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The Ecological Elements Method for adjusting the Murray–Darling Basin Plan Sustainable Diversion Limit

Overview of method development and evaluation

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Executive summary

The Murray–Darling Basin is one of Australia's premier environmental assets, and is a vital resource for Australian agriculture, industry and local communities. The Australian federal and Basin state governments are committed to the Murray–Darling Basin Plan to protect this asset and ensure it is managed sustainably.

Adjusting sustainable diversion limits

The Basin Plan (MDBA, 2012) aims to achieve a healthy, sustainable, working Basin by balancing environmental, economic and social considerations. A key component of the plan is 'sustainable diversion limits' (SDLs). These are the maximum amount of surface and groundwater that can be taken from the Basin for agricultural and human consumptive use. The Murray–Darling Basin Authority (MDBA) estimated that the environmentally sustainable level of take is 10,873 gigalitres per year (GL/y), averaged over the long term. This has been set as the current SDL. This is, on average, 2,750 GL/y less than what was used in the Basin in June 2009.

The Basin Plan allows SDLs to be increased or decreased (within limits) as long as environmental, social and economic outcomes are maintained or improved. SDLs can be increased if changes to infrastructure or water management or river operating practices enable the same environmental outcomes to be achieved with less water.

The plan includes details of an 'environmental equivalence test' which the MDBA will use to assess whether environmental outcomes are maintained if the SDL is increased. CSIRO has developed a method to test the environmental equivalence of potential SDL adjustments — the Ecological Elements Method. The Ecological Elements Method compares environmental outcomes at the regional scale for benchmark and SDL-adjusted scenarios. The test requires the region environmental outcome score for the SDL-adjusted scenario to be equivalent or higher than the score for the benchmark scenario. The region is the southern connected Basin of the Murray-Darling Basin.

Developing and using the Ecological Elements Method

A CSIRO-led team has developed the Ecological Elements Method over two years. The method uses 12 elements from three ecological classes: vegetation, waterbirds and fish. It takes into account the life cycles, breeding and recruitment requirements to define stress and recovery times for each ecological element (expressed as preference curves). The development of the method involved developing the preference curves and rules which relate ecological response to changes in flow, metrics for weighting environmental significance and rules for combining scores to provide an aggregate environmental outcome score at the region scale. The method was based on published literature sources and the expert knowledge of scientists and consultants engaged as part of the CSIRO-led team. It also took account of input from an independent review panel, Basin governments, and the MDBA. The method is consistent with requirements of the Basin Plan (Chapter 7 and Schedule 6), including that the method be independently reviewed. An independent panel of scientists have reviewed the method at key stages throughout the method development and subsequent trial (Jones *et al.* 2014; Jones *et al.* 2015).

(See also *Development of the Murray–Darling Basin Plan SDL Adjustment Ecological Elements Method,* CSIRO, 2014)

Trialling and reviewing the Ecological Elements Method

Following an initial testing phase on two reaches in the River Murray, the MDBA trialled the method over all reaches in the southern connected region. The CSIRO-led team designed a program to test the trial results, reviewed the trial implementation for consistency and fidelity with the Ecological Elements Method, and assessed whether ecological outcome scores are 'ecologically meaningful' at local and regional scales (i.e. scientifically justifiable and fit-for-purpose). CSIRO also examined scaling and sensitivity issues.

(See also *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

Conclusion

Overall, the review of the trial implementation found that *the method as described and implemented is considered scientifically rigorous, compliant with Schedule 6 of the Basin Plan and an appropriate balance between sensitivity and uncertainty.*

It found that the Ecological Elements Method can be used to assess environmental equivalence of potential SDL adjustments.

The MDBA will ultimately decide if the method is fit-for-purpose to assess an SDL adjustment, taking into close account the advice of the CSIRO-led team, Basin governments and the Independent Review Panel.

Recommendations

The CSIRO-led team review noted that it is important that scores are used only to test environmental equivalence for a management purpose, which is determining an SDL adjustment as per the Basin Plan. The method cannot be used to compare absolute scores between ecological elements, between ecological classes or between reaches. This is because the absolute scores are only meaningful when compared to scores developed from the same base assumptions (reach, ecological element, etc). Only difference scores – comparisons between benchmark and SDL-adjusted scenarios – are to be compared. The scores cannot be used to assess ecological condition but only to assess environmental equivalence.

The review provided recommendations to clarify aspects of the method that were open to interpretation, and to make minor revisions to the method as informed by further testing. These revisions included recommendations on the spatial information used to inform area weighting, the provision of additional waterbird rules, and revisions to existing rules and preference curves. It is recommended that MDBA implement these refinements to the method before formal assessment of SDL adjustments in 2016.

The review also recommended that any region scores and equivalence test outcomes be accompanied by additional reporting of changes to reach, ecological class and ecological element scores compared to benchmark so that trade-offs are made clear.

River Murray in South Australia. ***Photo: Ian Overton***

1 Adjusting sustainable diversion limits

The Murray–Darling Basin Plan, adopted by the Australian Government in November 2012, aims to achieve a healthy, sustainable, working Basin by balancing environmental, economic and social considerations. The plan provides a coordinated approach to water use across the Basin's four states and the ACT.

1.1 What are sustainable diversion limits?

The Murray–Darling Basin Plan sets a limit on the amount of water that can be taken from the Basin's rivers for consumptive use. A 'sustainable diversion limit' (SDL) is the amount of water that can be taken for town water supplies, industry, agriculture and other human or 'consumptive' uses, while still ensuring there is enough water to sustain healthy river and groundwater systems. Ensuring a balance between the water needs of communities, industries and the environment is key to achieving a healthy, working Basin.

The Basin Plan sets a surface water SDL for each catchment in the Basin, as well as an overall limit for the Basin as a whole. There are also SDLs set for groundwater.

SDLs were set to balance environmental, economic and social outcomes, taking into account current science, socio-economic knowledge, and system constraints that may limit flows. MDBA has determined that 10,873 GL/y, averaged over the long term, is an environmentally sustainable level of take across the Basin. This is a reduction of 2,750 GL/y of water over a long-term average from the 2009 baseline diversion limit of 13,623 GL/y. Water returned to the environment will be used to maintain and improve the health of Basin rivers, lakes, major wetlands and floodplains as well as important habitats for animals and plants that rely on the Basin's rivers.

(See also *Sustainable diversion limits,* MDBA, www.mdba.gov.au/what-we-do/water-planning/sdl)

1.2 What is the sustainable diversion limit adjustment?

The Basin Plan provides an opportunity to change SDLs up or down to achieve better outcomes for communities, industries and the environment. The 'SDL adjustment' allows the MDBA to propose changes to the SDL in the Basin Plan in response to efficiency or supply measures.

Efficiency measures are projects that decrease the quantity of water required for consumptive use. An example would be improving the efficiency of farm irrigation. The Australian Government has announced a funding program to recover an additional 450 GL of water through such projects.

This report deals with supply measures and specifically the environmental equivalence test required for the SDLs to be increased.

Supply measures are environmental works or changes to river operations or practices that enable the same environmental outcomes to be achieved with less water. An example is the installation of infrastructure such as regulators and levee banks on a floodplain that allow a wetland to be inundated using less water than would be needed in a typical 'overbank' flooding event.

Supply measures must pass the environmental equivalence test. If projects to implement supply measures can be found by Basin states to achieve equivalent environmental outcomes to the Basin Plan, then the SDL can be increased.

In addition, an SDL adjustment for supply measures can also only go ahead under the Basin Plan if:

- the overall scale of net change to the Basin-wide SDL is no more than 5%.
- there are no detrimental impacts to the reliability of supply for consumptive water users.
- selected Basin Plan flow and environmental outcomes are met (specified as 'limits of change' within the Basin Plan).

Basin states will develop a package of supply measures to be considered by the MDBA for SDL adjustment. MDBA will then assess the package using the Ecological Elements Method to determine whether there should be a one-off adjustment to the SDLs. The adjustment will be informed by public feedback and will need to be approved by the Minister and Parliament.

States will have until 2019 to incorporate any adjustments to SDLs in their water resource plans. All SDL adjustment projects will need to be completed by 2024. At this time, MDBA will review the projects to reconcile the anticipated outcomes with the achieved outcomes and make any final SDL adjustments accordingly.

1.3 Why is the sustainable diversion limit adjustment important?

The SDL adjustment provides additional flexibility to achieve a better balance between social, economic and environmental factors in the Basin and help to protect the Basin over the longer term.

Recognising that an opportunity exists to build further on the environmental, social and economic outcomes contained in the Basin Plan, Basin water ministers asked that a mechanism to adjust the sustainable diversion limits be incorporated into the Basin Plan when it was being drafted.

The SDL adjustment recognises that the Murray–Darling Basin is a complex system and that environmental, economic and social needs must be balanced. It also recognises that, although the environmentally sustainable level of take in the Basin Plan has been estimated based on current conditions, improvements in technology or infrastructure may allow the same outcomes to be achieved using less water. Supply measures would allow the 2,750 GL recovery target to be reduced, thereby reducing the social and economic impacts of water recovery.

