assessment of River and Wetland Health (FARWH) is being developed as part of the Australian Water Resources 2005 project being undertaken by the National Water Commission (the Commission) under the National Water Initiative (NWI).

The FARWH is based on a hierarchical model of river and wetland function, which addresses: environmental components to be represented by a national assessment, reporting scale, reference condition, discussion on selection of indices, methods for integrating and aggregating indices for assessment, sensitivity analysis, range standardisation, and managing missing data. An additional document covering Potential Comparative Indices for the FARWH presents examples of indices used during the 2002 National Land and Water Resources Audit, the Victorian Index of River Condition (ISC), the Tasmanian Conservation of Freshwater Ecosystem Values program (CFEV), and the Murray–Darling Basin Sustainable Rivers Audit.

The FARWH proposes that six key components are appropriate for the assessment of river and wetland health, all of which are considered to represent ecological integrity. These are:

- catchment disturbance
- hydrological change
- water quality
- physical form
- fringing zone
- aquatic biota.

The FARWH describes how to develop and combine indices so that nationally comparable assessments of river and wetland health can be achieved. This is designed to enable states and territories to include data that are already being collected (e.g. AUSRIVAS) and to compare these data between regions. In some cases, such as the Victorian Index of Stream Condition, little change may be needed to report the data in the framework.

To lend confidence to the comparability of different indices, tests were conducted in Victoria and Tasmania comparing the ISC and CFEV assessments with another set of indices selected from the Potential Comparative Indices document. It is not intended to report the second set of indices but to investigate three important aspects. First, the degree of comparability between different kinds of indices that represent the same components of the environment (e.g. measured and modelled data for water quality). Second, the spatial scale at which differences may become acceptable (e.g. reach scale up to Surface Water Management Area scale). Third, if different indices are used, how might that add additional information to the assessment?

To undertake the testing, six Surface Water Management Areas were chosen, three each in Victoria and Tasmania. Generally, the relationships between the alternative set of indices and the ISC indices were strong, but some problematic issues came to light. For example, the ISC does not include a Catchment Disturbance index and the water quality data were so sparse (only eight values) that a comparison could not be made. Given the expense and difficulty of measuring water quality data, a modelling approach (or combination of measured and modelled data) may prove useful. Also, the hydrology data are ranked state-wide for the ISC; however, for national comparisons they need to be unranked. Positively, the alternative index for the fringing zone, which was based on remote-sensed and historical GIS data, correlated reasonably strongly with the measured data from the ISC ($r^2 = 0.53$) and had similar variability. This indicated it may be possible to use such an approach in place of measured data that are expensive and time-consuming to collect.

Relationships between the ISC and alternative indices were strong for aquatic biota ($r^2 = 1$), fringing zone ($r^2 = 0.53$), and hydrology ($r^2 = 0.89$), suggesting that they could be compared between regions with reasonable confidence. In contrast, only physical form and water quality exhibited weak relationships. In the overall assessment using the alternative set of indices, the relationships with the ISC indices were quite strong ($r^2 \approx 0.5$), indicating that alternative indices (or indeed the ISC indices themselves), which may be chosen in other jurisdictions, would still allow reasonable comparisons between regions.

Relationships with the CFEV indices were not as strong ($r^2 \approx 0.45$) as they were for the ISC. However, CFEV does not include water quality or physical form variables that might be suitable for comparison with FARWH. As expected, the inclusion of fish in the Aquatic Biota Index introduced variability that did not occur in the alternative invertebrate-only index used for comparison. The inclusion of fish may work well in meeting Tasmania's needs, but it highlights the importance of selecting biota that are meaningful to the particular jurisdiction being assessed. Also, the CFEV Hydrology Index is emphasises flow diversions rather than changes in regime. Thus, the CFEV Hydrology Index is weighting different aspects of flow compared to the alternative Flow Stress Ranking (FSR), suggesting the two would not be strongly comparable in different jurisdictions. CFEV is intended to be a baseline for the future Tasmanian Index of River Condition (TIRC). It is expected that these current issues would be addressed by the TIRC. Given the strong relationships between the alternative test indices used here and the ISC, the relationships would probably greatly improve if the TIRC adopts indices more closely related to the ISC.

The overall comparisons were generally still acceptable, but at present the Tasmanian CFEV is not as strongly comparable to the ISC as might be expected (relative to the same set of alternative indices). However, it is expected that the future TIRC will be developed along lines even more similar to the ISC, which would improve the comparability between these two sets of indices.

1 Introduction

The National Framework for the Assessment of River and Wetland Health (FARWH) is being developed as part of the 'Australian Water Resources 2005' project being undertaken by the National Water Commission (the Commission) under the National Water Initiative (NWI).

The FARWH is based on a hierarchical model of river and wetland function, which addresses: environmental components to be represented by a national assessment, reporting scale, reference condition, discussion on selection of indices, methods for integrating and aggregating indices for assessment, sensitivity analysis, range standardisation, and managing missing data. An additional document covering Potential Comparative Indices for the FARWH presents examples of indices used during the 2002 National Land and Water Resources Audit, the Victorian Index of River Condition, the Tasmanian Conservation of Freshwater Ecosystem Values program, and the Murray–Darling Basin Sustainable Rivers Audit.

The FARWH proposes that six key components are appropriate for the assessment of river and wetland health, all of which are considered to represent ecological integrity. These are:

- catchment disturbance
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- water quality
- physical form
- fringing zone, and
- aquatic biota.

The FARWH describes how to develop and combine indices so that nationally comparable assessments of river and wetland health can be achieved. This is designed to enable states and territories to include data that are already being collected (e.g. AUSRIVAS) and to compare these data between regions. In some cases, such as the Victorian Index of Stream Condition, little change may be needed to report the data in the framework.

1.1 Testing

The aim of this Framework for the Assessment of River and Wetland Health (FARWH) is to develop an approach that can be used by all Australian states and territories to provide assessments of river and wetland health that are comparable nationally. It is intended to incorporate a range of river and wetland attributes that indicate key ecological processes. Different measures will be used in different jurisdictions; therefore, testing has been undertaken in three catchments in Victoria and three in Tasmania to establish the comparability of alternative indices that might be used in other jurisdictions. The indices used for comparison have been selected from those presented in the Potential Comparative Indices document. It is in no way suggested that these alternative indices should be adopted by Victoria or Tasmania. The tests described here also bring to light the effects of various procedures, such as integration of sub-index scores, on the overall assessments.

1.2 FARWH and ISC/CFEV index comparisons

1.2.1 Matching reaches

In Victoria on-ground measurements are made at reaches defined by ground observations and based on land use and other factors. Some of the indices chosen for comparison to the ISC – such as Catchment Disturbance, Fringing Zone, and Water Quality – are based on remotely sensed and modelled data at reaches defined as noted in the FAWRH document (section 2.4) using a digital elevation model. Thus it was necessary to match the ISC and FARWH reaches before making comparisons. This matching has resulted in some differences in assessment because, in some cases, reaches did not match exactly.

The CFEV program in Tasmania uses river links (sections of river between tributaries) derived from a 25-m digital elevation model. In this case it was a simple matter of using the rules described in the FAWRH document (section 2.4) to amalgamate links and form larger reaches. However, some differences in assessments are also introduced, for two reasons. First, the rule to begin the first reaches was a minimum contributing catchment area of 20 km^2 (50 km^2 was suggested in the FAWRH document, but because of the highly developed river networks in Tasmania this was reduced). This rule meant that many small tributaries, especially in upland areas, were omitted from length calculations, although measures related to their catchment areas still contributed. In some Surface Water Management Areas with many small streams, such as King Island, this could downweight the headwater parts of the Surface Water Management Area. Second, sets of expert rules were used to derive assessments at the link scale, and so the outcome could, after weighting for length of links within a reach, differ slightly from applying the rules to the whole reach.

2 Index of Steam Condition (ISC) compared to alternative indices

The indices included in the Index of Stream Condition closely match the indices representing the main components of the environment recommended in the FARWH. The main variation is that the ISC does not have an index for Catchment Disturbance (Table 1).

Table 1. Comparisons undertaken between possible alternative indices and components of the Victorian Index of Stream Condition (ISC). Note, index names are the variable names used in the analysis.

FARWH Theme	FARWH index	ISC index for comparison
Aquatic biota	AWRABIOTA	ISCBIO
Catchment disturbance	AWRACDI	
Fringing zone	AWRAFRINGE	ISCRIPV
Hydrology	AWRAHYDROLOGY	ISCHYD
Physical form	AWRAPHYS	ISCPHYS
Water quality	AWRAWQ	ISCWQ
Integrated River Health with FARWH water quality and catchment disturbance – ISC total index	AWRADATA_w_WQ_w_CDI	ISC_TOTALCONDITIONINDEX
Alternative 1 – without FARWH Water Quality and Catchment Disturbance – ISC without Water Quality	FARWH RIVER HEALTH (includes ISC ranked HYDROLOGY and WQ but not CDI)	ISC TOTAL CONDITION INDEX
Alternative 2 – without FARWH Water Quality and with Catchment Disturbance	FARWH RIVER HEALTH (includes ISC ranked HYDROLOGY but is without WQ or CDI)	ISC TOTAL CONDITION INDEX
Alternative 3 – with FARWH Water Quality and without Catchment Disturbance – ISC without ranked Hydrology	FARWH RIVER HEALTH (with WQ but not CDI)	ISC DATA USING FARWH AGGREGATION

2.1 Aquatic biota

AUSRIVAS and SIGNAL data were used for both assessments, the only difference being the method of creating the reaches. Thus, the high level of agreement between the two measures is not surprising and it demonstrates that the method of determining the reaches has little effect on the overall Aquatic Biota index (Figure 1).

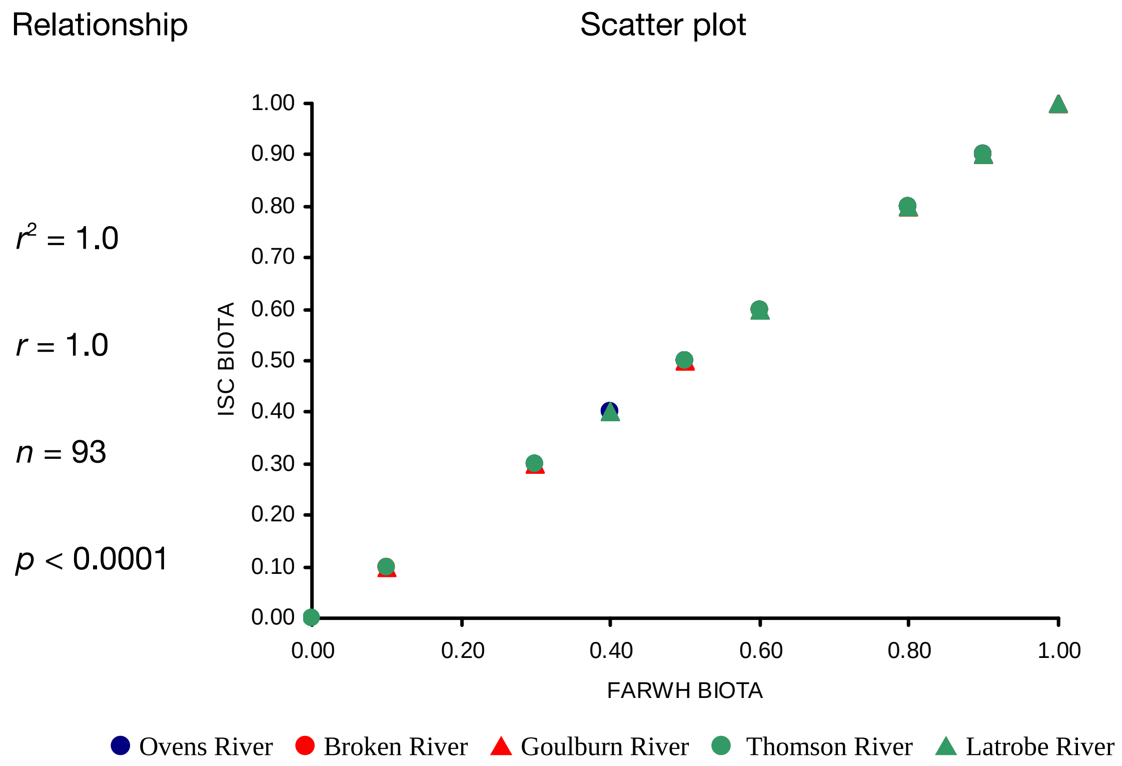


Figure 1 FARWH Aquatic Biota assessment using the ISC data – river links are amalgamated to reaches to match ISC reaches as closely as possible.

2.2 Fringing zone

The correlation between the GIS and remote-sensed data with the ISC measured data for the fringing zone is quite good (Figure 2). This needs to be considered in the light of measurement error for both indices (see Ladson et al. 2006 for ISC error optimisation: 30–40 percent error in riparian vegetation). The strong relationship indicates that the riparian vegetation measure tested here may be a useful alternative in other jurisdictions and still provide an assessment that is comparable to the ISC as used in Victoria. Further, similar trends in the fringing zone measurements for each catchment between the FARWH and ISC (Figure 3) also indicate that the FARWH measurements should be applicable to other areas and comparable to the ISC.

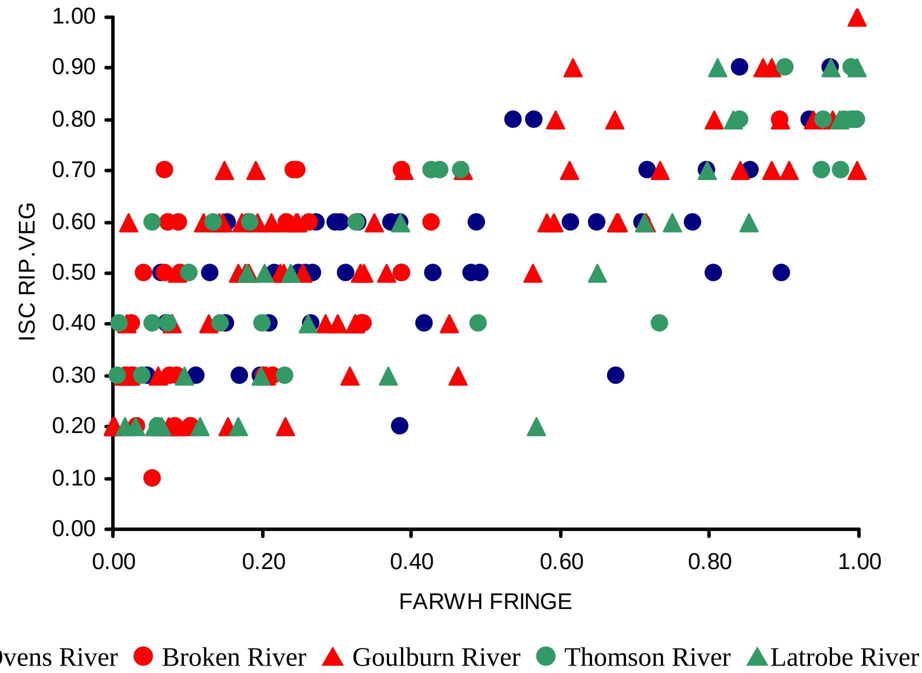
Relationship	Scatter plot
$r^2 = 0.53$ $r = 0.73$ $n = 200$ $p < 0.0001$	

Figure 2. FARWH fringing zone assessment includes an assessment of structural cover based on percentage of each reach with vegetation and measure of change of vegetation post-European settlement using GIS and remote-sensed data. The ISC assessment is based on a range of attributes measured at up to nine transects.

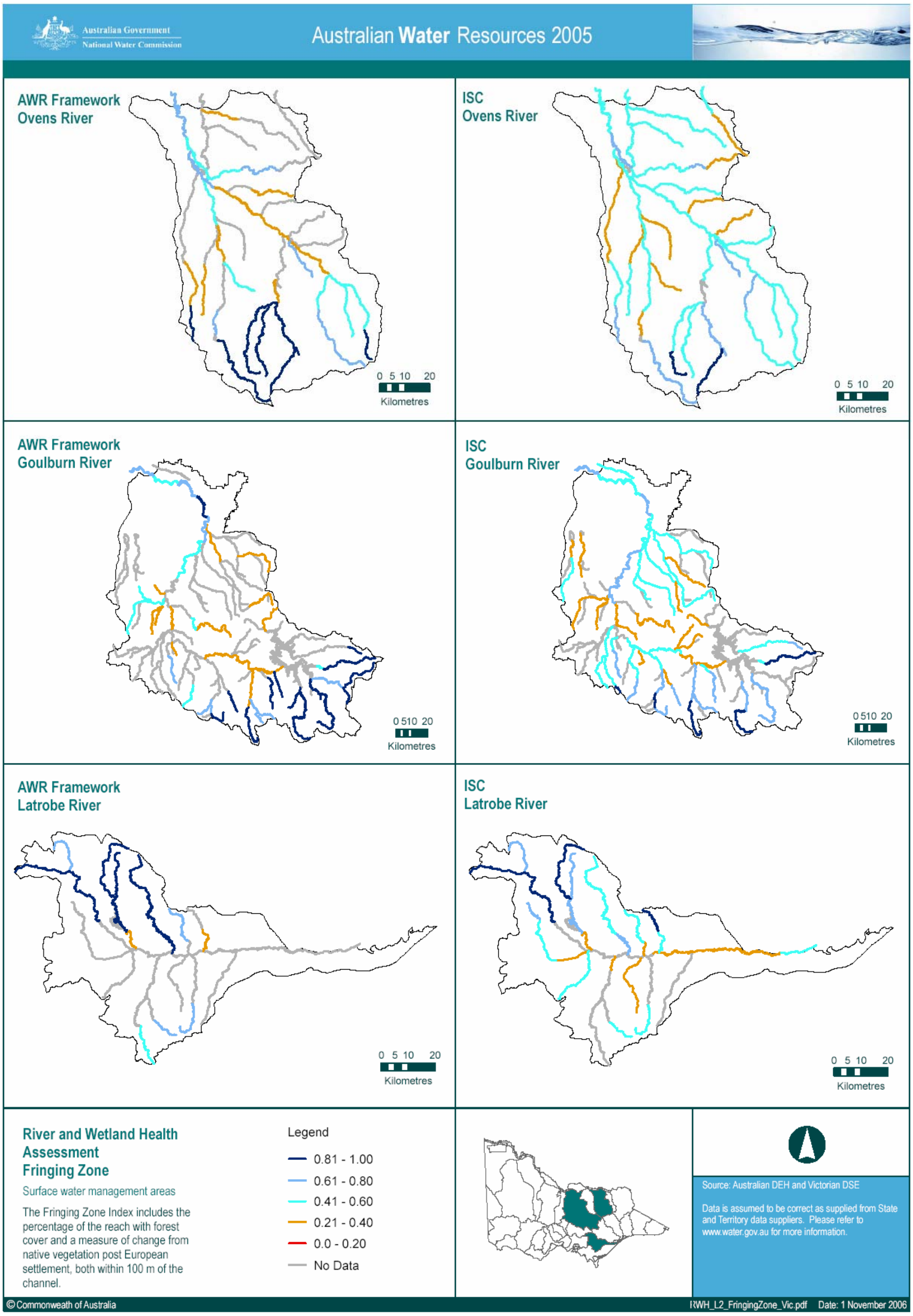


Figure 3 FARWH and ISC assessment of fringing zone for the Ovens, Goulburn, and Latrobe Rivers, Victoria.

