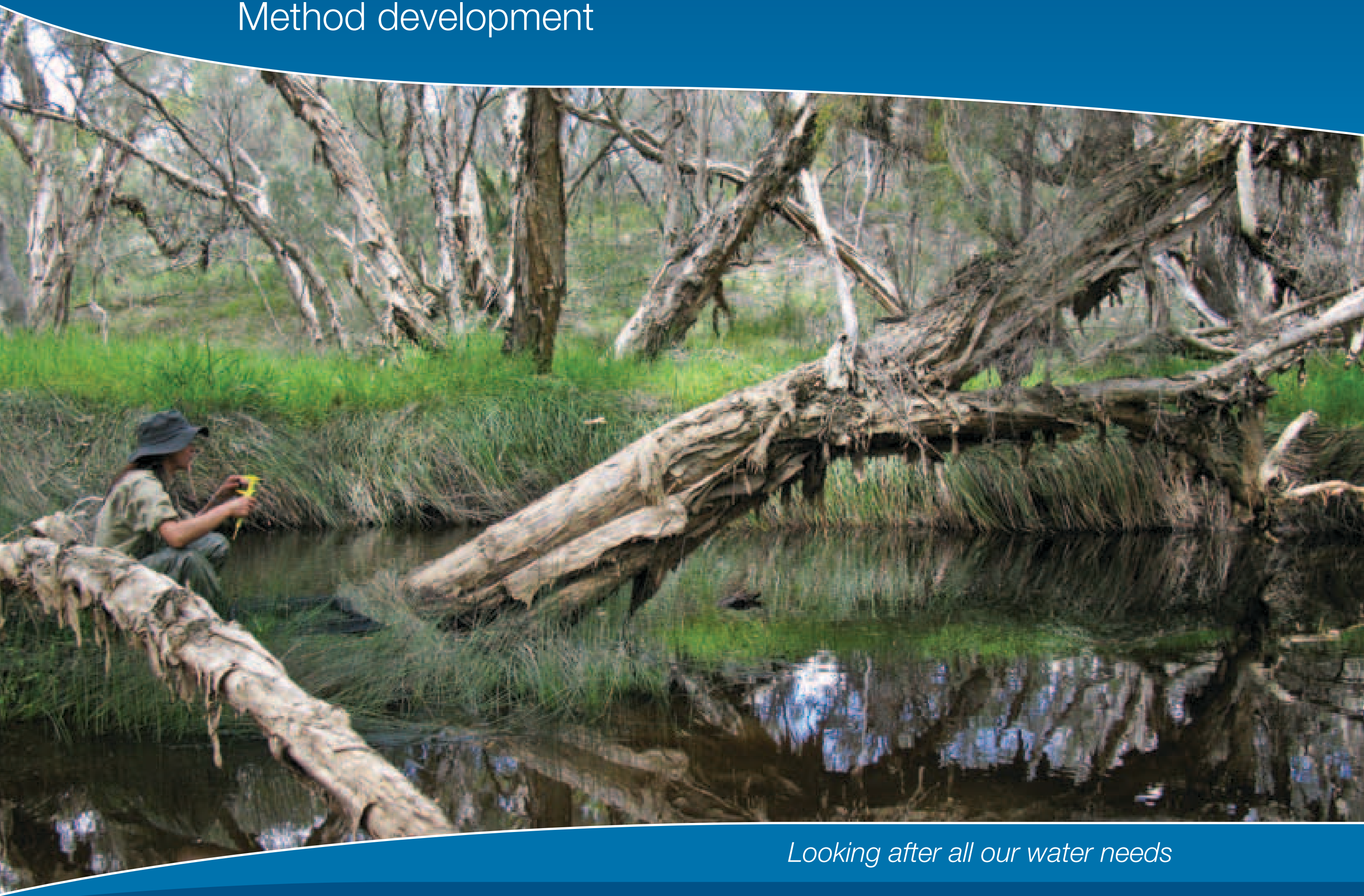
Government of **Western Australia**
Department of **Water**

The Framework for the Assessment of River and Wetland Health (FARWH) for flowing rivers of south-west Western Australia

Method development



Looking after all our water needs

Water *Science*
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Report no. WST 40
September 2011

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1 Introduction

This is the second of two reports on the Framework for the Assessment of River and Wetland Health (FARWH) trials conducted in the south-west of Western Australia (SWWA). The first report, *The Framework for the Assessment of River and Wetland Health (FARWH) for flowing rivers of south-west Western Australia: project summary and results, Final report* (Storer et al. 2011), describes the outcomes of the SWWA-FARWH trials and presents the results of the field trials (2008 and 2009) and the Australian Water Resources (AWR) 2005 baseline-year assessment. The second report (this report) details indicator selection, development and testing and, as such, is a technical supplement to the first report. The results of the 2008 and 2009 field trials are re-presented in this report as they are relevant to indicator development and testing.

The underlying purpose of the FARWH trials was to complete the SWWA component of the Australian Water Resources (AWR) 2005 baseline-year assessment of river and wetland health, from which the effectiveness of the National Water Initiative (NWI) could be benchmarked.

Due to insufficient data to apply the FARWH directly to SWWA, a significant data-gathering phase (field and desktop) was required; including the development of indicators. Nine surface water management areas (SWMAs) were chosen for field assessment between 2008 and 2009 (to develop and test assessment methods), and all SWMAs in the study area (except that of the Avon River, which was excluded due to ecological and logistical constraints) were assessed for the 2005 baseline-year review (using available data and protocols developed through the trials). The results of the 2005 assessment can be found in Storer et al. 2011.

2 Applying the FARWH to south-west Western Australia

The SWWA-FARWH project focuses on developing and implementing the FARWH for rivers in all natural resource management (NRM) regions except Rangelands. The project's geographical extent is approximately from Kalbarri in the north to Esperance in the east (Figure 1).

Figure 1 Study area for assessment of the SWWA-FARWH (all natural resource management areas except Rangelands)

SWWA has a Mediterranean climate with cool wet winters and hot dry summers. Annual rainfall decreases rapidly with increasing distance from the coast, from between 900 to 1400 mm/yr to about 350 mm/yr in the most inland areas. Evaporation ranges from 800 to 1200 mm/yr on the coast to more than 2000 mm/yr in inland areas. Accordingly, runoff is limited and primarily from a narrow corridor within 50 to 150 km from the coast. As a result of this, SWWA rivers vary significantly in their degree of ephemerality.

Due to the relatively dry climate and associated low flows, SWWA rivers are among the smallest (length and discharge volume) in Australia. For reference, the Blackwood River, which is the largest in SWWA, discharges approximately 740 GL/yr, compared with 22 000 GL/yr by the Murray River (Australia's largest catchment). Due to these features, surface water is a limited resource in SWWA. The region's rivers also frequently represent unique ecosystem characteristics (e.g.

faunal assemblages show a high degree of endemism). Further, the limited water in many areas of SWWA means that rivers are particularly vulnerable to ecosystem change and contamination.

The FARWH is designed with sufficient flexibility to account for the complexities and data availability between states, allowing for:

- the use of data from established programs to be entered directly into the framework, following guidelines for data handling and scoring, to produce nationally comparable assessments
- situations where existing programs are not established and/or data are required to produce a reasonable assessment (in these cases, the framework provides guidance on a range of recommended indices and the associated data required)
- the data required and associated indicators to differ both between and within states.

Regardless of the FARWH's flexibility, application to SWWA presents a number of significant challenges, described in the following section.

2.1 Challenges in applying the FARWH to SWWA

The FARWH is built on scoring indicators of a range of ecological conditions based on departure from reference condition. Reference condition is typically a perceived current health status without the influence of human impact (accounting for a natural level of change following human settlement). How reference is defined is somewhat dependent on data availability and can therefore change depending on the situation.

Applying the FARWH in Western Australia is challenging because the health of our river systems is poorly understood. There are few historical records of pre-European condition (the generally accepted reference condition based on the form and function of rivers before European anthropogenic impacts) and limited current records (lack of consistency and spatial coverage in existing ecological monitoring programs). In addition, the uniqueness of rivers in SWWA means the applicability of indicators developed in other parts of Australia or elsewhere in the world is questionable.

The specific challenges for applying the FARWH to SWWA rivers are listed below:

Environmental challenges

River systems in SWWA are unique in many ways. This means not only that protecting them is vital, but also that established indicators of health (developed in other areas) are predominantly ineffective or require significant ground-truthing. Relevant attributes of SWWA rivers include:

- *High degree of endemism:* 80% of native fish (Allen 1982) and 100% of native crayfish are found only in local waters of SWWA. This is similar for macroinvertebrates; for example, Odonata, Trichoptera and Plecoptera orders consist of 39%, 100% and 70% endemic species respectively (Watson 1962;

Hynes & Bunn 1984; Neboiss 1982 – all cited in Sutcliffe 2003; Bunn & Davies 1990). Further, the general biology of these species is poorly understood and limited data are available on species dynamics before human impact. This is related to the historical isolation from the rest of Australia and increased aridity in the past.

- *Paucity of species:* SWWA has the lowest natural diversity of fish and invertebrate species in coastal Australia (Bunn & Davies 1990). For example, the native fish fauna of SWWA includes only nine species in five families, along with five diadromous species in three additional families (e.g. *Geotria australis*, the pouched lamprey) compared with around 50 species in 17 families known from the south-east (Allen 1982; Merrick & Schmida 1984). The expected diversity of fish and crayfish in SWWA is typically around six to seven species, with the exception of the coastal rivers east of Albany (south coast) where only two species are commonly found. Note: maximum diversity across the region rarely exceeds 10 species. Macroinvertebrates are typically restricted to less than 30 families in most SWWA systems, with less than 50% of the number of species expected in the east (Bunn & Davies 1990). Note: SWWA does contain the most representatives of *Cherax* spp. within Australia (approximately one third of those recognised within Australia) (Riek 1969; Austin & Knott 1996).
- *Low diversity:* This reduces the robustness of many established indices due to the high degree of impact that would be interpreted if species were not collected at a particular site. For instance, if only one of the two fish species in the south coast area is collected (which could be attributed to catchability alone) this would relate to a 50% loss of diversity, yet a 50% reduction in health score in this case is unlikely to be an accurate representation of fish health.
- *Ephemeral, episodic and seasonal systems:* SWWA is dominated by non-permanent systems, with many rivers forming a series of disconnected pools during the summer months or even drying out completely. Field sampling is mostly conducted in spring to comply with national standards for macroinvertebrate assessments (AUSRIVAS), which is the time when systems are beginning to dry up. Most indicators for river health assessment assume flowing water, especially indices of aquatic biota.
- *Low productivity:* Low nutrient inputs combined with infertile soils equates to low productivity in south-west streams: the key driver of low species richness and diversity of the biota. This is highlighted by fewer grazing invertebrates, smaller body size and low diversity in feeding groups (Bunn & Davies 1990).

Data and associated logistical challenges

There are no established statewide ecological assessment programs in Western Australia with which to form the basis for FARWH indicators. Programs that are currently active in SWWA include two localised ecological health monitoring programs (described below) and a number of wider-reaching programs that collect only specific elements of ecological information (primarily water quality and quantity).

Relevant 'specific-element' programs are included in the list of data sources examined within the SWWA-FARWH trials (see Table 68).

The River Health Assessment Scheme (2007–10 and ongoing)

The River Health Assessment Scheme (RHAS) incorporates 20 sites within the Swan Coast SWMA that are monitored annually in spring for fish and crayfish, macroinvertebrates, riparian vegetation, water quality and physical form.

As part of evaluating the FARWH for SWWA rivers, data from the RHAS program has been tested against the framework. This information can be found in the first SWWA-FARWH report (Storer et al. 2011).

Ecological values of waterways of the south coast region (2008)

This program was conducted for the Department of Water by the Centre of Excellence for Natural Resource Management (CENRM) in Albany, with funding from South Coast Natural Resource Management (SCNRM). It set out to conduct a comparative assessment of the ecological values of selected river systems in the south coast region. An ecological snapshot was taken of fauna and flora, habitat and water quality. This was a once-off sampling effort, conducted in 2008, which was designed to help identify the presence and location of biodiversity hotspots, rare species and areas of high endemism. At the time this report was compiled there was no intention to repeat this survey. In addition, it was not designed to assess 'river health'. Where applicable, data collected were used as background information for the SWWA-FARWH trials, both in terms of site selection and as interpretive data to compare and contrast results (but were not put through the framework).

Given the lack of pre-existing programs from which to form the basis for selecting indicators for the SWWA-FARWH trials, indicators had to be developed and/or tested and associated data had to be sourced either through desktop analysis or field collections. Specific data deficiencies are summarised below:

- Surface water management areas (SWMAs) were defined for the National Land and Water Resources Audit (NLWRA) and are broadly based on river basins with some amendment for management purposes as determined by each state. All states except Western Australia and Tasmania split basins into smaller areas – consequently SWWA has a number of large SWMAs. This has implications for sample size (number of reaches required to adequately represent the range of conditions within the SWMA) and for logistical arrangements (travel between sites). Figure 2 demonstrates the large size of SWMAs in SWWA and differences in SWMA size between regions, comparing the Avon River SWMA in SWWA with Tasmania.

Figure 2 Comparison of Avon River SWMA in SWWA with Tasmania

- Reaches defined for the Assessment of River Condition (ARC reaches, see Table 68) were coarse (derived from a nine-second digital elevation model (DEM)) and poorly aligned with watercourses (up to 2 km away in places), while validation against topographic mapping data was incomplete (i.e. reaches were defined through swamps and included reservoirs and estuaries). Considerable effort was required to manually validate the 990 reaches in the study area.
- ARC reaches (the grain size used for the FARWH assessment) were not topographically homogenous, with a number of reaches extending from upland to lowland areas. It is understood that this occurred because reach delineation was based on algorithms developed in the eastern states where topographic differences are greater than in SWWA. Even though the changes in topography are less pronounced in SWWA they are still of ecological significance; for example, the structure of macroinvertebrate communities changes between upland and lowland rivers in south-western Australia (Davies 2005).
- A network of river health sampling sites does not exist in SWWA. Established sites exist for water quality and macroinvertebrate sampling, but often these are unsuitable for fish and crayfish sampling methods, and are closer to road crossings than is desirable for river health assessment field work.
- A number of spatial datasets are not available at a currency or resolution ideal for analysis. For example, the most current land use data covering the whole study area is from 1996 to 2001 (NLWRA Land Use, see Table 68). The Department of Agriculture and Food Western Australia (DAFWA) updates the dataset on an ongoing basis, however it does not provide a snapshot of land use in a single year. Other examples include farm dams (incomplete coverage for SWWA), artificial channels (at a finer resolution than 1:250 000 scale) and fire scar mapping (at a finer resolution than 1 km pixels).

In addition, SWWA does not have spatial datasets for stream order, stream width, riparian vegetation mapping or vegetation structure of pre-European vegetation communities.

Summary

SWWA's lack of existing monitoring programs, limited data for determining current and historic ecological conditions, and unique environmental conditions have resulted in a poor understanding of ecological health – this made it challenging to apply the FARWH to the region's rivers.

To trial the framework, many fundamental datasets required creation or modification (e.g. reach definition datasets), in addition to the generation of ecological data to develop appropriate indicators of health for SWWA systems. To do this, a significant field and desktop data-gathering exercise was required: the approach taken is described below.

2.2 Description of the SWWA-FARWH trials

As introduced above, application of the FARWH to SWWA rivers required a significant field and desktop component to generate sufficient data to develop and test appropriate ecological indicators.

Two field trials were conducted to meet this need, the first in spring 2008 and the second in spring 2009 (incorporating lessons from the first trial). These trials were designed to test indicators that could then be applied to generate the 2005 baseline-year assessment. Indicators that were not directly applicable to 2005 (due to insufficient data to populate) were also included in readiness for ongoing assessments.

Note: for the field-based component of the SWWA-FARWH, systems where water was not present, or not flowing, at the time of sampling were not included because they would have required a separate scoring protocol. Given time constraints this was not possible. As such, the SWWA-FARWH protocol reported here applies to systems where flow was present at the time of sampling. For those themes that were desktop based (such as Catchment Disturbance), all reaches were assessed.

3 Summary of approaches used in the FARWH trials

The approaches used for the SWWA-FARWH trials follow the general guidelines outlined in the FARWH documents (NWC 2007a; NWC 2007b) created as part of the AWR 2005.

3.1 General principles of the framework

The FARWH attempts to achieve two key objectives: the first being nationally standardised scoring and reporting and the second being an ecologically robust and accurate assessment protocol.

To achieve the first objective, the FARWH recommends a number of standard methods; for example, indices need to be:

- relative to reference (generally pre-European conditions)
- linear and range standardised to 0–1, in increments of 0.1
- divided into condition bands (Table 1).

Table 1 Condition bands used for scoring in FARWH

Band definition	Score range
Largely unmodified	0.8–1.00
Slightly modified	0.6–0.79
Moderately modified	0.4–0.59
Substantially modified	0.2–0.39
Severely modified	0–0.19

To achieve the second objective, the FARWH is based on the premise that ecological integrity is represented by all the major components of the aquatic ecosystem. In light of this, to adequately determine health the FARWH recommends assessment within six themes. These are:

1 Catchment Disturbance

2 Hydrological Change

3 Water Quality

4 Physical Form

5 Fringing Zone

6 Aquatic Biota.

This recognises the importance of capturing multiple lines of evidence when assessing any complex environment, as supported by most waterway health monitoring programs around the world (e.g. EMAP in the United States, WFD4 in Europe and RHP in South Africa) [see example provided in Summary Box 1].

Summary Box 1: Example of the importance of multiple lines of evidence

Biota is often recognised as the most important indicator of river condition (NWC 2007a). However, unless monitoring is continuous and includes all types of biota, certain types of disturbance may go undetected, may only be detected after severe impairment, or a lag may exist between impact and response. Further, monitoring biota alone may only indicate a level of disturbance rather than cause; therefore measures of habitat and catchment condition are also recommended.

3.2 Reporting and assessment scales

For national consistency, reporting within the FARWH is conducted at the SWMA scale. SWMA boundaries are taken from the Australian Surface Water Management Areas (ASWMA) dataset (see Table 68 and Figure 3). These boundaries were created for the NLWRA and are broadly based on river basins with some amendment for management purposes as determined by each state. Note that the Department of Water has subsequently further refined the SWMAs in Western Australia but these changes are not currently reflected in the ASWMA dataset.

The minimum grain size used for assessments to generate SWMA scores is the river reach. River reaches were developed as part of the Australian ARC (known as ARC reaches, see Table 68), and subsequently modified following validation within the SWWA-FARWH trials.

SWMA selection: 2008 and 2009 trials

Field trials for the SWWA-FARWH project focused on the development, trialling and refinement of indicators. To this end, a number of SWMAs were chosen for investigation in 2008 and 2009 to represent the range of conditions present in SWWA, thus enabling the development of indicators appropriate to the scales of impact, catchment types and general ecological diversity. That is, an attempt was made to capture the existing natural and impacted chemical, physical and biological variability in order to test scoring protocols.

The SWMAs selected for assessment in the SWWA-FARWH trials are shown in Figure 3.