2 Developing and using the Ecological Elements Method

2.1 Introduction

The sustainable diversion limits (SDLs) in the Murray–Darling Basin Plan balance environmental, economic and social needs. Any adjustment to SDLs must deliver equivalent or better environmental, economic and social outcomes.

(See also *Development of the Murray–Darling Basin Plan SDL Adjustment Ecological Elements Method,* CSIRO, 2014)

2.2 How do we make sure Sustainable Diversion Limit adjustments still meet Basin needs?

The environmental, economic and social outcomes achieved from the 2,750 GL recovery target in the Murray–Darling Basin Plan are the benchmark against which proposals for SDL adjustment will be assessed. If supply projects can be found by Basin states to achieve equivalent environmental outcomes in the Basin Plan, but using less water, then the SDL can be increased and therefore more water diverted for consumptive use. To ensure that these projects still meet the environmental outcomes of the Basin Plan, they will need to undergo science-based testing.

The Basin Plan outlines the requirements for an ‘environmental equivalence test’ to assess whether SDL adjustment proposals will achieve equivalent environmental outcomes.

The test compares regional environmental outcome scores for vegetation, waterbirds and fish for:

- the 2,750 GL/yr long-term average reduction in diversions under the Basin Plan (benchmark scenario).
- a package of proposed supply measures (SDL-adjusted scenario).

The SDL adjustment can only go ahead if the package of supply measures produces at least the same region environmental outcome score as the benchmark (and other safeguards outlined in Section 1.2 are also met) (Figure 1).

Although overall region environmental outcome scores must be maintained, the test does allow for trade-offs between selected outcomes. These can be trade-offs within and/or between river reaches (e.g. improved outcomes in one reach and decreased outcomes in another reach), or a trade-off between different ecological classes and elements (e.g. improved outcomes for plants and decreased outcomes for fish). The limits of change in the default method in the Basin Plan limit extreme hydrological changes.

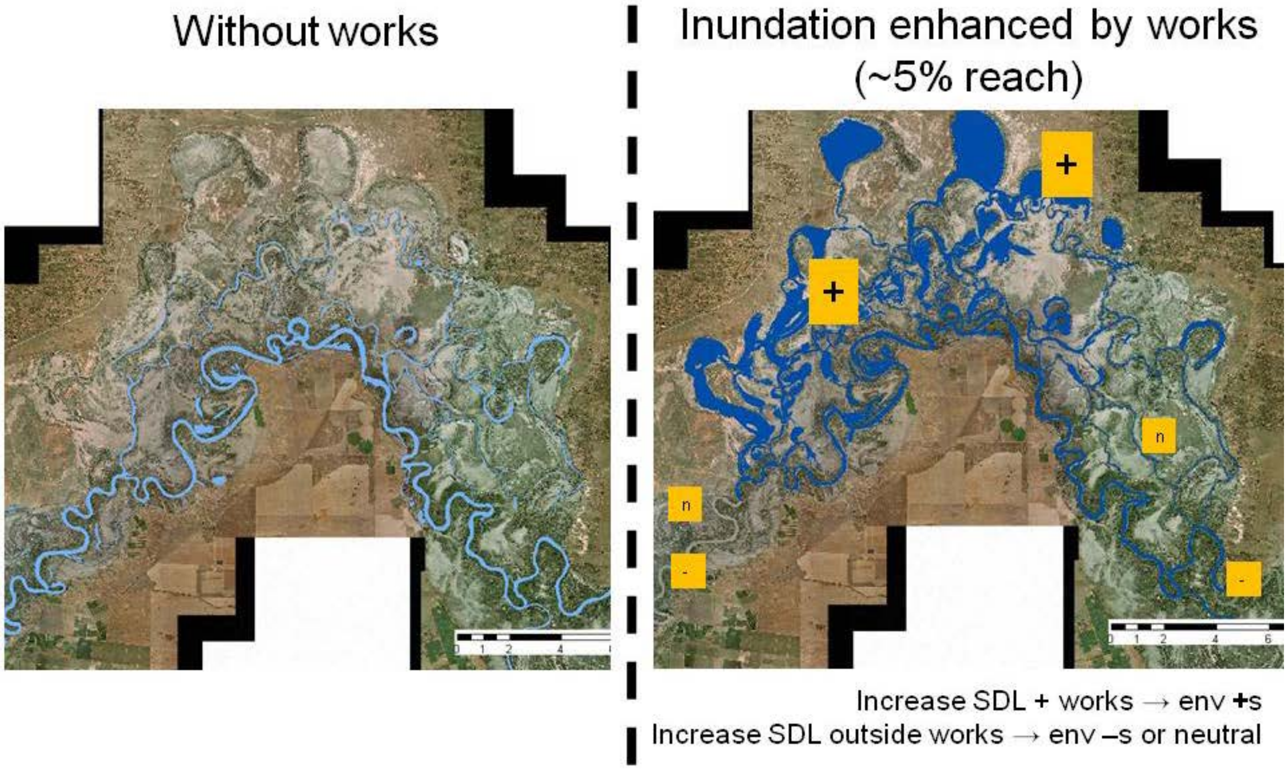

Figure 1 The Chowilla floodplain showing the extent of inundation from a low flow compared with the extent of inundation from the same flow but using an environmental regulator. Parts of the floodplain will score environmental benefits while other areas will score lower due to the SDL adjustment.

(See also *Fact sheet: environmental equivalence test,* MDBA, 2014)

2.3 Why is an environmental equivalence test required?

An environmental equivalence test is a Basin Plan requirement for the assessment of supply measures.

Supply measures can include environmental works and measures that allow inundation of part of the natural floodplain through structures like weirs and levees, as well as changes to the rules and policies for operating the river system that could for example reduce losses.

Such projects coupled with higher SDLs are likely to lead to trade-offs between environmental outcomes. For example, a works project may enable the environmental outcomes to be improved at a particular site. However, the higher SDLs means there is less water available for the environment and that some of overbank environmental flow events will not be achieved to the same extent.

Hence, an environmental outcomes assessment method is required that can assess whether overall environmental equivalence is still maintained, despite the trade-offs.

2.4 What is the Ecological Elements Method?

The Ecological Elements Method is the basis of the assessment of environmental equivalence.

Schedule 6 of the Basin Plan prescribes the default method for assessing the relative environmental outcomes of a flow regime that includes a proposed suite of supply measures against benchmark environmental outcomes established by the Basin Plan. The assessment is to be made on the southern connected Basin of the Murray–Darling Basin (Figure 2), where supply measures will be brought forward by Basin states for assessment of their SDL adjustment potential.

Schedule 6 of the Basin Plan prescribes how the SDL adjustment for supply measures needs to be assessed. The potential increase in SDLs must be calculated using a comparative assessment method, with the benchmark model run representing 2,750 GL/y annual average reduction in diversions, and the associated environmental benefits, as the reference point for the comparison.

The Basin Plan requires that the assessment is based upon a suite of science-based, independently reviewed, fit-for-purpose preference curves. These curves score an environmental outcome based on the relationship between an environmental outcome and flow statistics, such as flood frequency or dry spell. The regional assessment is then based on the combined scores of multiple preference curves for multiple reaches.

The CSIRO-led team was commissioned to develop the ecological elements of this default method. The CSIRO-led project initially considered a large number of ecological elements, and through the project this was narrowed to 12 ecological elements from three ecological classes: six vegetation, four waterbird, and two fish species or functional groups.

The Ecological Elements Method is based on best available science, expert opinion and published literature and is compliant with the Basin Plan's default method. The method is also compatible with the models and tools originally applied for determining the environmentally sustainable level of take. The method is based upon the same hydrological models that underpinned the Basin Plan.

All models make a number of assumptions and are constrained in the detail that can be included. Constraints to the model used in the Ecological Elements Method, which were also constraints in the environmentally sustainable level of take method, include:

- a simple representation of flow inputs is used, meaning that continuous periods of inundation and partial flow events cannot be represented.
- other water sources and other system influences (e.g. climatic influences, pests and diseases, land management) are not included.
- ecological elements do not exhaustively represent the species diversity and processes of the southern Murray–Darling Basin.
- response relationships are limited in how they represent fine-scale responses.

The method determines an environmental outcome score that can be used to compare hydrological modelling scenarios between a benchmark and an adjusted flow incorporating supply measures. It does not attempt to model the actual health of ecological elements that may be identified in the field. The method is therefore not a condition assessment.