2.3 Physical form

The physical form index used for testing against the ISC is based on SedNet modelling of sediment accumulation. Although the relationship is poor in this case (Figure 4), both the ISC and SedNet approaches have been well tested and evaluated in the scientific literature. The differences between the two indices indicate that different components are being assessed by each. By considering what each assesses, the two habitat indices can be considered complementary and a combination of the two indices may provide a more comprehensive assessment than each on their own (as illustrated in Table 2). Therefore, clear objectives as to the nature of assessment will be needed to direct choices.

Relationship | Scatter plot

$r^2 = 0.003$

$r = -0.06$

$n = 203$

$p = 0.41$

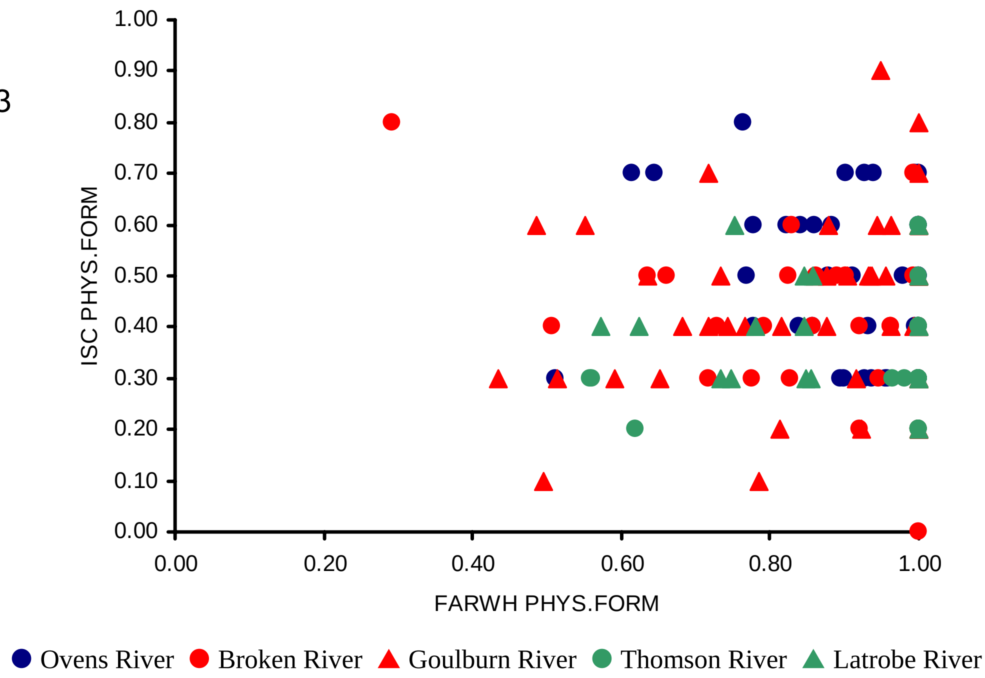


Figure 4 FARWH Physical form assessment includes a measure of sediment aggregation based on the process-based SedNet model. ISC uses several locally assessed features, including sediment aggregation.

2.4 Hydrology

The ISC and FARWH use the same data and the same initial aggregation. However the ISC score is then converted to a ranked score that is relative to scores across the whole state. This has the effect of stretching the best and worst scores to 1 and 0 respectively. For example, as the graph shows, reaches that are rated as 0.5 or 5/10 according to the initial aggregation (AWRAHYDROLOGY using the framework) may score a zero on the ISC score. Statistically speaking, this is not sound because if a new reach was added that scored say 3/10, this would then make the zones that are currently on 4/10 receive a higher ranked score, even though they have not changed condition. Alternatively, imagine an index that described a variable indicating all high scores, where all sites scored between say 8 and 10 (on the ISC scale). Then to force a ranking on these sites would force healthy sites to be rated poor.

The same data are used and therefore the relationship is very strong although strongly skewed (Figure 5). The shift from a 1:1 relationship is the result of the ranking and re-scaling and demonstrates the effect that such procedures may have on outcomes. In this case the ISC will score many reaches much lower than may actually be indicated by the degree of change in their hydrology. This would explain the conclusion in the 2004 ISC assessment that many sites scored more poorly than in 1999 despite there being no obvious cause for a change in condition apart from the new index and its method of calculation.

Relationship

$r^2 = 0.89$

$r = 0.94$

$n = 137$

$p < 0.0001$

Scatter plot

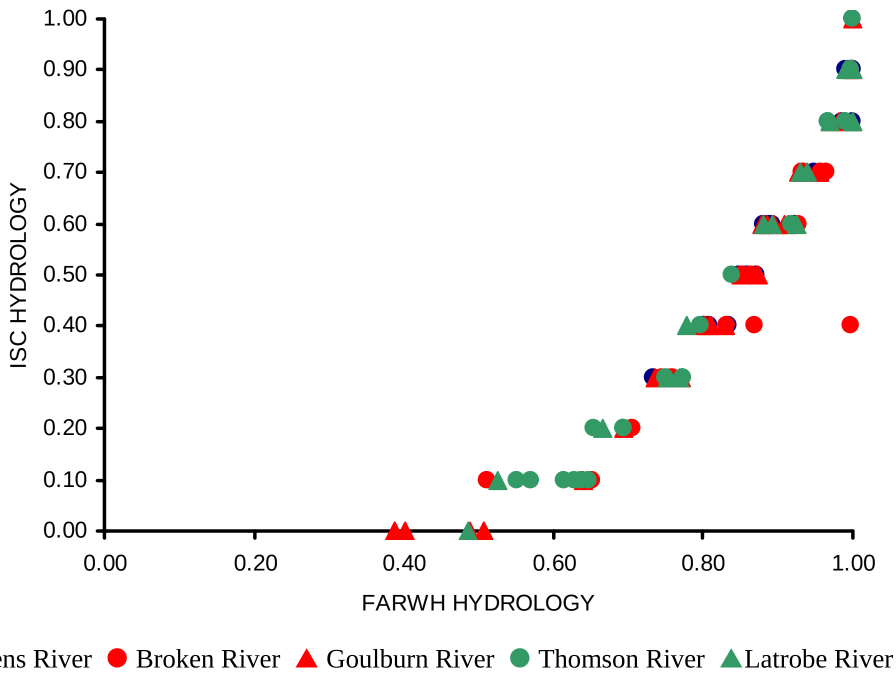


Figure 5 Both FARWH Hydrology assessment and ISC use the FSR hydrology data but the ISC ranks all reaches in the state and scales the data from 0–10 (rescaled 0–1 here).

2.5 Water quality

There were very low numbers of sites with Water Quality scores in the ISC.

The ISC uses spot measurements of water quality while the approach chosen for the FARWH was based on the NLWRA (section 4.6). The collection of chemical data is very expensive and routine measurements are sparse for the three Victorian catchments assessed (only 8 data sets from >200 reaches, Figure 6).

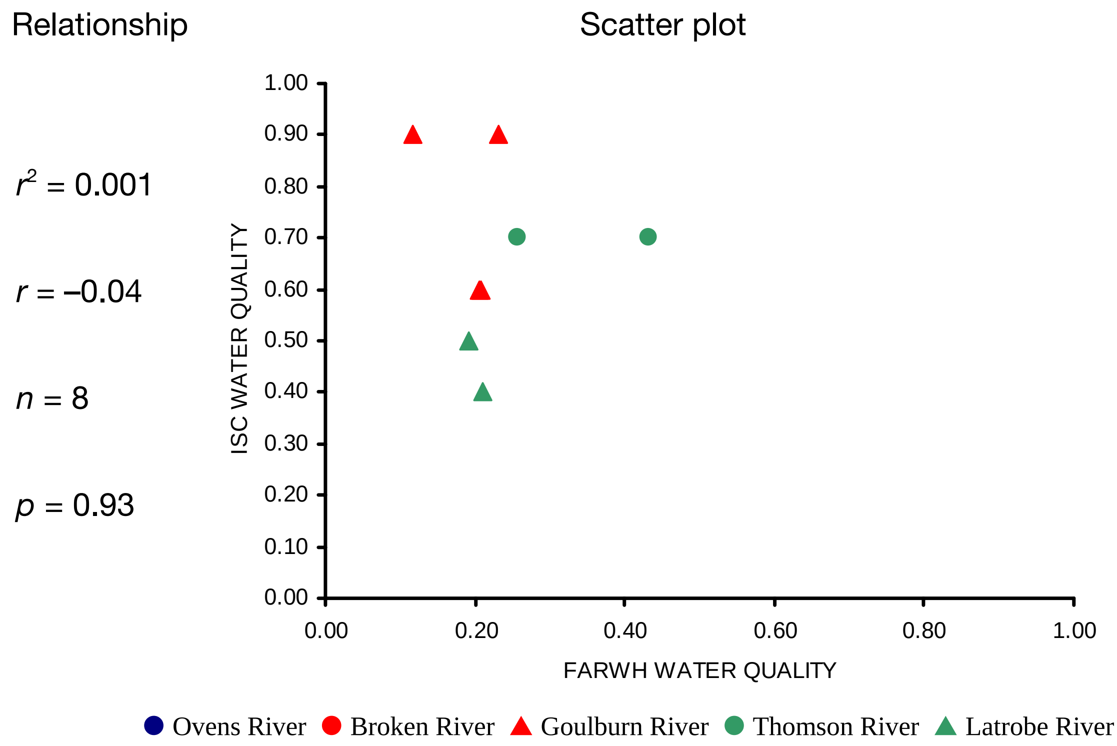


Figure 6 FAWRH Water quality assessments are based on process-based modelled annual loads and ISC indices are based on spot measurements giving concentrations.

While water quality is considered an important component of river and wetland health, if resources limit the collection of useful data, alternative methods such as those based on modelling may prove useful. The following section provides an evaluation of the approaches that may help in making decisions on which approach to adopt.

Options and features of each assessment approach

There are four main alternatives for selecting indices to assess water quality and habitat:

1) Where they are available, existing jurisdictional indices may comply with the Framework provided results are analysed as described below.

2) Assessment using the SedNet/ANNEX-based indices that were applied in NLWRA 1, with an option to update these assessments to capture data and model improvements since NLWRA 1.

3) Combined assessment using existing jurisdictional indices in combination with the NLWRA 1 SedNet/ANNEX-based indices. This approach provides several benefits over (1), as described below.

4) Assessment using other indices that comply with the Framework.

The following sub-sections describe the advantages and disadvantages of the first three alternatives.

Existing jurisdictional indices

Jurisdictional indices of water quality and habitat considered here are those from the Victorian Index of Stream Condition (ISC), which are sparse, and the Tasmanian Conservation of Freshwater Ecosystem Values Framework (CFEV), which are indirect and not really relevant measures of water quality. In both cases, as noted above, water quality programs are very expensive and extensive data were not available.

Advantages

- The water quality indices in at least the ISC assessment are based on concentration data.
- The approach has the advantage that the indices directly represent current and recent conditions and reflect the end result of all factors affecting water quality. Such an approach is important where local issues not accounted for in modelling approaches are affecting condition.
- Available concentration data generally represent ambient low-flow conditions. Thus, these indices can be regarded as measures of ambient condition, which might be impaired by factors such as upstream activities or local livestock access, for example.

Disadvantages

- Water quality measurement programs are expensive and data covering most reaches of interest are sparse.
- Event processes such as erosion and nutrient wash-off can also impair condition by supplying excess levels of sediment and nutrients to a reach. High-flow events are poorly represented in the concentration data as currently used in these assessments.
- The resolution of measurement-based indices is limited by the ability and methods to effectively interpolate condition between measurement points. For example the ISC regionalisation for turbidity has only three bands of condition across Victoria.
- Being based on measurement rather than process modelling, the existing jurisdictional indices do not identify the causes of impaired condition. This is important in setting management priorities to improve condition in the future.

The SedNet-based indices can overcome some of these limitations as described later.

NLWRA 1 SedNet- and ANNEX-based indices

Indices used in NLWRA 1 were based on assessments of sediment and nutrient fluxes made using the SedNet model and associated ANNEX model (Prosser et al. 2001). These models construct sediment and nutrient budgets for river networks that represent the primary sources and sinks within catchments. Sources included are hillslope erosion, gully erosion, and stream bank erosion, as well as dissolved and point sources of nutrients. The model routes material through the river network and the spatial contribution of upstream sources at any point in the river network considers intervening sinks including river bed, floodplains, and reservoirs.

The water quality index assesses changes to sediment and nutrient fluxes against a pre-European reference, as does the habitat index in assessing changes to bed material accumulation. Full description of the index composition is given in the Potential Comparative Indices document, sections 4.5 and 4.6.

Development of the SedNet and ANNEX models subsequent to the NLWRA 1 has improved prediction of spatial patterns in material fluxes. The models are available for general use using software in the Catchment Modelling Toolkit [www.toolkit.net.au/sednet] and current description of the modelling methods is documented in the SedNet User Guide (Wilkinson et al. 2004).

Advantages

- SedNet assesses different aspects of condition from those that can be assessed using direct measurement or field surveys. For assessing water quality, for example, SedNet assesses the sediment and nutrient fluxes carried by each river reach and how they have changed since the pre-European reference condition. Given that fluxes are generally delivered during high-flow events, this focus complements that of indices based on concentration measurements.
- Modelling enables assessment over large regions over which there are limited or no field data with which to directly assess water quality or habitat condition. This benefit is most important in extensively managed areas where data availability is poorest.
- SedNet identifies the upstream processes and spatial sources of sediment causing current condition (as described in the previous section), thus connecting sources to their downstream impacts at the catchment scale. Adding process understanding to condition assessments enables development of priorities for improving condition in the future. The process basis of SedNet is useful when compared to statistical or 'black box' approaches (for details see CRC for Catchment Hydrology, 2005).
- The methods are based upon national and state data sets that have been collected for the purpose of assessing land and water processes at these spatial scales. As a result, the predictions are normally spatially continuous and logically consistent across regional and state boundaries.
- The methods draw heavily upon historic data measuring soil and gully erosion, seasonal presence of vegetative cover, and variability in catchment runoff to account for variation in process rates associated with cycles of drought, land degradation, and climate. This feature is important for separating variations in

condition because of historical management and long-term climate from variations resulting from recent hydrological variability.

- The methods have had limited but spatially distributed evaluation against available independent datasets (Prosser et al*.* 2001; DeRose et al*.* 2003; DeRose et al. 2005a; DeRose et al*.* 2005b; McKergow et al*.* 2005; Wilkinson et al*.* 2005a; Wilkinson et al. 2005b; Cogle et al*.* 2006; Wilkinson et al*.* 2006). Of course, there are limitations to this process, partly because of limitations in data availability. These limitations are briefly described in the following section.
- The collection of methods in SedNet is reproducible and therefore readily updated when improved datasets or new data becomes available.

Disadvantages

- The methods rely on data that is available everywhere or can be reasonably interpolated. At locations where detailed observational data are available the model may differ from these observations, in part because of the use of less precise spatial inputs.
- As the prediction of the SedNet methods are presented as long-term averages it can be difficult to compare its predictions to recent or short-term observations. For example, the model may predict large bank erosion rates because of poor riparian condition, but field observation may indicate that re-vegetation has been undertaken and banks are stabilising. These two assessments are not necessarily contradictory: the prediction of high erosion rates is useful in identifying the importance of protecting vegetation. In the following section some suggestions are made in terms of the interpretation that can be made by combining the SedNet and local assessments.
- SedNet uses climate input data from the past 20–30 years and as a consequence may not reflect very recent climatic conditions or climate change trends. This effect can be accommodated in purpose-designed predictions.
- Local issues affecting condition may not be addressed by the SedNet assessments and are better assessed using available data and field surveys. For example, carp or livestock access can adversely affect ambient water quality while having relatively little effect on sediment fluxes.

Combining NLWRA 1 and existing jurisdictional indices

Combining measurement-based condition assessments with NLWRA 1 SedNet process-based assessments adds value to both indices when considered on their own and ensures that the benefits of both approaches are realised. This approach is also consistent with the recommendations for index improvement made in the NLWRA 1 Assessment of River Condition

(Norris et al. 2001). In particular, the following benefits are realised by combining the assessments:

1) Provides a more comprehensive assessment of conditions and is sensitive to a wider range of factors impairing condition. For water quality, the ISC water quality index is based directly on concentration measurements that represent ambient or low-flow conditions well, while high-flow event conditions are better assessed considering the fluxes used in the NLWRA 1 indices. For habitat, the ISC assessment of habitat has components for longitudinal connectivity, large wood, and bank stability, whereas the NLWRA 1 assessment assesses the accumulation of bed material sediment caused by upstream erosion as well as the riparian zone and river connectivity.

2) Improves the spatial resolution of the assessments. Existing jurisdictional habitat assessments incorporate detailed point data that depend on data availability but can direct attention to local processes, while SedNet assesses processes throughout river networks using more widely available spatial datasets to connect catchment sources with downstream impacts.

3) Broadens the temporal base of the assessments. Jurisdictional indices incorporate recent measurement data to capture recent changes and the NLWRA 1 indices use longer-term data to provide a time-integrated measure less sensitive to short-term hydrological variation.

4) Provides information on both current condition and the processes that cause it, enabling priorities for improving condition to be identified.

Further development of both assessment approaches and the means for their integration will enhance the benefits listed above.

In Tables 1.2–4 we make suggestions as to how jurisdictional assessments such as the ISC may be combined with the NLWRA 1 type assessments, and set out some interpretations for management priorities that the combined approach enables. Of course, these suggestions are preliminary because they have not been systematically evaluated.

Table 2 Suggested method for combining water quality assessments.