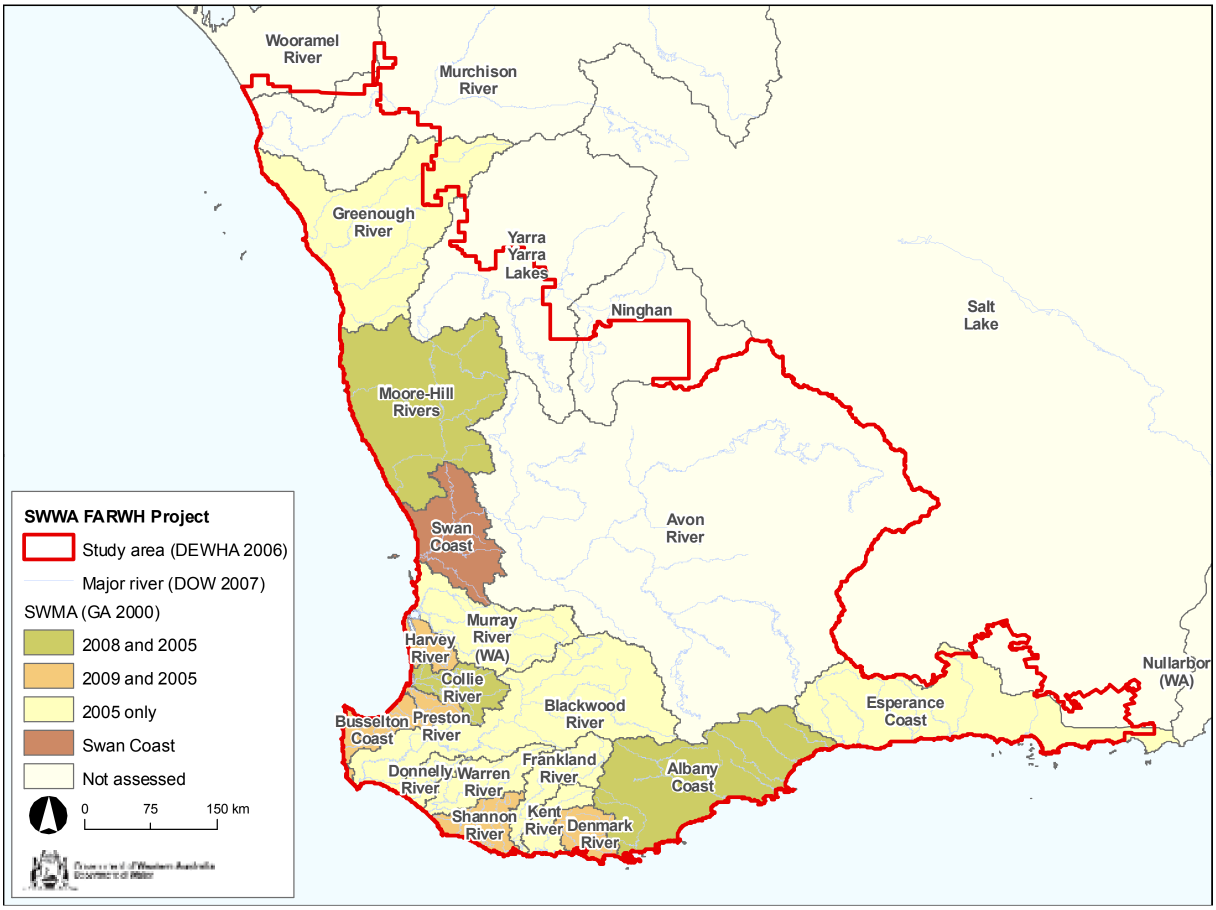

Figure 3 SWMAs chosen for assessment in the SWWA-FARWH trials

An overview of the conditions associated with each of these SWMAs, justifying their inclusion in the trial design, is provided below. This information is provided to support discussion of the scores that follow later.

Moore-Hill Rivers SWMA (2008)

The Moore-Hill Rivers SWMA lies north of Perth and has an area of 24 533 km^2 (see Figure 4). It has three main rivers: the Moore, the Hill and the Nambung. Rainfall varies across the SWMA from approximately 650 mm in the south-western corner to approximately 300 mm in the north-eastern corner (mean annual rainfall 1975–2003, see Table 68). A large proportion of the SWMA has been cleared and the predominant land use is non-irrigated cropping. While there are no major dams in the SWMA, there is a heavy reliance on groundwater. Areas of nature conservation are present, predominantly near the coast, although there are no identified Wild Rivers (near-pristine rivers as identified by the Wild Rivers Project in the 1990s).

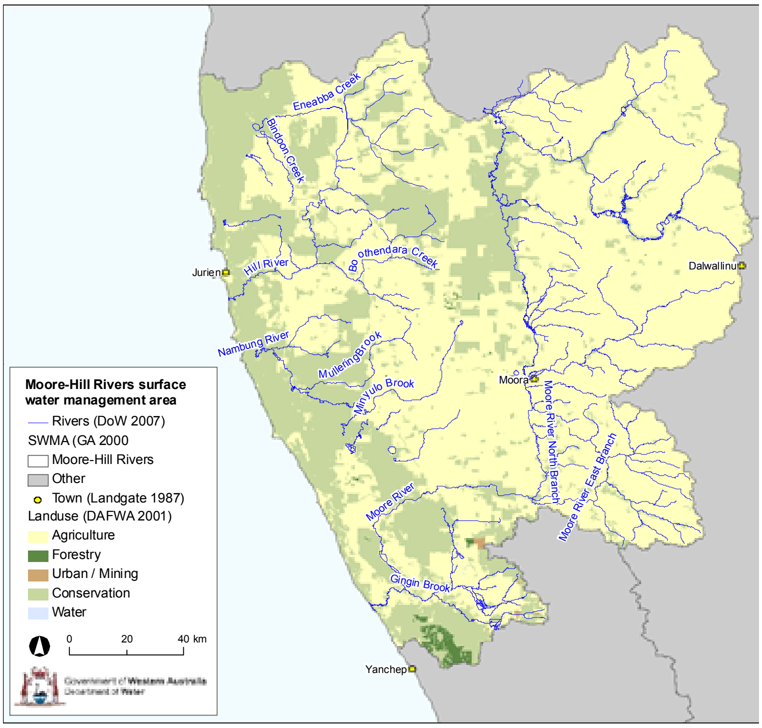

Figure 4 Moore-Hill Rivers surface water management area

Collie River SWMA (2008)

The Collie River SWMA lies south of Perth and covers 3717 km^2 (see Figure 5). The Collie River system extends approximately 100 km inland, draining forested areas, wetland and farmland of the Darling Range and the edge of the Yilgarn Plateau before discharging into the Leschenault Inlet. There is one main river system in the SWMA: the Collie River. Rainfall near the coast is approximately 800 mm annually, increasing to 900 mm over the Darling Scarp and then decreasing again to approximately 550 mm on the eastern boundary (mean annual rainfall 1975–2003, see Table 68).

More than half of the SWMA remains uncleared, with large areas of forest still present east of the Darling Scarp. There are a number of coal mines in the SWMA as well as coal-fired power plants. Two large dams are present, one on the Collie River (Wellington Dam – irrigation) and one on the Harris River (Harris Dam – potable water) as well as numerous smaller ones. Other hydrological modifications include training of the river around the Collie townsite to reduce flooding and diversions around coal mines. Many rivers are brackish due to clearing for agriculture and mining, with trend data highlighting increasing salinity in some areas (Mayer et al. 2005). There are no Wild Rivers present in this SWMA.

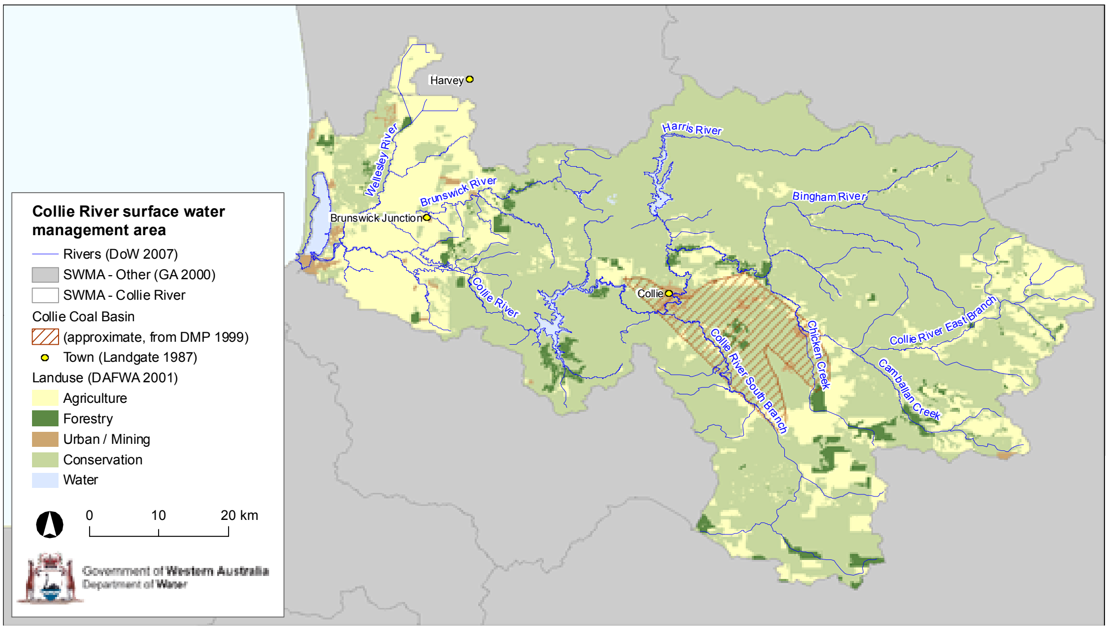

Figure 5 Collie River surface water management area

Albany Coast SWMA (2008)

The Albany Coast SWMA lies on Western Australia's south coast and extends from Albany to Bremer Bay (see Figure 6). It is 19 604 km^2 and has approximately 15 river systems, the largest of which are the Pallinup, Kalgan and Fitzgerald. Rainfall varies from around 950 mm annually at the western point on the coast to 350 mm along the northern boundary (mean annual rainfall 1975–2003, see Table 68). Cropping constitutes the major land use and there is a large nature conservation area in the SWMA's south-east, as well as another small area in the central west (Figure 6). Areas of plantation forestry are present in the SWMA's south-western corner (mostly Tasmanian blue gums). There are no large dams present (though there are many farm dams). Two Wild Rivers catchments (the Saint Mary and Dempster rivers) are present, both in the nature conservation areas in the south-east.

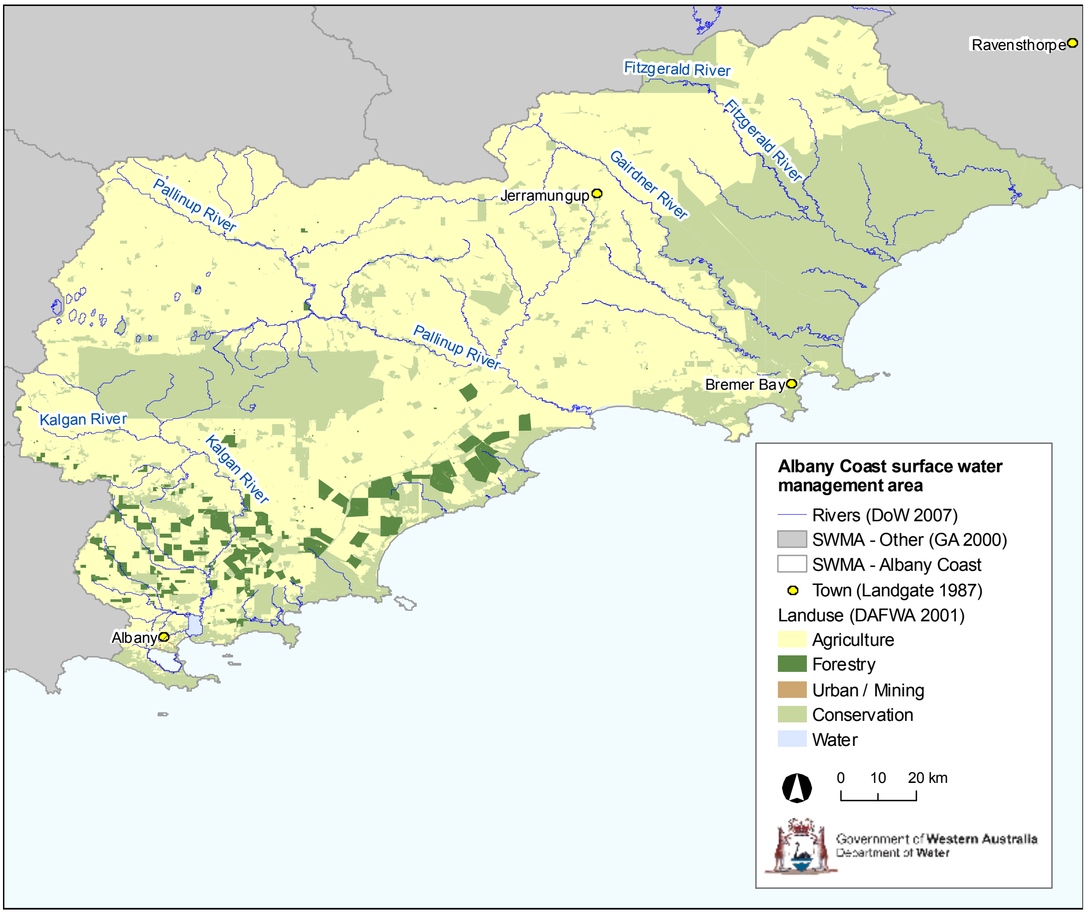

Figure 6 Albany Coast surface water management area

Harvey River SWMA (2009)

The Harvey River SWMA is 2001 km^2 with the main river, the Harvey, extending approximately 20 km from the coast into the Darling Range (Figure 7). Its headwaters drain forested areas of the scarp and the intensely farmed regions of the Swan Coastal Plain before discharging into the Harvey Estuary. Most of the coastal plain has been cleared to support agricultural and mining activities. The Harvey River's hydrology has been highly modified via drainage developments constructed in the 1930s to prevent flooding and enable farming. It formerly meandered through an extensive low-lying seasonal wetland system but is now represented by a network of straight drains with varying levels of maintenance (some are excavated annually). The hydrology is further altered by the construction of a major diversion to the ocean and two dams supplying water to the Perth metropolitan area. Water flow in the river has increased dramatically, primarily because the watertable has been raised due to clearing. Nutrients, especially nitrogen and phosphorus, are elevated. The SWMA has some of the most nutrient-enriched waters of the South-West Drainage Division (Bussemaker et al. 2004, unpublished). Turbidity in the river is also high – a result of significant riparian vegetation loss, catchment clearing and possibly mining activities near the scarp. Annual rainfall varies between 750 mm near the coast to 1000 mm annually along the eastern margins (mean annual rainfall 1975–2003, see Table 68).

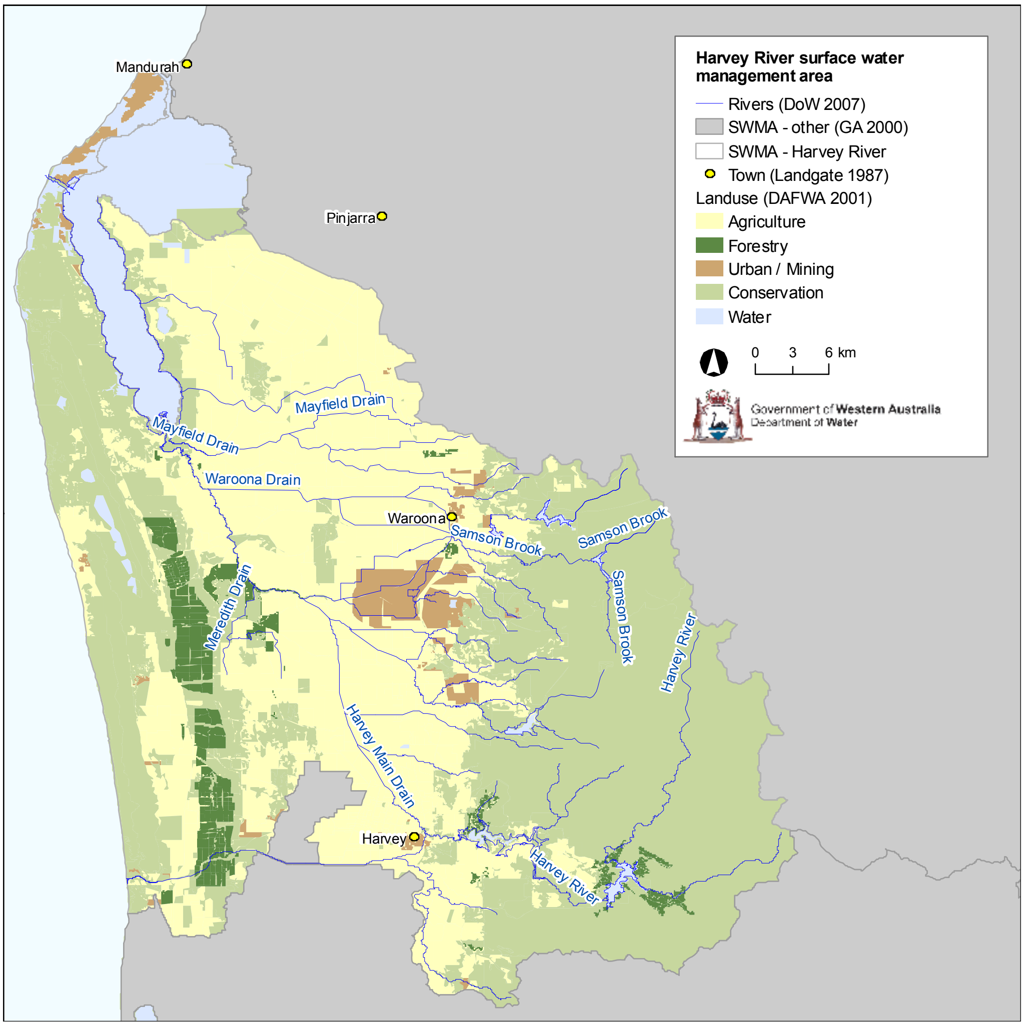

Figure 7 Harvey River surface water management area

Preston River SWMA (2009)

The Preston River SWMA is 1135 km^2. The Preston River's headwaters are situated 80 km inland in the Darling Range. It then runs through the Blackwood Plateau and Swan Coastal Plain (Figure 8). Forested remnant vegetation remains throughout the headwaters, but most of the lower catchment has been cleared. The hydrology has been altered via river straightening near the Bunbury townsite (to reduce flooding) and a water supply dam (Glen Mervyn Dam above Thomson Brook which is used for irrigation and recreational purposes). Most of the system is fresh, due to low levels of land clearing in the upper catchment, with a trend of decreasing salinity over recent years at Thomson Brook (measurement station 611111) and Preston River (measurement station 611004) (DEWHA 2009b), potentially due to improved management practices in agricultural areas.

Annual rainfall varies between 750 mm along the western and eastern parts of the SWMA to 900 mm in the centre (mean annual rainfall 1975–2003, see Table 68).