(See also Sections 1.3 and 1.4, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

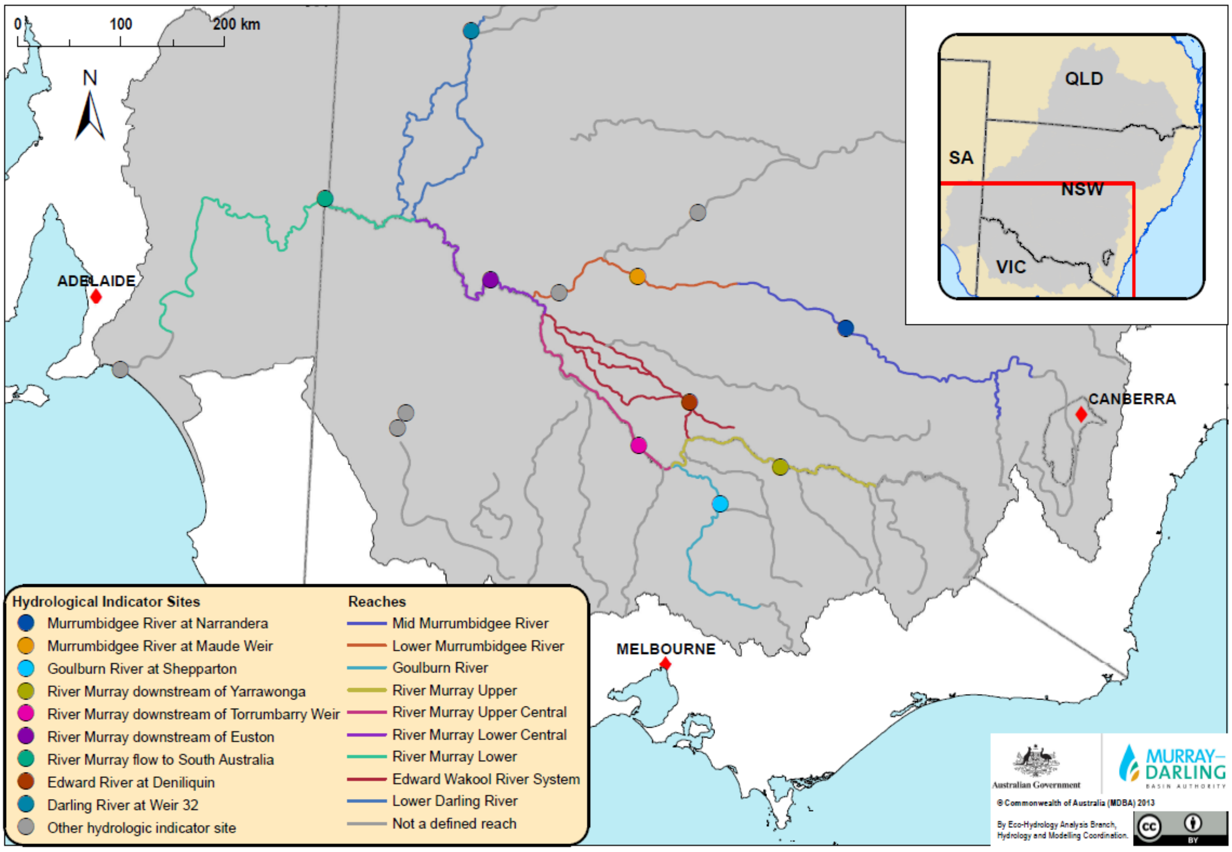

Figure 2 The hydrologic indicator sites and longitudinal extent of associated reaches to be used in the Ecological Elements Method for the southern Basin

2.5 What does the Ecological Elements Method consider?

Twelve ecological elements from three different ecological classes (vegetation, waterbirds, and fish) were selected to represent the range of biotic flow requirements for scoring ecosystem responses to changes in flow (Table 1). The ecological elements were chosen because they:

- represent the ecology of floodplains of the southern Murray–Darling Basin.
- cover a broad range of species and processes that respond to flow.
- have sufficient data and scientific advice about their ecology and relationships.

The ecological elements selected cover the spectrum of flow dependencies, such as life history, habitat and connectivity requirements. This coverage is important because flow pulses and overbank flooding affect different ecological elements in different ways (e.g. triggering growth, reproduction, dispersal and migration processes), and provide opportunities to improve condition so that the element can build resilience for dry periods. Flood-dependent ecological communities have adapted to flood regime characteristics such as frequency, sequencing, timing and duration, and river regulation can change these characteristics.

The flow regime is assessed using site-specific flow indicators (SFIs) used during development of the Basin Plan. An SFI is a simple representation of the hydrological habitat produced by river flows. It includes a flow magnitude, a duration and a season of inundation. The SFIs are discrete flow bands representing different parts of the floodplain. Other hydrological factors such as rate of rise and fall, water quality such as temperature, turbidity and salinity, and multi-year flooding are not considered by the SFIs.

The Ecological Elements Method compares the influence of flow only (as represented by SFIs), all other influences being equal. It is acknowledged that there may be other influences on environmental outcomes, such as the prior condition of the catchment, access to groundwater, soil types, and accumulated run-off, but these are not included and do not change between scenarios. It is also worth noting that the Ecological

Elements Method does not score the entire flow regime. That is, partial flow events that do not satisfy the particular characteristics of a SFI are not part of the scoring method (e.g. a flow event might achieve the desired flow magnitude or volume but not for the desired duration or at the wrong time of the year).

Table 1 Ecological class and elements used in the Ecological Elements Method

Ecological class	Ecological element
Vegetation	Benthic herblands (macrophytes, reeds)
	Tall grasslands, sedgelands and rushlands
	Shrublands
	River red gum forests
	River red gum woodlands
	Black box forests and woodlands
Waterbirds	General health and abundance – all species
	General health — wetland bird species (bitterns, crakes and rails)
	Breeding – colonial nesting species
	Breeding – other waterbirds
Fish	Short-lived small-bodied species
	Long-lived large-bodied species

Ecological element responses for vegetation, fish and some waterbirds consider site changes to wet (flood) and dry events. Ecological responses for other waterbird elements incorporate larger spatial scales and take into account more than one flow band or SFI.

(See also Section 2.4, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

Ecological elements include vegetation, waterbirds and fish. *Photos: Ian Overton*

VEGETATION

Elements

Vegetation ecological elements were selected to represent the major riparian, floodplain and wetland communities that occur broadly across the southern Murray–Darling Basin. Preference was given to vegetation elements that have a wide distribution and that are perennial, relatively well known, and functionally important. Communities with restricted distributions (e.g. Moira grass) were not included in the method.

The selected elements for the method are:

- benthic herblands (macrophytes, reeds).
- tall grasslands, sedgelands and rushlands.
- Shrublands.
- river red gum forests.
- river red gum woodlands.
- black box forests and woodlands.

Collectively, these ecological elements span the range of water regimes occurring in floodplain and wetland habitats of the southern Murray–Darling Basin, and are relevant to all reaches. They allow whole-of-site evaluations to be made, as they cover a vertical range from lower and more frequently flooded habitats to higher and infrequently flooded habitats.

Approach

In the method used to determine the environmentally sustainable level of take, most of the hydrological indicator sites have an ecological target to *provide a flow regime which ensures the current extent of native vegetation of the riparian, floodplain and wetland communities is sustained in a healthy, dynamic and resilient condition.* This target shaped the approach for vegetation. Basin Plan objectives and the method used to determine the environmentally sustainable level of take were also considered.

Assessment considerations

Different species of vegetation differ in their response to inundation and drought. Recovery from dry spells is dependent on the degree of stress (i.e. length of time with no water) and the sequence of inundation events that allow vegetation to recover from a declined condition.

Under minor stress, above-ground plant parts (i.e. the canopy or foliage) are affected, showing yellowing, thinning or dieback. Vegetation readily recovers from minor stress, and in a relatively short time, because there has been little loss of plant parts and regenerative tissues are largely unaffected.

Under increased stress, other parts of the plant begin to be affected, such as roots. Critically, the tissues needed for growth begin to lose viability, and begin to die. Recovery from major stress means re-building structural tissues. This takes time and therefore requires favourable growing conditions over extended periods.

Stress and recovery do not necessarily progress at the same rates and these rates vary among ecological elements. For example, in highly stressed floodplain eucalypts the recovery pathway is longer than the stress pathway; in lignum shrublands, which are resistant to drought, the stress pathway is longer than the recovery pathway.

Therefore, the method for assessing vegetation ecological elements:

- takes a whole plant perspective (both above- and below-ground plant parts).
- includes diverse strategies for recovery (e.g. re-growth from below-ground parts, re-establishment of the canopy, asexual reproduction).
- includes diverse strategies for persistence (e.g. longevity, below-ground parts such as a rhizome).
- recognises that recovery to healthy condition depends on the prior condition.

Four condition states are used for vegetation ecological elements (*good* 0.9, *medium* 0.6, *poor* 0.3 and *critical* 0.1). (For floodplain eucalypts, there is an additional *intermediate* state in the recovery pathway, scored as 0.5.)

The ecological target of maintaining the '*current extent*' is interpreted as maintaining the presence of existing and established vegetation. Establishment of new individual plants from seed or other means requires hydrologic conditions that are different from those that maintain an established plant. These are not explicitly included in the Ecological Elements Method. It is assumed that vegetation in a healthy condition will successfully recruit.

(See also Section 2.6, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

WATERBIRDS

Elements

Waterbirds include a range of species with diverse diets, foraging and life history strategies. They are often grouped into two subclasses:

- colonial nesting waterbirds (e.g. Australian white ibis, cormorants, darters, eastern great egret, glossy ibis, herons, intermediate egret, pelicans, royal spoonbill, straw-necked ibis).
- non-colonial nesting waterbirds (e.g. crakes, ducks, grebes, rails, shorebirds, swans).

The groups selected to capture the breeding, foraging and survival requirements of both colonial and non-colonial nesting waterbirds are:

- general abundance and health – all waterbirds.
- general health – bitterns, crakes and rails.
- breeding – colonial nesting waterbirds.
- breeding – other waterbirds.