		NLWRA 1 water quality index: High (sediment and nutrient fluxes are similar to reference)	NLWRA 1 water quality index: Low (sediment and nutrient fluxes are much higher than reference)
Jurisdictional water quality index	High (good ambient water quality)	**Interpretation**: The catchment is in an undisturbed or near-pristine state **Possible action**: Ensure catchment protection measures are in place to ensure continued high water quality	**Interpretation**: (*Likely*) Sediment is transported in infrequent events that are not reflected in the ambient water quality. (*Possible*) Local effect such as saline groundwater inflow or upstream wetland clarifies water in low flows **Possible action**: Investigate cause and put measures in place that reflect final assessment
Jurisdictional water quality index	Low (poor ambient water quality)	**Interpretation**: Local processes like road crossing, livestock access, or carp infestations result in poor ambient conditions **Possible action**: Investigate local sediment source and put appropriate measures in place	**Suggested interpretation**: A combination of local and upstream catchment processes are contributing to poor water quality **Possible action**: Use SedNet contributor to guide catchment priorities for remediation action

Table 3 Suggested method for combining riparian condition assessments.

		NLWRA 1 riparian condition assessment using spatial data: Minimal tree cover loss	NLWRA 1 riparian condition assessment using spatial data: Considerable tree cover loss
ISC riparian condition index	Index of riparian condition is good	**Suggested interpretation**: Riparian zone in good condition **Possible action**: Ensure protection of the riparian zone remains in place	**Suggested interpretation**: Issue with spatial data: possibly recent revegetation is not captured. **Possible action**: Further investigation
ISC riparian condition index	Index of riparian condition is poor	**Suggested interpretation**: Livestock access beneath intact canopy or woody weed infestation **Possible action**: Local remediation; priority for further investigation and treatment	**Suggested interpretation**: Riparian zone in poor condition **Possible action**: Remediation will improve local riparian condition and local and downstream water quality

Table 4 Suggested method for combining habitat condition assessments.

		NLWRA 1 habitat assessment	
		Habitat index is good	Habitat index is poor
ISC habitat condition index	Habitat index is good	**Suggested interpretation**: Stream habitat in good condition **Possible action**: Ensure protection of local and upstream riparian vegetation	**Suggested interpretation**: Upstream erosion is causing bed material accumulation **Possible action**: Treat upstream erosion
	Habitat index is poor	**Suggested interpretation**: Channel is deficient in large wood **Possible action**: reintroduce large wood to the channel	**Suggested interpretation**: Habitat in poor condition **Possible action**: Identify the limiting processes to help prioritise treatment

2.6 Overall assessment

The relationship between the combined overall indices for the two sets of data is quite strong ($r^2 = 0.5$, Fig 1.7). The relationship is certainly helped by the use of the same or similar data for biota and hydrology. The FARWH score is a little higher than the overall ISC score because of the scaling and weighting applied to the Hydrology data in the ISC. When comparing overall condition using the FARWH and ISC indices, including Water Quality and Catchment Disturbance data, similar trends are observed (Figure 8). Elevated condition scores are generally found in the upper parts of the three catchments for both the FARWH and ISC, with overall scores decreasing in the lower segments of the catchments. This trend suggests that, overall, a set of indices conforming to the FARWH may be applied in catchments in other jurisdictions and still be comparable to the Victorian ISC.

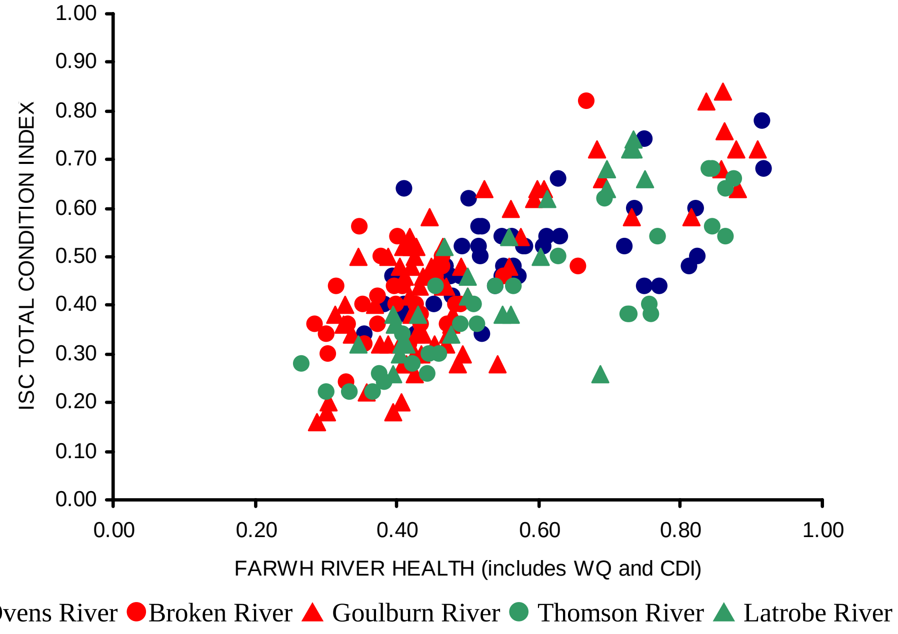
Relationship	Scatter plot
$r^2 = 0.50$ $r = 0.70$ $n = 202$ $p <$ 0.0001	

Figure 7 FARWH Overall index, including Water Quality and Catchment Disturbance, compared with ISC overall index at reach scale. The ISC index does not include Catchment Disturbance or Water Quality.

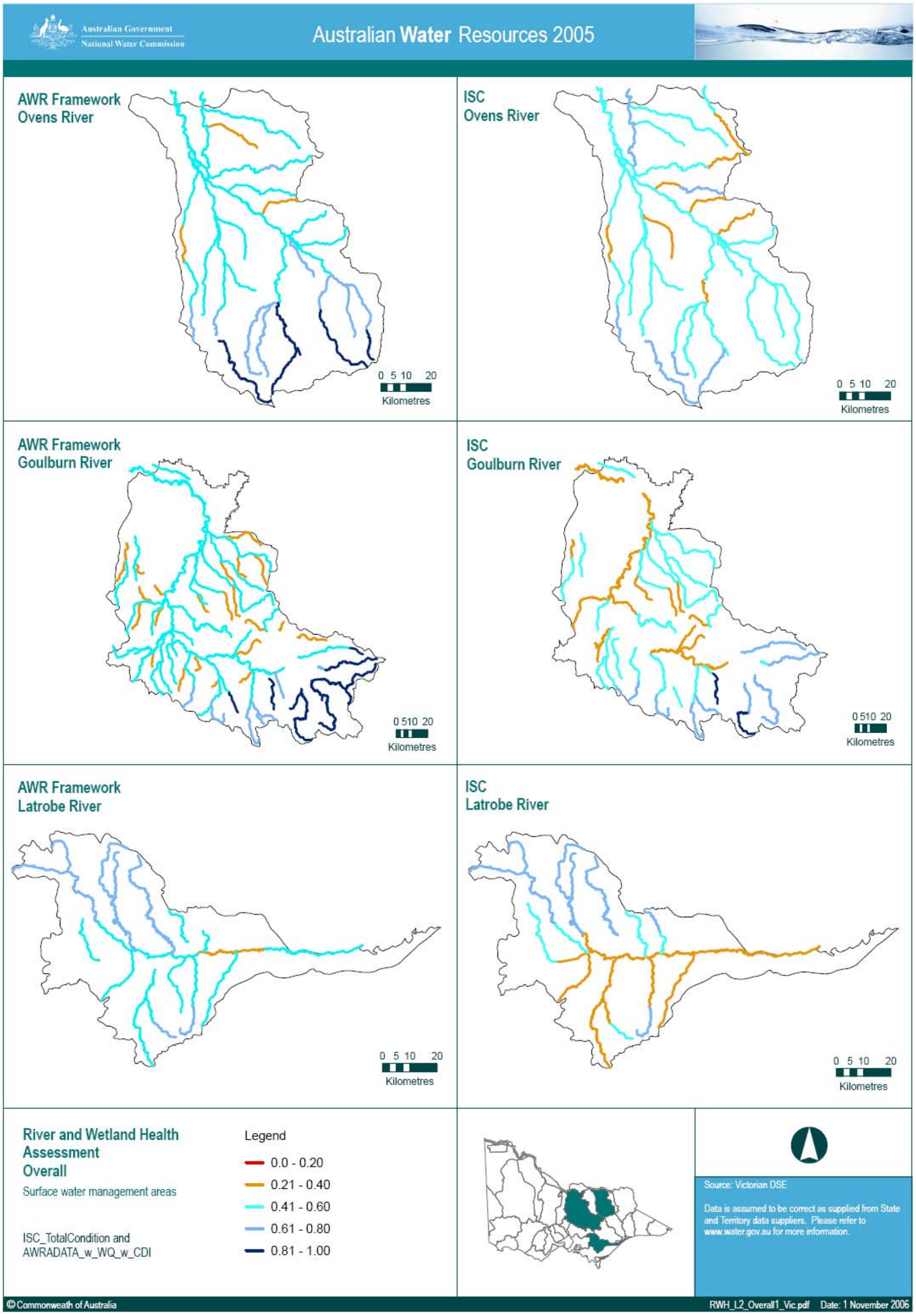


Figure 8 FARWH and ISC overall assessment of condition, including Water Quality and Catchment Disturbance data, for the Ovens, Goulburn, and Latrobe Rivers, Victoria.

When the Victorian method of state-wide ranking of sites before finalising the hydrology score is used in the FARWH overall index, and compared with the currently used ISC overall condition metric, the relationship is improved and the slope is close to one with the intercept near zero (Figure 9). Thus, the effect of the hydrology ranking and weighting is to lower the overall index score. Removing Water Quality improves the relationship further (Figure 10) because it removes some variability from the FARWH that is not present in the ISC because of the sparseness of ISC water quality data. The general trends were similar between the FARWH and ISC when comparing overall condition without the inclusion of the Water Quality and Catchment Disturbance data (Figure 11), with reaches in the upper parts of the catchments showing the greatest health, which decreased in the more downstream areas. This similarity suggests that indices conforming to the FARWH may be appropriate for assessing overall condition in other jurisdictions and that they will be comparable to assessments in Victoria produced by the ISC after only small changes.

Relationship	Scatter plot

$r^2 = 0.55$

$r = 0.74$

$n = 217$

$p < 0.0001$

Intercept = 0

Slope = 0.95

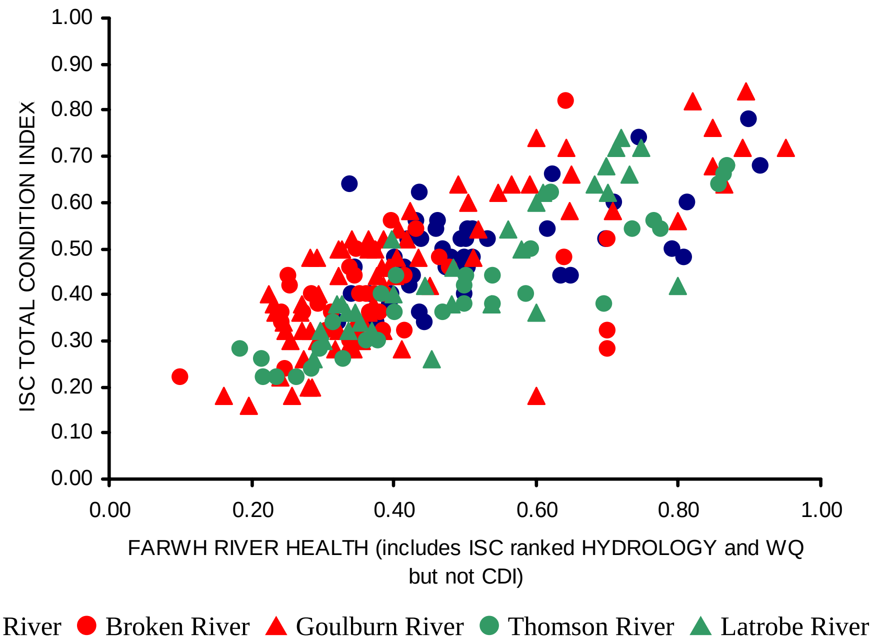
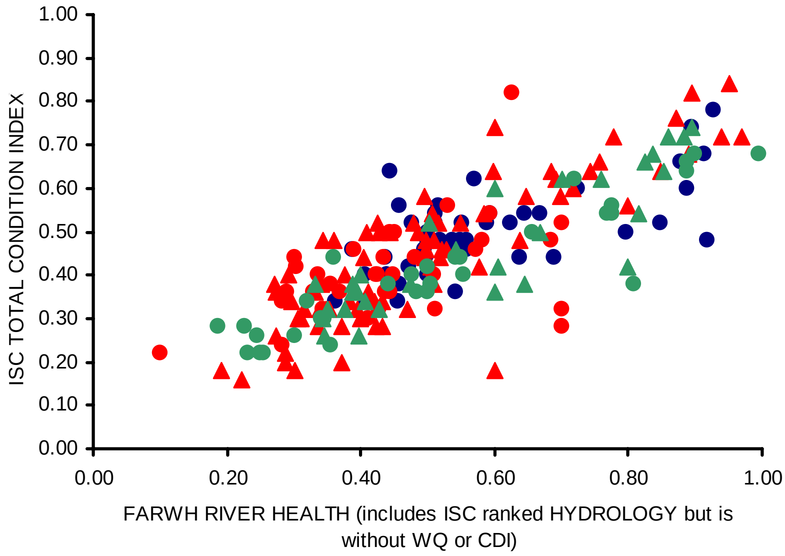


Figure 9 FARWH Overall index, including Water Quality and Catchment Disturbance, compared with ISC overall index at reach scale. The ISC index does not have Catchment Disturbance or Water Quality. The ISC weighted Hydrology Index was included in the FARWH overall index.

Relationship	Scatter plot
$r^2 = 0.58$ $r = 0.76$ $n = 202$ $p < 0.0001$ Intercept = 0.08 Slope = 0.87	

● Ovens River ● Broken River ▲ Goulburn River ● Thomson River ▲ Latrobe River

Figure 10 FARWH Overall index, without Water Quality and Catchment Disturbance, compared with ISC overall index at reach scale. This is the most closely related overall index comparison. Hydrology data in FARWH have not been weighted but in ISC they have been ranked and weighted.

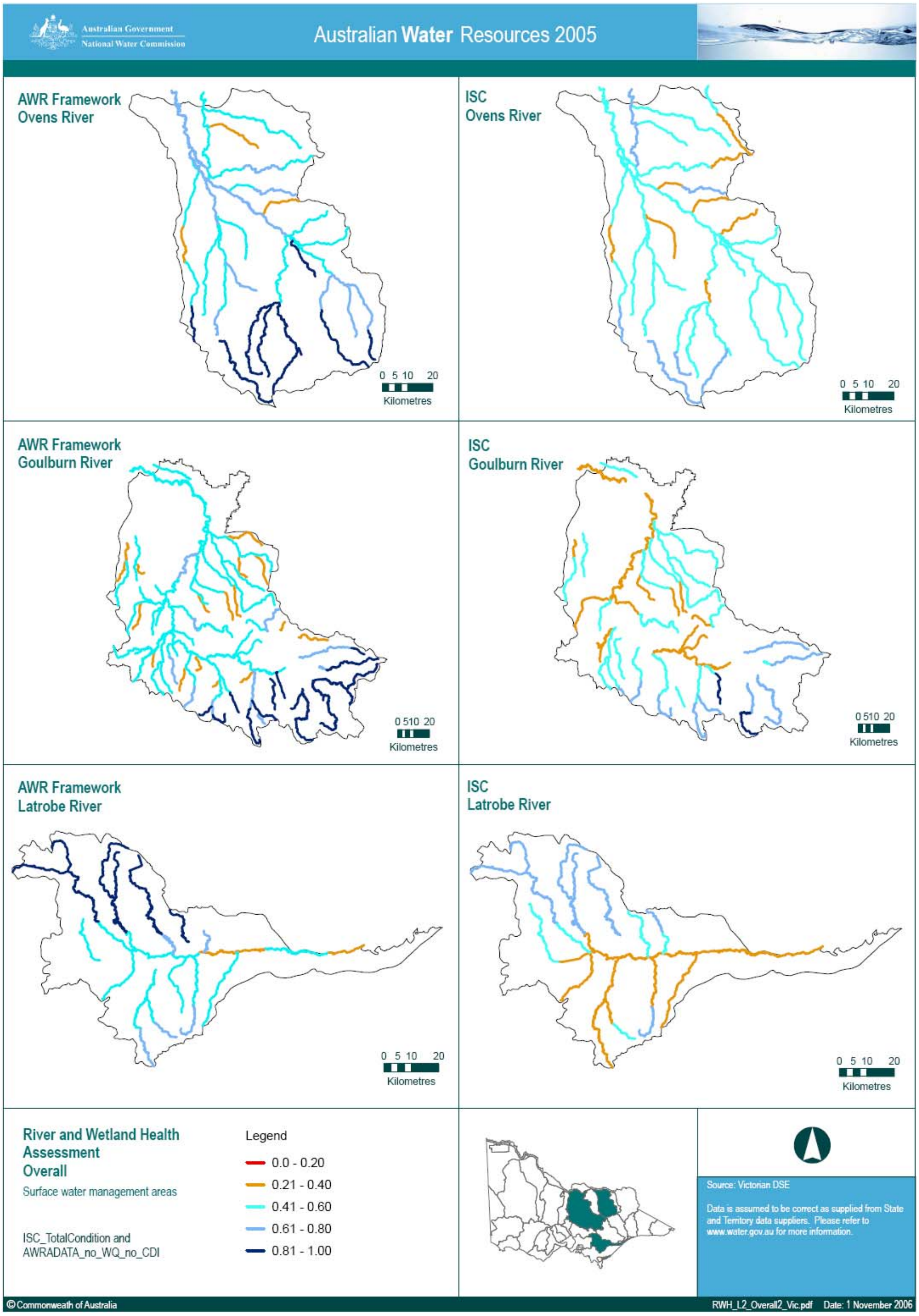


Figure 11 FARWH and ISC overall assessment of condition, excluding Water Quality and Catchment Disturbance data, for Ovens, Goulburn, and Latrobe Rivers, Victoria.

In the following example (Figure 12) the vertical axis is the alternative FARWH data (without Catchment Disturbance, with Water Quality and without ranked Hydrology). The five ISC metrics have been used but without the ISC method of aggregation (reverse ranking weighted for all sub-indices), and instead using standardised Euclidean distance to combine them. The ISC data have been weighted by reach length but not ranked. A likely source of variability is that for most FARWH values Water Quality was used, but for most ISC reaches Water Quality was not available. The overall relationship is quite strong, although a little lower than without the Water Quality data, and again indicates the effect of weighting the sub-indices and the additional variability that may contributed by Water Quality data.