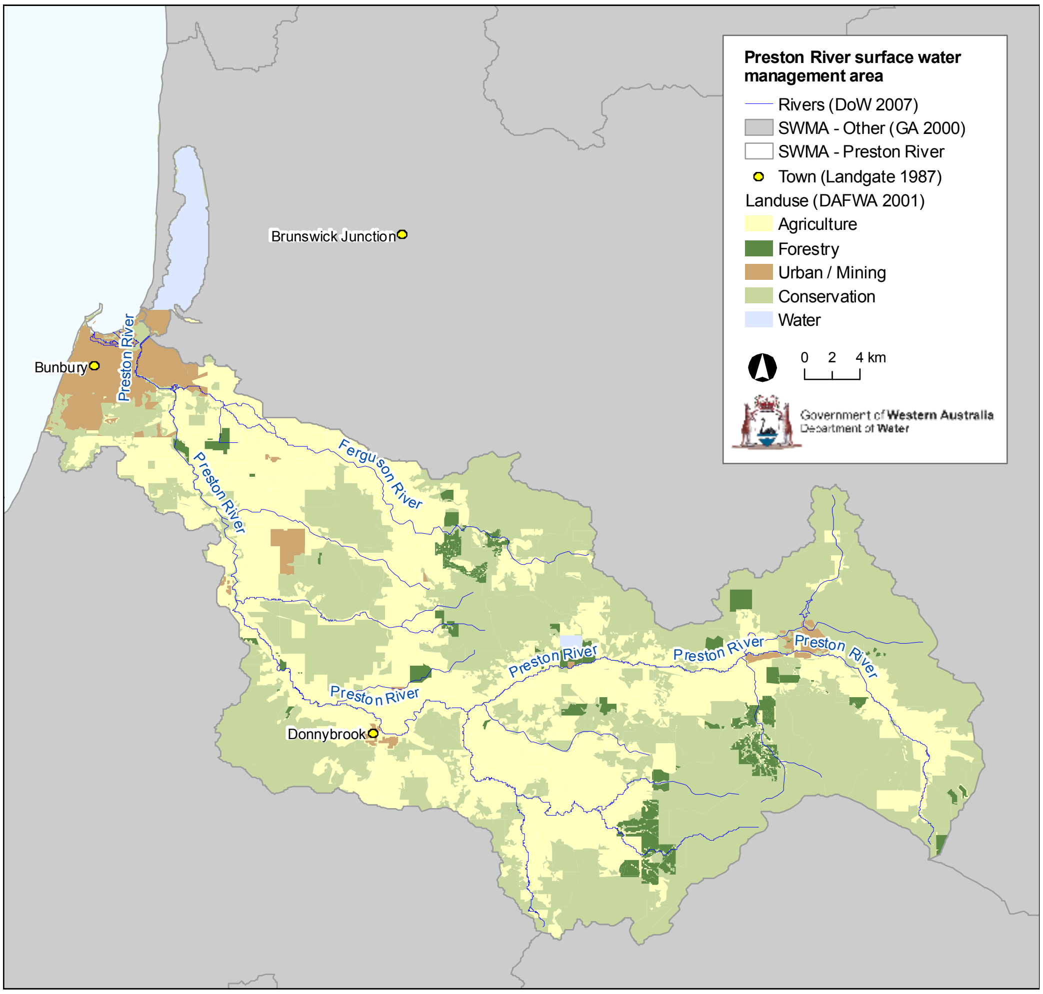

Figure 8 Preston River surface water management area

Busselton Coast SWMA (2009)

The Busselton Coast SWMA is 3057 km^2 and consists of many short river and creek systems primarily confined to the coastal plain between Bunbury and Augusta (Figure 10). The larger river systems – the Capel, Ludlow, Abba and Sabina – have headwaters in the Darling and Whicher ranges. Rainfall varies between 800 and 1100 mm annually, with the highest rainfall occurring in the south-western corner (mean annual rainfall 1975–2003, see Table 68). The natural drainage has been highly modified to drain low-lying areas of the Swan Coastal Plain for agriculture, primarily dairy farming. Five of the river systems have been diverted from the Vasse-Wonnerup estuary to discharge directly to the ocean. A number of creeks along the Leeuwin-Naturalist Ridge, discharging to Geographe Bay, contain near-intact fringing vegetation.

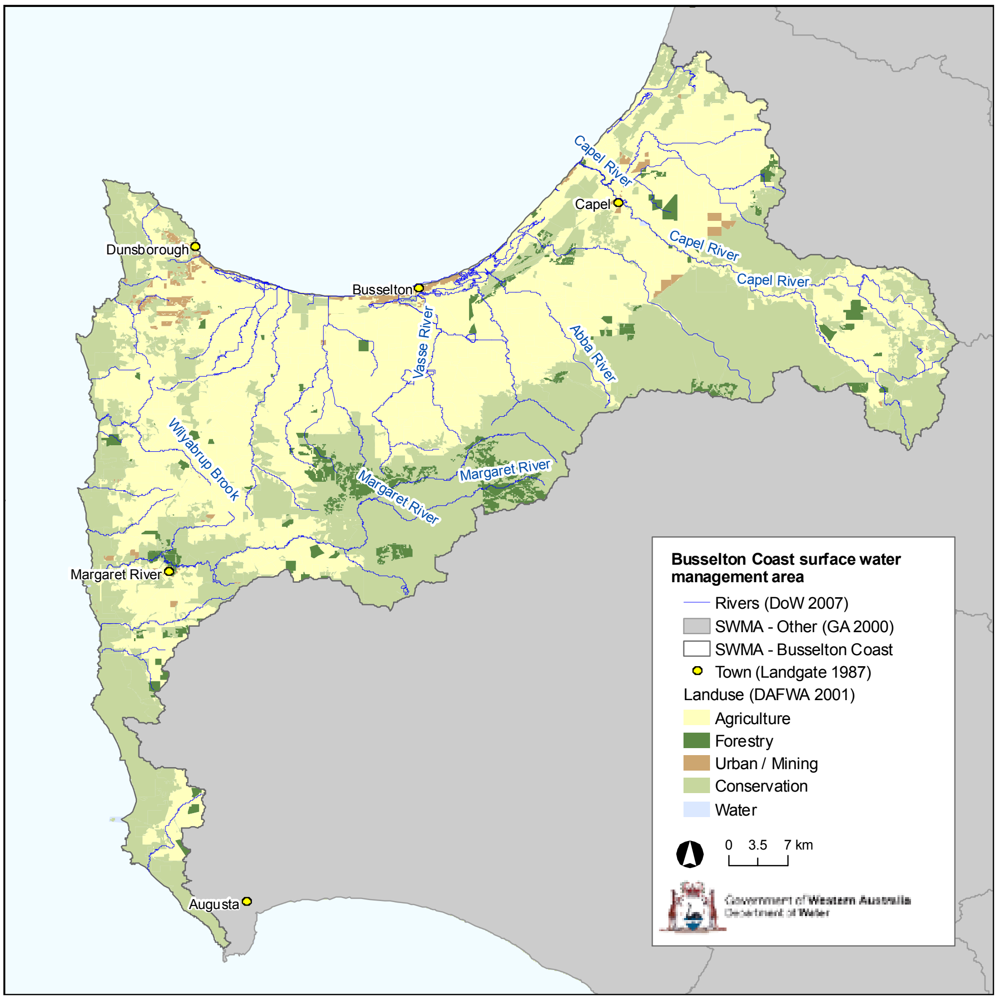

Figure 9 Busselton Coast surface water management area

Shannon River SWMA (2009)

The Shannon River SWMA is 3295 km^2 and incorporates the southern Darling Plateau and parts of the Ravensthorpe Ramp and Scott Coastal Plain (Figure 10). Three main rivers, each less than 50 km in length, are present: the Gardner (discharging directly to the ocean), the Shannon (discharging to Broke Inlet) and the Deep (discharging to Walpole-Nornalup Inlet). This region has the highest rainfall in SWWA, in excess of 1150 mm/yr in the south-western corner and along coastal margins, but decreasing to 700 mm in the SWMA's northern section (mean annual rainfall 1975–2003, see Table 68).

Only small areas of the Shannon River SWMA are cleared for agriculture, with the majority of the catchment being covered in dense remnant vegetation. A large percentage of the Broke Inlet is protected by conservation estates (the remainder being managed resources and some horticulture), while most of the inland waters of the SWMA are fresh.

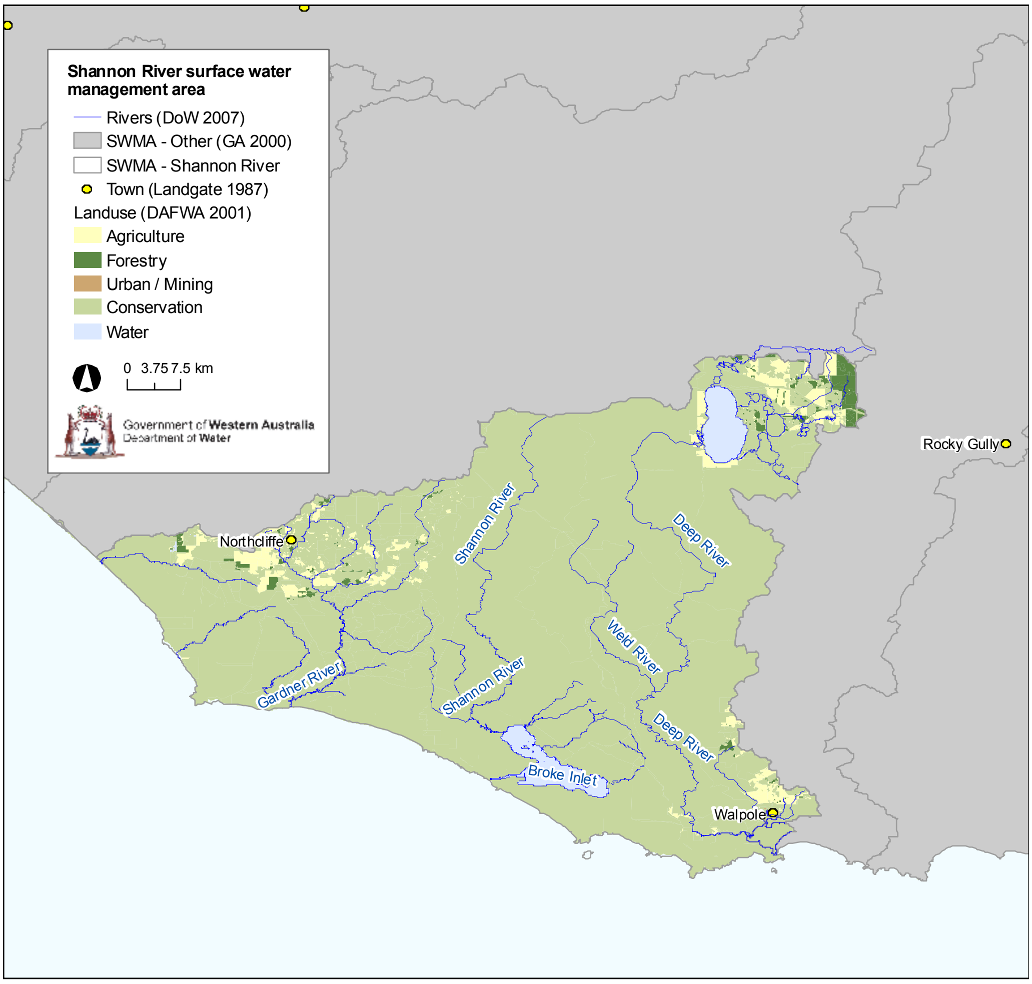

Figure 10 Shannon River surface water management area

Denmark River SWMA (2009)

The Denmark River SWMA is 2617 km^2. It is predominantly drained by the Denmark River, which extends approximately 50 km inland, and the Hay River, which extends around 80 km inland (Figure 11). Wilson Inlet, a seasonally open estuary (by an artificial opening determined by inlet water levels), is the receiving environment for both systems. Rainfall varies from 1050 mm in coastal areas to 650 mm/yr around the headwaters (mean annual rainfall 1975–2003, see Table 68). Native jarrah forests and wetlands become increasingly cleared for farming from west to east. A number of smaller systems exist between Parry Inlet and Oyster Harbour (e.g. Sleeman River). This area is predominantly cleared and contains rural drains. The Denmark River SWMA has signs of salinisation due primarily to clearing, however the extent is difficult to quantify because surveillance is limited. The Denmark River is also the most eastern river to be dammed for public water in SWWA, although the dam has recently been decommissioned.

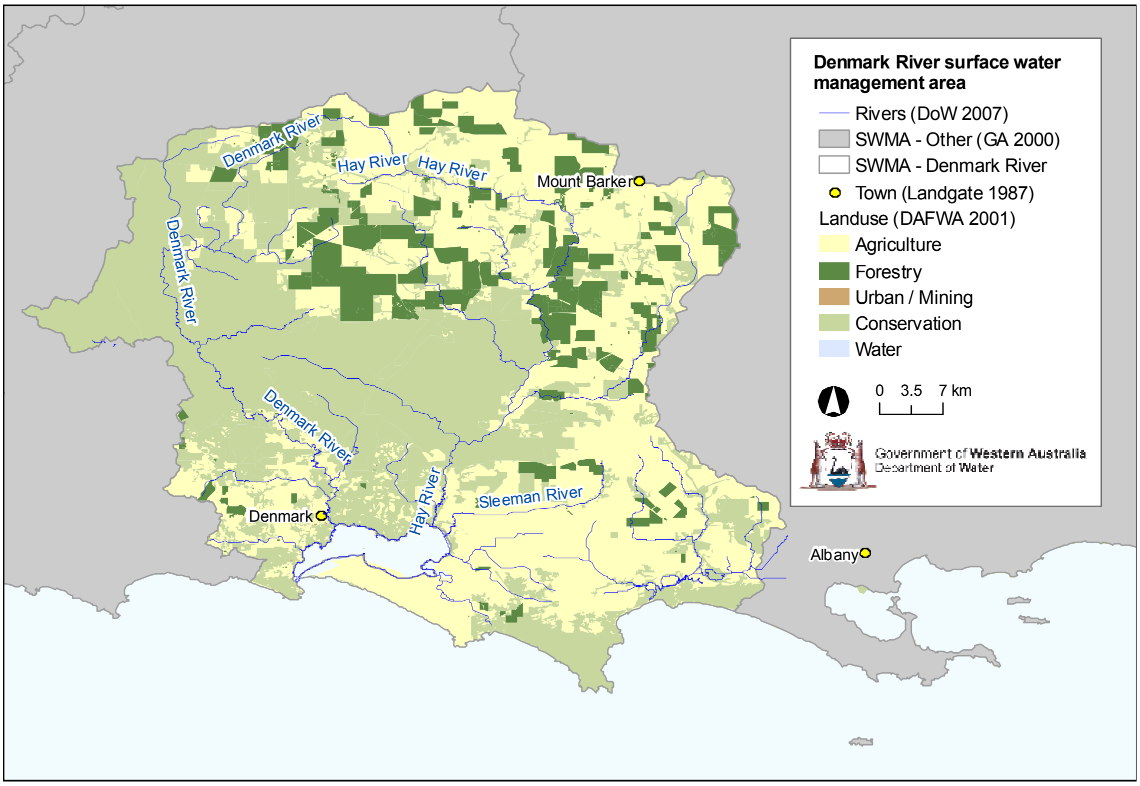

Figure 11 Denmark River surface water management area

3.3 Indicator selection

The FARWH organises ecological data within six themes representing ecological integrity. Indicators are recommended within each theme to capture the various elements that comprise the theme's ecological niche. Indicators can be derived from a number of component measures, which capture specific aspects of the ecological niche. For instance, the Aquatic Biota theme may comprise three sub-indices (e.g. *fish/crayfish sub-index*, *macroinvertebrate sub-index* and *macrophyte sub-index*) and each sub-index may be calculated from a number of components (e.g. *fish/crayfish sub-index* is derived from the *nativeness* and *expectedness* components). In this example, the *Aquatic Biota index* is the scoring protocol for combining all indicators.

As existing data for 2005 were known to be limited, indicator development centred on data collected for 2008–09. As such, many of the indicators selected as part of this project did not have data available for use in 2005.

The selection and testing of indicators was done under strict guidelines to maintain consistency and comparability. Indicator selection methods are elucidated below.

While some ad-hoc collection of data has occurred in Western Australia, either for the specific purpose of assessing river health or as part of other programs, there has been no broadscale, coordinated approach using standard sampling techniques, data analysis and reporting methods[1]. As such, there are no existing locally-derived indicators available for direct adoption into the SWWA-FARWH.

Given this, potential SWWA-FARWH indicators required development and testing. Selection of appropriate indicators was achieved by analysing the indicators recommended by the FARWH and other river health assessment programs from around Australia and the world, and by generating new indicators based on assessment of existing and generated data.

When selecting indicators consideration was given to ensure that wherever possible indicators were:

- proven, preferably in Western Australia (testing indices used in small-scale programs) with guidance from programs within Australia or worldwide
- relevant and assessable at the SWMA scale and applicable at the reach scale
- cost efficient
- rapid
- easy to use and therefore repeatable (associated degree of training is reasonable)
- able to reflect health and condition – as far as possible detecting changes occurring from management activities
- appropriate for long-term reporting (e.g. new data can be generated for future assessments)
- preferably applicable across the entire south-west region (however not required)
- capable of being compared with reference.

These attributes reflect the need for indicators both to capture ecological health and be easily adopted by a range of future users (in terms of labour/equipment cost and ease of application). It is anticipated the FARWH indicators will be used by regional offices and NRM groups after the development phase is complete.

Ultimately, the choice of indicators is governed by available data. To address this, a significant field data collection component was included in SWWA-FARWH trials and numerous existing datasets were analysed for testing existing indicators for their applicability to SWWA or to derive new indicators, some examples include:

- various GIS datasets (e.g. land use, vegetation)
- water quality data stored in the Department of Water’s Water Information Network (WIN) database

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[1] One exception is the Australian River Assessment Scheme (AUSRIVAS) developed from the National River Health Program. The AUSRIVAS model combines data collected throughout the state between 1994 and 2000 to develop a tailored program for Western Australia. The AUSRIVAS prescribes standard methods, which are employed in ongoing macroinvertebrate sampling, however the original Channel model requires further development to improve sensitivity and spatial fitness. This work has not been undertaken since its inception.

- Wild Rivers data
- ad hoc biological data (e.g. AUSRIVAS data).

For a complete list of the datasets reviewed for indicator development, see the list of data sources in Table 68. This table includes a brief review of each dataset for its relevance to river health assessment, including whether it was used in the SWWA-FARWH.

Trialling and developing the indicators

In addition to the more logistical aspects described above, identifying and selecting indicators for any multi-parameter index requires a rigorous selection process including several components (compiled from Bailey et al. 2004 and expert opinion):

- sampling must occur across the gradient of human disturbance, which requires assessment of sites with different types, extent and intensity of human influence in order to capture the associated biological responses
- the attribute must have a reliable empirical relationship across the human influence gradient
- the associated monitoring must adhere to rigorous standards regarding methods for measurement and scoring
- knowledge of ecological theory and natural history will guide the definition of attributes and predictions of how they will behave under varying human influences.

To determine whether indicators are appropriate signals of human influence a number of techniques are employed:

- Mapping biological response indicators against a measure of human impact.
- Use of conventional statistics based on multivariate analysis of biological measure versus human impact.
- Correlation statistics between indicators to highlight whether redundancies exist and alternatively identify where different indices provide additional information to the assessment. Note: some indices may behave similarly through much of the impact scale but become individually sensitive at certain ends; for example, one index may be sensitive to low-level disturbance but not high, whereas another may only show a response if conditions are at the extreme upper end of the impact scale.
- Understanding the temporal and spatial variability for each indicator is also important in indicator selection. Suitable statistical analysis techniques, such as classification and ordination, should be used to determine the spatial variability. Note: determining temporal variability is outside the scope of this project (as it only covers two sampling periods) for most indicators, because there will not be enough data collected to allow temporal analysis.

- Attention to analysis of spatial scales at which differences become acceptable (from reach to SWMA).
- Tests to avoid double-weighting (use of the same data in multiple places). However, if the data provide information on different ecological aspects, their inclusion twice may be warranted. This must be justified.
- Power analysis to determine if sampling size is sufficient and therefore whether the indicator is useful given potential cost-effectiveness constraints.
- Scenario testing (highlight effectiveness and sensitivity).
- Comparison with knowledge of regional natural history.

3.4 Reference condition

As was stated in the previous section, one of the most critical aspects of choosing ecological indicators is the ability to determine reference condition. An assessment of river health following this approach is based on determination of indices, which are scored based on measurement of the deviation of observed values from predicted theoretic values, representing the reference conditions.