There is overlap between some of the ecological elements in terms of species and habitats. However, all the ecological elements are considered necessary and the overlap does not make these redundant as they address different aspects of the ecology.

Approach

In the method used to determine the environmentally sustainable level of take, the ecological target flow specifies the provision of *a flow regime which supports the habitat requirements of waterbirds and is conducive to successful breeding of colonial nesting waterbirds*. This target shaped the approach for waterbirds.

Assessment considerations

The cycle of wetting and drying on the floodplain is vital to the maintenance of healthy waterbird habitats, and hydrological variability encourages a diversity of wetland types and states, which in turn fosters diversity in waterbird species.

Waterbirds require habitat for both foraging and breeding, and flows are essential to maintain habitat.

Foraging, migratory shorebirds, such as the black-tailed godwit, Latham's snipe, shanks, stints and the sharp-tailed sandpiper, generally favour extensive areas of shallow water, variable water levels and muddy shorelines. Larger, overbank floods that inundate large parts of the floodplain and fill temporary wetlands will be beneficial for this group (as for colonial nesting waterbirds), with August–September (inward migration) and March–May (outward) being especially important periods.

In the method for assessing waterbird ecological elements, two habitat types were selected to represent foraging habitats: the broad floodplain habitat (targeting 'general abundance and health – all waterbirds') and reed, rush and sedge dominated habitats (targeting 'general health — bitterns, crakes and rails'). The hydrological needs of these two habitats differ. Broad floodplain habitats require a variable hydrological regime, characterised by an episodic occurrence of large floods. Reed, rush and sedge habitats prefer a more regular inundation but still with hydrological variability.

For breeding, different flow regimes are required for different species. Bitterns, crakes and rails require a short duration overbank flow. Colonial nesting waterbirds require extended flooding periods. More dispersed and uncommon species of waterbird with shorter breeding cycles require smaller spatial extents of flooding.

Colonial nesting waterbirds and non-colonial nesting waterbirds typically have different habitat and flow regime requirements. However, it is assumed that the longer-duration breeding requirements of colonial nesting waterbirds will satisfy the breeding requirements of most non-colonial nesters. Therefore, in deriving the preference curve and rule-based relationships, breeding of non-colonial nesters is considered to be inclusive of the entire waterbird ecological class in the scoring of ecological elements.

While the timeframe for a breeding event is a single year, waterbird foraging habitats need to be maintained over longer periods. The response relationships in the method focus on waterbird habitat between breeding events.

Preference curves were used to represent time-dependent site-dependent processes and prior conditions. Rule-based combinations were used to represent breeding outcomes, with an emphasis on prolonged durations.

(See also Section 2.5, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

FISH

Elements

The selected elements for the method are:

- short-lived small-bodied species (e.g. Australian smelt, bony bream, carp gudgeon, dwarf flat-headed gudgeon, flat-headed gudgeon, Murray hardyhead, Murray–Darling rainbow fish, purple-spotted gudgeon, unspecked hardyhead).
- long-lived large-bodied species (e.g. freshwater catfish, golden perch, Macquarie perch, Murray cod, spangled perch, trout cod).

Together, these two groups represent the range of life history, habitat requirements and diets displayed by native fish, and should therefore reflect the way in which different species would be expected to respond to changes in flood frequency and dry spells.

Approach

In the method used to determine the environmentally sustainable level of take, one of the ecological targets is *provision of a flow regime which supports the recruitment and populations of native, water-dependent species including fish and macroinvertebrates*. This target shaped the approach for fish. Basin Plan objectives and other aspects of the method used to determine the environmentally sustainable level of take were also considered.

Assessment considerations

Floods affect fish recruitment and populations by creating and maintaining habitat, by changing food availability, and by providing the breeding cues needed for some species (e.g. golden perch, silver perch). International research has demonstrated that loss of floods, through river regulation or otherwise, can have a significant effect on fish communities.

The response of different fish species to changes in flood frequency and dry spells depends strongly on their longevity.

Short-lived species typically survive for 3–4 years, and would be expected to undergo more rapid population declines during dry periods because reduced growth and survival during early life stages without flooding (from increased competition) will affect the size of the adult population more quickly.

In the Ecological Elements Method, response relationships for short-lived species use preference curves based on the following assumptions:

- some wetlands will persist as fish refuges on the floodplains.
- during long dry spells, all wetlands become dry and floodplain populations are extinguished.
- a proportion of the population will persist during long dry spells in the main river channel.
- recruitment after dry spells occurs via source water from the river channel.
- if a flow is successful, fish are able to move laterally onto the floodplain from the river channel.

Long-lived species can survive for several decades and will typically take longer to decline during dry periods, even though there will be marked changes in the age structure. They will also often be slower to recover following flood events, although there are some long-lived species such as carp and golden perch that may recover more rapidly (being highly fecund and producing many small eggs) when compared to species such as Murray cod and river blackfish (which produce a low number of large eggs).

Many studies separate long-lived species based on whether or not they require floods to spawn, both groups benefit from floods in terms of individual growth and overall population condition.

In the method, flooding is expected to improve both individual body condition and the overall age structure and population abundance. Population persistence can occur over relatively long periods without flooding, however population health declines with increases in dry spell durations.

(See also Section 2.7, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

2.6 How does the Ecological Elements Method test environmental equivalence?

The equivalence test is based upon the same hydrological models that underpinned the Basin Plan. The models are used to simulate the river flows under benchmark conditions and after implementation of the supply measures over 114 years. Achievement of each SFI is determined based on modelled river flows. Resulting annual time series, indicating for each year if the SFI was achieved (wet year) or not achieved (dry year), form the basis of the environmental outcomes scoring.

A regional score for environmental equivalence is calculated using the following steps.

1 Ecological element scores are generated for the benchmark scenario.

Ecological response relationships are developed for 12 ecological elements. These describe how ecological elements transition through a set of states or conditions given annual wet and dry sequences over a 114-year timeframe (1895–2009). Ecological outcomes are represented by a set of ecological states, which are assigned a numerical value for scoring (e.g. *good* 0.9, *medium* 0.6, *poor* 0.1 and *absent* 0.0). Response relationships are characterised using either rules (for example, see Table 2) or preference curves (for example, see Figure 3). The preference curves consider the starting ecological condition and determine the end ecological condition for a given wet or dry spell.

Using the response relationships as inputs, scores are calculated for each ecological element within an SFI by averaging the scores for each year in the time sequence. Figure 4 shows the resulting ecological element scores for river red gum woodlands using the relevant preference curves. This shows that the preference curves give sensible results. In wet years, conditions tend to be better for flood-dependent plants and therefore there are higher scores. In dry years, condition declines and therefore there are lower scores. For example, the 1950s was a very wet decade and there were high scores for all ecological elements.

Table 2 Rules-based recovery for wet periods for river red gum woodlands

Transition	Rule
Critical to *Intermediate*	Five (or more) wet years in 15 years
Poor to *Intermediate*	Three (or more) wet years in 9 years
Intermediate to *Good*	Two (or more) wet years in 7 years
Medium to *Good*	One wet year

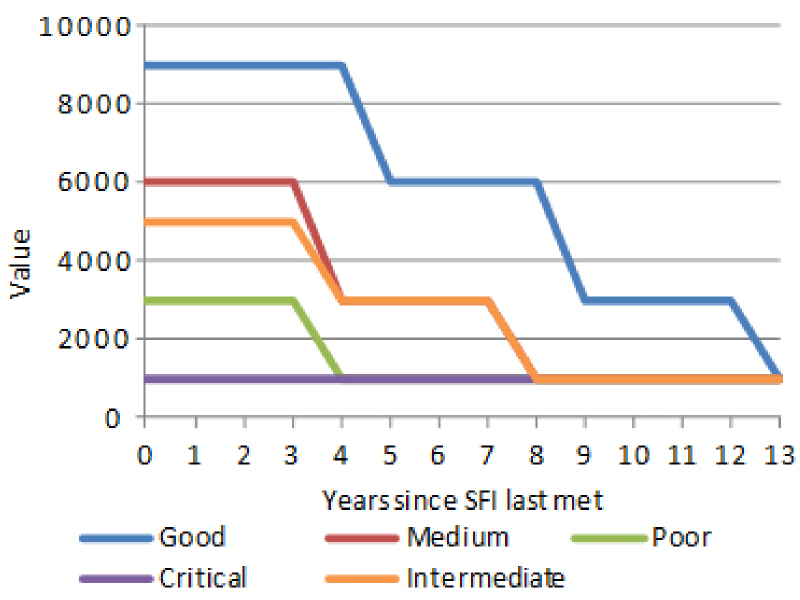

Figure 3 Default Ecological Elements Method dry spell preference curve for river red gum woodlands