Relationship

$r^2 = 0.45$

$r = 0.67$

$n = 203$

$p < 0.0001$

Intercept = 0.08

Slope = 0.87

Scatter plot

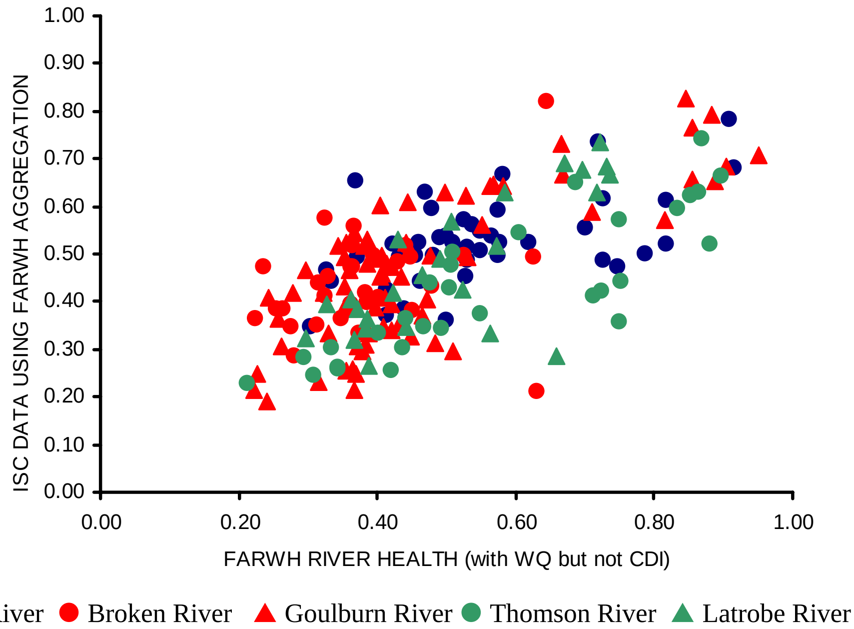


Figure 12 FARWH Overall index, with Water Quality and no Catchment Disturbance, compared with ISC overall index at reach scale. The inclusion of Water Quality in the FARWH increases variability. Hydrology data in the ISC have not been ranked and weighted.

3 Conservation of Freshwater Ecosystem Values Framework (CFEV) compared to alternative indices

The indices included in CFEV are similar to the main components of the environment recommended for assessment in the FARWH. The main differences are that CFEV does not have Water Quality or Physical Form indices that that are directly comparable to the FARWH (Table 5). Also, riparian vegetation (Fringing Zone) had to be disaggregated from the CFEV Biological Condition Index and was tested separately against the FARWH Fringing Zone Index. The FARWH Aquatic Biota index was compared with CFEV's combined Exotic Fish Condition and Macroinvertebrate Condition indices rather than its Biological Condition. It has not been possible to fully reconstruct the Biological Condition Index using the CFEV expert rules after the removal of riparian vegetation. Also, the CFEV Catchment Disturbance Index includes water quality related information based on the presence of mines and sediment addition. It is intended that the CFEV will be used as a baseline for comparisons with the forthcoming Tasmanian Index of River Condition, which at this early stage of development looks like being similar to the Victorian ISC. Several of the issues raised by the following comparisons will need to be resolved to maximise the comparability of CFEV with the TIRC.

Table 5 Comparisons undertaken between possible alternate indices and the Conservation of Freshwater Ecosystem Values (CFEV) indices. Note index names are the variable names used in the analysis.

FARWH Theme	FARWH Index	CFEV Index for comparison
Aquatic Biota	FAWRA_BIOTA	CFEVBIOTA
Catchment Disturbance	FAWRACDI	CFEVCDI
Fringing Zone	FAWRARIPVEG	CFEVRIPV
Hydrology	FAWRAHYDROLOGY	CFEVHYDROLOGY
Physical Form	FAWRAPHYS	
Water Quality	FAWRAWQ	CFEVWQ
Integrated River Health	FAWRA OVERALL	CFEV OVERALL
Alternative 1 without FARWH water quality	FAWRA OVERALL (without WQ)	CFEV OVERALL
Alternative 2 without FARWH Water Quality and Physical Form	FAWRA OVERALL (without WQ or PHYSICAL FORM	CFEV OVERALL

3.1 Aquatic biota

The CFEV biota has been weighted by 'link' length to the FARWH aggregated reaches. The biota score used for the FARWH is the mean of the CFEV macroinvertebrate condition score for the river section (based on composition and abundance) and exotic fish score for the river section after they have been weighted to the FARWH reaches. The CFEV Macroinvertebrate Condition Index is based on measured and modelled data similar to that described in the Potential Comparative Indices document.

The significant relationship lends confidence to the assessment and the variability largely results from the weighting from links to reaches without re-applying the CFEV expert rules and from the removal of native fish (Figure 13). The presence of exotic fish is a fish index that might be applied in many jurisdictions and was deemed an important component of the CFEV assessment to meet Tasmania's needs. Some differences exist when comparing the alternative biotic index with CFEV indices of biota (Figure 14). The values of biotic health were more variable in the CFEV assessments and there were no clear trends across catchments, particularly in the case of the Pittwater–Coal catchment. This suggests that the FARWH selected index based only on macroinvertebrates and CFEV may not be as comparable; however, it is more likely to result from the inclusion of fish data. This underlines the importance of clear decisions on the biota considered important in the jurisdiction being assessed, because biota, such as fish are considered important in many places.

Relationship

$r^2 = 0.36$

$r = 0.60$

$n = 107$

$p < 0.0001$

Intercept = 0.31

Slope = 0.30

Scatter plot

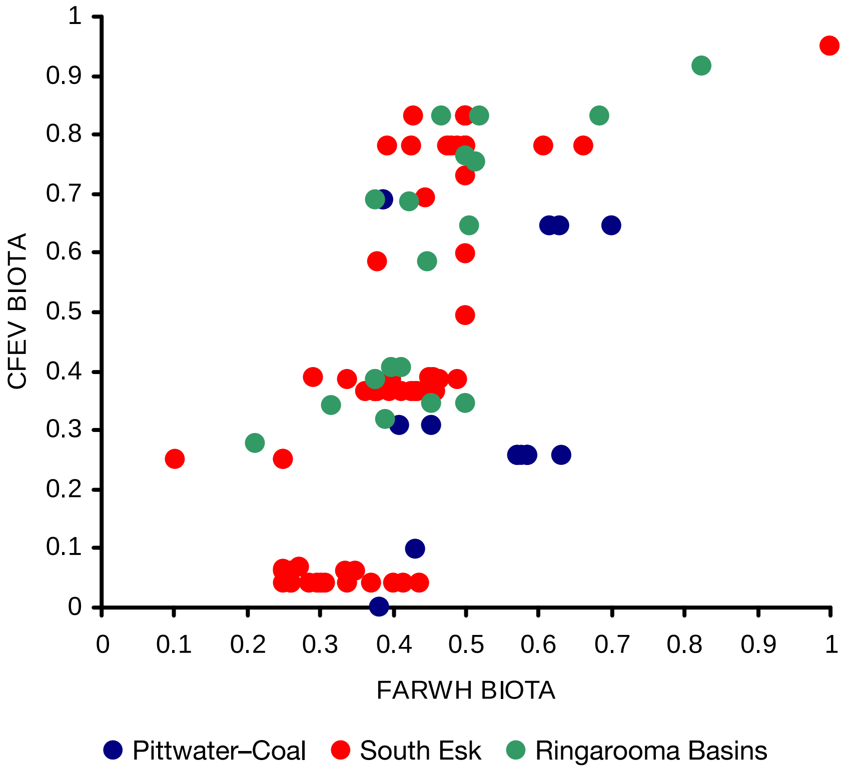


Figure 13 FARWH Aquatic Biota uses the measured and modelled macroinvertebrate CFEV data and the CFEV exotic fish data. Native fish data were sparse and excluded.

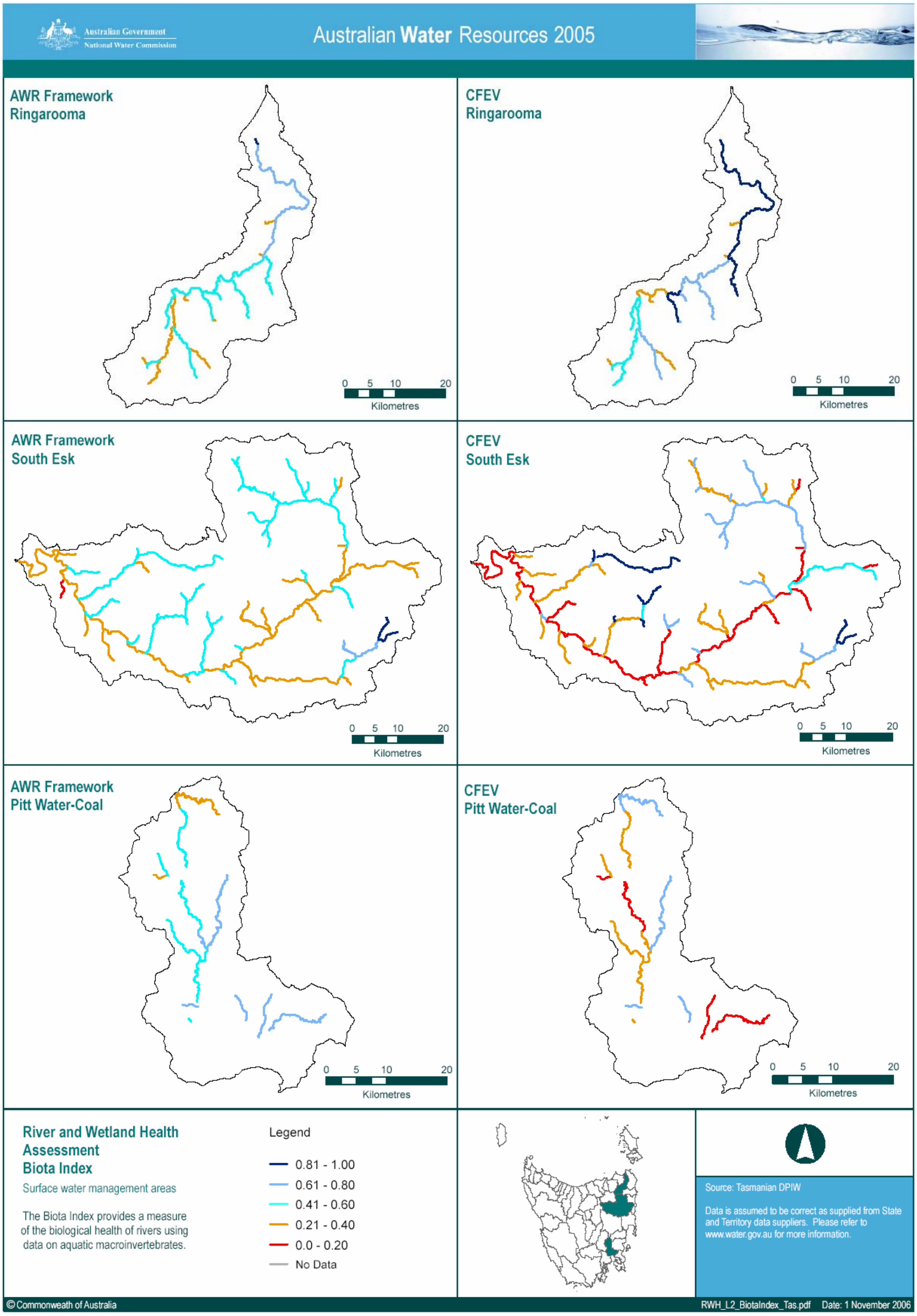


Figure 14 FARWH and CFEV assessment of biota for the Ringarooma, South Esk, and Pittwater–Coal Rivers, Tasmania.

3.2 Hydrology

Although the relationship is significant, it is poor and largely driven by outlying points (Figure 15). The Flow Stress Rank (FSR) method as chosen here for comparison within the FARWH, and used in the Victorian ISC, is being considered by the TIRC and if adopted would undoubtedly improve the relationship. Clearly, the two measures are measuring quite different aspects of flow and might not be comparable in different jurisdictions. The FSR method covers several aspects of flow, including changes in low flows, high flows, proportion of zero flow, monthly variation, and seasonal period. The CFEV index emphasises flow diversion (although it also includes data on flow abstraction [and diversion], flow regulation, and flow variability). However, because of differences in the indices, it is possible that marked changes to flow regime because of hydroelectricity production will not produce the level of response in the CFEV index seen with the FSR if water is not diverted from the river.

Relationship

$r^2 = 0.22$

$r = 0.46$

$n = 97$

$p < 0.0001$

Intercept = 0.34

Slope = 0.54

Scatter plot

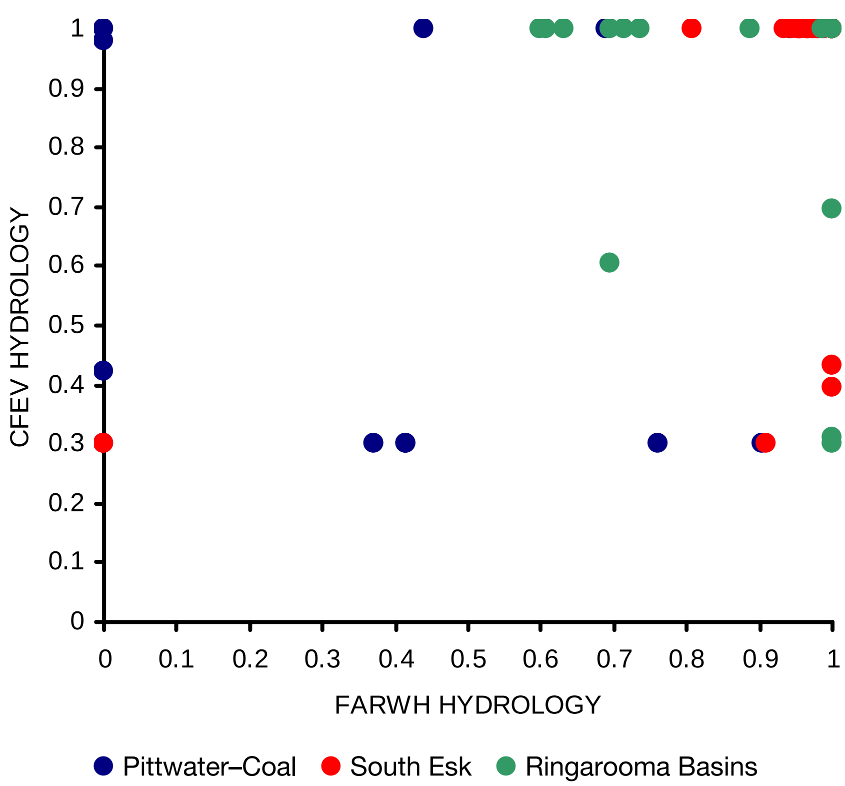


Figure 15 FARWH Hydrology uses Flow Stress Rank (FSR) for hydrology data and CFEV, an index that is largely influenced by changes in variability.

3.3 Fringing zone

The CFEV Fringing Zone index is the proportion of native riparian vegetation within a 50 m buffer zone either side of the river section (0 = 0 percent to 1 = 100 percent) weighted by link length to FARWH reaches. It does not include a structural component relating to non-native vegetation. While this index is used for comparison purposes, it does not include data from an on-ground survey of willows that were taken into account in the CFEV in a pre-processing step of the biological condition score. This step could not be recreated for the purposes of this comparison. Again the relationship is significant, but largely driven by high and low scores and with marked scatter, especially for the South Esk River Surface Water Management Area (Figure 16). The relationship is much better for the Ringarooma and Pittwater–Coal Surface Water Management Area. Similarly, a stronger trend is shown in the Ringarooma and Pittwater–Coal catchments, with greater values of fringing zone health in the upper parts of the catchments than the lower (Figure 17). In contrast, the fringing zone measurements are more variable in the South Esk catchment, both compared to the other catchments and also between the FARWH and CFEV. This result suggests that the FARWH may be less comparable with the CFEV when measuring the health of the fringing zone.

Relationship	Scatter plot

$r^2 = 0.57$

$r = 0.76$

$n = 107$

$p < 0.0001$

Intercept = 0.17

Slope = 0.63

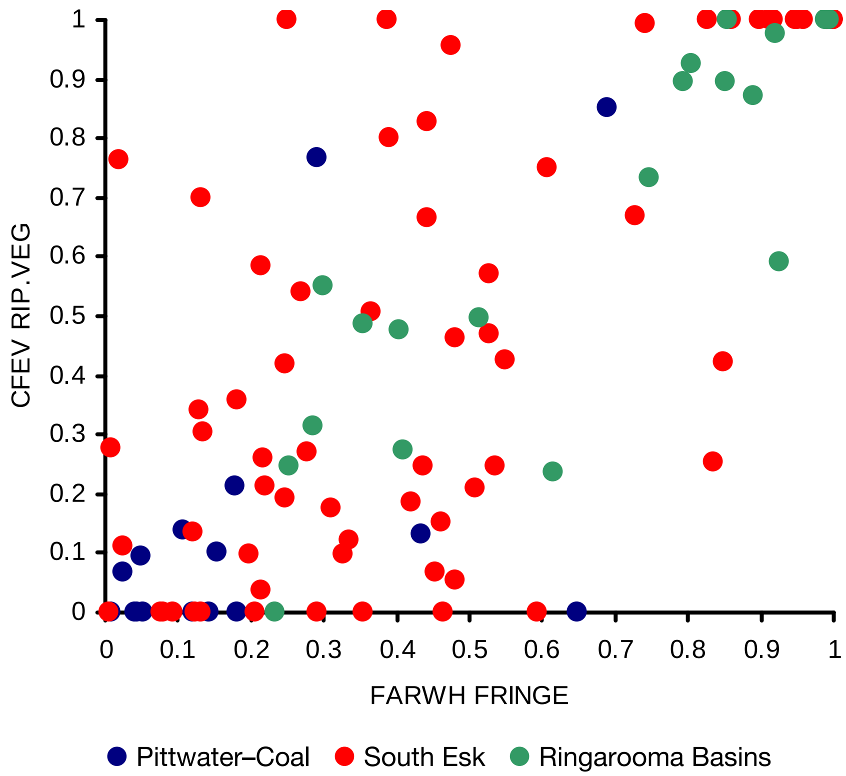


Figure 16 FARWH fringing zone assessment includes an assessment of structural cover based on percentage of each reach with vegetation and a measure of change of vegetation post-European settlement using GIS and remote sensed data. CFEV includes some similar measures.