As implied above, reference condition provides the benchmark to enable calculation of departure from this state when assessing current condition. However, the appropriate reference condition may reflect any number of benchmarks: for the FARWH the reference condition is defined as pre-European conditions, which can be refined to the current condition free from human impact. Note: this accounts for natural change since European settlement, but is confounded by climate change. Climate change inherently requires assessment of temporal indicators, however as the FARWH is designed as a snapshot of river health, assessment of climate change was not directly possible with the current trials.

Determining expectations is a fundamental principle of condition assessment but often the most difficult to quantify. Where there is limited historical data available to set expectations, reference condition can be determined from either reference sites (used to interpolate or extrapolate conditions expected at other sites) or, failing this, from expert opinion.

The typical approach for selecting reference sites involves a series of criteria that would be expected in a minimally disturbed system, such as no intensive land use or no dam within a certain distance of the site. These principles were briefly examined, however generally appeared not to apply to south-west systems because most sites contained some degree of catchment modification. The lack of available reference sites in other parts of the world has been reported, mostly for areas dominated by lowland rivers given the increased potential for development and reduced chance that undeveloped equivalents exist (Marchant et al. 1995; Norris & Thoms 1999; Thoms et al. 1999 – cited in Bailey et al. 2004). This scenario is matched by the form and function of SWWA rivers and further illustrates the inability to match techniques with other parts of Australia – presenting very different typologies.

Based on the review above, expert opinion was employed to determine reference for the SWWA-FARWH trials, drawing on available data and local knowledge of system ecology. In many cases this approach is non-problematic; for instance, weeds are an obvious departure from reference. However, this becomes increasingly difficult with the response indices (especially Aquatic Biota). Ultimately, expert opinion – in conjunction with all available data – was used to assign standard values representing threshold conditions for ecosystem protection, which were delineated based on knowledge of biotic tolerances.

The assigned reference condition and how this was developed for each indicator is summarised in Table 57 and discussed in more depth in the relevant theme sections below.

3.5 Dealing with missing data

Missing themes

The FARWH documents suggest that data need to be available for three of the six themes to allow an overall assessment to be made (NWC 2007a). Determining whether this was appropriate for SWWA and if some themes/indices were more critical than others was an objective of the SWWA-FARWH project. For the 2008 and 2009 SWWA-FARWH trials, all themes were assessed and compared to achieve this objective. The results are discussed in detail in each theme section, although to summarise – based on statistical analysis and supported by a general understanding of aquatic ecology – it is difficult to omit any of the themes (certainly with the current level of data). Further, individual themes appear to have different strengths depending on the scale being assessed, and no two themes show a consistent correlation (similarly there are no obvious redundancies). Using Aquatic Biota as the response indicator: variability is sometimes explained by Catchment Disturbance, other times by Fringing Zone and other times by Water Quality. There are fewer examples where Physical Form or Hydrology have provided direct links to response (where another theme has not also highlighted the response), however examples can be conceived where this would be the case – certainly at different scales (e.g. impact of major dam on biota).

Missing indicators or data

The approach to dealing with missing data for an individual index is often specific to that index. As such, how missing data were managed is discussed within reviews of the indices.

3.6 Integration and aggregation

The term ‘aggregation’ is used to denote assembling measures of the same index in different locations into a measure at a larger spatial scale (e.g. aggregating reach index scores to a SWMA index score). The term ‘integration’ denotes assembling measures of different indices at a given scale to generate a combined assessment at the same scale (e.g. integrating sub-index scores to calculate an index score) (NWC 2007b). Aggregation is more appropriate when crossing spatial scales, and integration is more appropriate for combining different indices.

Integration and aggregation are applied at a number of levels in generating an overall score for a SWMA.

Following the methods outlined in the FARWH guideline documents (NWC 2007b), indicators within each theme were integrated to produce a theme score for each reach. The method of integration of indicator scores to theme scores, such as whether weighting was applied, is index dependent. This is described in the relevant theme sections below [see Summary Box 2 for a brief overview]. Theme scores for each reach are reported and also aggregated together to produce a theme score for the SWMA. Aggregation of theme scores to the SWMA was reach-weighted, in that the relative length of a reach matched the contribution of the associated theme score to the SWMA score (see Figure 12).

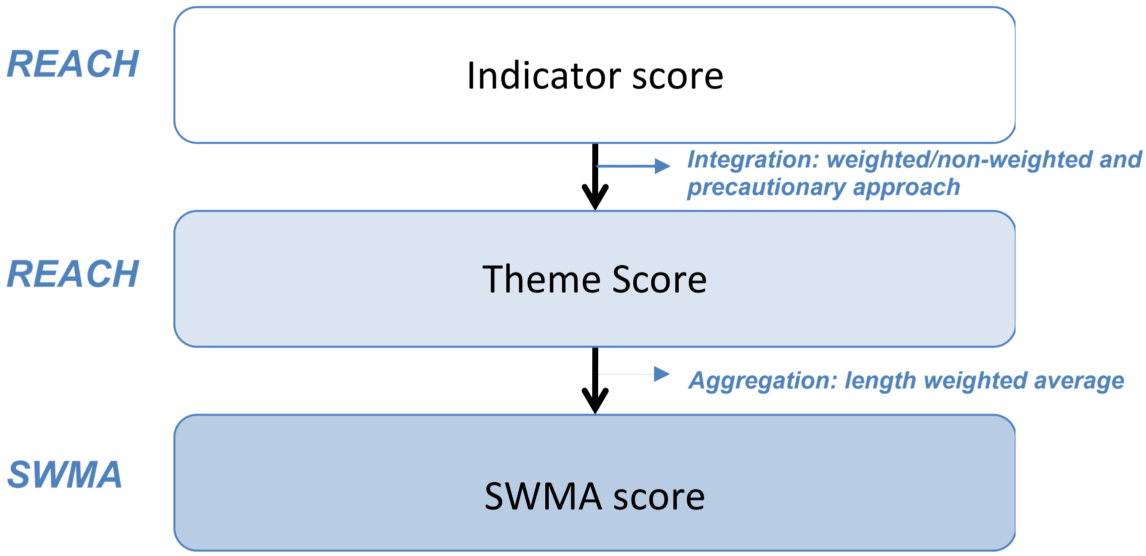


Figure 12 Integration-aggregation pathway for developing FARWH scores

Summary Box 2

Whether an average, Euclidian Distance or other method was employed for weighting and aggregation was dependent on data. For instance, Euclidian Distance was used in combining sub-indices of the *Physical Form index* where the index comprised different but complementary data. An average was used where sub-indicators or components provided discrete elements of impact on river health; for example, *high flow* and *low flow* components of hydrology.

3.7 Data analysis and verification

Statistical analysis methods were discussed at a workshop of representatives from the state FARWH trials, along with experts selected by the NWC, to ensure a nationally agreed and consistent approach to tackling this component of the project. The following elements were agreed:

Sensitivity analysis

Sensitivity analysis is the determination of how much something would need to change in order to illicit a response that would be detected by a scoring protocol.

Sensitivity analysis was conducted in trials, primarily through scenario testing. This was conducted as per the recommendations in the framework document (NWC 2007a). A statistical technique analogous to the ‘jackknife’ method was used where one sub-index at a time is removed from the dataset and the mean absolute change in overall assessment is calculated (Norris et al. 2001).

Power analysis

Power analysis is used to determine the sampling effort required to adequately represent the data population being assessed. Power has been assessed for all indicators examined in the SWWA-FARWH trials (except those where a score for each reach was determined) using a two-tailed t-test to predict the number of samples required to detect a given percentage change in the mean. Alpha has been set at 0.05 and Beta at 0.8 (to minimise the potential type I and type II error rates respectively). Because the analysis was conducted using one year’s worth of data for each SWMA (as this was all that was available) there is no knowledge of how variable repeat visits to the same site are. Therefore the results of the power analysis are indicative only at this stage and will need to be repeated once more data becomes available.

For the SWWA-FARWH trials the number of samples required to represent an effect size of both 10% and 20% has been reported, along with the power based on the sampling effort employed in the trials. This information is presented in Appendix C (which at this stage, as noted above, is indicative only). Power analysis was done post-hoc.

Double-weighting

Double-weighting refers to use of the same data in a number of indicators: effectively weighting that particular element more than others.

This is generally avoided, although in some cases apparent double-weighting is permitted, where data offer different aspects or multiple impacts. For example, crossing points between roads and rivers/streams are scored in both the *longitudinal connectivity sub-index* within the Physical Form theme (because they indicate potential barriers to fish migration) and the *infrastructure sub-index* under the

Catchment Disturbance theme (due to the potential impact from increased sedimentation and other pollutants associated with infrastructure). In this instance, different impact aspects of the same disturbance feature are scored in separate themes.

Redundancy

Following development and scoring of indicators within themes, the raw data, indicators and theme scores were compared through multivariate analysis to determine whether any redundancies existed. That is, whether any indicators were measuring the same response given high correlation – any such indicators would be deleted from the overall index – targeting the indicator that contributed most to labour/capital cost, thus maximising efficiency of assessment.

Data verification

Verification of all data is conducted to ensure that errors do not result from incorrect data entry. For field data, the process requires that one person enters data from field sheets and then re-checks the entry once finished. A different person is chosen to select sites at random and confirm that data are consistent. Where errors are found the number of sites selected for random checks is increased. The same process is employed for generation of scores. Minimal data entry errors were discovered through this process, all of which were corrected.

All GIS datasets were evaluated based on the lineage, positional and attribute accuracy information provided in the associated metadata statement: this helps determine whether the dataset is appropriate for the intended analysis. In addition, data were verified against other sources; for example, the Land Monitor Vegetation Extent datasets used to calculate *extent of fringing zone* scores were checked against aerial photographs to ensure the perennial vegetation delineated represented vegetation visible in the fringing zone.

An independent technical review of all methods, including data collection, was conducted as part of the FARWH program through the steering committee.

Statistical analysis

The response of the macroinvertebrate and fish-crayfish assemblage to a range of environmental and disturbance (impact) variables was examined separately by non-parametric multivariate analyses performed using the PRIMER (Plymouth Routines in Multivariate Ecological Research) package (Clarke & Gorley 2006). Results of these analyses are presented in Section 5.2.

Relationships between theme indices and indicators (components and metrics) were examined to determine whether any redundancies existed at the theme level and between indicators within a theme. Relationships were determined through scatter plots and linear regressions (correlations). The results of these statistical analyses can be found in Section 5.2.

4 Development of the assessment protocol

The assessment protocol is the index (and associated methods) that measures the departure of current condition from reference. Protocols developed for each theme, incorporating the associated indicators, are discussed below, including methods for indicator selection and testing, data collection and analysis, scoring and statistical analysis. Figure 13 illustrates the terminology in relation to the hierarchy of indicators that are used to calculate scores.

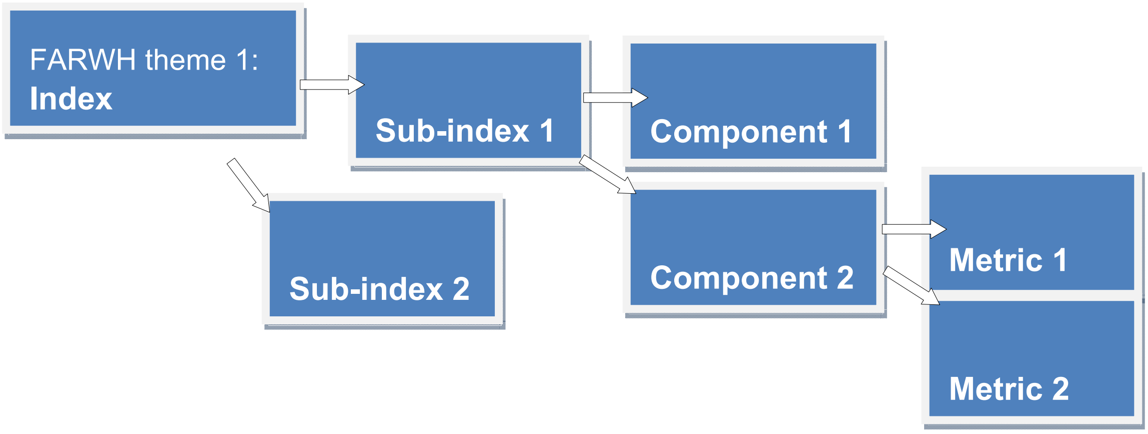


Figure 13 Terms used in the indicator hierarchy of the SWWA-FARWH

Statistical analysis: power, sensitivity and multivariate analysis

Statistical analysis for power and correlation/redundancy within and between themes and SWMA scores was conducted as the final stage in the project and is presented in this report. Because analysis required indicators to be developed and scored based on data generated within the SWWA-FARWH trials, there was generally insufficient time to retrial new indicators if statistical assessments highlighted any inadequacies in results. Ideally, power analysis should be undertaken prior to sampling, but this could not be done given an existing dataset (with which to conduct this analysis to determine optimal sampling regimes) was not available.

The performance of indicators from an analysis of power, sensitivity and multivariate statistical techniques perspective is discussed within the theme reviews below.

Scoring

To represent the scores graphically the bands recommended in NWC 2007a (shown in Table 2) have been used.

Table 2 Mapping bands and definitions

Category	Description
0 – 0.19	Severely modified condition
0.2 – 0.39	Substantially modified condition
0.4 – 0.59	Moderately modified condition
0.6 – 0.79	Slightly modified condition
0.8 – 1.0	Largely unmodified condition

Assessment of the ability of FARWH scores to reflect SWWA conditions requires an understanding of the major ecosystem drivers, such as natural landscape, climatic features and anthropogenic impacts. The following figures detail some of the major ecosystem drivers in SWWA, including:

- reach hierarchy (main stream, major and minor tributaries)
- topography/altitude
- rainfall
- geology
- land use.

Note: these figures are included for reference against scores provided in the following theme reviews.