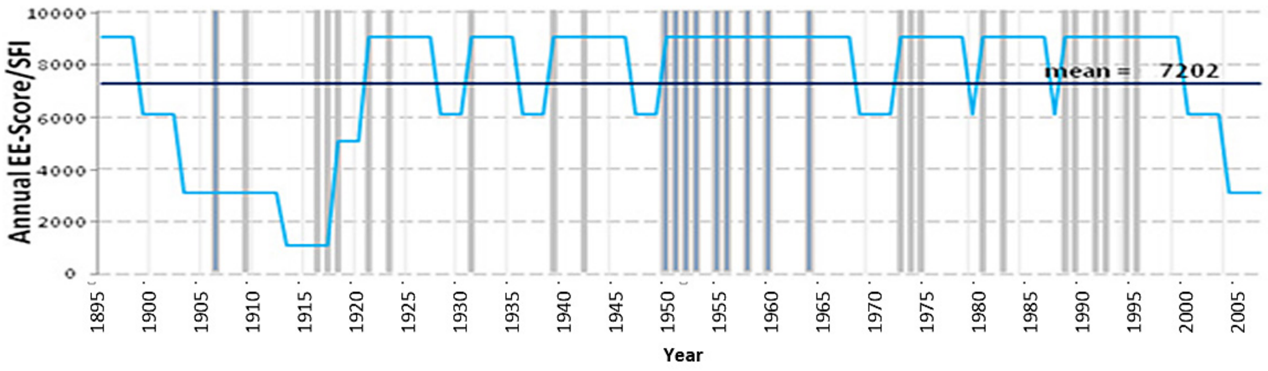

Figure 4 Environmental outcome scores for the river red gum woodlands ecological element. Benchmark scenario environmental outcome scores are shown for the 60,000 ML/d for 60 days SFI at Lower River Murray reach containing the Riverland–Chowilla Floodplain hydrologic indicator site. The grey vertical bars indicate the years when the SFI was achieved, the blue line shows the annual ecological element scores, with mean for whole 114 year hydrological modelling period shown as a black line (7,202).

2 The ecological element scores for the various SFIs are combined based on area weighting.

Ecological element scores for each SFI are area weighted by the proportional total reach area of the ecological element to calculate an ecological element score for each reach.

For example, if a particular SFI represents 20% of the total area of an ecological element within a reach such as river red gum forest, then the river red gum forest score for that SFI is multiplied by 0.2 to determine its proportional contribution to the river red gum forest reach score.

3 The scores are then combined into ecological class and reach scores before being combined to generate a region score.

The weighted ecological element scores are averaged to generate three ecological class scores per reach (vegetation, waterbirds and fish). Ecological class scores are then averaged to give a reach score (Figure 5).

Ecological elements within an ecological class are considered equal and are therefore equally weighted through the combination process to generate an average ecological class score. Each ecological class is considered equal and therefore equally weighted through combination to generate an average reach score.

The reach scores are then averaged to give a region environmental outcome score for the southern connected Murray–Darling Basin. The region benchmark environmental outcome score is the basis for the environmental equivalence test against which a SDL-adjusted scenario will be assessed. Scores range from 0 to 10,000.

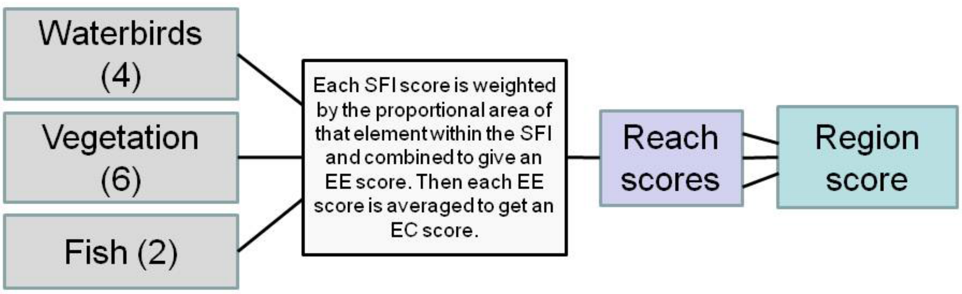

Figure 5 Aggregation steps in the Ecological Elements Method to derive a region scale environmental outcome score

4 In a parallel process, ecological element scores are generated for the SDL-adjusted scenario.
For the scenario that examines the impact of the proposed supply measures, if specific areas are affected by the supply measures (e.g. environmental works which influence a particular part of the floodplain) these are scored separately to the rest of the reach and then scores generated for both inside works affected

areas and outside works areas are combined (in proportion to their relative areas) to generate the reach score. Any reduction in the ability to achieve SFIs through run-of-river flows as a result of increasing the SDL (i.e. the adjustment volume) is explicitly scored in this scenario.

5 The scores for the SDL-adjusted scenario are similarly combined into reach and region scores.

6 The benchmark and SDL-adjusted region scores are compared.

To assess environmental equivalence, the region environmental outcome score calculated for the benchmark scenario is compared to the region environmental outcome score for the SDL-adjusted scenario. An SDL adjustment can only occur if the environmental outcome score for the SDL-adjusted scenario is the same or higher than the benchmark score.

The equivalence test is modelled with different SDL adjustments to determine the maximum adjustment amount (Figure 6). An iterative modelling process is applied, whereby the package of proposed supply measures is included in the hydrological models and an estimate of the SDL adjustment volume is made. If the environmental outcomes of the scenario are found to be equivalent to benchmark (and all other requirements are also met), a higher SDL adjustment volume is modelled, until the maximum supply contribution volume is determined.

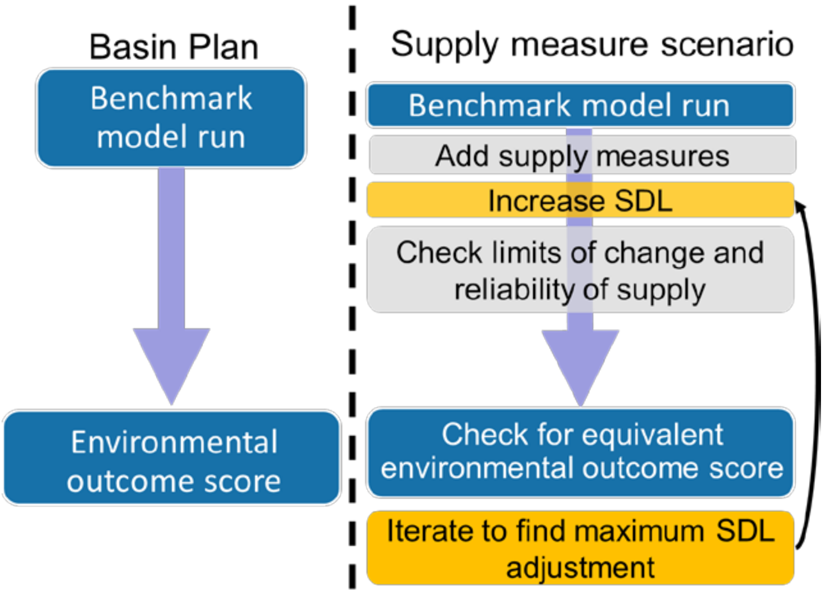

Figure 6 Key steps in the assessment of the supply contribution

(See also Section 2.2, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

3 Trialling and reviewing the Ecological Elements Method

3.1 Introduction

During the method development phase, initial analysis of demonstration reaches and sensitivity testing were undertaken to assess the performance of the method. This testing showed that the method produces reach-scale environmental outcome scores that are sufficiently sensitive to changes in flow regime. Environmental outcome scores responded in a logical and expected way based on the differences in the inter-annual sequences of wetting and drying in the benchmark and sustainable diversion limit (SDL) adjusted scenarios. The assessments associated with method development provided confidence that the method is suitable for supporting implementation of the SDL adjustment mechanism, however it remained untested at the broader region scale at which the environmental equivalence test is to be applied.

The Murray–Darling Basin Authority (MDBA) produced a tool for calculating environmental outcome scores using the Ecological Elements Method in a consistent and repeatable way. This is a key part of the framework for assessing SDL adjustments. The scoring tool was used to apply the Ecological Elements Method in a trial implementation across the entire southern Basin region. This involved calculating a benchmark environmental outcome score and subsequently assessing 'The Living Murray' environmental works and one policy change (change to Hume Dam airspace rules) for their SDL adjustment potential.

The CSIRO-led team reviewed the sensitivity of the method in a range of areas and the overall performance of the method at the region scale.

(See also Section 3, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

3.2 What did the trial implementation involve?

The CSIRO-led team reviewed the suitability of the scoring tool for calculating environmental outcome scores and the performance of the Ecological Elements Method. The team designed a testing program for the trial implementation.

The review aimed to verify results against expected ecological outcomes. It examined scaling and sensitivity issues to assess performance of method at the regional scale, including:

- the sensitivity of environmental outcome scores to the choice of starting conditions, and the appropriateness of the chosen starting conditions.
- the number of ecological elements and ecological classes, to assess whether representation of too many functional groups reduces the sensitivity of the method.
- whether the minimum score values for each ecological class are appropriate.
- the method to combine reach scores to derive a region score and whether the aggregated environmental outcome scores converge as they are combined .
- whether there is any method bias towards higher scores for lower-magnitude site-specific flow indicators (SFIs) which are not necessarily reflective of ecological outcomes.
- whether the level of reporting precision in environmental outcome scores is appropriate for determining equivalence at the region scale.
- whether applying area-scaled weighting to reach scores when calculating region scores is appropriate.
- whether the method is sufficiently sensitive to supply measures (i.e. can the effects of just one measure be seen).
- whether ecological element, ecological class and reach scores should be normalised.