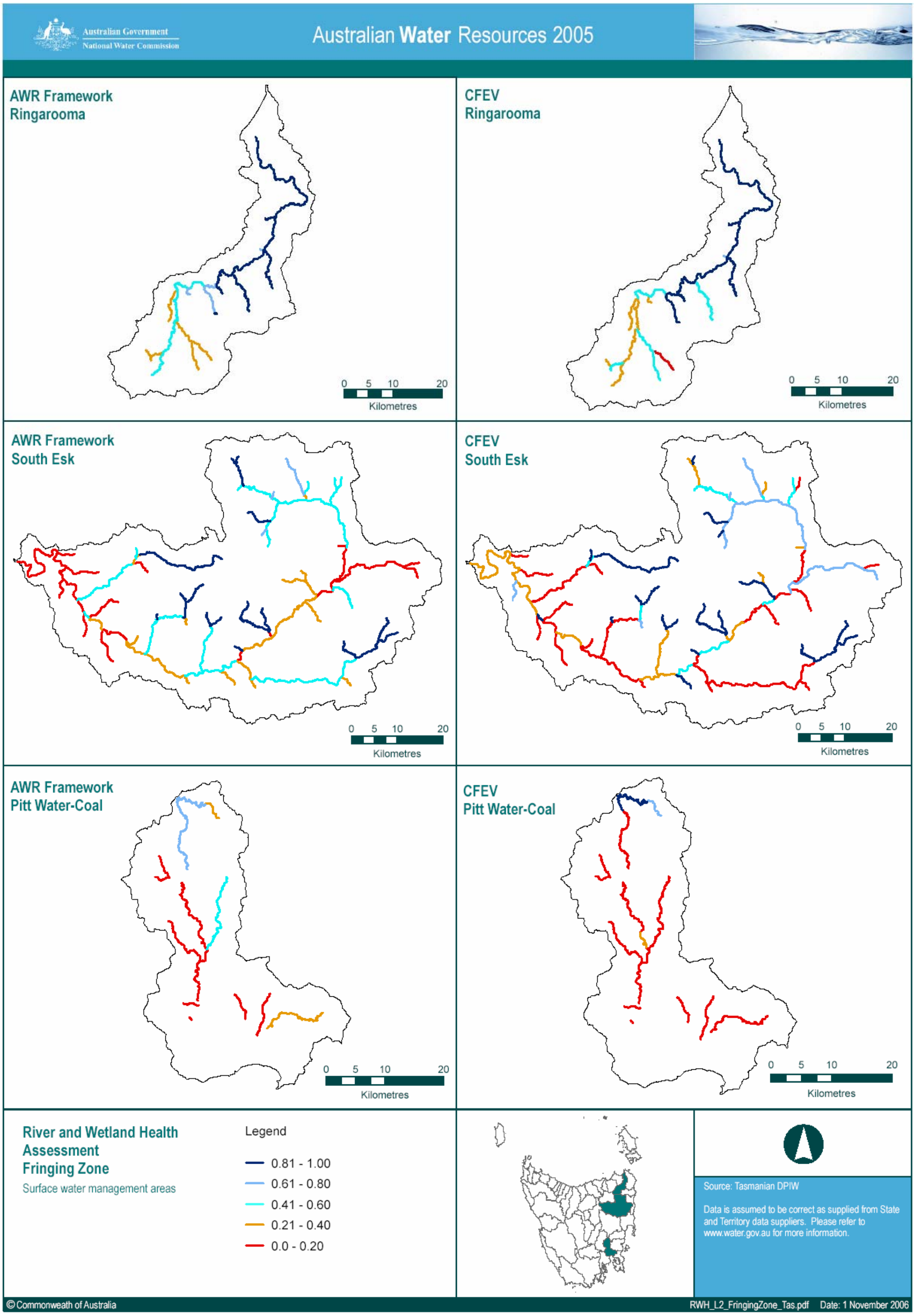


Figure 17 FARWH and CFEV assessment of fringing zone for the Ringarooma, South Esk, and Pittwater–Coal Rivers, Tasmania.

3.4 Water quality

CFEV has estimates of sediment addition that have been used for an approximate comparison with the FARWH water quality based on modelled data. Thus, this not really a direct comparison for water quality and demonstrates the potential value of adopting process-based models for this assessment (Figure 18). There is interest in the SedNet modelling approach within DPIW, and this could potentially be considered as a surrogate sub-index for water quality in the FARWH (section 1.3.3).

Relationship

$r^2 = 0.07$

$r = 0.27$

$n = 104$

$p = <0.01$

Intercept = 0.00

Slope = 0.47

Scatter plot

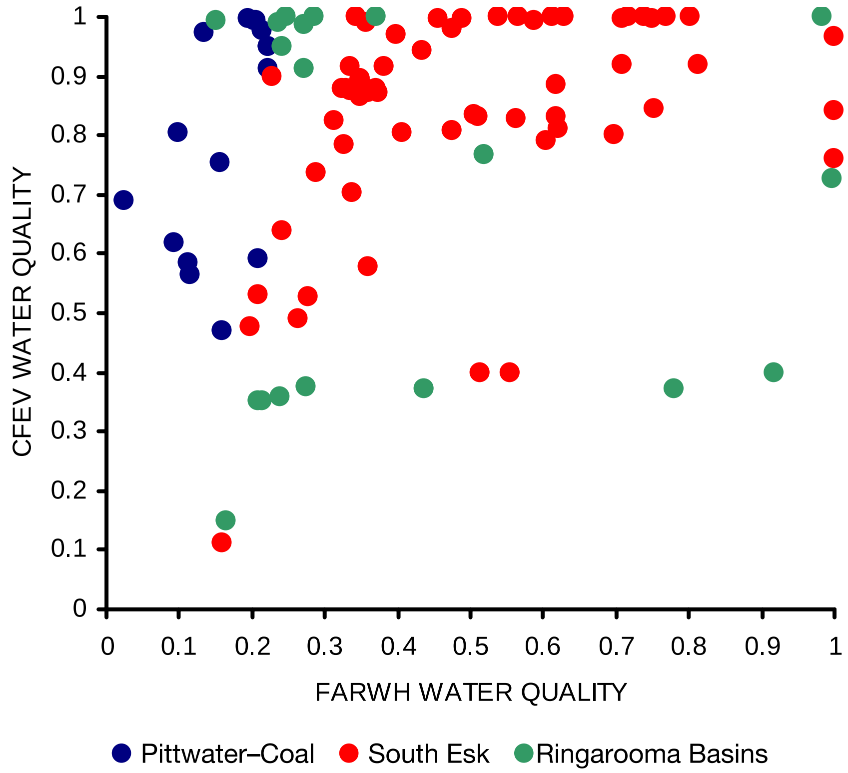


Figure 18 Water Quality. FARWH data are based on process-based modelled annual loads. CFEV has no clear water quality indices and estimates of sediment addition were used here.

3.5 Catchment disturbance

CFEV has no direct comparison for catchment disturbance index. The FARWH index assesses land-use types in categories of runoff, estimated from the literature that would run off into each reach. The CFEV index assesses the percentage of land use itself without a weighting for the area and type of runoff expected. Thus, the comparison made here between the catchment variables used in CFEV resulted in a poor relationship (Figure 19). No clear trends were apparent between FARWH and CFEV across the catchments when comparing catchment disturbance scores (Figure 20), particularly for the Ringarooma and Pittwater–Coal catchments. Although the values of catchment disturbance are slightly more comparable between the FARWH and CFEV in the South Esk catchment, in general it would appear that these two measures are not comparable and FARWH may not be useful in other jurisdictions if the data are to be compared with CFEV.

Relationship

$r^2 = 0.08$

$r = 0.28$

$n = 106$

$p < 0.005$

Intercept = 0.66

Slope = 0.15

Scatter plot

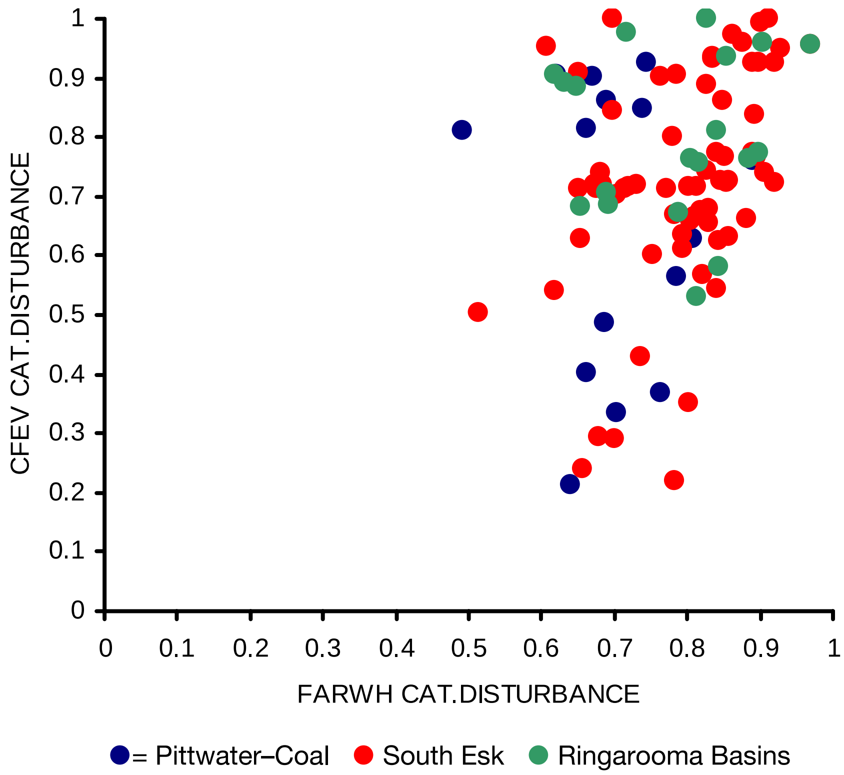


Figure 19 FARWH Catchment Disturbance data are based on process-based modelled annual loads. CFEV has no clear water quality indices and estimates of sediment addition were used.

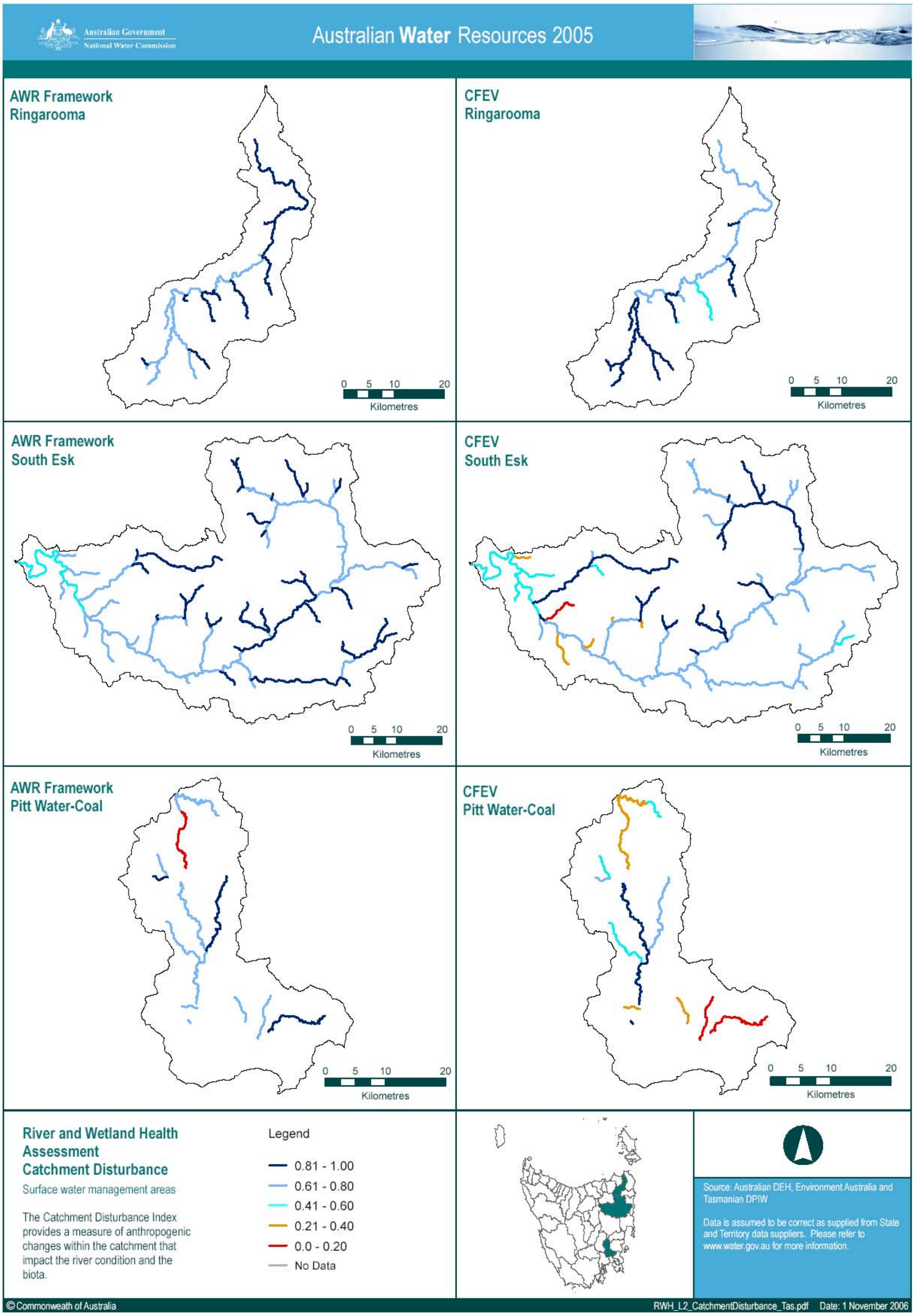


Figure 20 FARWH and CFEV assessment of catchment disturbance for the Ringarooma, South Esk, and Pittwater–Coal Rivers, Tasmania.

3.6 Overall assessment

The overall relationship between CFEV and FARWH is encouraging with more than 40 percent of the variability explained (Figure 21), suggesting that reasonable inter-jurisdictional comparisons could be made at the Surface Water Management Area scale. Note that CFEV did not include water quality because it was felt that the measure tested above was not a good representation in this context and there was no physical form index.

Possible developments in water quality and hydrology indices would probably vastly improve these comparisons. Also, a stronger trend is evident in the comparisons of the FARWH and CFEV for the overall catchment condition than for individual components, with the inclusion of water quality and catchment disturbance data in the FARWH (Figure 22).

Overall catchment health was generally higher in upper sections of the three catchments, although there were some differences in the actual values between the indices chosen for the FARWH and CFEV indices. These results suggest that indices conforming to the FARHW may be applicable to other jurisdictions. However, the indices chosen for comparison with the ISC and CFEV were not as closely related to CFEV as they were to the Victorian ISC. Therefore, the relationship between the ISC and CFEV is not as good as hoped for. It is likely that methods being developed for the Tasmanian Index of River Condition, including water quality measures, physical form, and a revised hydrology index would, if adopted, greatly improve the relationship.

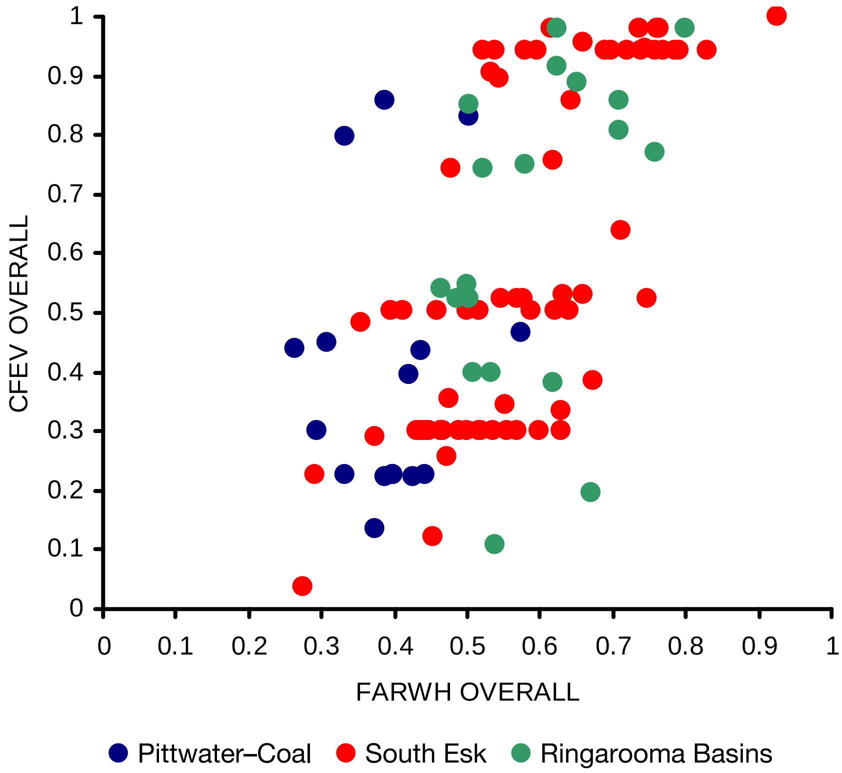
Relationship	Scatter plot
$r^2 = 0.43$ $r = 0.66$ $n = 107$ $p < 0.0001$ Intercept = 0.38 Slope = 0.33	

Figure 21 FARWH Overall data include modelled water quality and catchment disturbance. The standard CFEV integration using expert rules is used at link scale and then length-weighted to river reaches aggregated from initial CFEV links.