Figure 14 Watercourse hierarchy of SWWA

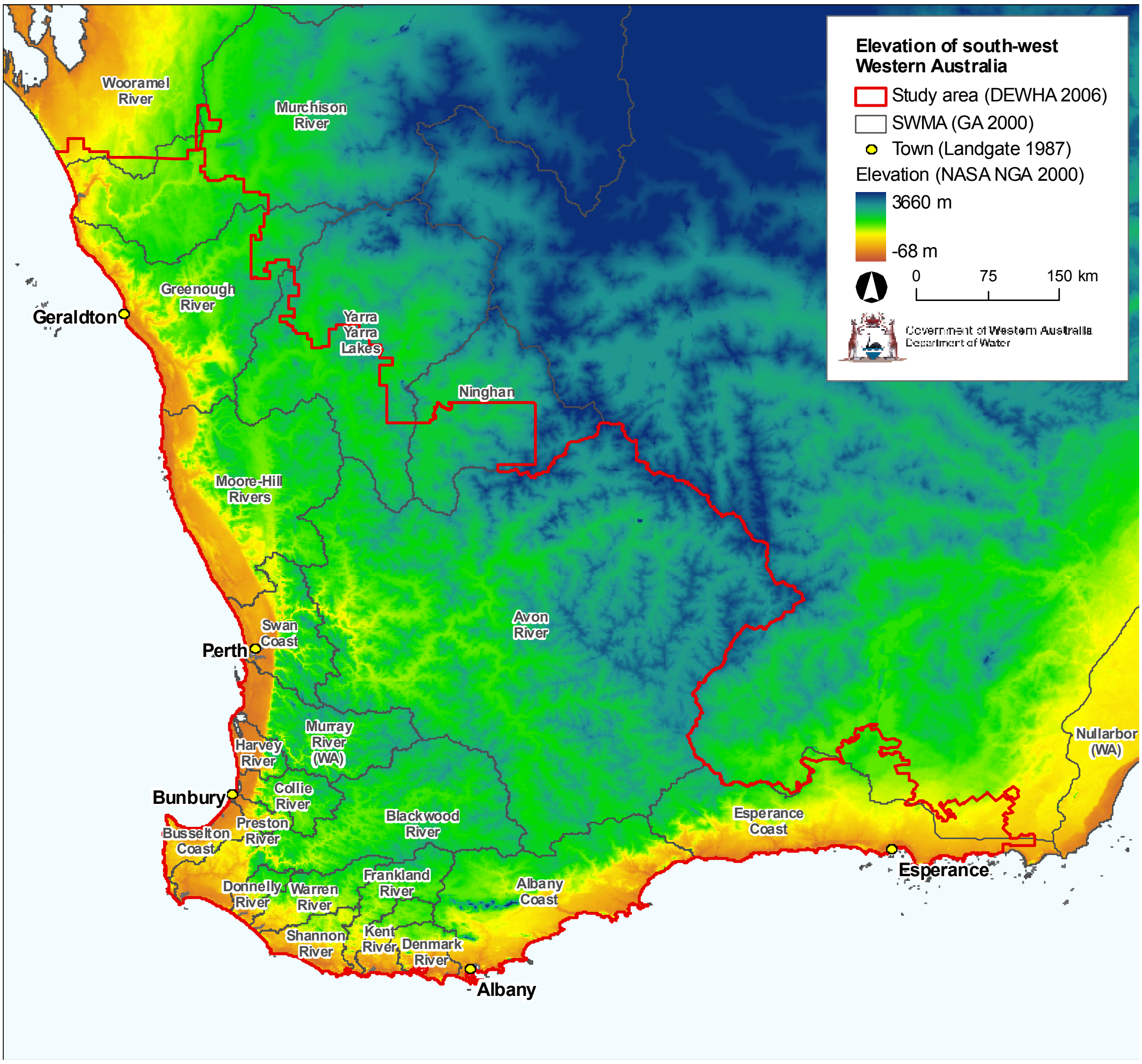


Figure 15 Elevation of SWWA

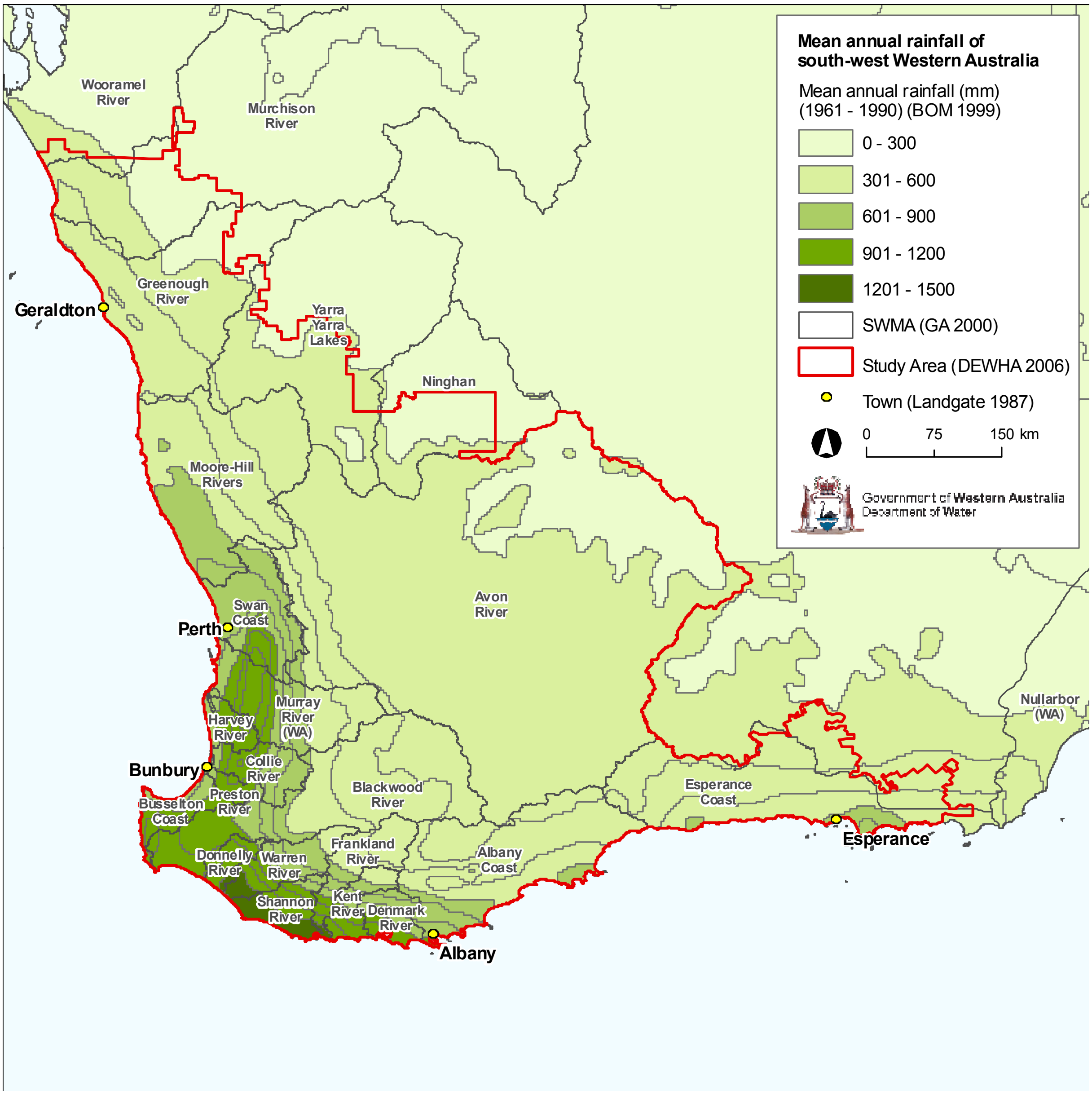


Figure 16 Mean annual rainfall of SWWA

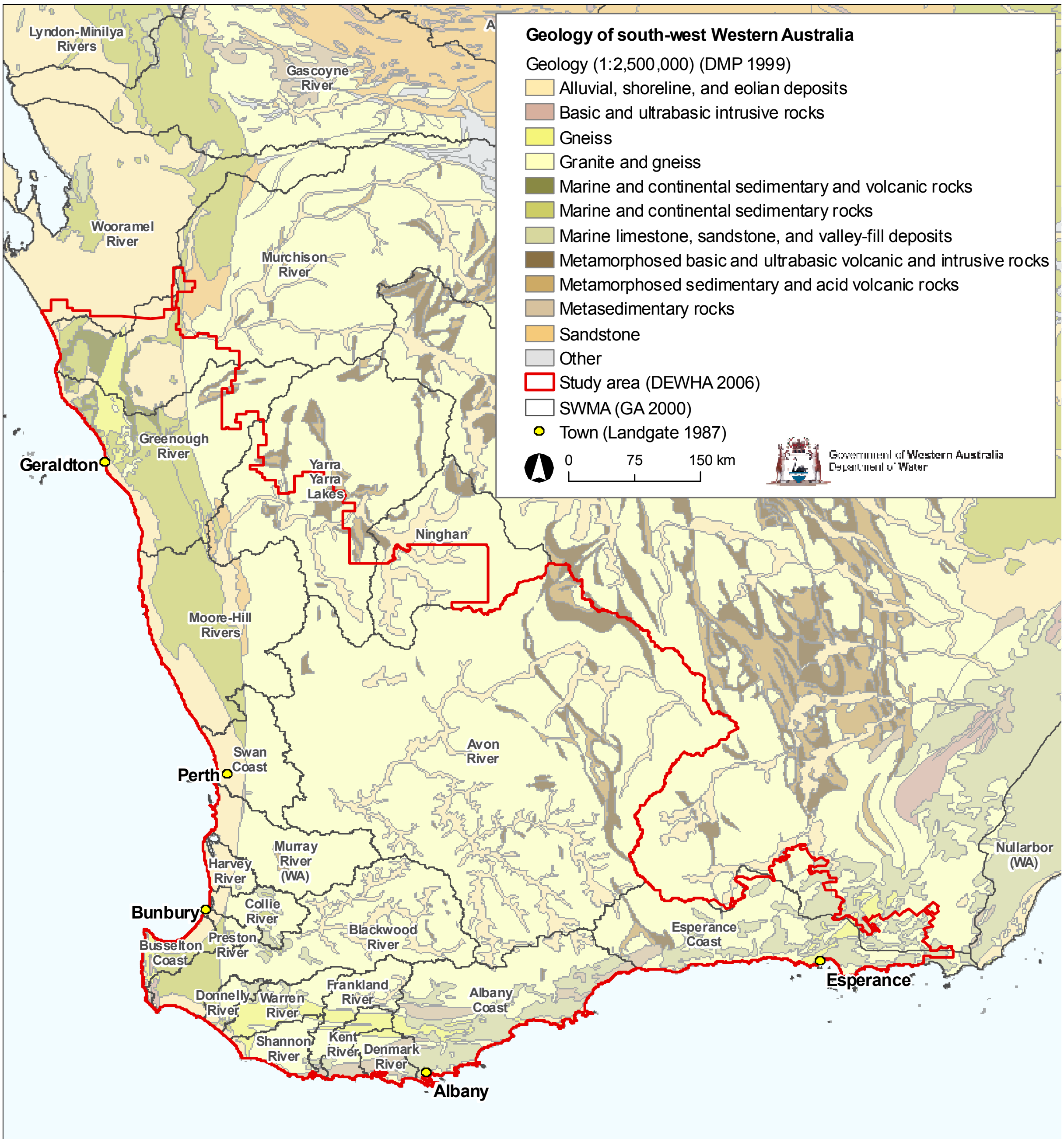


Figure 17 Geology of SWWA

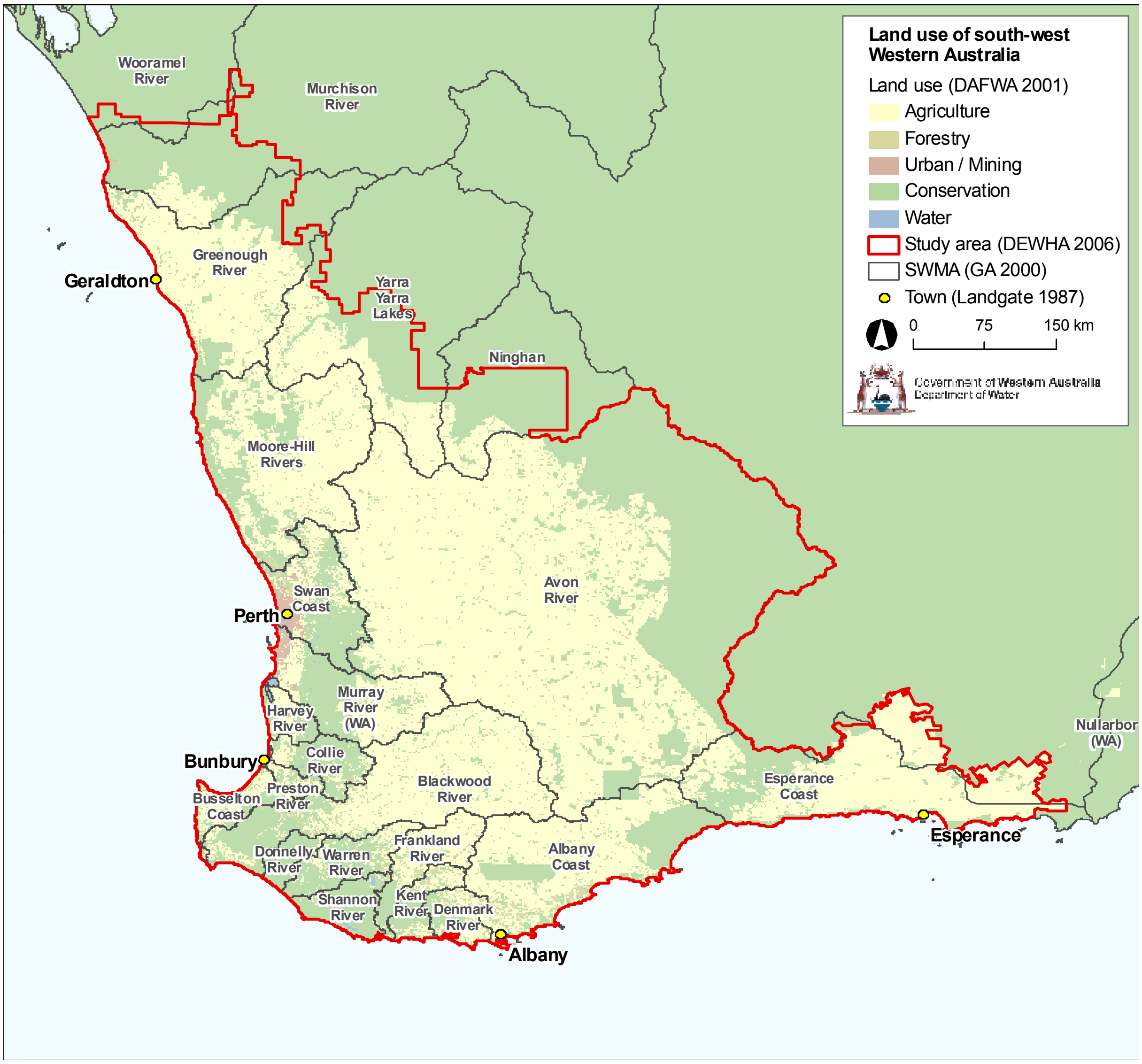


Figure 18 Land use of SWWA

4.1 Theme: Catchment Disturbance

The physical characteristics of a catchment influence the river system via large-scale controls on hydrology, sediment delivery and chemistry (Allen & Johnson 1997). Consequently, disturbance within the catchment can affect the health of a river system (Boulton & Brock 1999; Allen 2004). For example, clearing the native vegetation from a catchment may lead to increased runoff and therefore higher flows, which can cause erosion of banks and sedimentation of channels and pools. It can also lead to increased groundwater recharge, potentially mobilising salt stored in the soil profile, resulting in the salinisation of land and river systems (Pen 1999). Other impacts of catchment disturbance include loss of riparian vegetation, eutrophication and contamination (e.g. herbicides, pesticides) (NWC 2007b).

The Catchment Disturbance theme is the primary pressure indicator of the FARWH: it has a direct relationship with, or impacts on, all other themes. Assessing the amount of anthropogenic disturbance in a catchment provides information about causes of river health issues and highlights potential future impacts (NWC 2007a).

Indicators of catchment disturbance

The FARWH recommends assessing disturbance to a catchment through three sub-indices: *land use, land cover change* and *infrastructure* (NWC 2007b). These sub-indices characterise changes made to the land surface which can result in hydrological and riparian vegetation change, and increased runoff of sediments, nutrients and pollutants into rivers (i.e. large-scale diffuse source contaminants) (NWC 2007a; NWC 2007b).

These three sub-indices were assessed in the SWWA-FARWH trials using the general approach suggested in the FARWH guidelines (NWC 2007b). Given this index applies at a catchment scale (as opposed to site scale), desktop analysis methods were used to conduct the assessment. A summary of the impacts of *land use, infrastructure,* and *land cover change* is provided in Table 3, and the principle mechanisms by which they influence river health is given in Table 4. The similarities between the indicators are acknowledged and the reasons for their inclusion are explained below.

Table 3 Examples of impacts of catchment disturbance on river health

Indicator	Examples of impacts
Land use	Different land uses can have a range of impacts including salinisation, eutrophication, sedimentation, acidification, other contamination, alteration of hydrological regimes and alteration of riparian vegetation (Allan 2004; Boulton & Brock 1999). For example, fertiliser applied in agricultural and urban areas, along with effluent from livestock and sewerage treatment plants, can lead to increased nutrients in rivers (NWC 2007a).
Land cover change (vegetation clearing)	Reduced interception by vegetation can cause increased overland flow, leading to increased sediment supply into rivers. Higher flows can also cause bank erosion and subsequent sedimentation (Pen 1999). Reduced interception and uptake of water by non-native vegetation can lead to increased groundwater recharge. Rising groundwater tables can mobilise salt stored in the soil profile, resulting in salinisation of land and rivers (Pen 1999). Removal of riparian vegetation can affect river health in a number of ways (see Table 47 in the Fringing Zone theme).
Infrastructure	Infrastructure can cause a number of impacts on river health including increased concentrations of nutrients and other contaminants, changes to the hydrological regime via increased runoff from sealed roads and other hard surfaces and increased sediment delivery (NWC 2007a). For example, poorly designed road crossings can alter natural flow dynamics leading to erosion and sedimentation (Boulton & Brock 1999). In agricultural and forested catchments unsealed roads are a significant source of sediment and associated nutrients to rivers (Motha et al. 2004; Sheridan & Noske 2007).

Table 4 Principle mechanisms by which land use influences stream ecosystems (taken from Allen 2004)

Environmental factor	Effects	References (cited in Allen 2004)
Sedimentation	Increased turbidity, scouring and abrasion; impairs substrate suitability for periphyton and biofilm production; decreases primary production and food quality causing bottom-up effects through food webs; in-filling of interstitial habitat harms crevice-occupying invertebrates and gravel-spawning fishes; coats gills and respiratory surfaces; reduces stream depth heterogeneity, leading to decrease in pool species.	Burkhead & Jelks 2001, Hancock 2002, Henley et al. 2000, Quinn et al. 2000, Sutherland et al. 2002, Walser & Bart 1999, Wood & Armitage 1997
Nutrient enrichment	Increases autotrophic biomass and production, resulting in changes to assemblage composition, including proliferation of filamentous algae, particularly if light also increases; accelerates litter breakdown rates and may cause decrease in dissolved oxygen and shift from sensitive species to more tolerant, often non-native species.	Carpenter et al. 1998, Delong & Brusven 1998, Lenat & Crawford 1994, Mainstone & Parr 2002, Niyogi et al. 2003

Environmental factor	Effects	References (cited in Allen 2004)
Contaminant pollution	Increases heavy metals, synthetics, and toxic organics in suspension associated with sediments and in tissues; increases deformities; increases mortality rates and impacts to abundance, drift, and emergence in invertebrates; depresses growth, reproduction, condition, and survival among fishes; disrupts endocrine system; physical avoidance.	Clements et al. 2000, Cooper 1993, Kolpin et al. 2002, Liess & Schulz 1999, Rolland 2000, Schulz & Liess 1999, Woodward et al. 1997
Hydrologic alteration	Alters runoff/evapotranspiration balance, causing increases in flood magnitude and frequency, and often lowers baseflow; contributes to altered channel dynamics, including increased erosion from channel and surroundings and less-frequent overbank flooding; runoff more efficiently transports nutrients, sediments and contaminants, thus further degrading in-stream habitat. Strong effects from impervious surfaces and stormwater conveyance in urban catchments and from drainage systems and soil compaction in agricultural catchments.	Allan et al. 1997, Paul & Meyer 2001, Poff & Allan 1995, Walsh et al. 2001, Wang et al. 2001
Riparian clearing/canopy opening	Reduces shading, causing increases in stream temperatures, light penetration and plant growth; decreases bank stability, inputs of litter and wood, and retention of nutrients and contaminants; reduces sediment trapping and increases bank and channel erosion; alters quantity and character of dissolved organic carbon reaching streams; lowers retention of benthic organic matter owing to loss of direct input and retention structures; alters trophic structure.	Bourque & Pomeroy 2001, Findlay et al. 2001, Gregory et al. 1991, Gurnell et al. 1995, Lowrance et al. 1984, Martin et al. 1999, Osborne & Kovacic 1993, Stauffer et al. 2000
Loss of large woody debris	Reduces substrate for feeding, attachment and cover; causes loss of sediment and organic material storage; reduces energy dissipation; alters flow hydraulics and therefore distribution of habitats; reduces bank stability; influences invertebrate and fish diversity and community function.	Ehrman & Lamberti 1992, Gurnell et al. 1995, Johnson et al. 2003, Maridet et al. 1995, Stauffer et al. 20002

Similarities between indicators

The three indicators quantify similar impacts of catchment disturbance on river health, but via different activities. The *land cover change* indicator measures the acute (severe, short-term) impacts of vegetation clearing; for example, nutrient and sediment export resulting from the clearing process and step-change in runoff. By comparison, the *land use* indicator measures the chronic (long-term) impact; for example, on-going effects from hydrological change, nutrient and sediment supply (dependent on actual land use) and supply of toxicants (NWC 2007b).

It is acknowledged that infrastructure is a form of land use, although it is not well delineated in land use datasets. Where it is included there is little information about the type of infrastructure present. Consequently the variation in sediment, nutrient and toxicant exports from different infrastructure surfaces cannot be included in calculations. Given this particular land use comes into close proximity with rivers via crossing points and river corridors it is important to quantify the amount of infrastructure within a catchment separately to other land uses.

The similar nature of the impacts caused by the three forms of catchment disturbance is accounted for via the integration approach (see Section 3.6: *Integration and aggregation*).

Sub-index: land use

Scoring and reference condition

For the 2008 and 2009 assessments the impact of land use on river health was quantified by calculating the area of each land use type present in the catchment of a reach, and multiplying that by a weighting to give a *land use sub-index* score.

The weightings for each land use type were devised by ranking land use types by their relative contribution to seven impact factors. The rankings were based on those recommended in the FARWH documents (NWC 2007b) with some modifications for local conditions (Table 5).

The mean ranks were converted to a weighting by scaling them to a range between 0 and 0.7, as recommended in the FARWH documents. A maximum weighting of 1.0 was not used because this implies the land use's impact on river health could not get any worse: this was felt to be unrealistic and so an arbitrary maximum weighting of 0.7 was applied (NWC 2007b).

The *land use sub-index* scores were calculated using Equation 1. The scoring protocol uses an assumed reference condition of 'all land being equivalent to conservation use in pre-European times'; that is, any use of the land by Aboriginal people for hunting and gathering is assumed to have had no impact on river health.

Equation 1 $$LUSI = 1 - \left((F_1 \times w_1) + (F_2 \times w_2) \ldots + (F_7 \times w_7)\right)$$

Where: LUSI = land use sub-index; F_n = fraction of the catchment of land use category n and w_n = the weight for land use category n. (Note: there are seven possible land use categories.)

Table 5 Rankings for different land use types and resulting weightings for SWWA (those recommended by the FARWH shown in brackets)

Land use	Impact factor ranking							Mean rank	Weight
	Nutrients	**Salinity**	**Biocides**	**Hydrological change**	**Sediment supply**	**Riparian change**	**Toxicants**		
Urban	5	2	3	6	3	6	6	4.43	0.66 (0.68)
Intensive and irrigated agriculture	6	5 (6)	6	5	4	3	4 (2)	4.71 (4.57)	0.70
Dryland cropping	4	5 (4)	4	3	3	3	2 (1)	3.43 (3.14)	0.51 (0.48)
Grazing	2	4 (3)	3	1	2	3	1	2.29 (2.14)	0.34 (0.33)
Plantation forestry	1	2 (3)	3	2	1	1	1	1.57 (1.71)	0.23 (0.28)
Managed resources	1	1	–	1	1	–	–	0.57	0.08
Conservation	–	–	–	–	–	–	–	0	0

Note: the weightings differ from those given in the first-round trials report (van Looij et al. 2009). Scaling from mean rank to weighting in the first round trial used 4.57 as the maximum mean rank in accordance with guidance in the FARWH documents, whereas Table 5 shows the weightings scaled based on a maximum mean rank of 4.71 calculated for SWWA conditions.

Modification of rankings for SWWA

Modifications to the rankings, and subsequent weightings, were made based on a review of literature for SWWA which found the following:

Toxicants

The rankings recommended in the FARWH for toxicants were based on the likelihood of different land uses contributing hydrocarbons and other toxicants to the rivers. For SWWA the impact of hormones and fertiliser use has also been taken into account.