The review checked:

- procedure: the scoring tool was visually checked line by line to ensure that the tool correctly followed the procedural steps for the Ecological Elements Method. This was supplemented by comparing a number of results against expected output.
- area mapping: the spatial mapping of the ecological elements was considered to be a critical component of the Ecological Elements Method. The origin of the spatial layer for each ecological element was reviewed to ensure best available datasets were being used.
- ecological sense: results of ecological element, ecological class, reach and region scores for trial implementation scenarios, Basin Plan scenarios, and project test scenarios were collated as absolute scores, difference scores and time series plots for analysis. The outputs were reviewed for ecological sense.
- sensitivity: specific test scenarios were run to produce scores to assess the sensitivity of the method to a number of different method assumptions.
- precision: to determine the most appropriate level of method precision for assessing environmental equivalence at the region scale, a number of lines of evidence were investigated.

A range of hydrological modelling scenarios were used for this review to test the scoring tool. These included:

- without development: this is the best available representation of the natural conditions. It is based on the baseline scenario, but removes from the system all dams, irrigation and environmental works or infrastructure, all consumptive use and the rules governing flows such as channel capacity constraints.
- baseline: this represents a starting point against which the effect of implementing the Basin Plan (in particular, the introduction of SDLs) can be assessed. This scenario is the best available estimate of current use of water resources and water sharing arrangements of the Basin as at 30 June 2009.
- benchmark: this scenario represents MDBA's best estimate of the potential changes to the flow regime in the river systems if the settings outlined in the Basin Plan are implemented, which includes the recovery of on average 2750 GL/y of water from consumptive users returned to the environment.
- trial SDL-adjusted: The Living Murray works plus Hume Dam airspace rules with a 200 GL increase to SDL (i.e. 2550 GL/y recovery of water for environment). This is a trial implementation scenario representing 200 GL/y of SDL adjustment based on implementation of The Living Murray works and the Hume Dam airspace rules proposal. It represents a potential SDL-adjusted scenario that achieves regional environmental outcomes equivalent to the benchmark, using less water.

3.3 What did the trial implementation results show?

The tests conducted confirmed that each step of the Ecological Elements Method is represented in the scoring tool, and the output files are comprehensive in providing unweighted time series of ecological element scores for each reach (in works and outside-of-works areas), time-averaged unweighted scores, area-weighted scores, ecological class scores, reach scores (total, outside-of-works and inside-works) and region score.

Testing and evaluation has indicated that the scoring tool calculates each step of the Ecological Elements Method correctly and the results are in agreement with scientific expectations. This means that the environmental responses are as expected, with good responses following wet years and poor responses following dry years, and cumulative patterns for different species as has been described from actual events.

The area mapping inputs to the scoring tool were derived using best available datasets and information, with some minor changes recommended for future implementation.

The review recommended that minor revisions to the method as informed by further testing be made, and clarified a few aspects of the method that were open to interpretation.

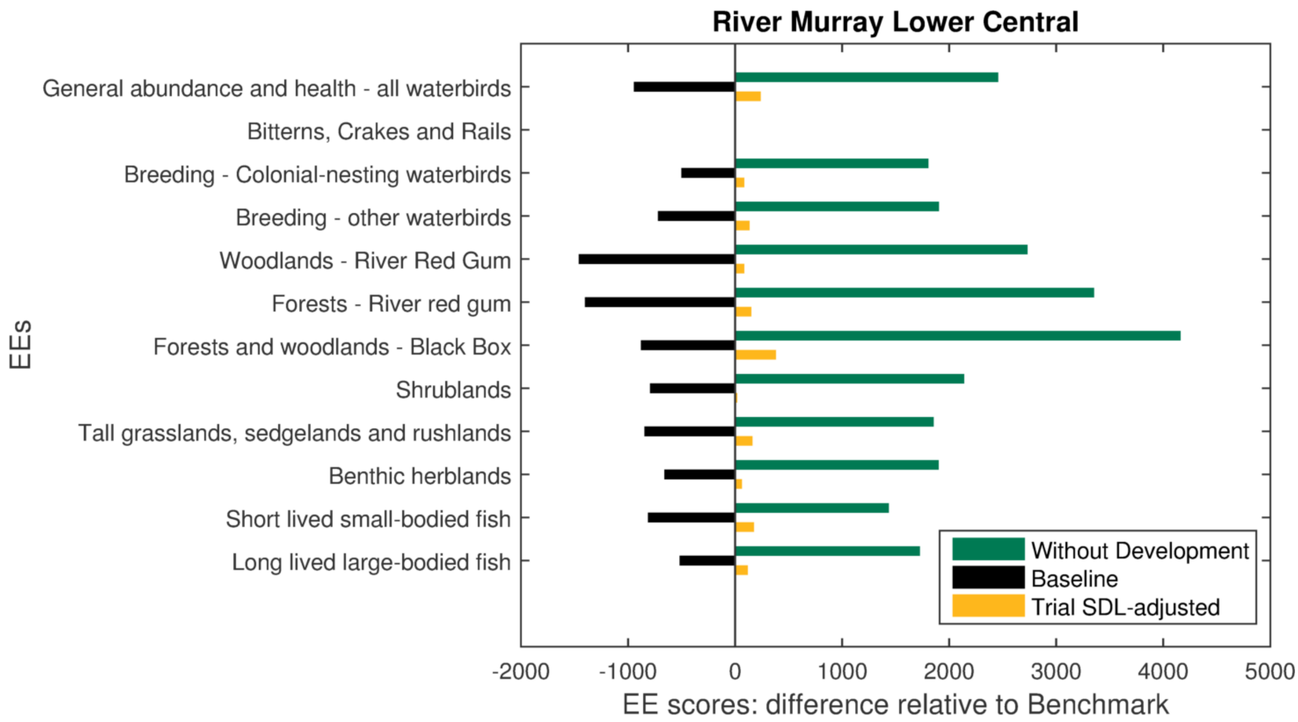

Figure 7 Ecological elements results for the River Murray Lower Central reach that contains the Hattah Lakes hydrologic indicator site. The results compare the without development, baseline and the trial SDL adjusted scenarios to the benchmark scenario.

Figure 7 shows the relative change in environmental outcome scores for one of the nine reaches in the southern Basin for all 12 EEs for the without development, baseline and SDL adjusted scenario compared to benchmark. The key points are that the without development scenario is consistently higher relative to benchmark and baseline scores. This makes ecological sense given the different levels of consumptive use represented by these scenarios. The SDL-adjusted scenario scores higher for this reach relative to benchmark which is consistent with expectations as this scenario includes The Living Murray environmental works at Hattah Lakes that allow improved environmental outcomes using less water.

VEGETATION

The trial implementation for vegetation showed that the preference curves and the choice of ecological elements is an appropriate representation of the system.

The vegetation ecological elements scores are consistent with expectations. After testing, minor modifications were recommended to the ‘shrublands’ ecological element.

Absolute scores are not similar among reaches because the SFI specifications are not defined consistently, and are more easily met in some reaches than others. Vegetation scores for the Lower Darling are consistently lower than for other reaches because fewer SFIs are being met in this reach relative to other reaches, and vice-versa for higher scores in the Lower Goulburn. There is no evidence of scores being inconsistent within a reach, and the reach-to-reach differences are apparent across all scenarios and internally consistent. Differences in the absolute scores between reaches does not matter, as the method is concerned only with relative changes in score.

The conclusion is that vegetation ecological element scores are consistent with expectations, and the effect of a long period with no SFI being met is appropriately represented.

(See also Section 3.2, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

WATERBIRDS

The ecological element scores for the four waterbird ecological elements generally met expectations, in that:

- the ‘breeding – colonial nesting waterbirds’ ecological element scored lower than the ‘breeding – other waterbirds’ ecological element
- the anticipated trade-offs occurred between higher scores in reaches with works and lower scores in reaches without works.

However, there were some unexpected results, namely:

- the very low scores for the ‘general health — bitterns, crakes and rails’ ecological element in some reaches
- some sensitivity to minor changes in the input sequence of SFI successes, however the effect did not warrant method revisions.

The low scores for bitterns, crakes and rails led to further tests: a modified bitterns, crakes and rails preference curve; a change to the SFIs included in scoring for this ecological element for some reaches; and a change in the application of area scaling factors. As a result of this testing, a change to the SFIs selected for scoring bitterns, crakes and rails and the application of area scaling factors were recommended.

(See also Section 3.1, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

FISH

The fish scores were comparatively sensible between the scenarios.

It is also notable that fish are less sensitive to dry spells than other ecological classes (vegetation and waterbirds), reflecting their ability to persist within the main channel of the river. This is an accurate representation of the differences between fish and floodplain species.

It is recognised that inundation events achieved by pumping will not provide equivalent benefits to fish as natural inundation events, and the method prescribes rules to modify the fish response relationships when inundation is achieved through pumping. Further interpretation was required to implement these rules in practice and further details were developed as part of the CSIRO review.