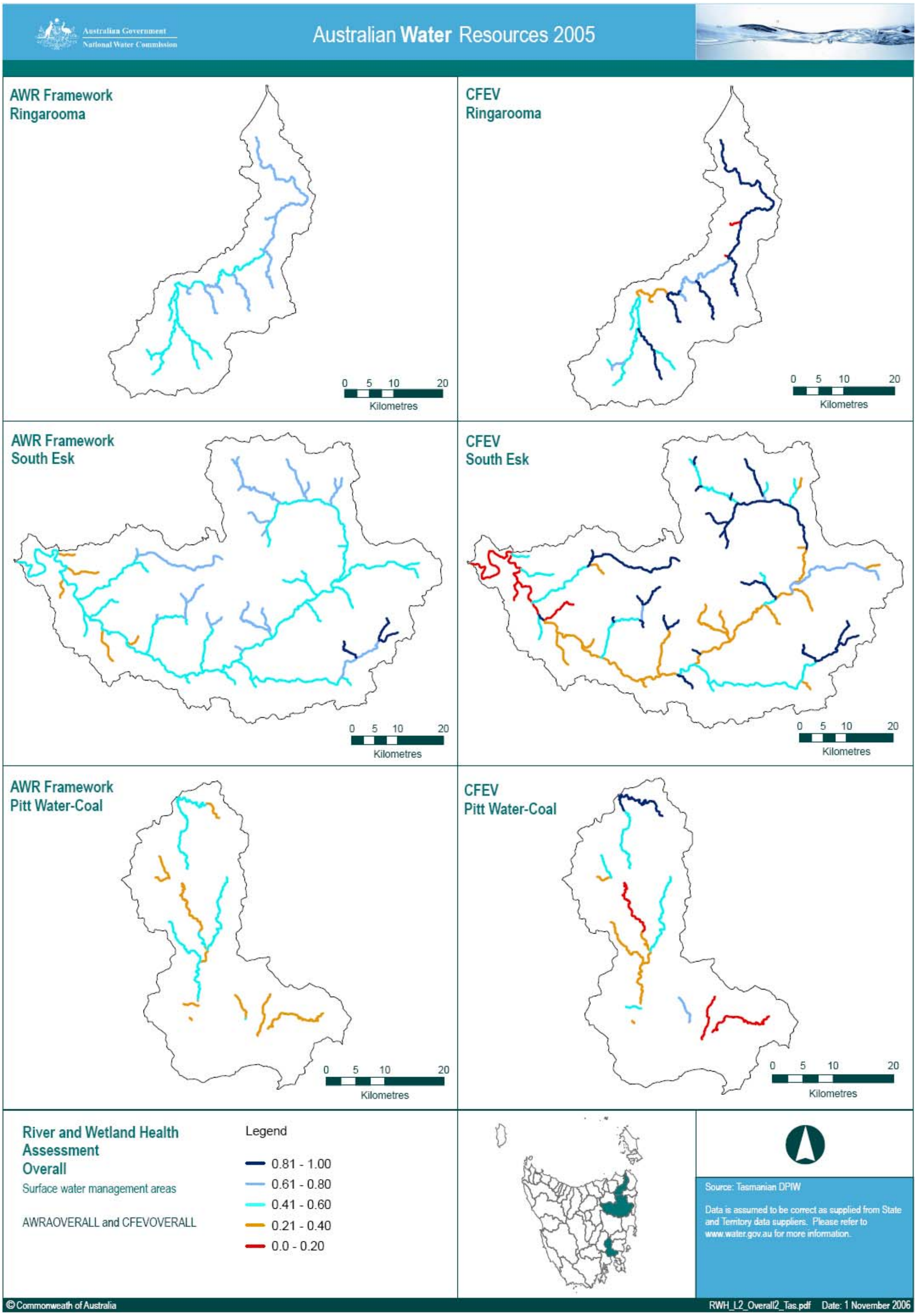


Figure 22 FARWH and CFEV overall assessment of condition, including Water Quality and Catchment Disturbance data, for Ringarooma, South Esk, and Pittwater–Coal Rivers, Tasmania.

Removing the FARWH Water Quality index only marginally improved the relationship of the overall indices (Figure 23).

Relationship

$r^2 = 0.45$

$r = 0.67$

$n = 107$

$p < 0.0001$

Intercept = 0.41

Slope = 0.32

Scatter plot

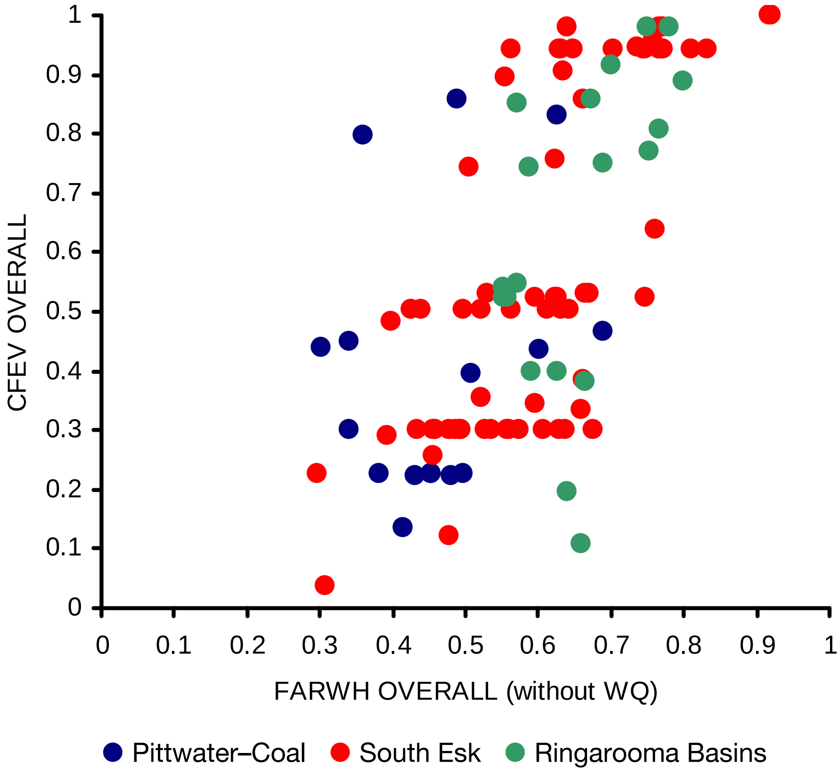


Figure 23 FARWH Overall data exclude modelled water quality. The standard CFEV integration using expert rules is used at the link scale and then length-weighted to river reaches aggregated from initial CFEV links.

Removing the Water Quality Index and Physical Form Index from the FARWH also did little to improve the relationship (Figure 24), primarily because neither were represented in the CFEV assessment. However, the overall assessment is still reasonable. There was a general trend of increased health in the upper sections of the catchments when comparing the overall condition (excluding the Water Quality and Physical Form data), although there were differences in the values between the FARWH based indices and CFEV (Figure 25).

Relationship

Scatter plot

$r^2 = 0.46$

$r = 0.68$

$n = 107$

$p < 0.0001$

Intercept = 0.34

Slope = 0.36

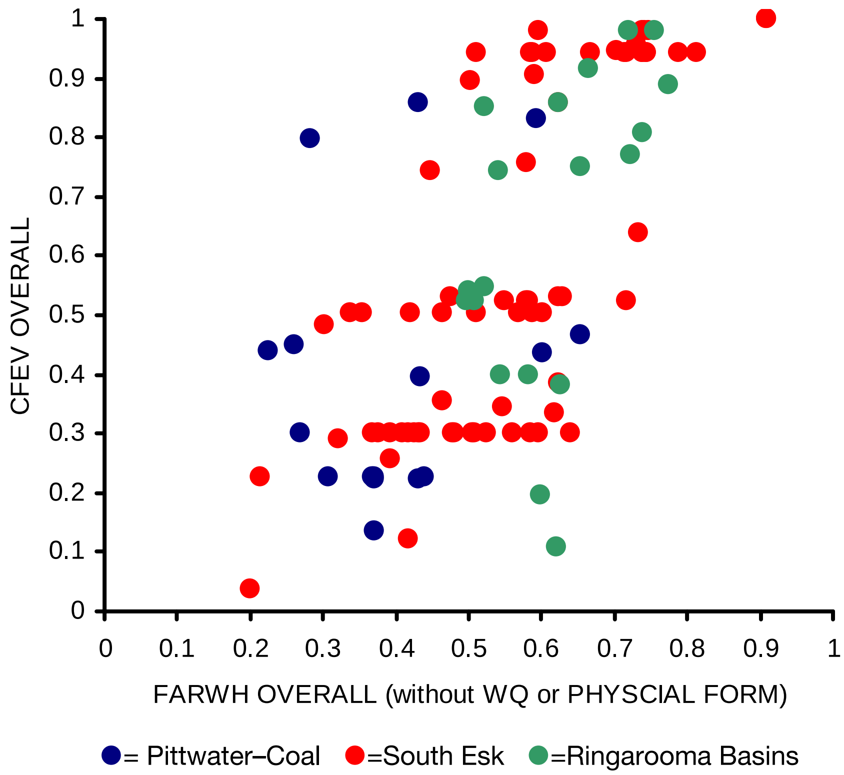


Figure 24 FARWH Overall data exclude modelled water quality and physical form. The standard CFEV integration using expert rules is used at link scale and then length-weighted to river reaches aggregated from initial CFEV links.

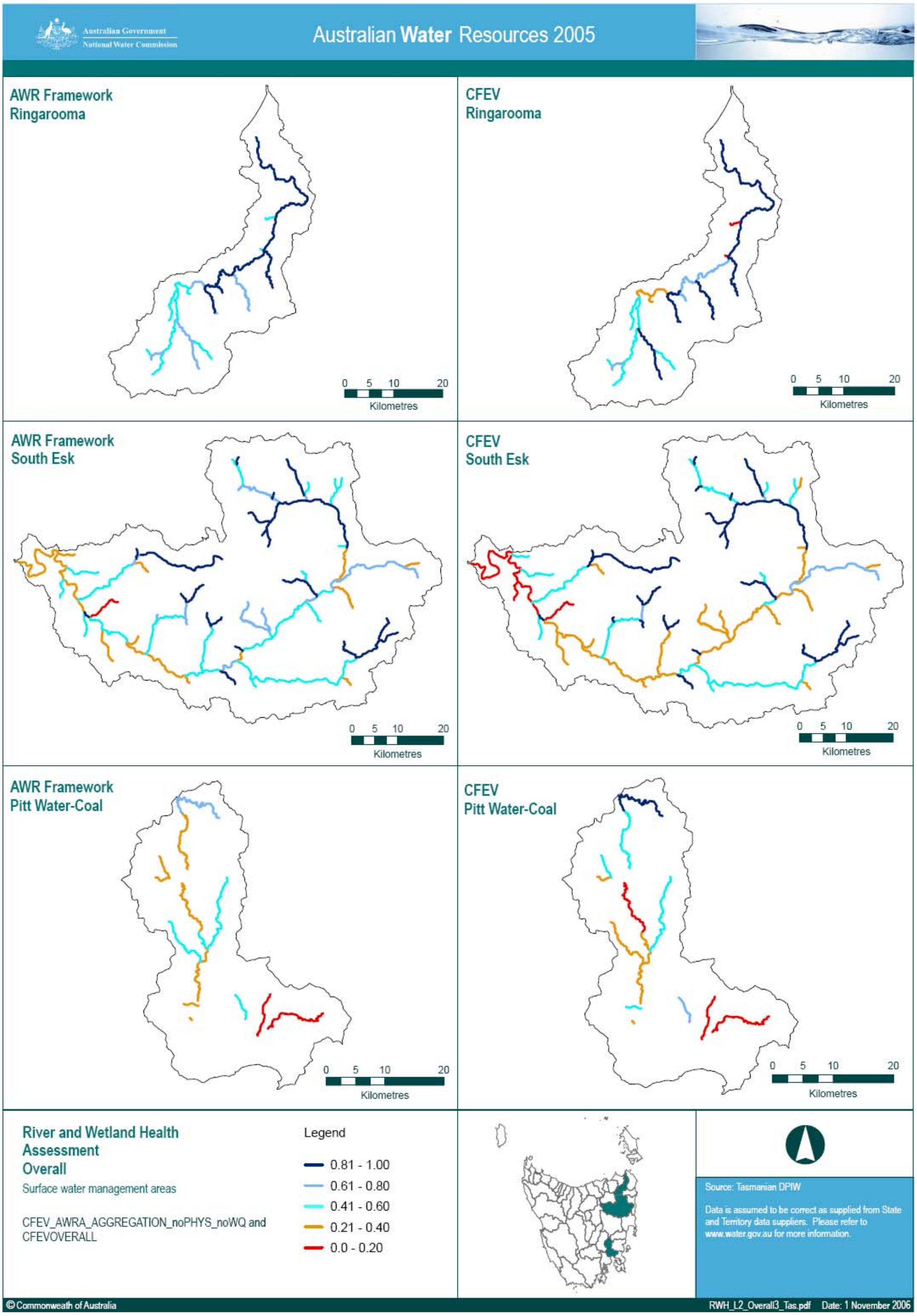


Figure 25 FARWH and ISC overall assessment of condition, excluding Water Quality and Physical Form data, for Ringarooma, South Esk, and Pittwater–Coal Rivers, Tasmania.

The best comparison of the effects of the aggregation is demonstrated where FARWH uses standardised Euclidean distance and the CFEV expert rules (Figure 26). There is also an effect from weighting differences up to the FARWH reaches from the CFEV links. These are the same data but the vertical axis shows the result of weighting the individual indices to the FARWH reaches and then calculating standardised Euclidean distance to integrate them. The horizontal axis is the CFEV scores for the same data converted to the CFEV overall 'naturalness' score for each link which are then length-weighted to the FARWH reaches.

Relationship

$r^2 = 0.81$

$r = 0.90$

$n = 107$

$p < 0.0001$

Intercept = 0.25

Slope = 0.60

Scatter plot

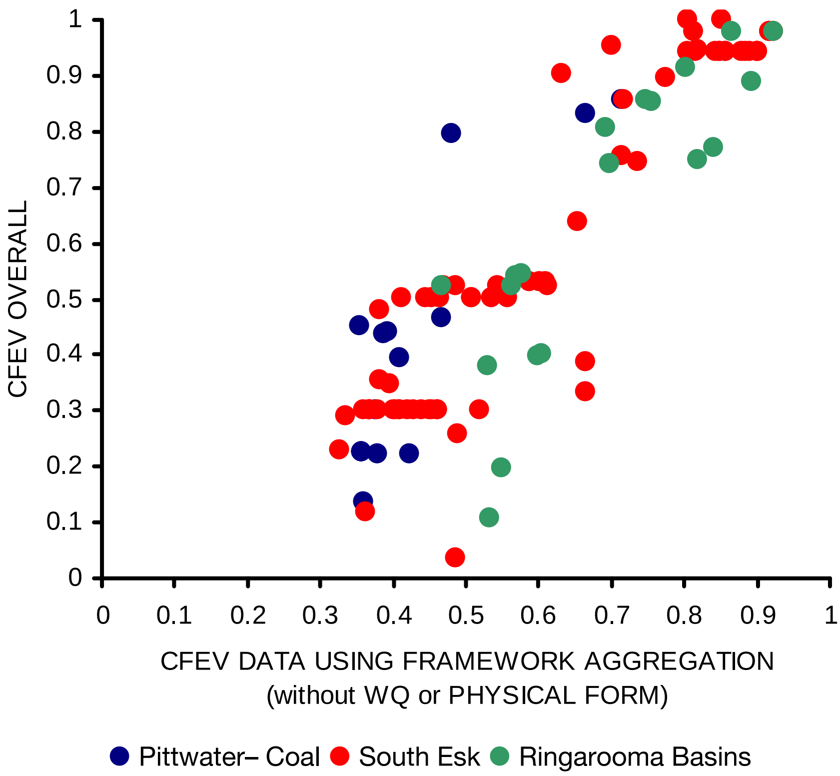


Figure 26 FARWH Overall data exclude modelled water quality and catchment disturbance. The standard CFEV integration using expert rules has been used at the link scale and then length-weighted to river reaches aggregated from the initial CFEV links.

4 River condition: managing different assessments

The following section is taken from a paper prepared by Richard Norris, Peter Liston, Simon Linke, of the eWater Cooperative Research Centre, University of Canberra.

Testing in the National Land and Water Resources Audit I. Comparison of the ARC (2000) with the ISC (1999)

4.1 Introduction

Practical methods of providing clear assessments of river condition, understanding of ecosystem functioning, and demonstration of change can help managers and citizens make decisions on protection, amelioration, or rehabilitation of rivers. Many methods are available for assessing rivers, but they often provoke vigorous debate as to their relative merits (e.g. Karr and Chu 1999, Reynoldson et al*.* 1997, Norris and Hawkins 2000). Debate about the relative merits of various methods is healthy, although it may sometimes obscure the reasons surrounding their initial development.

In some form, indices of various kinds have been used for river assessment since early this century when Kolkwitz and Marsson (1908, 1909) first proposed their 'Saprobiensystem' using coded responses of microbiota to gauge the severity of organic pollution. Europeans have developed this original idea into dozens of new indices using many different kinds of organisms (see Ghetti and Ravera 1993). Similar indices arose in the USA and Britain, although with little recognition of other work (Hynes 1993), a situation that continues today (Norris 1995). The search for better indices continues world wide (e.g. Oberdorff and Porcher 1994 in France; Stark 1993, 1998 and Roberts et al*.* 1998 in New Zealand; Chessman 1995, 1997 in Australia; Bard 1998 in Canada; van Vliet et al*.* 1994 and Chutter 1995 in South Africa; Hugueny et al*.* 1996 in East Africa; Graca and Coimbra 1998 in Portugal; Lang and Reymond 1995 in Switzerland), and has accelerated, especially with the development of the US EPA rapid biological assessment procedures (Barbour et al. 1996).

Proponents of particular assessment methods often argue that their approach is best (see reviews edited by Norris et al. 1995). However, objective evaluations have seldom been made. Marine scientists, faced with a similar dilemma, have responded by running workshops to test the various methods side by side, using stringent statistical requirements and sampling regimes (Bayne et al*.* 1988; Addison and Clarke 1990; Stebbing and Dethlefsen 1992). Methods for assessing rivers have attracted much development work, but less on objective testing of individual methods and little on comparisons.

Two methods have been developed independently in Australia for comprehensive, large-scale assessment of river condition. These are the state-wide Victorian Index of Stream Condition (ISC, Ladson et al*.* 1996) and the national Assessment of River Condition (ARC, Norris et al*.* 2001). Both were designed to provide information to governments and communities from the reach scale, through to the catchment scales, and to the state or nation. Both use similar (in the case of biota, the same) environmental features to build the overall assessment. The principal difference is that the ISC depends on site assessments whereas the ARC uses a combination of site measurements, remotely sensed data, and process-based models. Differences in assessments have the potential to undermine the conclusions from either method.

Comparisons of how various assessment methods perform is certainly needed. However, most methods, such as the ISC and ARC, have been developed with similar objectives in mind, mainly to gauge environmental condition and to provide information for effective management and protection. Each method has particular merits, and river assessments provided by multiple methods can provide additional information by which better decisions can be made. Scientists and managers commonly are faced with having to accommodate various sources of information and drawing sensible conclusions from them. If various river assessment methods set out to meet underlying common needs, the information they supply should be complementary. Thus, it makes sense to put more effort into finding ways of blending together the results from different methods in order to strengthen conclusions, instead of devaluing one or the other through unproductive criticism. Following this philosophy, *the aim of this paper is to determine ways of reconciling differences and making full use of data from methods with similar river assessment goals*.

4.2 Methods

4.2.1 The Index of Stream Condition

The Index of Stream Condition (ISC) has been standardised in the Australian state of Victoria. It is an aggregate indicator of the environmental condition of rivers and streams (Ladson et al*.* 1996, 1999). It integrates information on major components of river systems that are important from an ecological perspective – current flow regime, water quality, condition of the channel, streamside zone, and invertebrate communities.