Soils throughout SWWA are characteristically limited in nutrients; as such, water-soluble fertilisers are widely used to improve agriculture production. Fertilisers can contain a range of chemicals which may cause deleterious effects in the environment; for example, cadmium, mercury and lead are typically found in fertilisers and are likely to accumulate in soils (FIFA 2008). Bennet-Chambers et al. (1999) estimate that almost 300 tonnes of cadmium has been added to Western Australian soils through the application of superphosphate fertilisers between 1982 and 1999 (50% of which is water soluble). They suggest that cadmium leaches into aquatic systems and bioaccumulates in the flesh of *Cherax tenuimanus* (smooth marron) and *Westralunio carteri* (freshwater mussels), with the highest bioaccumulation in the latter species occurring in degraded catchments.

Agricultural activities, especially the cattle industry and dairy farms, use a variety of hormones to increase production to commercially viable levels. Large amounts of compounds that may interfere with the normal functioning of endocrine systems have been found in animal waste effluents (Kjr et al. 2007; Khan et al. 2008). Recent studies have shown that hormone metabolites can remain in manure piles for more than 260 days (Orlando et al. 2004), and that they can be leached from spread manure into streams for up to three months (Kjr et al. 2007). While the intensive and irrigated agriculture land use category encompasses more than just intensive cattle and dairy farming, it is felt the potential environmental effects of hormones and their metabolites should not be overlooked. As such, their impact has been considered when assigning the ranking for toxicants to intensive and irrigated agriculture land use.

Based on these findings the rankings for toxicants for intensive and irrigated agriculture (fertilisers and hormones) and dryland cropping (fertilisers) were increased compared with those suggested in the FARWH documentation.

Salinity

Salinity rankings were modified for SWWA conditions: the rankings for intensive and irrigated agriculture and forestry were reduced, while the rankings for dryland cropping and grazing were increased. Much of the intensive and irrigated agricultural land use in SWWA lies in the high-rainfall areas, where the effects of salinity are not as severe as in lower-rainfall areas. Correlations have been shown between the increase of salinity in cleared catchments and decreasing rainfall (Mayer et al. 2005; Schofield & Ruprecht 1989; Bari & Schofield 1991). For the same reason, the rankings for dryland cropping and grazing have been increased. As salinity in SWWA is predominantly caused by the removal of deep-rooted vegetation, its reintroduction is used as a means to rehabilitate saline lands. Planting of commercial tree plantations, along with other salinity management measures, has been shown to be successful in salinity reduction management (Bari & Schofield 1991). While there may be pulses of salinity associated with the clearing of mature trees, this is short-lived over the cropping cycle used in plantation forestry. The salinity ranking for plantation forestry was therefore reduced.

Managed resources

A separate land use category – managed resources – has been added to the land use types in Table 5 and given its own ranking. This recognises that those land uses classified as 'managed resources' in the NLWRA Land Use dataset (see Table 68) for calculating the land use measure are actually managed as production forests (known as state forests). These are areas of natural bushland managed by the Department of Environment and Conservation (DEC) that are zoned for logging. Clearing in these areas is usually conducted on a 50-year cycle although this is subject to a number of factors (e.g. location). This clearing frequency is lower than plantation forests which are typically logged every 12 to 15 years (Tasmanian blue gums) or 20 to 30 years (pine plantations). As these areas are periodically logged it is misleading to classify them as conservation (as per NWC 2007b). The impact from this land use is minimal and tends to be acute, occurring over a short period of time immediately after an area has been logged. Riparian zones are not typically cleared during these logging exercises because they do not generally include the targeted tree species, hence no ranking was assigned to riparian zones. Further, biocides and toxicants are not used in this kind of forestry, again leading to no ranking being assigned for these impacts.

Data sources

The *land use sub-index* scores for the 2008 and 2009 assessments were calculated using the NLWRA Land Use dataset (see Table 68), which shows land use at a property scale as assessed by DAFWA field officers between 1996 and 2001 (based on the primary source of income for each cadastral block) (Beeston et al. 2002). Land use is classified according to Australian Land Use Management (ALUM) classification devised by the Bureau of Rural Sciences (BRS).

A number of datasets were investigated for calculating the *land use sub-index* scores, including the Land Use of Australia Version 3 2001/02 dataset (see Table 68). This is the most recent in a series of country-wide land use raster datasets with a resolution of 0.01 degree pixels (approximately 1 km square). An evaluation of this dataset for the Collie River SWMA found it did not accurately reflect the known land use in the area. While the attributes in the NLWRA Land Use dataset are approximately 10 years old, this dataset provides the only comprehensive coverage of land use at a property scale for the study area, hence it was selected for this indicator. (Note: DAFWA has a rolling program to update the NLWRA Land Use dataset but the coverage of completed areas did not match the SWMA boundaries, so use of this data would have resulted in land use being assessed over a wide range of different years within one SWMA).

Data from the NLWRA Land Use dataset were grouped into broad land use types based on those recommended in the FARWH documents (NWC 2007b) (Table 6).

Table 6 NLWRA Land Use categories and associated SWWA-FARWH categories

Secondary land use description (NLWRA Land Use dataset)	SWWA-FARWH land use category	Notes
Nature conservation	Conservation	
Other minimum intervention use	Conservation	
Lake	Conservation	
Reservoir/dam	Conservation	
River	Conservation	
Artificial waterbody	Conservation	
Conserved natural waterbody	Conservation	
Managed natural waterbody	Conservation	

Secondary land use description (NLWRA Land Use dataset)	SWWA-FARWH land use category	Notes
Managed resource protection	Managed resources	Managed resources category added to accommodate state forest in WA which is managed differently to conservation areas.
Plantation forestry	Plantation forestry	
Irrigated plantation forestry	Plantation forestry	
Grazing and improved pastures	Grazing	
Cropping	Dryland cropping	
Seasonal horticulture	Intensive & irrigated agriculture	
Irrigated modified pastures	Intensive &irrigated agriculture	
Irrigated cropping	Intensive & irrigated agriculture	
Irrigated perennial horticulture	Intensive & irrigated agriculture	
Intensive animal production	Intensive & irrigated agriculture	Grouped intensive and irrigated agriculture as rankings for the seven impact factors would be similar.
Manufacturing and industrial	Urban/mining	
Residential	Urban/mining	
Services	Urban/mining	
Mining	Urban/mining	Grouped with urban as rankings for the seven impact factors would be similar.

Data verification

According to the metadata statement for the NLWRA Land Use dataset (see Table 68) the positional accuracy of the data varies depending on the accuracy of the cadastral dataset in the late 1990s, however the error margin has not been quantified. The statement suggests that a number of errors have been corrected (polygon overlaps/slivers removed; waterbodies, stock routes and additional plantations added; status of conservation areas updated).

The attribute accuracy is also variable although the error margin is not stated: the metadata statement suggests the attributes are subjective for properties where DAFWA field officers and Landcare officers had little contact with the landholder.

Data frequency

The NLWRA Land Use dataset (Table 68) was produced as a one-off ‘snapshot’ of land use for the NLWRA. DAFWA has a rolling program to update the land use data, however the updates available in January 2010 did not correspond with whole SWMAs, and hence were not used for the 2008 and 2009 assessments. Based on the limited spatial coverage of updates (i.e. a small number of catchments in SWWA are updated each year) it is recommended the *land use sub-index* scores be recalculated every five years, however it could be calculated more frequently if new data were released at a suitable spatial and temporal scale.

Sensitivity and scenario testing

Due to scaling of the weightings between 0 and 0.7, the lowest score able to be obtained for the *land use sub-index* is 0.3, while the best score is 1.0 (Table 7). As discussed previously (in *Scoring and reference condition*), this has been devised to allow for future revision of the weightings if the impacts of land use on river health worsen. However, a disadvantage of this approach is that it limits the scoring protocol's range, effectively reducing the ability to differentiate between levels of disturbance in different catchments. For example, the catchment of reach 6131912, which represents part of the Harvey Main Drain, is covered by 50% intensive and irrigated agriculture and 30% grazing (and 20% other uses): under the current scoring protocol the reach scores 0.5 for land use. The catchment of the neighbouring reach, 6131990, has a much higher proportion of grazing (60%) and a lower proportion of intensive and irrigated agriculture (30%) (plus 10% other uses) but it scores the same for land use as reach 6131912.

It is difficult to accurately determine sensitivity given the infinite permutations of land use proportions. A review of final scores is provided to highlight spread against known impacts (Figure 82).

The sensitivity of the *land use sub-index* to temporal change depends on the land uses within the catchment. For example, if the land use of a catchment was 100% conservation originally and then 8% was cleared for intensive and irrigated agriculture, the score would reduce from 1.0 to 0.9. The same change in score would occur if 59% of the catchment was changed from conservation to managed resources (Table 7).

Table 7 The range of land use sub-index scores obtainable and change scenarios

Scenario	Land use sub-index score
Catchment 100% conservation (best-case scenario)	1
Catchment 50% conservation, 50% intensive and irrigated agriculture (middle-case scenario)	0.6
Catchment equal proportions of all land uses	0.6
Catchment 100% intensive and irrigated agriculture (worst-case scenario)	0.3
Catchment 92% conservation, 8% intensive and irrigated agriculture	0.9
Catchment 41% conservation, 59% managed resources	0.9

Reach scores

The *land use sub-index* scores for reaches assessed in the 2008 and 2009 field trials are shown in Figure 19 and can be found in Appendix A. Scores ranged between 0.5

and 1.0 (out of a possible 0.3 to 1.0). The lowest-scoring reaches occurred in Minyulo Brook and the upper reaches of the Moore River in the Moore-Hill Rivers SWMA; the Pallinup River and the upper reaches of the Gairdner, Bremer and Kalgan rivers in the Albany Coast SWMA; and in the Harvey Main Drain in the Harvey River SWMA. Land use in these areas is dominated by agriculture, whereas many of the higher-scoring reaches fall in conservation areas.

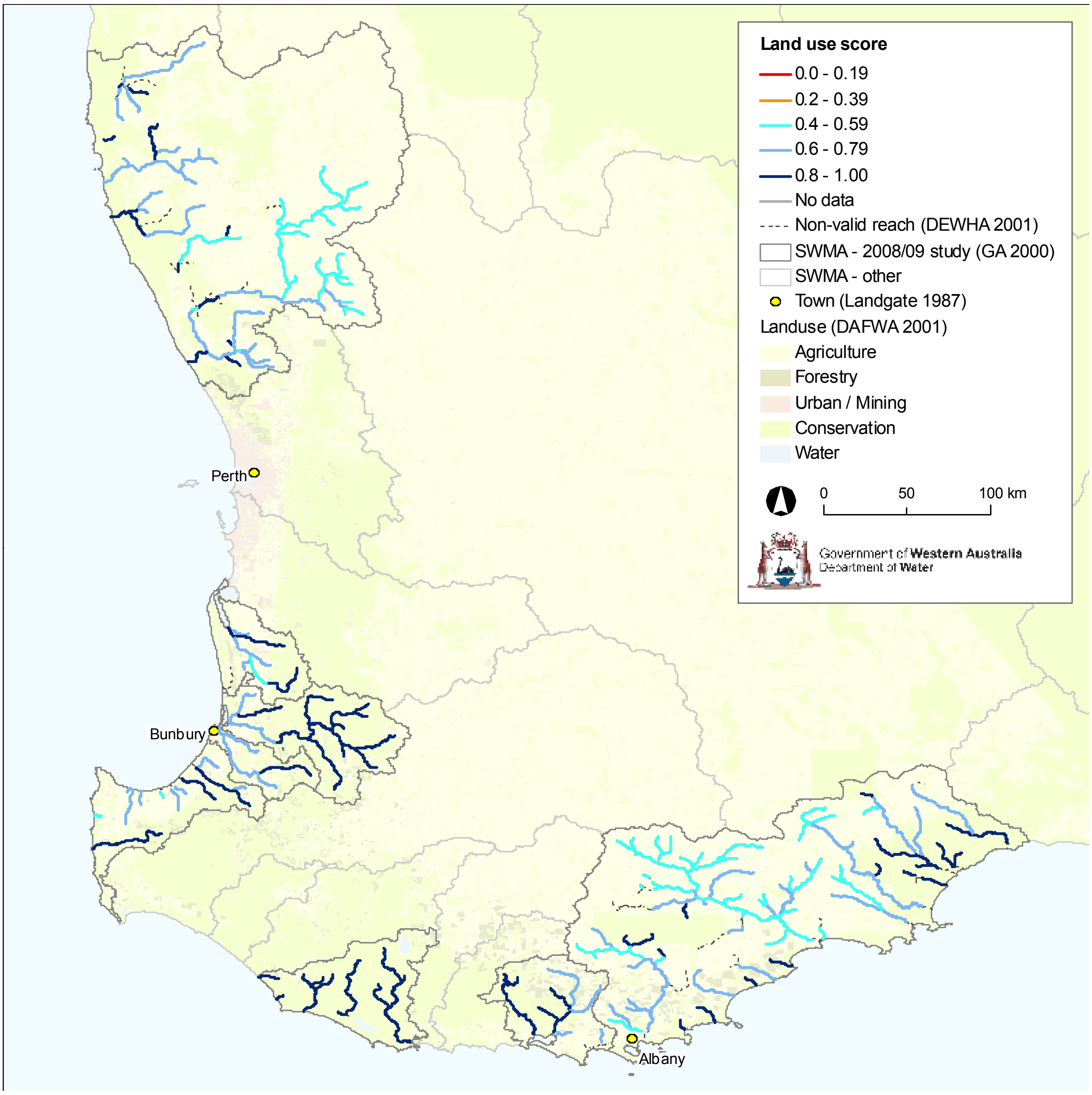


Figure 19 Land use sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Power analysis

As this sub-index was calculated for all reaches a power analysis was not conducted.

Limitations

A limitation of the *land use sub-index* is the currency of land use datasets. The NLWRA Land Use dataset (see Table 68) was selected because it was the best-available in SWWA in terms of spatial coverage of the study area at a fine-scale resolution, however the data represents land use during the period 1996 to 2001. Land use in rural catchments is unlikely to have changed significantly since that period; for example, in the Scott River catchment the percentage of land covered by different agricultural uses varied by only 3 or 4% of the whole catchment between 2000 and 2007 (DoW 2009a). By contrast land use in catchments covering urban and peri-urban areas is likely to show more variation based on the expansion of urban settlement; for example, the area covered by urban land use in the Perth region has expanded from 378 km^2 in 1974 to 631 km^2 in 2002 (WAPC 2009).

A further limitation is the reduced range of the scoring protocol, with the minimum possible score being 0.3 instead of 0, which results in less differentiation between levels of disturbance in different catchments.

Recommendations for future development

It is recommended that:

- consideration be given to the feasibility of mapping land use in Western Australia as single-year snapshots; for example, via interpretation of satellite imagery (This would complement the rolling program of property-scale land use change mapping being undertaken by DAFWA, and provide valuable information for a range of uses within the state such as nutrient modelling and land use planning.)
- the scoring protocol be developed further to increase the differentiation between levels of disturbance; for example, by allowing a minimum score of 0 instead of 0.3
- literature relating to the impacts of land use on river health be reviewed regularly and the rankings and weightings adjusted accordingly.

Other indicators

No other indicators were investigated as part of the *land use sub-index.*

Sub-index: infrastructure

Scoring and reference condition

For the 2008 and 2009 assessments the impact of infrastructure on river health in the catchment of a reach was quantified by calculating the area covered by each infrastructure type, and multiplying that by a weighting to give an overall *infrastructure sub-index* score.

The weightings for each infrastructure type were devised by ranking them by their relative contribution to five impact factors. The rankings were based on those suggested in the FARWH documents (NWC 2007b) with some modifications for local conditions (Table 8).

The mean ranks were converted to a weighting by scaling them to a range between 0 and 0.7, as recommended by the FARWH. A maximum weighting of 1.0 was not used because this implies the impact of infrastructure on river health could not get any worse: this was felt to be unrealistic and so an arbitrary maximum weighting of 0.7 was applied (NWC 2007b).

Infrastructure sub-index scores were calculated using Equation 2. The scoring protocol uses an assumed reference condition of ‘no presence of infrastructure in pre-European times’; that is, any walking tracks used by Aboriginal people are assumed to have had no impact on river health.

Equation 2 $ISI = 1 - \left((I_1 \times w_1) + (I_2 \times w_2) \ldots . + (I_7 \times w_7)\right)$

Where: ISI = Infrastructure sub-index; I_n = fraction of the catchment of infrastructure category n and w_n = the weight for infrastructure category n. (Note: there are seven different infrastructure types.)

Table 8 Rankings of different infrastructure types and resulting weights for SWWA (those recommended by the FARWH shown in brackets)

	Rankings					**Mean rank**	**Weight**
Infrastructure type	**Nutrients**	**Agricultural biocides**	**Hydrological change**	**Sediment movement**	**Toxicants**		
Main sealed road	3	1	6	3	6	3.8	0.7
Other sealed road	3	1	6	3	6	3.8	0.7
Railway	1	1	–	1	3	1.2	0.22
Unsealed road	4 (6)	–	2	6	1	2.6 (3.0)	0.48 (0.55)
Vehicle track	4 (6)	–	2	6	1	2.6 (3.0)	0.48 (0.55)
Utilities (power, pipes)	1	–	–	1	–	0.4	0.07
Walking track	–	–	–	–	–	0	0

Modification of rankings for SWWA

Modifications to the rankings, and subsequent weightings, were made based on a review of literature for SWWA, which found the following:

Nutrients

The ranking for the nutrient impacts of unsealed roads and vehicle tracks was reduced from six to four. Limited research has been done in Western Australia regarding the impact of different infrastructure types on river health, although a 2003 study in a forested catchment showed that while suspended solids generated from gravel and unsurfaced roads were much higher than the surrounding catchment, the ratio of suspended solids to total phosphorus varied between roads. On a catchment scale the roads were found to contribute 3.5% of the suspended sediment exported but only 1.5% of the total phosphorus. The total nitrogen contribution was found to be minor (Sheridan & Noske 2007). Given the generally poor nutrient-holding capacities of Western Australian soils, and the practice of applying inorganic water-soluble fertilisers to farmland, it was decided that the nutrient ranking of unsealed roads and vehicle tracks should be reduced.

Data sources

Four datasets were used to calculate scores for the *infrastructure sub-index*:

- Road Centrelines DLI (last updated 2008)
- Railways – WA state (last updated 2000)
- CALM operational graphic trails (last updated 2005)
- WA petroleum pipelines (last updated 2008).

Several other datasets were investigated, namely the Spatial Cadastral Database (SCDB) and 1:250 000 topographic mapping data from Geoscience Australia's GEODATA TOPO 250K Series 3 (see Table 68). The SCDB contains data on land ownership boundaries including road reserves, but other forms of infrastructure (tracks, pipelines) are not represented in the database. The 1:250 000 topographic data is mapped at a coarser scale than the four datasets listed, so would have underestimated the proportion of each catchment covered by infrastructure. The four datasets listed above were selected because they were the most current infrastructure datasets available for SWWA at a resolution finer than 1:250 000.

The infrastructure types in the datasets were grouped into broad categories based on those identified in the FARWH (NWC 2007b) (Table 9).

The features in these datasets are represented by polylines, but the *infrastructure sub-index* score is calculated from the area of catchment covered by the different infrastructure types, so a buffer was placed around each polyline to create polygons. Using aerial photographs, the width of a sample of each infrastructure type was measured to calculate an average buffer width for each infrastructure type (Table 9). The resulting polygon datasets were merged together and any overlaps between features (e.g. at an intersection between a 'main sealed road' and 'other sealed road') were removed.