(See also Section 3.3, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

ECOLOGICAL CLASS SCORES

Results from the scoring tool were used to compare ecological classes across the reaches and across different hydrological modelling scenarios. The ecological class scores comparing trial SDL-adjusted and benchmark scenarios are shown for the nine reaches within the southern Basin region in Figure 8.

In this trial SDL-adjusted scenario, supply measures are included in three reaches: River Murray Upper Central (Gunbower–Koondrook–Perricoota Forest), River Murray Lower Central (Hattah–Kulkyne Lakes) and River Murray Lower (Riverland–Chowilla Floodplain).

The results show that the environmental outcome scores produced from ecological classes are sensible.

The difference between the trial SDL-adjusted and benchmark scenario scores for each reach show the contributions that each ecological class in each reach is making to the final equivalence test.

The score difference is most pronounced in the River Murray Upper Central reach because the environmental works in the Koondrook–Perricoota Forest and Gunbower Forest represent a large proportion of the reach. The ecological class and reach score differences are positive in these reaches, reflecting the impact of the supply measures. Score differences are mostly small and negative in other reaches reflecting the impact of the SDL adjustment volume reduction, fewer SFIs are met in these reaches. The overall region environmental outcome score is higher, which means there is environmental equivalence.

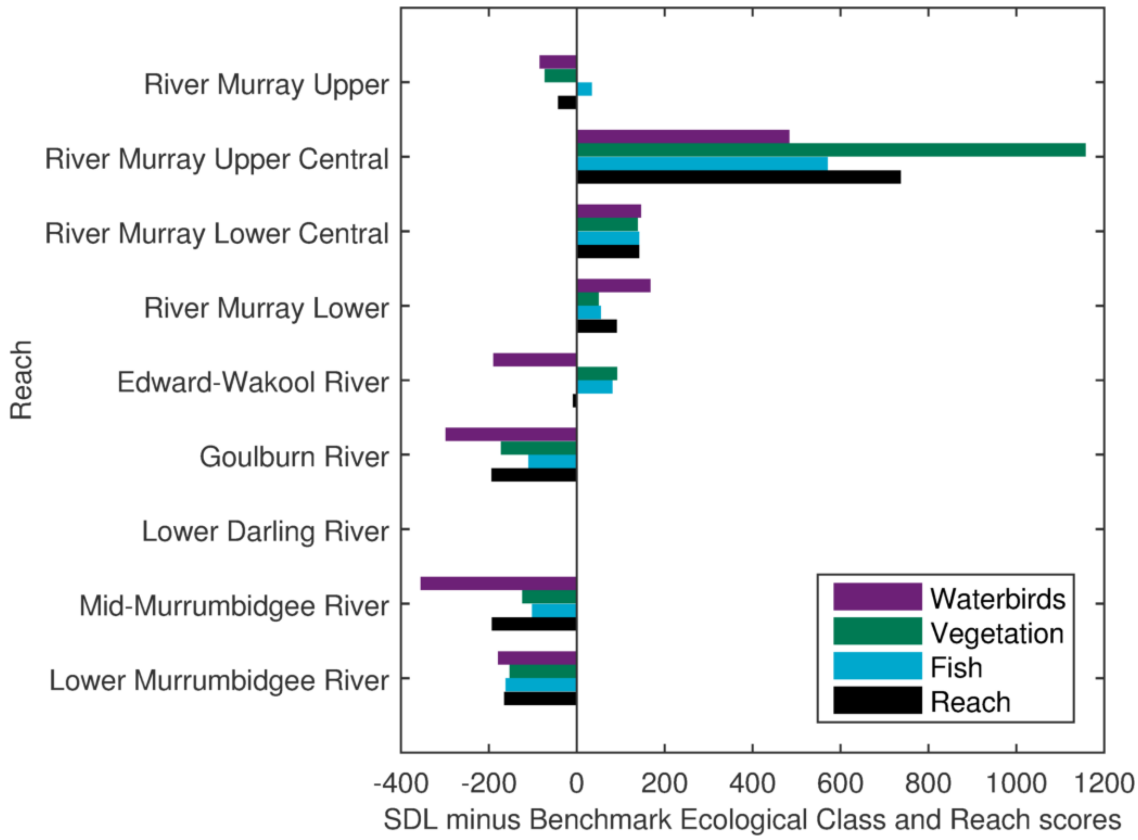

Figure 8 Comparison of environmental outcome scores for trial SDL-adjusted and benchmark scenarios for each ecological class in each reach. The reach score is the average of the Waterbirds, Vegetation and Fish Ecological Class scores.

(See also Section 3.4, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

REACH SCORES

The ecological class scores were averaged to generate the reach scores. The pattern of scores for the different scenarios follows that of each of the ecological classes, as expected. The reach score is highly correlated with the frequency of SFI success and the number of years between successful SFIs (dry spells).

(See also Section 3.5, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

REGION SCORES

The region environmental outcome score is calculated by averaging the reach scores. As expected from a knowledge of the scenarios and the behaviour of the method for the ecological class and reach scores, the region scores are highest for the without development scenario and lowest for the baseline scenario (Table 3).

The score for the trial SDL-adjusted scenario is higher than the benchmark score, thus satisfying the environmental equivalence test. This shows that the addition of these supply measures produces better environmental results than the benchmark scenario, although distributed differently across the southern Basin.

Table 3 Region environmental outcome scores for four scenarios – without development, benchmark, trial SDL adjusted, and baseline

Without development	Benchmark	Trial SDL-adjusted	Baseline
6,629	4,992	5,033	3,978

If supply measures are operated to favour one ecological element, one ecological class or one reach over another, then the aggregation method will combine positive and negative changes into a single region score. It is recommended that in reporting the region score and the equivalence test, that changes to reach, ecological class and ecological element scores at the subregion scale are also reported. One option is to also report on any scores (reach, ecological class or ecological element) that decrease as a result of the scenario so that such trade-offs are explicit.

(See also Section 3.6, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

Wetland near Mildura. ***Photo: Ian Overton***

3.4 What did the sensitivity analysis involve?

In the development of the Ecological Elements Method, extensive sensitivity analyses were conducted (see Section 3.1). The CSIRO-led team review built upon these findings and reviewed the impacts of particular method assumptions on a realistic trial SDL-adjusted scenario. In this way, it was possible to judge whether assessments of equivalence or not between benchmark and SDL-adjusted scenarios are likely to be significantly affected by altered method assumptions.

3.5 What did the sensitivity analysis show?

Overall, the analysis found that the method had appropriate levels of sensitivity, and that input components of the method such as the starting conditions and number of ecological elements had been appropriately chosen and delivered sensible results.

The review analysed a range of issues identified as potential risks to the robustness of the Ecological Elements Method (see Section 3.2; Table 4).

Table 4 Potential sensitivity issues with the Ecological Elements Method and analysis results

Issue	Analysis result
The starting conditions of the ecological elements at the beginning of the 114 years	The starting condition of the ecological elements has a significant impact on absolute region scores and the comparative equivalence test. A method was recommended that would remove any influence of the choice of starting condition. The recommendation is to calculate the scores for each scenario three times: once with EEs starting at their minimum value, once with a middle starting condition and once at their maximum value. The SDL adjustments should comply with the test of equivalence for all of these runs.
The number of ecological elements and ecological classes	A reduction in number of ecological elements is not recommended. There is a strong conceptual basis for the selection of the elements, there is no penalty in having 12 elements, and results at this resolution allow more specific and targeted traceability of environmental equivalence test results. Testing demonstrated that reducing the number of EEs is likely to have a significant effect on the environmental equivalence test.
The minimum score values for each ecological class	The recommendation is to keep the minimum scores as they are because to change these would alter the ecological element stress and recovery pathway scoring which is based on established scientific literature and expert opinion.
The aggregation method used for ecological elements, ecological classes and reaches	Recommendation is to retain averaging of reach scores to calculate region scores. Based on trial implementation results, the CSIRO-led team's judgement is that averaging of reach scores is a suitable approach which does not mask particular reach(es) having a disproportionate influence on region environmental outcome scores. In addition, the Limits of Change in the Basin Plan default method provides limits on extreme hydrological changes .Environmental outcome scores are based on SFI successes and as such there is some protection against extreme ecological changes through the limits of change on hydrological changes.
The influence of SFIs	Testing did not show an inappropriate method bias towards low or high SFIs. Lower SFIs occur more often than higher SFIs which is reflected by biota on the lower parts of the floodplain needing more frequent flooding and those on the higher parts needing less frequent floods to maintain condition. Lower SFIs have higher scores than higher SFIs because they are successful more often.
Precision (number of significant figures) for the ecological equivalence test	Four significant figures is the appropriate precision for the equivalence test from three perspectives: sensitivity to hydrology (ability to detect small changes in SFI success), sensitivity to area mapping uncertainty and the relationship between SDL volumes and changes in environmental outcome scores.
The influence of area scaling	Analysis substantiates our recommendation that the appropriate precision for interpreting score differences between benchmark and SDL-adjusted scenarios is four significant figures. It is not unreasonable to expect that area scaling factors will be accompanied by at least a 10% error, and this corresponds to a change in the equivalence test that is detectable at the fourth significant figure.
Sensitivity to supply measure changes	The method is able to detect the effects of a single supply measure (environmental work) operated in a single year depending on when the measure is operated and the proportion of the reach area that the measure can influence. If it does not translate to a significant effect at the region scale, it is because the supply measure is not inundating a large enough area or because most SFIs are met that year regardless of whether the supply measure is operating or not. This is as it should be: a supply measure should be detectable at the region level only if it is making an effective difference. Where the effect is not large enough to be significant at the region scale, its contribution to any regional scale score improvement is not lost if it is operated in more dry spells and in conjunction with other supply measures.
The need to normalise ecological element, ecological class and reach scores	Normalisation to attempt to correct for intrinsic differences between SFI specifications in the reaches is not recommended. Two approaches were tested and judged inappropriate as they effectively masked the influence of SFIs on scores rather than fully correcting for them.