Table 40 Sub-indices used in the Victorian Index of Stream Condition (from Ladson et al. 1996).

Hydrology	Streamside zone	Physical form	Water quality	Aquatic life
Hydrologic deviation – amended annual proportional flow deviation Presence of 'peaking' hydro power stations Catchment permeability	Width Longitudinal continuity (percent of bank vegetated and number of gaps) Structural intactness Cover of exotic vegetation	Bank stability Bed condition Presence of artificial barriers Instream habitat diversity and origin of coarse woody debris for lowland sites; epifaunal substrate for upland sites Regeneration of indigenous woody vegetation Billabong condition	Total phosphorus concentrations Turbidity Electrical conductivity pH	SIGNAL biotic index AUSRIVAS (taxonomic quality)

Nineteen key indicators were used to assess the quality aspects of stream condition (Table 40). Existing data sources were used where possible. Where data were not available, appropriate data collection procedures were developed. Methods were developed to extrapolate existing water quality and macroinvertebrate scores to surrounding reaches, and to transform habitat data collected as part of the AUSRIVAS sampling regime (Simpson and Norris 2000) so they could be used in the physical form and streamside zone sub-indices.

The index of stream condition is reported as a bar that shows the score between 0 and 10 for each of the five sub-indices (Figure 29). The overall score is an inverse ranking to the five sub-index scores, scaled back to a maximum score of 50. The overall score of the ISC will be between zero and 50 and can be used to classify stream condition on a five-point scale from very poor to excellent (Table 41).

The ISC provides assessments for stream reaches typically between 10 and 30 km long. These reaches are chosen so that they are relatively homogeneous in terms of the five sub-indices. The boundaries between reaches will commonly be based on significant changes to:

- hydrology (dams, significant diversions, confluence of similar size streams)
- physical form (artificial barriers, head cut at upstream end of an incising reach)
- streamside vegetation (significant change in topography or land use adjacent to the stream)
- water quality and aquatic life (point-source pollution, towns, or drainage outfalls).

Table 41 Victorian Index of Stream Condition reporting classifications.

Overall score	Stream condition
49–50	Excellent
39–41	Good
26–34	Marginal
20–25	Poor
0–19	Very poor

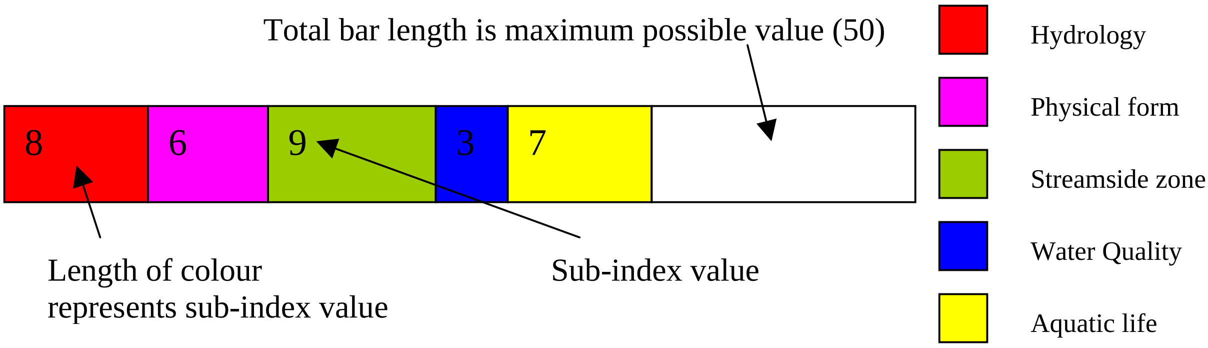


Figure 29 Victorian Index of Stream Condition reporting bar chart.

4.2.2 The Assessment of River Condition

The Assessment of River Condition (ARC, Norris et al. 2001) consists of components representing the environment (ARC_E) as the drivers and a measure of biological response (ARC_B). The components of the ARC_E are the catchment disturbance index, hydrological disturbance index, habitat index, and nutrient and suspended sediment load index. These indices and the ARC_B are described below, and full details can be found in Norris et al. (2001).

The Biota Index (ARC_B) is based on extensive national sampling of invertebrates sensitive to disturbance. The Australian River Assessment System models (AUSRIVAS, Simpson and Norris 2000) were used to assess these sites, providing a measure of the biological health of rivers throughout Australia. Reference sites, defined as minimally disturbed, provide the basis for the models and for comparisons that finally determine the condition of test sites. These data were also used for the Aquatic Life Index of the ISC and with another index, SIGNAL (Chessman 1995). Given the similarity, a direct comparison of this component will not be undertaken.

4.2.3 Overall environment index (ARCE)

The overall measure of environmental condition is made up of four constituent indices: the catchment disturbance index, the habitat index, the hydrological disturbance index, and the nutrient and suspended sediment load index. These four measures were combined, unweighted, using the standardised Euclidean distance procedure, to calculate the ARC_E (Table 42).

Table 42 Summary of integration procedures for sub-indices and indices

Index Sub-indices	**Integration approach and weighting**
Hydrological Disturbance Index	
Change in mean annual flow	Standardised Euclidean distance Components unweighted
Change in flow duration curve	
Change in seasonal amplitude	
Change in seasonal periodicity	
Nutrient and Suspended Sediment Load index	
Total nitrogen	Worst measure in reach taken as water quality assessment Components unweighted
Total phosphorus	
Suspended solids	
Toxicants	Not used for reach assessment – data too sparse
Salinity	
Habitat Index	
Bedload condition	Standardised Euclidean distance Components unweighted
Riparian vegetation	
Connectivity	
Catchment Disturbance Index	
Land use	Impacts summed Components unweighted
Land cover change	
Infrastructure	
ARC_E	
Hydrological Disturbance Index	Above 4 sub-indices integrated to make ARC_E Standardised Euclidean distance Components unweighted
Nutrient and Suspended Sediment Index	
Habitat Index	
Catchment Disturbance Index	

The ARC_E assessments from the NLWRA were used to generate an index that ranged from 0 to 1 and was comprised of an assessment of the four sub-indices. The ARC_E was divided into four categories to represent river condition based on environmental features (Table 42).

Table 42 Condition bands for the Assessment of River Condition (ARC_E).

ARC_E	River condition
0.75–1	Good
0.5–0.75	Poor
0.25–0.5	Very poor
0–0.25	Extremely poor

The differences between the ARC and the ISC were noted (Table 43) with a focus on how they may affect each index and the intended comparison. In some cases there is agreement on an underlying variable of interest (e.g. phosphorus or nitrogen), although it is measured or presented differently (e.g. concentrations versus annual loads, Table 43).

Table 43 Comparison of features of the Australian Assessment of River Condition (ARC_E) and the Victorian Index of Stream Condition (ISC).

Features of methods and approaches	ISC		ARC_E	
Spatial scale	River reaches were defined using cartographic maps as the primary source of data. Sections of river, 'reaches', were tentatively defined as sections of river between tributaries. Reaches were finalised following a subjective assessment of the homogeneity of each reach in terms of the five components of condition. A level of subjectivity was employed but tempered by observed uniformity in features that may respond independently from stream power. Reach length was generally 10–30 km.		River reaches defined using a digital topographic surface generated from a Digital Elevation Model as the primary source of data. Sections of river, 'links', were defined as sections of river between tributaries. Links were aggregated to "reaches" until the total stream power (a geomorphological process measure) doubled. Therefore a quantitative definition was rigidly applied. Reach length was generally 10–30 km.	
Spatial correspondence	Start and finish points of reaches could be arbitrary. <50 percent of reaches coincided with the ARC_E.		Start and finish points always at a tributary. <50 percent of reaches coincided with the ISC.	
Resolution	Usually 1:100,000 maps + on-ground inspection.		1:250,000 digital topographic surface.	
Converting scores to categories	Not specified but it appears that categories have been defined from the distribution of scores at all with cutpoints set at different percentiles.		Explicitly specified – based on range in condition from pristine to totally ruined, with the range of scores split evenly across the distribution	
Index components	*Data*	*Source/scale*	*Data*	*Source/scale*
Hydrology	Mean annual flow deviation Presence of barriers Catchment permeability – response to run-off	Gauged or estimated Map & observation Soil & geology maps	Mean annual flow deviation Seasonal period Seasonal amplitude Flood frequency	All gauged or modelled
Water quality	TP Turbidity EC pH	Concentrations all sampled at sites within a reach and reach value depicted as measured values	TP SS TN Ec Toxicants	Annual loads from process models with high resolution remote sensed data & ground-truthing Estimated
Physical form **Streamside zone** **Habitat**	Stream geomorphological features Riparian features	Measured and estimated at sites within a reach	Sediment aggradation Riparian condition Connectivity	Modelled Remote sensed data River onnectivity, map data and modelled effects
Biota	AUSRIVAS Index SIGNAL Index	All site measurements aggregated to a reach	AUSRIVAS Index	Site measurements and modelled via relationships with physical features

An initial issue with comparing ARC data to ISC data was the differences in spatial scales for which these data were reported, and the poor spatial registration between the ARC and ISC reaches. The reach determination process for the ISC is a subjective assessment of the homogeneity across the five components, whereas ARC reaches are derived from a process-based model (Table 43). The ARC reaches have been generated from digital elevation data (280-m point spacing) and are generally of coarser resolution than the ISC reaches. The ARC reaches model requires a minimum catchment area of 50 km^2 before reaches are initiated, with the result that more of the smaller streams are represented by the ISC reaches. Consequently, matching reaches (and their associated data) was not straightforward. Several GIS approaches were tested to match the datasets objectively, but the errors arising from these approaches led us to a manual comparison of data from ISC reaches with that from ARC reaches. Where an ARC reach physically matched more than the one ISC reach, the ARC components for that reach were compared to each of the ISC reaches. A full suite of data was not always available for each reach, and hence the number of reaches available for validation varied between the indices. These procedures resulted in a database of 470 reaches throughout catchments in Victoria that were determined as appropriate for comparison.

In the first instance, the overall ARC_E was compared with the overall ISC by summary statistics and visual examination of frequency histograms to assess whether they represented a similar spread of scores over the region. The scores were also correlated with each other to see if they were related and at what level.

The Australia-wide ARC_E was designed to be aggregated up to the size of river basins recognised by the Australian Water Resources Council. These basin summaries have been compared spatially on a map showing the reach determinations of the ISC. In both cases these have been coloured to represent the categories used by both methods since this is the way the data are usually presented to managers and the community.

The categories, or bands, of condition (Tables 1.40, 1.42) are often used for presenting the assessments for both indices. Changes in the number of reaches falling into each category may be used as an indication of improvement or degradation. Therefore, reach scores were compared on the same scale to determine the number that differed by more than one category width, by half a category width, and by less than half a category width. The reaches for which the scores differed by more than one category were mapped to determine if there was a spatial pattern that would indicate bias in assessment by either of the indices. Data representing examples of these mismatched reaches were then examined to see if causes for the differences in assessment could be found. Identifying a case where the two approaches scored a reach in two different categories was complicated by the different numbers of categories used by each approach (Tables 1.40, 1.42) and by the unequal size categories used by the ISC approach. We were also concerned that reaches very near category boundaries might be identified as a category mismatch as a result of only a small difference in scores. The pragmatic solution was to define a category mismatch as a difference of 25 percent or more between the ISC and ARC_E reaches, a figure based on the mean width of categories in the ARC_E (25 percent range) and the ISC (20 percent range).

4.3 Results

Overall features

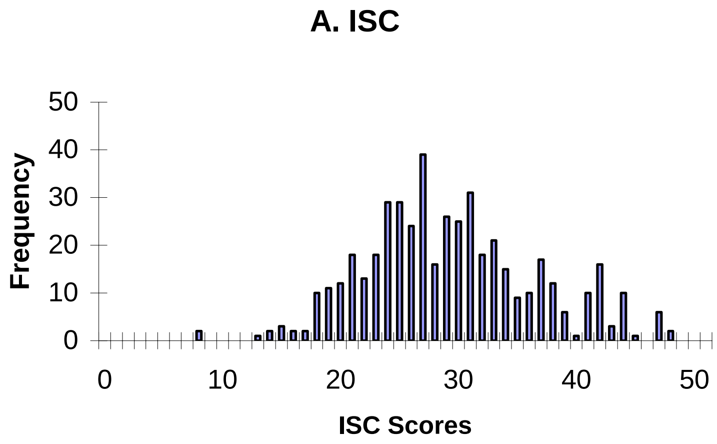
Both the ISC and the ARC_E are based on a similar philosophy that river or stream condition depends on certain features of the physical and chemical environment. However, these have been implemented slightly differently in each. Thus, the ARC_E sees biota as indicating the response to environmental features and keeps this sub-index separate. As a result, the ISC might show a difference here because this important component is included in the calculation and it may not depend linearly on the other variables. Again, the ISC does not include a measure of catchment condition, a major component of the ARC_E, and so large-scale changes to land use and run-off may be only marginally picked up in its measure of catchment permeability. Finally, the ISC has two sub-indices covering the riparian zone and the physical features of the channel, whereas the ARC_E combines these into one index.

The ISC predominantly relies on measurement at sites within a selected reach. Extensive testing has been conducted (Ladson et al*.* 1996, 1999) to determine the number of sites to be sampled and their representativeness of a reach. While errors have been brought down to acceptable levels for the purposes to which the index is usually put (Ladson et al. 1996), they are nevertheless significant and can only be neglected if one assumes that the reach is generally representative. Also, components may often be missing simply because they have not been measured. The ARC_E uses coarse remotely sensed data and process models for many of the features included in its assessment (Norris et al. 2001). Thus, data tend to be more complete than for the ISC and the modelling may be more representative of a whole reach, especially for those features that depend on contributions from the catchment such as sediments and nutrients.

Frequency distributions of both the ISC and the ARC_E indices demonstrate that they cover similar ranges of possible scores and that neither show obvious bias (Figure 30). When allowance was made for the different scoring scales of each index, both had similar overall means and distribution of scores (Table 44).

Table 44 Index of stream condition (ISC) and Assessment of River Condition (ARC_E) summary statistics for 470 stream reaches in Victoria, Australia. The ISC has also been divided by 50 to place it on the same scale as the ARC_E; similarly, the ARC_E has been multiplied by 50.

	ISC score	ISC/50	ARC_E score	ARC_E*50
Mean	29.3	0.57	0.58	29.0
Standard deviation	7.24	0.15	0.14	7.20
10th percentile	21	0.42	0.41	20.5
90th percentile	41	0.82	0.79	39.5
Possible range	0–50		0–1	



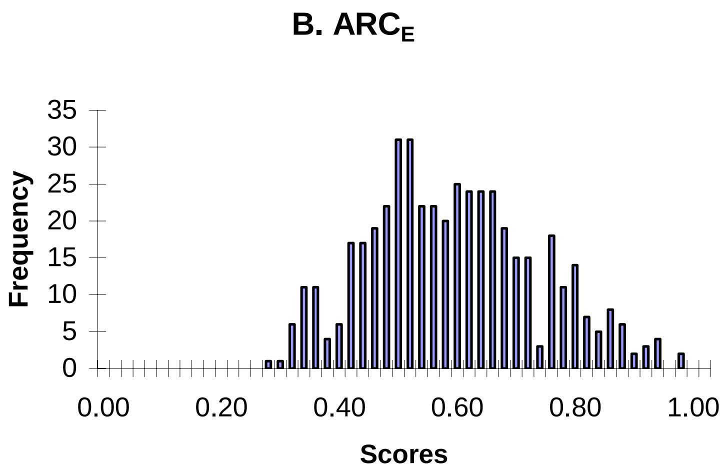


Figure 30 Frequency distributions of the Index of Stream Condition (ISC) and the Assessment of River Condition (ARC_E) scores for 470 stream reaches in Victoria, Australia.

At the largest scale of river basins, both indices also indicated similar overall condition, with basins to the west of the state considered to be in poorer condition and those in the east better condition (Figure 31). Therefore, these overall assessments, when the sample size is large, clearly suggest that confidence could be placed in the results from either index.

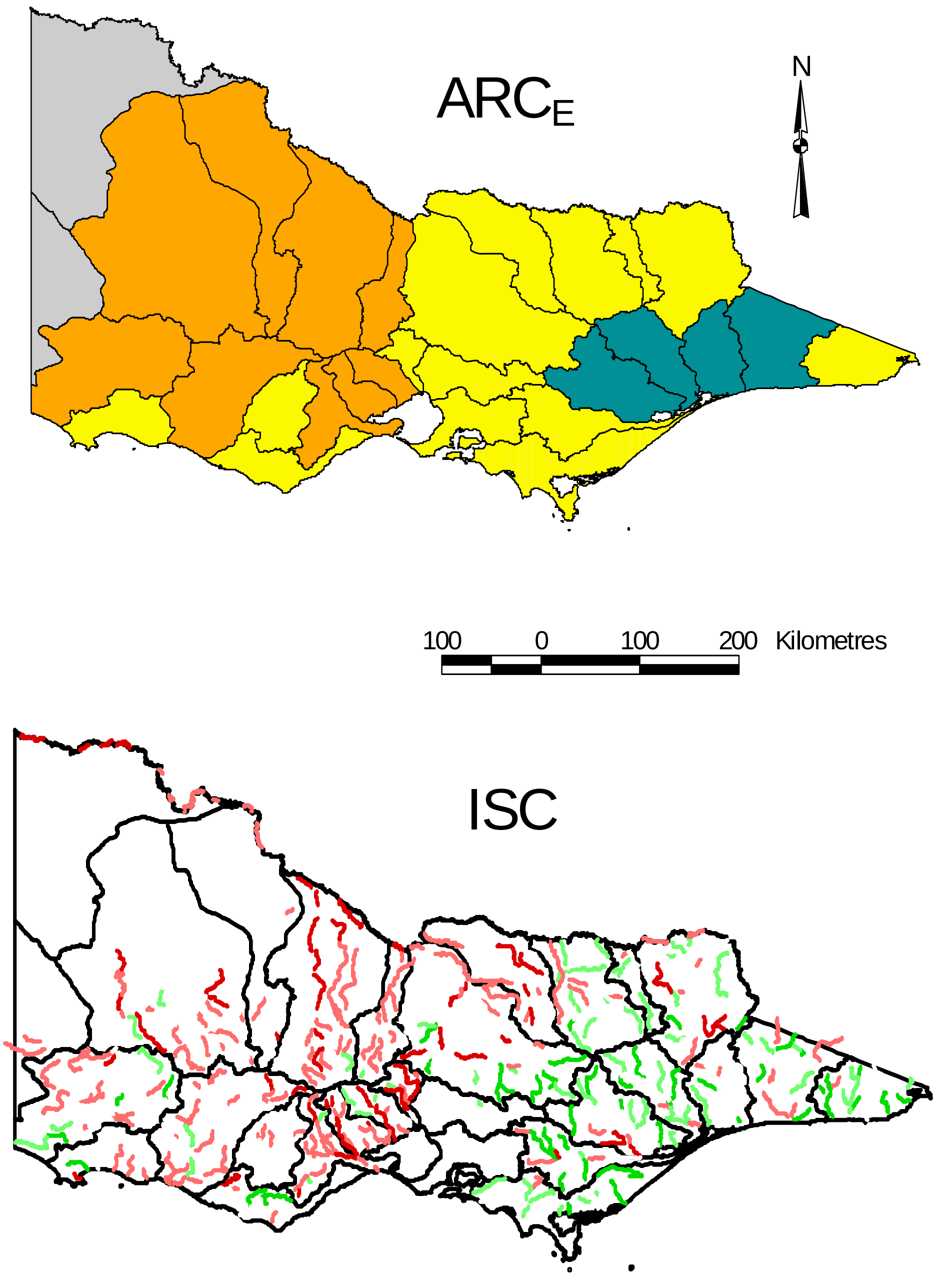


Figure 31 Comparison of the Assessment of River Condition (ARC$_E$) basin-scale assessment with Index of Stream Condition (ISC) reach scores. Note that the ISC does not aggregate reach scores to provide a basin-wide assessment.