Table 9 Average widths for the different infrastructure types

Infrastructure type from datasets	FARWH infrastructure category	Average width (m)
Trails	Walking track	2.0
Pipelines	Utilities (power, pipes)	9.25
Railways	Railway	13.75
Roads – highway	Main sealed road	11.8
Roads – main road	Main sealed road	8.7
Roads – local sealed road	Other sealed road	7.0
Roads – local road other	Unsealed road	7.7
Roads – track	Vehicle track	4.0
Roads – no classification	Unsealed road	4.0

Data verification

The positional and attribute accuracy of the source datasets is shown in Table 10, based on information in the associated metadata statements. The accuracy of the data varies depending on the methods used to create the data and the intended purpose.

Table 10 Positional and attribute accuracy of infrastructure datasets

Dataset title	Positional accuracy	Attribute accuracy
Road Centrelines DLI	Ranges between 6.25 m and 25 m	Accuracy of the road name, suffix and direction is estimated to be better than 95%.
Railways – WA state	Not documented	Not documented
CALM operational graphic trails	85% of points are within +/- 12.5 m from the true position; remainder should be no worse than +/- 50 m.	Not documented
WA petroleum pipelines	Features have been obtained from various sources and have varying positional accuracy.	Dependent on information in the Electronic Petroleum Register database.

Data frequency

All four datasets have an irregular update frequency according to the associated metadata; that is, they are only updated as required by the data custodian. Based on the limited temporal coverage of updates (i.e. it is highly unlikely that all four source datasets would be updated in a single year), it is recommended the *infrastructure sub-index* scores be recalculated every five years, although they could be calculated more frequently if data were released at a suitable temporal scale.

Sensitivity and scenario testing

Due to the scaling of the weightings between 0 and 0.7, the worst score able to be obtained for the *infrastructure sub-index* is 0.3, while the best score is 1.0 (scenarios

A and B in Table 11). As discussed previously (in *Scoring and reference condition*), this has been devised to allow for future revision of the weightings if the impacts on river health worsen.

While scenario testing has been conducted for a range of hypothetical scenarios, the reality is that for most catchments the proportion of land covered by infrastructure is relatively low, and hence the sub-index scores are generally high (see scenario C in Table 11). In the 2008 and 2009 assessments all 234 reaches scored 1.0 for the *infrastructure sub-index*. To obtain a score of less than 1.0 a catchment would need to have a minimum of 8% coverage of main sealed roads (the highest weighted infrastructure type) (see scenario D in Table 11). This suggests the indicator is not sensitive enough to detect differences in infrastructure between catchments, but this cannot be confirmed until a highly urbanised catchment is assessed (where a greater area of infrastructure coverage is anticipated) (the SWMAs assessed in the 2008 and 2009 trials were mostly rural).

Table 11 Range of infrastructure sub-index scores obtainable and example scenarios

Scenario	Description	Infrastructure sub-index score
A	100% of catchment covered by main sealed road (worst-case scenario)	0.3
B	0% of catchment covered infrastructure (any type) (best-case scenario)	1.0
C	1.5% of catchment covered by infrastructure (main sealed road, other sealed road, vehicle track and railway) (reach 6110873, Ferguson River, Preston River SWMA)	1.0
D	8% of catchment covered by main sealed road	0.9

Reach scores

The *infrastructure sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 20. All reaches scored 1.0 – this is because the area of land covered by infrastructure is very low compared with the total area of each catchment assessed.

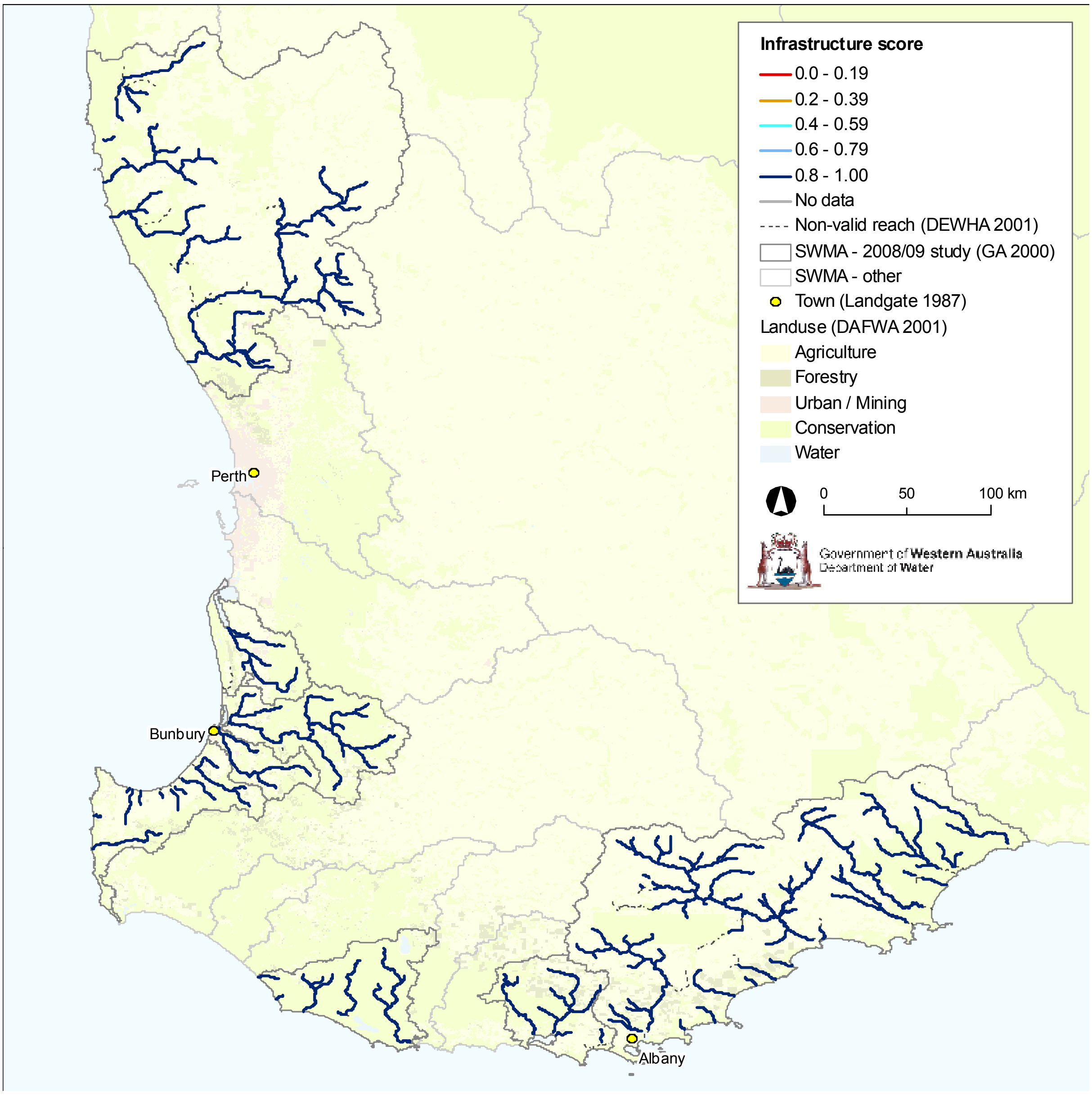


Figure 20 Infrastructure sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Power analysis

As this sub-index was calculated for all reaches a power analysis was not conducted.

Limitations

The key limitations of the *infrastructure sub-index* are the lack of ability to distinguish between different levels of disturbance in different catchments, and the lack of ability to detect temporal change unless it occurs on a large scale. Both limitations occur because the area of land covered by infrastructure is very low compared with the total area of each catchment.

While the best-available infrastructure datasets were used to calculate scores for the 2008 and 2009 assessments, it would have been preferable to use more current data, and data produced at a more consistent frequency and scale, so that a snapshot of catchment disturbance for a single year could be provided.

Recommendations for future development

It is recommended that:

- the *infrastructure sub-index* be modified to make it sensitive to spatial and temporal differences in disturbance (One option would be to assess disturbance within a corridor either side of the river, as opposed to the entire catchment, because this would quantify the amount of infrastructure in relatively close proximity to the river – which is likely to have a greater impact than infrastructure further away in the catchment. A trial of the river corridor approach was beyond the timeframe of the SWWA-FARWH project, but is recommended for future development.)
- consideration be given to the feasibility of mapping infrastructure at a consistent scale and timeframe for the whole of Western Australia (It may be possible to combine this with the land use mapping recommended for the *land use sub-index*.)
- literature relating to the impacts of infrastructure on river health be reviewed regularly and the rankings and weightings adjusted accordingly.

Other indicators

No other indicators were investigated as part of the *infrastructure sub-index.*

Sub-index: land cover change

Scoring and reference condition

In the 2008 and 2009 assessments the land cover change was quantified by calculating the area of each catchment where perennial vegetation was cleared during the five years before and including the year of assessment; for example, the 2009 assessment was made using the years 2005 and 2009.

The area of clearing was converted to a sub-index score using Equation 3. As recommended in the FARWH documents (NWC 2007b) the weighting factor applied was the same as that applied to the urban category in the *land use sub-index*, based on literature which suggests the sediment yield from forest clearing is similar to that from urban areas (Lawrence 2001 cited in NWC 2007b).

The scoring protocol uses an assumed reference condition of ‘no vegetation clearing during pre-European times’; that is, any clearing of the land by Aboriginal people is assumed not to have caused an impact on river health.

Equation 3 $$LCCSI = 1 - \frac{Area_d \times w}{Area_t}$$

Where: LCCSI = land cover change sub-index; $Area_d$ = area of catchment in which perennial vegetation was cleared; $Area_t$ = total area of catchment for which there are data; w = weight (0.68).

Data sources

The *land cover change sub-index* scores for 2008 and 2009 were calculated using the Vegetation Change products from the Land Monitor II Project (see Table 68). Satellite imagery for SWWA is interpreted annually to produce data showing the extent of perennial vegetation at a resolution of 25 m (pixel size).

The Agricultural Land Cover Change 1990–1995 dataset (see Table 68) was also investigated for use. This dataset provides a measure of the increase and decrease in woody vegetation cover, mapped to a resolution of 250 m (pixel size). The data was coarser and less current than data available from the Land Monitor II Project, so was not selected for use.

Data verification

Documentation supplied with the Vegetation Change products describes the following accuracy issues with the data (Furby et al. 2009):

- Perennial vegetation mapping is based on the spectral signature of light being reflected from different types of land cover, which is detected by a satellite sensor. Classification of land cover types requires contrast between spectral signatures, and a certain density of vegetation is required to categorise an area as perennial vegetation, hence areas with sparse coverage of perennial vegetation (e.g. tracks, rocks, fire scars, salt-affected areas) may be classified as non-perennial cover.
- Areas of revegetation will not be classified as perennial vegetation until the density reaches a sufficient level, hence there is a lag in the detection of revegetated areas.
- Land cover with a similar spectral signature to perennial vegetation (e.g. persistent dark soil, lake fringes and changes from dry to wet lake surfaces) may be incorrectly classified. Data smoothing techniques are applied but some areas of error may remain.

An assessment of the accuracy of the vegetation extent data compared with detailed aerial photography found the overall accuracy of the data was 99% (Bryant & Wallace 2001).

Data frequency

The Vegetation Change products are updated annually as part of the on-going Land Monitor II Project in Western Australia. As such, the *land cover change sub-index* scores can be recalculated annually, however the minimum data requirements recommended for the *Catchment Disturbance index* are the *land use sub-index* and the *infrastructure sub-index* (NWC 2007b). As such no advantage would be gained from recalculating the *land cover change sub-index* more frequently than the other sub-indices (which have a recommended recalculation frequency of five years).

Sensitivity and scenario testing

The scoring protocol was tested to ensure the full range of scores between 0 and 1 could be obtained and that scores would respond sensitively to change.

The inclusion of the weighting factor in Equation 3, as recommended in the FARWH documents (NWC 2007b), limits the lowest score obtainable to 0.3 for vegetation loss across the whole catchment (Table 12).

The sensitivity of the *land cover change sub-index* to temporal change is determined by use of the weighting, as well as guidance in the FARWH documents (NWC 2007a) that scores should be expressed in increments of 0.1 (i.e. to 1 decimal place). The amount of change in vegetation clearing required to result in a change in score varies depending on the starting point for the change. For example, if 7% of a catchment was cleared during the five-year assessment period it would score 1.0; if 8% of vegetation was cleared during the period up to the subsequent assessment it would score 0.9. This difference of just 1% in the total clearing occurring during the assessment period would result in a change in score from 1.0 to 0.9. However, if 40% of a catchment was cleared during the first assessment period and 50% was cleared during the second, the *land cover change sub-index* score would be the same for both assessments (0.7) (Table 12).

In reality the amount of land cover change occurring in catchments in SWWA is relatively small compared with the total area of each catchment, consequently the indicator scores do not distinguish between different levels of disturbance in catchments, and are not sensitive to temporal changes occurring in the region (see *Reach scores* section below).

Note: the *land cover change sub-index* provides a measure of clearing during a five-year period, not the cumulative total of land cleared of vegetation. Cumulative impacts of vegetation clearing are accounted for in the *land use sub-index* as discussed in the section *Indicators of catchment disturbance.*

Table 12 Examples of land cover change sub-index scores obtainable

Scenario	Land cover change sub-index score
0% of catchment cleared in five-year period	1.0
5% of catchment cleared in five-year period	1.0
7% of catchment cleared in five-year period	1.0
8% of catchment cleared in five-year period	0.9
10% of catchment cleared in five-year period	0.9
20% of catchment cleared in five-year period	0.9
22% of catchment cleared in five-year period	0.9
23% of catchment cleared in five-year period	0.8
30% of catchment cleared in five-year period	0.8
40% of catchment cleared in five-year period	0.7
50% of catchment cleared in five-year period	0.7
53% of catchment cleared in five-year period	0.6
60% of catchment cleared in five-year period	0.6
70% of catchment cleared in five-year period	0.5
80% of catchment cleared in five-year period	0.5
81% of catchment cleared in five-year period	0.4
90% of catchment cleared in five-year period	0.4
96% of catchment cleared in five-year period	0.3
97% of catchment cleared in five-year period	0.3
100% of catchment cleared in five-year period	0.3

Reach scores

The *land cover change sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 21. Most reaches (94%) scored 1.0; this is because the area of vegetation loss during the five-year period of assessment was very low compared with the total area of each catchment.

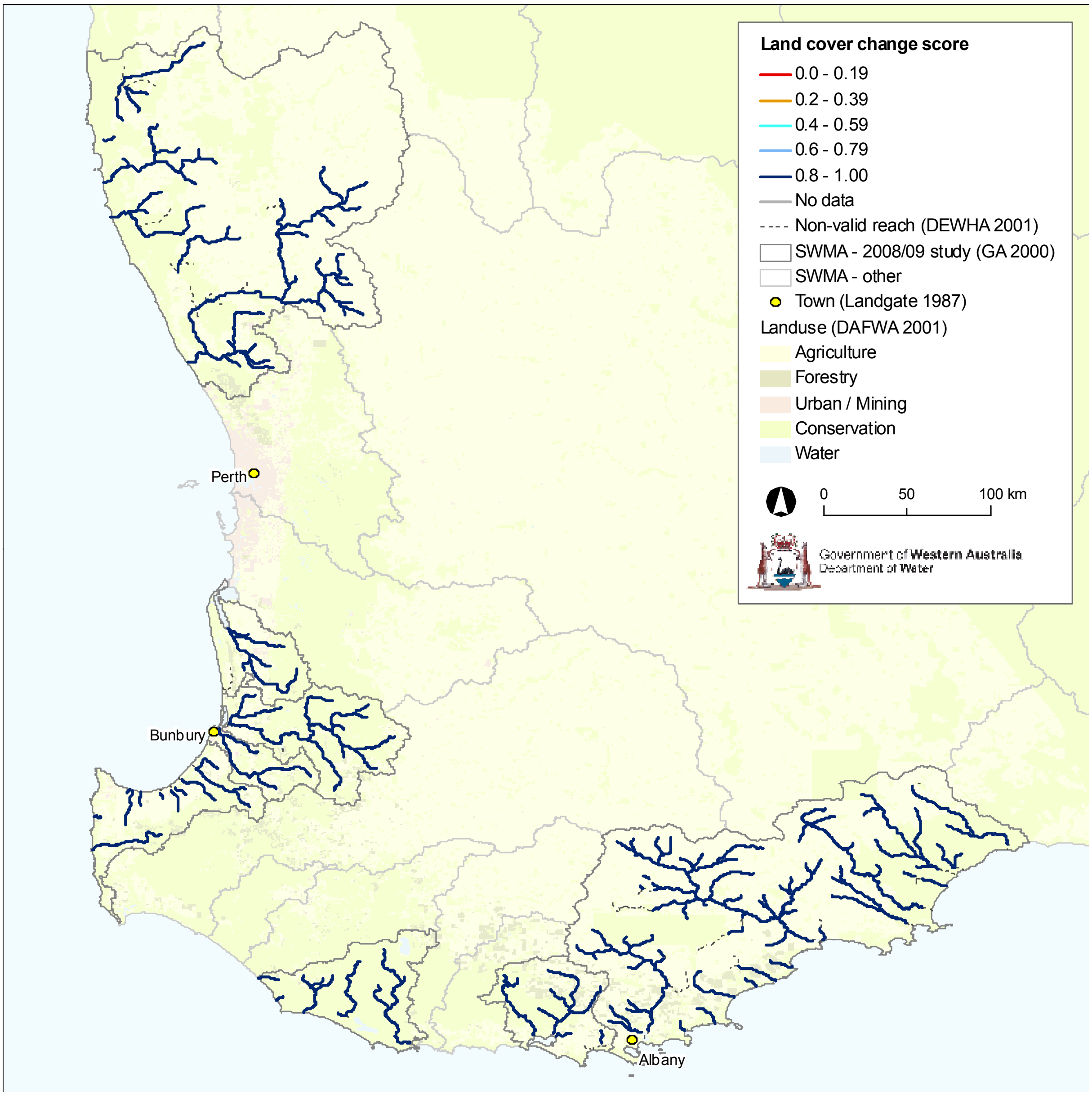


Figure 21 Land cover change sub-index scores for reaches in SWMAs assessed in 2009 within the SWWA-FARWH trials

Power analysis

As this sub-index was calculated for all reaches a power analysis was not conducted.

Limitations

The key limitations of the *land cover change sub-index* are not being able to distinguish between different levels of disturbance in different catchments or detect temporal change unless it occurs on a large scale. Both limitations occur because the area of land cleared over the five-year period is very low compared with the total area of each catchment.

The method for calculating vegetation loss over a five-year period does not account for any gain in vegetation during the same period. It may be possible to include data on vegetation gain from the Vegetation Change products in the calculations.

The Land Monitor Vegetation Change products do not include any data on the cause of vegetation loss, unlike the Agricultural Land Cover Change 1990–1995 dataset. To overcome this limitation the National Oceanic and Atmospheric Administration (NOAA) fire-affected areas datasets (see Table 68) were investigated, but these data do not distinguish between wildfires and those caused by human influence, so their use was not pursued. Consequently vegetation loss due to naturally occurring fires has been included in the *land cover change sub-index*; this is likely to have caused an over-estimation of vegetation loss by anthropogenic causes, but the over-estimate would be consistent across the study area, and would be minor in nature because the total area of vegetation loss is small relative to the area of each catchment.

Recommendations for future development

It is recommended that:

- the *land cover change sub-index* be modified to make it sensitive to spatial and temporal differences in disturbance (One option would be to assess disturbance within a corridor either side of the river, as opposed to the entire catchment, because this would quantify the vegetation loss relatively close to the river – which is likely to have greater acute impacts than vegetation loss further away in the catchment. A trial of the river corridor approach was beyond the timeframe of the SWWA-FARWH project, but is recommended for future development.)
- vegetation gain (revegetation) data be incorporated into future calculations of *land cover change sub-index* scores
- if data about the causes of vegetation loss at an appropriate spatial and temporal resolution become available, the method used to calculate *land cover change sub-index* scores be modified accordingly.