(See also Section 4, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

4 Conclusions and recommendations

4.1 Introduction

The Ecological Elements Method has been developed to allow the Murray–Darling Basin Authority (MDBA) to ensure that any changes to the sustainable diversion limits (SDLs) established in the Murray–Darling Basin Plan deliver equivalent or better environmental outcomes. The method assesses the environmental equivalence of benchmark and SDL-adjusted scenarios, and has been developed and rigorously tested by scientific experts.

(See also Section 5, *SDL Adjustment Ecological Elements Method Trial Implementation Review,* CSIRO, 2015)

4.2 What were the conclusions of the trial implementation?

The CSIRO-led review of the Ecological Elements Method concluded that *the method as described and implemented is considered scientifically rigorous, compliant with Schedule 6 of the Basin Plan and an appropriate balance between sensitivity and uncertainty.*

The MDBA will ultimately decide if the method is fit-for-purpose to assess an SDL adjustment, taking into close account the advice of the CSIRO-led team, Basin governments and the Independent Review Panel.

The review also noted that it should be recognised that scores should be used only for equivalence testing and determining an SDL adjustment, and not as a condition assessment. The method cannot be used to compare absolute scores between ecological elements, between ecological classes or between reaches.

The review made specific findings in three areas.

- Implementation tool: Overall, the scoring tool is consistent with the Ecological Elements Method, had no unfixed errors, and the best available datasets have been used as inputs to the tool. Additional findings include:
  - A number of minor coding issues in the software tool could be risks to future code updates and the potential of code changes introducing errors, however these are not critical.
- Ecological sense: Overall, the Ecological Elements Method is ecologically meaningful for individual ecological elements, ecological classes and overall scores within a reach, across reaches and the region. Additional findings include:
  - Use of inter-annual sequencing of wet (flood) and dry (drought) spells is an improved approach to assessing ecological response over single values of flooding frequency (the approach used during the determination of the environmentally sustainable level of take).
  - The number of ecological elements used in the method (12) is an acceptable balance between including the major ecological types and the risk of overlooking large individual ecological changes with too many ecological elements.
  - Although there is a high degree of correlation between some ecological element scores, each ecological element is considered important in the method and removal of any one has the potential to change the region score significantly.
  - The averaging method for aggregating ecological element scores into ecological class scores and ecological class scores into a reach score is appropriate, and there is no scientific justification to weight one ecological class more than another.
  - Each reach and its biota are considered equally ecologically valuable and area weighting reach scores to calculate an aggregated region score is not appropriate.
  - Averaging reach scores does not result in a disproportionate influence of a reach(es) on the region score. Similarly, the averaging aggregation method was not found to hide any extreme changes in ecological class or ecological element scores.

- Sensitivity: Overall, the Ecological Elements Method is appropriately sensitive to inputs. The method is not too sensitive to small hydrological changes but responds appropriately to detect differences in an SDL-adjusted scenario. Additional findings include:
  - The starting condition of the ecological elements has a significant impact on region scores and on the difference between scenario scores for the equivalence test.
  - Area mapping inputs carry some uncertainty, and testing indicates that an uncertainty of 10% in the spatial layers for the area estimates (which is reasonable) leads to a difference in the region score equivalence test at the fourth significant figure.
  - The region score is able to detect a difference at the fourth significant figure of a single SFI event change in a single year depending on when the supply measure is operated and the proportion of the reach area that the measure can influence.
  - Overlapping of SFIs is not considered an issue in the method as they have been chosen based on their significance to different biota and are part of the MDBA's method to determine the environmentally sustainable level of take. Testing indicated there is no bias that would favour low floodplain supply measures over higher floodplain measures or vice versa.
  - Four significant figures is the appropriate precision for the equivalence test from three perspectives: sensitivity to hydrology (ability to detect small changes in SFI success), sensitivity to area mapping uncertainty and the relationship between SDL volumes and changes in environmental outcome scores.
  - The SFIs were specified in a way that does not allow direct comparison between reaches. Ecological element or ecological class scores cannot be normalised to correct for this effect.

4.3 What are the recommendations about the Ecological Elements Method?

The CSIRO-led review made a number of minor recommendations aimed at improving inputs to the Ecological Elements Method, to therefore further improve the method's accuracy and applicability. These recommendations include:

- The choice of starting conditions is significant to the final environmental outcome score so it is recommended that scenarios are run three times, using minimum, middle and maximum starting conditions, and the test of environmental equivalence is to be met in all cases.
- Improve spatial layers should be used to represent some ecological elements. Specifically, the area weightings for 'benthic herblands' and 'tall grasslands, sedgelands and rushlands' should be revised using attribute information in Australian National Aquatic Ecosystem (ANAE) database and permanent waterbodies should be excluded from the calculation of areas.
- Additional rules for determining waterbird breeding ecological element scores for SFIs above current river operating constraints have been developed for all relevant reaches and should be adopted in the scoring tool.
- Minor modifications should be made to the selection of relevant SFIs and the application of area scaling factors for 'bitterns, crake and rails'; the selection of SFIs relevant for 'general abundance and health – all waterbirds'; and the 'shrublands' preference curve.
- The aggregation method should be slightly modified to improve interpretation of scores reported for works and outside-works areas, and to provide ability to report on individual ecological element scores for each reach.

Regarding reporting, the review recommended that the score change for each reach and the maximum score change in an ecological element should be reported along with the test of equivalence for the region, so that it is clear if region score improvements are accompanied by worsened conditions relative to benchmark at a subregional scale (i.e. spatial trade-offs are explicit).

The review also made a general recommendation that supply measures should be considered and operated using best-practice principles to avoid environmental harm that the Ecological Elements Method cannot address, including flooding of durations less than desirable, prolonged flooding greater than desired durations, and inundation that restricts connectivity.

Glossary

benchmark scenario	The modelled hydrological outcomes achieved by the 2,750 GL/yr reduction in diversions under the Murray–Darling Basin Plan.
ecological class	Groups of ecological elements. In the Ecological Elements Method these are vegetation, waterbirds and fish.
ecological element	Species or groups of organisms.
Ecological Elements Method	A method that uses ecological elements to assess the environmental equivalence of an SDL-adjusted hydrological modelling scenario relative to the benchmark scenario.
efficiency measures	Works or changes that decrease the quantity of water required for consumptive use.
environmental equivalence	When region environmental outcome scores are the same for different flow scenarios (e.g. the 2,750 GL/yr reduction in diversions under the Basin Plan under the benchmark scenario compared to a package of proposed supply measures under an SDL-adjusted scenario).
environmentally sustainable level of take	The amount of water that can be taken for agricultural and human consumptive use, while still ensuring there is enough water to achieve healthy river and groundwater systems.
GL	gigalitres
GL/yr	gigalitres per year
MDBA	Murray–Darling Basin Authority
Murray–Darling Basin Plan	An Australian Government plan to improve the health of the Murray–Darling Basin by coordinating water use across all areas of the Basin.
recovery target	2,750 GL/y expressed as a long-term average The recovery target is the difference between the amount of water diverted for human use as at 2009 and the calculated environmentally sustainable level of take in the Murray–Darling Basin Plan.
response relationships	How ecological elements transition through a set of states or conditions given annual wet and dry sequences.
scoring tool	A tool developed by the MDBA to calculate environmental outcome scores using the Ecological Elements Method.
SDL	sustainable diversion limit The amount of water that can be taken for human use, while still ensuring there is enough water to achieve healthy river and groundwater systems, as established in the *Murray–Darling Basin Plan*. In the Basin Plan, the current SDL or Environmentally Sustainable Level of Take across the Basin is estimated as 10,873 GL/y, averaged over the long term.
SDL-adjusted scenario	The modelled hydrological outcomes achieved by a package of proposed supply measures.
SDL adjustment	An adjustment that is made to the Basin Plan sustainable diversion limit.
Schedule 6	The schedule of the Murray–Darling Basin Plan that identifies the default method by which supply measures can be used to adjust SDLs.
SFI	Site-specific flow indicator A simple representation of the hydrological habitat produced by river flows developed during the Basin Plan. SFIs are expressed in terms of a flow magnitude, a duration and a season of inundation. The SFIs are discrete flow bands representing different parts of the floodplain. The Ecological Elements Method converts successful and not successful annual SFI sequences into environmental outcome scores.
supply measures	Works or changes to river operations or practices that enable the same environmental outcomes to be achieved with less water.

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