ARC$_E$ = very poor condition, = poor condition, = good condition; ISC ~ = poor condition, ~ good condition

Given the relationships just presented, it was not surprising to find that the two indices were correlated, although the r^2 was not strong (Figure 32). A marked difference in the performance of the two indices can be seen in the relationship. The ARC_E tends to score higher than the ISC with reaches in poor condition and lower with reaches in better condition.

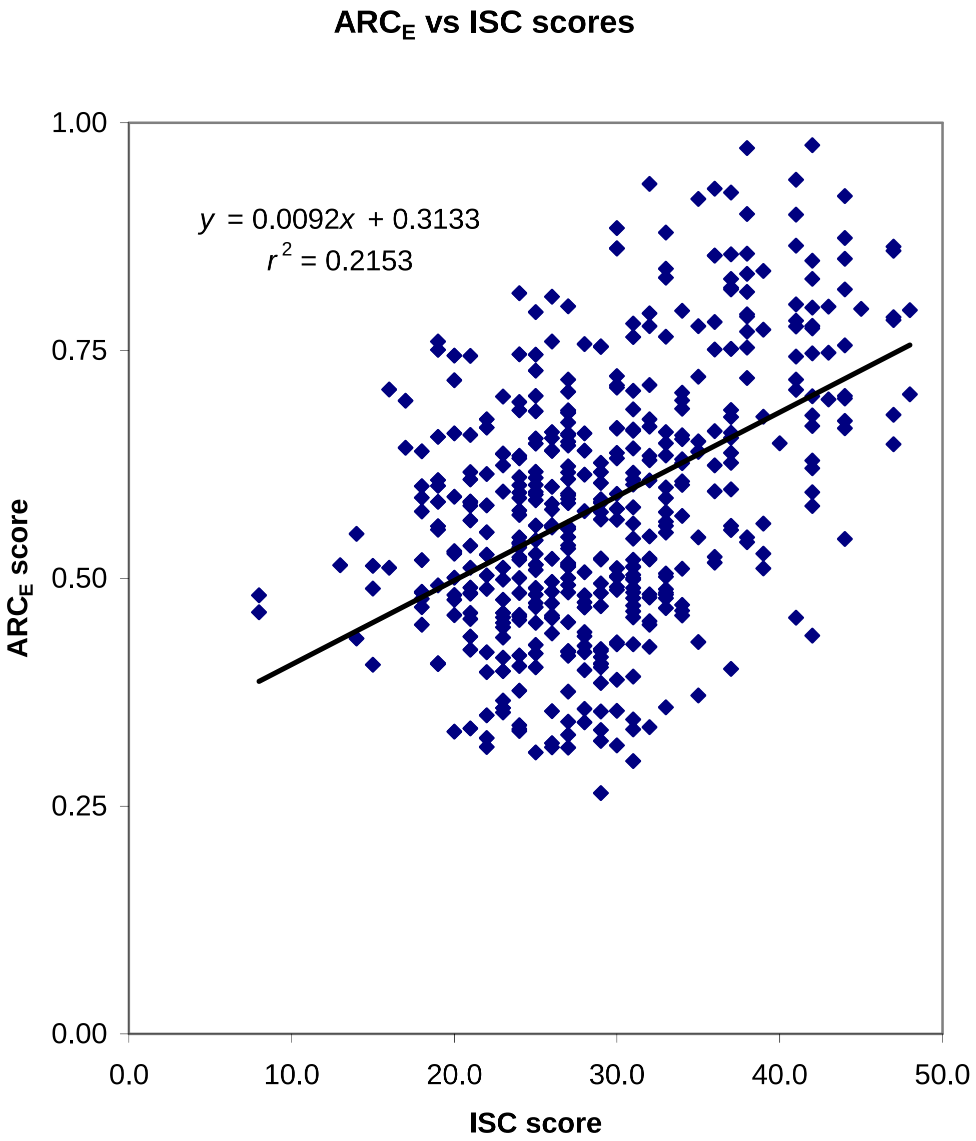


Figure 32 Relationship between Index of Stream Condition (ISC) and Assessment of River Condition (ARC_E) scores for 470 stream reaches in Victoria, Australia.

4.3.1 Sources of difference between the ARCE and ISC scores

Comparison of individual sites showed some marked difference between the ISC and ARC_E scores (Table 45). A useful measure of a significant difference between scores was deemed to be one where scores differed by one or more categories (category mismatches). Only 10 percent of the assessments failed this criterion (Table 45). A group of reaches in the centre of Victoria, from a lowland region of granitic soils impacted by poor land practices, was labelled "granite". A group of reaches in east of the State, from largely uncleared alpine catchments, was labelled "alpine". Differences between the ARC_E and ISC scores for these groups appeared to be the result of spatial differences in the ARC_E. The group mean of the ARC_E reaches in the granite group was significantly (t = 7.77, p<0.01) lower than that of the ARC_E of the alpine group. Similarly, each of the ARC_E sub-components in the granite group were significantly (t = 6.40, 4.03, 5.36, experiment-wide error rate p<0.01) lower than those in the alpine group. In contrast, neither the ISC score nor the scores of the ISC sub-components differed significantly between the two groups. Therefore, the ARC_E scores were indicating that, for these two groups of reaches, where mismatches tended to occur, river condition was much better in the mountains than in the agricultural regions in the centre of the state. The ISC scores were suggesting that both groups of reaches were in a similarly degraded condition.

Table 45 Summary of category mismatches between Index of Stream condition (ISC) and Assessment of River condition (ARC_E) for river reaches in Victoria, Australia. Index scores were compared after they were transformed to the same scale.

Category	Number	Percent of total comparisons (n = 470)
> 1 category difference (>25 percent difference)	49	10
1/2 to 1 category difference	155	33
< half category difference	266	57

Figure 33 shows the reaches in Victoria for which there was a mismatch in category. There appeared to be a group of sites in the eastern upland areas in which the ARC_E was >1 band higher than the ISC, and a group in the drier agricultural centre of the State in which the ISC scores were >1 band higher than the ARC_E.

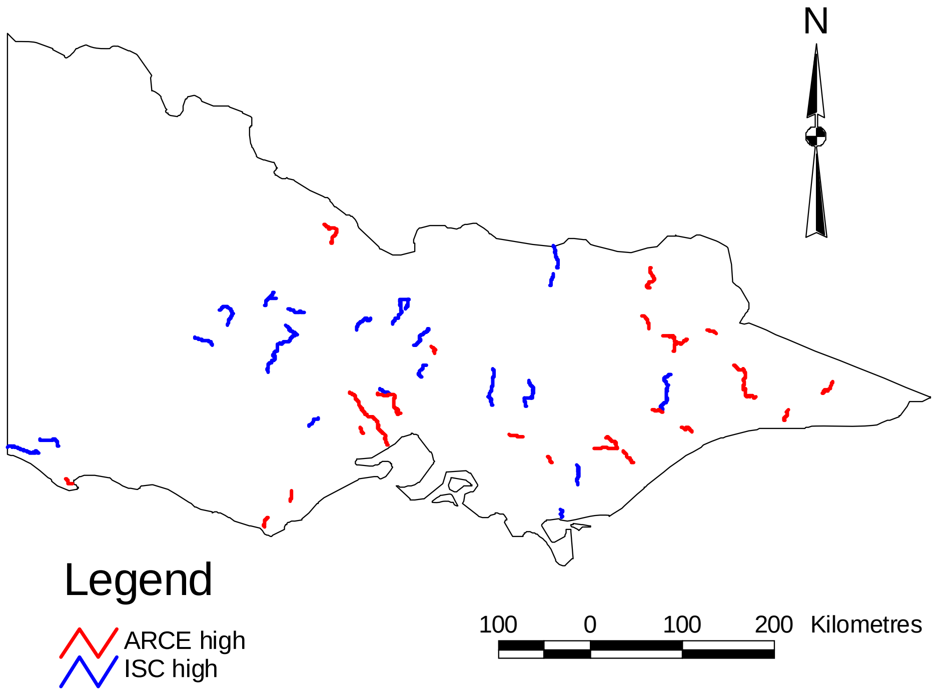


Figure 33 Reaches in Victoria that differed by more than one condition category for the Index of Stream Condition (ISC) and the Assessment of River Condition (ARC_E). Reaches in red are where the ARC_E is higher than the ISC; blue reaches, vice versa.

Inspection of features of the two sites that scored high on the ARC_E and low on the ISC clearly indicated degradation of the riparian zone at both sites (Figure 34). These sites provide examples of where the finer scale measured data are more appropriate than the coarser, remotely sensed data for riparian vegetation. The Kiewa River has a riparian zone of willows, some of which have been recently removed, and the remotely sensed data used in the ARC_E would not have picked up this change or that the riparian vegetation was an introduced species. Conversely, the riparian vegetation along Bet Bet Creek had been degraded for some time and was recorded as degraded by the ARC_E. In such circumstances, a conclusion on which index to use is straightforward.

Figure 34 Kiewa River (left) from 'alpine' group and Bet Bet Creek (right) from 'granite' group both showing significant degradation in riparian zone.

There is a different lesson from inspection of the data for the granite group of streams. For these streams, the ARC_E scores were lower than the ISC scores, largely as a result of low water quality scores in the ARC_E. ARC_E water quality scores are modelled based on catchment characteristics and were available for each of the 13 reaches in this group. In contrast, ISC water quality scores are measured, and only two reaches had data. In this situation the ISC procedure requires extrapolation of missing data from other measures, such as the hydrological score, and is then used to calculate the ISC score. The ISC component scores for the granite group reaches were relatively high, which may have resulted in an unrealistic inflation of the ISC scores for these reaches. The mean ISC score for the granite reaches put them into the marginal–good category. The mean ARC_E score placed the reaches in the poor category. While the true condition of these reaches is unknown, it is unlikely that limnologists would place them in a good category, given the surrounding land uses. The point from this example is that in some circumstances it is preferable to use comprehensive modelled values in preference to generalising from sparse site data.

4.4 Discussion

Protection, sustainable use, and restoration of rivers in good condition are important objectives of natural resource management (Gore 1985, Karr 1991, Rapport 1991). Information to meet these goals is needed at appropriate scales covering biological, chemical, and geomorphological features (Gore 1985, Boon et al. 1992, Brookes and Shields 1996). Degradation is often widespread and there is an urgent need to develop and implement strategies at the landscape scale (Hobbs and Norton 1996).

Decisions and strategies that are needed at the landscape scale must be based on information at a concomitant scale, but on-ground actions will often be undertaken locally and call for relevant information at that scale. Repair of ecosystems can be very expensive. The rehabilitation of the Florida everglades will cost nearly $8 billion of state and federal funds (Pelley 2000), whereas protection may well be considerably cheaper. It is essential for those involved in decisions (agencies, industries, and people) to understand what is in need of protection or repair, what has been damaged, and how bad a state it might be in.

As noted by Hobbs and Norton (1996), the first step in rehabilitation is identification of the problem, then, following implementation of a strategy, an assessment of the likelihood of success. Ecological assessment methods are necessary for these purposes and they have been generally developed with similar goals in mind. While it is important that relevant components of the environment are assessed at appropriate scales, the complexity of ecosystem responses makes it likely that no one set of measurements will cover all aspects. When the stakes are high and data are available from several sources, it makes sense to make the best use of all the information to hand, and not get bogged down in the minute details of each method's pros and cons.

Because our legal system is adversarial, this disposition spills over to many debates, and so the use of information from different sources by various parties will typically include criticism rather than accommodation. Real-estate developers tend to have an interest in showing that possible environmental effects of their activities will be for the better, whereas conservationists will tend to make things look worse. To find a workable solution, governments try to find certainty in the information pertaining to the issue. Unfortunately, waiting for certainty usually results in a stalemate until environmental damage becomes extreme and obvious to all. At this extreme stage, the costs of management may be extremely high. The thesis being put forward here is that it makes economic and ecological sense to err on the side of caution and that one way of achieving this is to devise a system for combining information from different sources, looking for common ground rather than differences.

The Index of Stream Condition (ISC, Ladson 1996) and the Assessment of River Condition (ARC, Norris et al*.* 2001) are two methods built on similar philosophies that have been developed with the aim of providing information for managing rivers. Differences in local assessments provided by each method (e.g. Table 45, Figure 33) have threatened to undermine each. The potential exists for arguments to develop to the point where each method can be used to discredit the other.

However, comparison of overall assessments by both methods for a large number of river reaches has revealed that the statistical distribution of the assessments is nearly identical (Table 45, Figure 33). Not surprisingly, the ISC and ARC_E are correlated (Figure 32), demonstrating that they are each pointing to the same overall assessment of condition. Admittedly, the correlation is not strong but this can be accounted for by differences in the sub-components of each index and the spatial differences in the way they are measured and compiled. When the condition assessments for these reaches were mapped (Figure 32), the overall conclusions were the same.

At the landscape scale, both methods deliver the same information and results from either can be confidently used. If it is necessary to choose one method, the choice at this scale will be determined by features such as cost, efficiency, presentation, ability to update, and completeness of coverage. The ARC_E relies partly on modelled and remotely sensed data, while the ISC depends on on-site measurements. Therefore, at the large scale of a whole state, or river basins, a sensible approach may be to use the ARC_E but to add assessments from the ISC in very flat areas where run-off models may not work well. Other data gaps may be filled in a similar way.

Differences between the two indices become apparent at the reach scale, and it is here that the evidence for the components of each index provide useful information for immediate on-ground management decisions. We know that all assessment methods have errors associated with them. The ISC provides reach assessments based on limited site measurements and here within-reach variability adds to within-site or transect error (Ladson et al. 1996). Obviously, the modelling approaches adopted in the ARC_E, such as erosion rates, are also subject to error (Norris et al. 2001). The scale of assessment also affects accuracy. For example, the ISC channel form assessment for a reach is based on spot measures only concerned with the channel itself, while the ARC_E uses a detailed model for the whole reach and the catchment draining into it. Therefore, care must be taken in accepting, or rejecting, assessments based on one index or the other and, given the differences in the way assessments are arrived at, each may provide useful information.

In nearly 60 percent of the 470 reaches compared, either index would have given essentially the same assessment (Table 45), within the bounds of error of measurement. About 30 percent of reaches were within 12–25 percent of each score. In these cases, if the purpose of assessment is to protect the environment, it would be sensible to accept the lowest score and err on the side of caution. Commonly, assessments such as these are categorised to bands (e.g. AUSRIVAS, Simpson and Norris 1999) and accepting the lowest scoring index may cause difficulties in interpretation if they lie near a band boundary. In such cases the condition rating will vary even though the scores are little different. Nevertheless, the principle of erring on the side of caution to protect the environment should still apply.

Only 10 percent of the 470 compared reaches differed by more than 25 percent (Table 45), or by the width of a band adopted for management (Ladson et al. 1996). These reaches deserve special consideration. Examination of the reach and of the information used in the index will usually reveal a clear reason for the discrepancy. The examples given here (Figure 34) of riparian degradation in the Kiewa River (not accurately assessed by the ARC_E because it was recent and involved exotic vegetation) and in Bet Bet Creek (where land use degradation led to an extensively degraded riparian zone) serve to make the point. In these cases the reasons for discrepancies are clear and the second assessment provides more information on which to base a decision. In the end, we have added confidence that the right outcome has been reached.

In the example provided here, the ARC_E is a component in a national assessment for reporting river condition (Norris et al. 2001). It emerged as a protocol by which the results from river assessments at the state or regional level could be incorporated into the national assessment, thereby augmenting, rather than detracting from it. No doubt this will strengthen the results of the Assessment of River Condition. The best available information will be able to be incorporated from the local, regional, and state levels without limiting the scope of the national assessment.

4.5 Conclusion

The case study presented here gives a general protocol for dealing with situations in which different measures have been used to assess river condition. The parameters governing the situation are that:

- The measures first need to be examined to ensure that they are similar enough to be jointly considered. The nature of the measures used, the spatial scale represented, or the purpose of assessments may preclude their comparison.
- The perspective of the evaluation needs to be established. Commonly, a more recent assessment will be evaluated in relation to an older assessment, or a more global assessment in relation to a regional assessment. In each instance there needs to be clarity on the flexibility of each system to accommodate change based on information from the other approach. For example, one assessment may be capable of incorporating information from a previous assessment, but not vice versa.
- Initially, a broad-scale assessment should be conducted to investigate whether there is concordance at large spatial scales and for overarching indices.
- The assessments should then be compared at the smallest valid scale (commonly, reach).
    - In cases where either assessment does not report a value for a particular river reach, then the assessment that has recorded a result will be used for that reach.
    - In cases where there are two assessments for a reach, it is worth considering whether any difference is significant in terms of management response (for example, is the reach assessed to be in a different category?).
- In the event of a significant difference between the assessments:
    - Where scores differ by less than 10 percent of their value (or some level appropriate to known or estimated errors), the most degraded assessment should be adopted (conservative or precautionary approach).
    - Where results differ by more than 10 percent (or as defined above by the errors) then a case-by-case review should be undertaken against underlying data and other relevant information before ascribing the river reach to a condition range.

We hope the above protocol might be useful in similar situations for making a general assessment of river conditions.

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