Other indicators

No other indicators were investigated for the *land cover change sub-index.*

Catchment Disturbance index summary

Integration and aggregation of indicators

Sub-index scores were integrated using Equation 4 as recommended in the FARWH documents (NWC 2007a).

Equation 4 $CDI = ISI + LCCSI + LUSI - 2$

Where: CDI = Catchment Disturbance index; ISI = infrastructure sub-index; LCCSI = land cover change sub-index; LUSI = land use sub-index.

Where Equation 4 returns a negative value the overall *Catchment Disturbance index* score is rounded to zero.

This integration approach (calculating the sum of the scores and scaling back to a score between 0 and 1) is recommended for use with indicators that quantify similar impacts on river health from different activities (NWC 2007a). Aggregation was completed by calculating the reach catchment area-weighted average of all reach scores.

Missing data

As recommended in the FARWH documents (NWC 2007b) the minimum data requirements for calculating the *Catchment Disturbance index* are the *land use* and *infrastructure* sub-indices. For the 2008 and 2009 assessments data was available for all three sub-indices, hence the minimum data requirements did not apply.

Sensitivity and scenario testing

The minimum score able to be obtained for each of the sub-indices is 0.3, due to the use of weighting in the calculations, however the integration approach used to calculate the *Catchment Disturbance index* scores results in a minimum score of 0.0. The maximum score obtainable is 1.0.

The integration approach also determines the sensitivity of the *Catchment Disturbance index* to change. Two is subtracted from the sum of the three sub-index scores to standardise the score to a range of 0 and 1, consequently high scores are required in two of the three indicators for the overall *Catchment Disturbance index* score to be greater than zero.

If two of the three sub-index scores are high (e.g. 1.0), the third sub-index score will effectively determine the overall *Catchment Disturbance index* score (Table 13, scenario A). If two of the three sub-index scores are mid range (0.5), then the third sub-index score must be ≥ 0.6 to give a *Catchment Disturbance index* score of 0.1 or above (Table 13, scenario B). If two of the three sub-index scores are minimal (0.3), then the overall *Catchment Disturbance index* score will be 0 regardless of the third sub-index score (Table 13, scenario C).

In reality most of the subcatchments assessed are likely to score 1.0 for both the *infrastructure* and *land cover change* sub-indices because the area of land covered by infrastructure or cleared of vegetation will generally be very low compared with the catchment's total area, except in extreme cases (e.g. a highly urbanised catchment).

Table 13 Catchment Disturbance index scenario testing

Scenario/example	**Land use sub-index score**	**Infrastructure sub-index score**	**Land cover change sub-index score**	**Catchment Disturbance index score**
A	1.0	1.0	0.5	0.5
B1	0.5	0.5	0.6	0.1
B2	0.5	0.5	0.5	0.0
C	0.3	0.3	1.0	0.0
D – reach 6110873, Ferguson River	0.7	1.0	1.0	0.7

Reach scores

The *Catchment Disturbance index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 22. Scores ranged from between 0.4 and 1.0 (out of a possible 0.0 to 1.0). The scores follow the same spatial pattern as the *land use sub-index* scores (Figure 22): this is due to the high scores calculated for the *infrastructure* and *land cover change* sub-indices, and to the integration approach used (see *Sensitivity and scenario testing* section above).

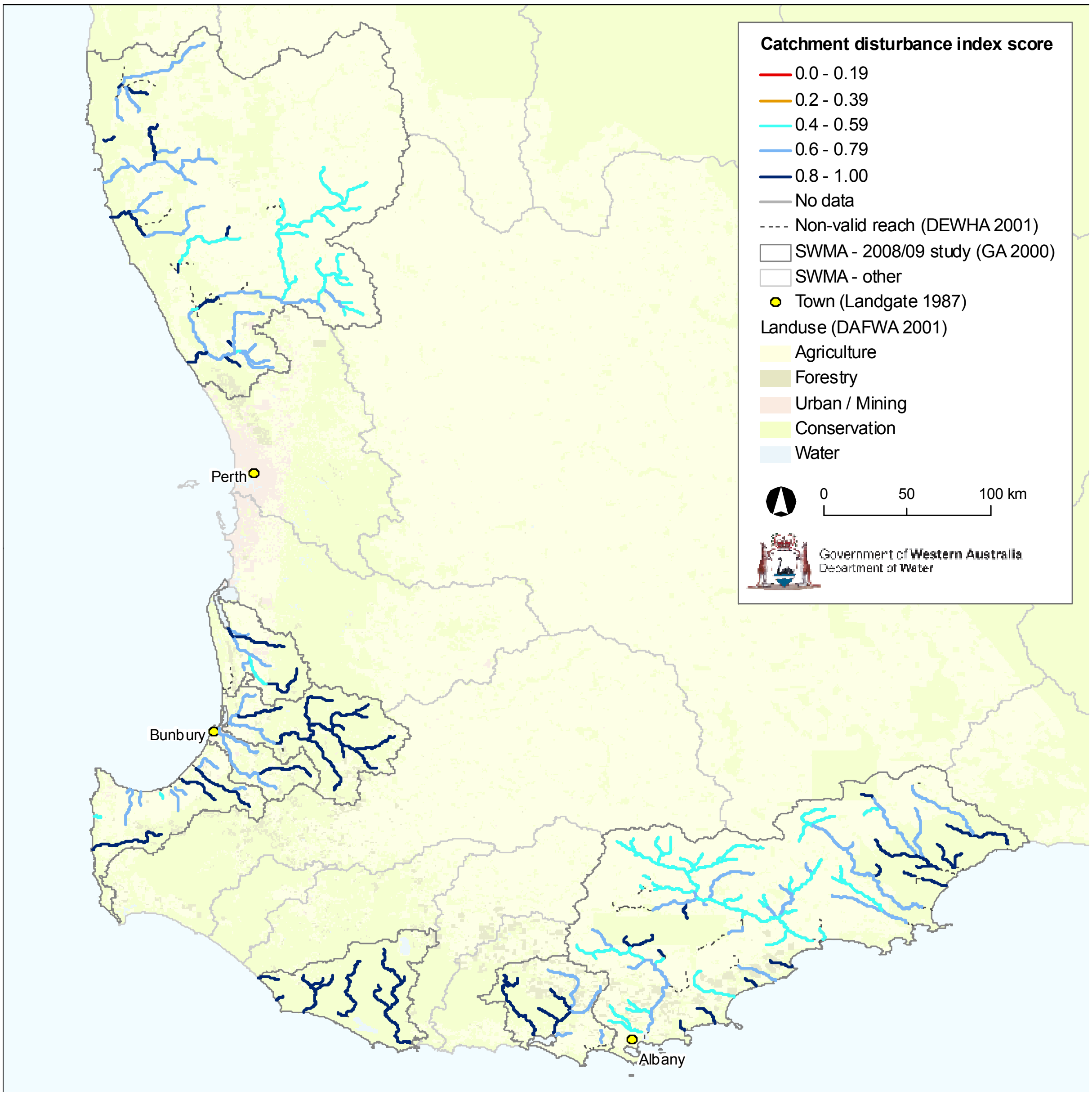


Figure 22 Catchment Disturbance index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Statistical analysis

An attempt was made to examine the relationships between the indicators of the *Catchment Disturbance index*, but there was insufficient variation in the scores of the *land cover change sub-index* and the *infrastructure sub-index* to allow statistical analysis to be undertaken.

Limitations

The limitations of each sub-index are discussed in the relevant sections of this chapter. In addition to these, a limitation of the *Catchment Disturbance index* is the lack of sensitivity in the *infrastructure* and *land cover change* sub-indices which results in the overall *Catchment Disturbance index* scores being primarily determined by the *land use sub-index*.

Another issue is the lack of currency and consistency of land use and infrastructure data, which precludes the calculation of scores for a single snapshot year (or even a period of two or three years). For example, the 2008 and 2009 assessments are based on data ranging from 1996 to 2008.

Recommendations

It is recommended that:

- trials are conducted for the *infrastructure* and *land cover change* sub-indices to assess disturbance within a corridor either side of the river, as opposed to the whole catchment, because this would quantify the disturbance in relatively close proximity to the river – which is likely to have a greater impact than disturbance further away in the catchment. (A trial of the river corridor approach was beyond the timeframe of the SWWA-FARWH project, but is recommended for future development.)

4.2 Theme: Hydrological Change

Flow regime is a key driver of river condition, being central to maintaining critical ecosystem elements, such as those related to connectivity and refugia; transporting nutrients and sediment; and controlling river geomorphology. Hydrological changes have been directly associated with anthropogenic impacts, such as land use changes and catchment activities. Table 14 outlines some of the major sources of alteration and those typical of impacts occurring throughout SWWA.

Table 14 Physical responses to altered flow-regimes (taken from Poff et al. 1997)

Source(s) of alteration	Hydrologic change(s)	Geomorphic response(s)	Reference(s)
Dam	Capture sediment moving downstream	Downstream channel erosion and tributary headcutting	Chien 1985, Petts 1984 and 1985, Williams & Wolman 1984
		Bed armouring (coarsening)	Chien 1985
Dam, diversion	Reduce magnitude and frequency of high flows	Deposition of fines in gravel	Sear 1995, Stevens et al. 1995
		Channel stabilisation and narrowing	Johnson 1994, Williams & Wolman 1984
		Reduced formation of point bars, secondary channels, oxbows, and changes in channel planform	Chien 1985, Copp 1989, Fenner et al. 1985
Urbanisation, tiling, drainage	Increase magnitude and frequency of high flows	Bank erosion and channel widening	Hammer 1972
		Downward incision and floodplain disconnection	Prestegaard 1988
	Reduced infiltration into soil	Reduced baseflow	Leopold 1968
Levees and channelisation	Reduced overbank flows	Channel restriction causing downcutting	Daniels 1960, Prestegaard et al. 1994
		Floodplain deposition and erosion prevented	Sparks 1992
		Reduced channel migration and formation of secondary channels	Shankman & Drake 1990
Groundwater pumping	Lowered watertable levels	Streambank erosion and channel downcutting after loss of vegetation stability	Kundolf & Curry 1986

Ecological impacts from altered flow encompass changes to riparian and macrophyte communities (Kingsford 2000; Mackay et al. 2001), fish communities (Gehrke et al. 1995), invertebrate communities (Quinn et al. 2000), riverine geomorphology and physical habitats (Milhous 1982; Williams & Wolman 1984) and waterbird communities (Kingsford 2000).

The flow-dependent ecological characteristics highlighted above identify a number of hydrological attributes. Characteristics of particular importance include variability, flow magnitude, high- and low-flow events, extent of no-flow periods, seasonality and mean annual flow (NWC 2007b). It is natural to see some variation in these characteristics but if this variation is too extreme or unexpected, it can cause stress within the ecosystem. Table 15 outlines some of the general effects from altered hydrology.

Table 15 Ecological responses to alterations of natural flow regime (taken from Poff et al. 1997)

Flow component	Specific alteration	Ecological response	Reference(s)
Magnitude and frequency	Increased variation	Wash-out and/or stranding of sensitive species	Cushman 1985, Petts 1984, Gehrke et al. 1995, Kingsolving & Bain 1993, Travnichek et al. 1995
		Increased algal scour and wash-out of organic matter	Petts 1984
		Lifecycle disruption	Scheidegger & Bain 1995
		Altered energy flow	Valentin et al. 1995
	Flow stabilisation	Invasion or establishment of exotic species, causing:	
		– local extinction	Kupferberg 196, Meffe 1984
		– threat to native commercial species	Stanford et al. 1996
		– altered communities	Busch & Smith 1995, Moyle 1986, Ward & Stanford 1979
		Reduced water and nutrients to floodplain plant species, causing:	
		– seedling desiccation	Duncan 1993
		– ineffective seed dispersal	Nilsson 1982
		– loss of scoured habitat patches and secondary channels needed for plant establishment	Penner et al. 1985, Rood et al. 1995, Scott et al. 1997
		– encroachment of vegetation into channels	Johnson 1994, Nilsson 1982
Timing	Loss of seasonal flow peaks	Disrupt cues for fish:	
		– spawning	Fausch & Bestgen 1997, Montgomery et al. 1993, Nesler et al. 1988
		– egg hatching	Naesje et al. 1995
		– migration	Williams 1996
		Loss of fish access to wetlands or backwaters	Junk et al. 1989, Sparks 1995
		Modification of aquatic food web structure	Power 1992, Wootton et al. 1996
		Reduction or elimination of riparian plant recruitment	Fenner et al. 1985
		Invasion of exotic riparian species	Horton 1977
		Reduced plant growth rates	Reily & Johnson 1982
Duration	Prolonged low flows	Concentration of aquatic organisms	Cushman 1985, Petts 1984
		Reduction or elimination of plant cover	Taylor 1982
		Diminished plant species diversity	Taylor 1982
		Desertification of riparian species composition	Busch & Smith 1995, Stromberg et al. 1996

Flow component	Specific alteration	Ecological response	Reference(s)
		Physiological stress leading to reduced plant growth rate, morphological change, or mortality	Kondolf & Curry 1986, Perkins et al. 1984, Reily & Johnson 1982, Rood et al. 1995, Stromberg et al. 1992
	Prolonged baseflow ‘spikes’	Downstream loss of floating eggs	Robertson 1997
	Altered inundation duration	Altered plant cover types	Auble et al. 1994
	Prolonged inundation	Change in vegetation function type	Bren 1992, Connor et al. 1981
		Tree mortality	Harms et al. 1980
		Loss of riffle habitat for aquatic species	Bogan 1993
Rate of change	Rapid changes in river stage	Wash-out and stranding of aquatic species	Cushman 1985, Petts 1984
	Accelerated flood recession	Failure of seedling establishment	Rood et al. 1995

In line with the key hydrological areas described above, the Sustainable Rivers Audit (SRA) identified a number of sub-indices to measure what the project considered as the most important hydrological characters: flow volume, seasonality, variability, low flow, zero flow, and high flow; using 12 different indicators. The Index of Stream Condition (ISC) moved on from this and developed the Flow Stress Ranking (FSR). In developing the FSR, 50 sites across Victoria were chosen for assessment, encompassing a range of climate, stream regulation and topographical factors. As a final result, a set of five components were selected to account for changes in hydrology; these being low flow, high flow, proportion of zero flow, monthly variation and seasonal period.

The FSR was trialled for the SWWA-FARWH, and the components were shown to reflect the range of flow patterns in SWWA. Following this, the FSR was selected for the SWWA-FARWH, with the methods and sensitivity analysis described below.

Scoring and reference condition

As stated above, the *flow stress ranking sub-index* incorporates five components. A brief description of these is provided below (taken from NWC 2007b). More comprehensive information about each of the components, their rationale for inclusion and the methods of calculation can be found in the *Assessment of River and Wetland Health: potential comparative indices* (NWC 2007b).

Sub-index: flow stress ranking

Component: low flow (LF)

The *low flow (LF) component* is a measure of the change in low flow magnitude under current and unimpacted conditions. These are calculated based on the 91.7% exceedance flow (11 months out of 12) and the 83.3% exceedance flow (10 months out of 12).

Component: high flow (HF)

The *high flow (HF) component* is a measure of the change in high flow magnitude from unimpacted to current conditions. The approach adopted to calculate the *HF component* is similar to that used to calculate the *LF component*. The monthly high flow is calculated based on the 8.3% and 16.7% exceedance flows (one and two months in 12 respectively).

Component: proportion of zero flow (PZ)

The *proportion of zero flow (PZ) component* compares the proportion of zero flow occurring under unimpacted and current conditions. The value of the component varies from zero to one and, similarly to other components, the direction of change is not evident from the score returned. If the number of cease-to-flow spells is unchanged between unimpacted and current conditions, then the value of the component is one.

Component: monthly variation or coefficient of variation (CV)

The *monthly variation (CV) component* compares the coefficient of variation of monthly flows between current and unimpacted conditions. This component is the same as that used in the SRA. The component is calculated as the ratio of the monthly flows under unimpacted and current conditions, where the coefficient of variation is defined as the standard deviation divided by the mean.

Component: seasonal period (SP)

The *seasonal period (SP) component* compares the unimpacted and current frequency distribution of maximum and minimum monthly flows. The first step in calculating this component is to create frequency distributions that show the percentage of years that peak and minimum annual flows fall within each given month under current and unimpacted conditions. The component is then calculated by summing the minimum proportions (from unimpacted or current) within each month. In Murray-Darling Basin Commission (2003) this is presented in terms of the number of years the peak or minimum flow falls within each given month. In this report the percentage of years the peak or minimum flow falls within each given month has been used.

To compute the *flow stress ranking sub-index*, two datasets are required:

Current monthly flow (current condition)

Current condition is derived from Department of Water gauged data.

The Department of Water collects data from thousands of surface and groundwater sites throughout Western Australia, including measurements of river level and flow. The department also has a State Reference Network comprising about 300 gauging stations among other hydrologic instrumentation and equipment. Note: The Water Information section of the Department of Water is dedicated to the management of data and ensures they are checked, referenced and stored appropriately and also places a strong emphasis on quality assurance.

Unimpacted monthly flow (reference condition)

In consultation with ecologists and hydrologists within the Department of Water, it was determined that the largest impact on hydrology in Western Australia is from clearing (increased flow), large reservoirs (decreased flow), farm dams (decreased flow) and abstraction (decreased flow). Thus, the reference condition for unimpacted flow should be calculated from sites where these impacts have not occurred. However, due to lack of available data the latter two could not be included at this stage of assessment [see Summary Box 3]. Reference condition was therefore defined as reaches with no large dams or diversions and the corresponding catchment being 100% vegetated. Reference condition was created by altering the 'current' dataset to reflect pre-clearing conditions. This was done using the Forest Cover Flow Change (FCFC) tool (Podger 2004), which uses evaporation, rainfall and flow data (see Table 68) to create flow time-series reflective of different vegetated conditions (in this case against a reference of 100% vegetation). [See Summary Box 4 for further detail on the FCFC process.] Where a large dam or diversion was located upstream of a reach then the catchment area was altered to pre-impact conditions.

Note: using this method, factors such as climate change are not directly assessed, which is understandable given the SWWA-FARWH is a snapshot assessment. Future direction may look at climate change to disentangle any interplay between climate change and the factors under assessment (clearing and dams): this would require long-term flow data.

Summary Box 3

The effects of abstraction were not accounted for due to lack of available data, in particular the volume and timing of abstraction as well as the subsequent ground and surface water interactions.

The effects of farm dams were also not included due to lack of data. Farm dams mapped within the 'hydrography linear' spatial dataset (see Table 68) range in accuracy from 1:25 000 to 1:100 000; this level of accuracy does not have enough sensitivity to be useful for the SWWA-FARWH. An accurate spatial coverage of farm dams only exists for eight catchments (SKM 2008; SKM 2007a), which accounts for only a small proportion of the study region (see Farm Dams dataset in data sources, Table 68).

Note: impacts of farm dams on river flow within the eight catchments assessed by SKM (2008; 2007a) were determined, and as such these impacts can be extrapolated if farm dam density is accurately mapped for the entire study area.

Note: clearing is assessed indirectly within the Catchment Disturbance theme and Fringing Zone theme (only small percentage of the catchment), but because hydrologic impacts from clearing are a separate and specific stressor there are no perceived replication issues.

Following comparisons between current and reference conditions, all components of the *flow stress ranking sub-index* are assigned values between 0 and 1. Where negative values were obtained (departure from reference was sufficiently large) the value was set to 0.

Summary Box 4: FCFC process

In creating unimpacted flow, the FCFC program first calibrates to the current flow. The match to the current flow is used as the baseline data to create a flow time-series that represents a catchment with pre-clearing conditions (100% vegetation). A mismatch in the calibration can therefore create error in the resulting time-series. If the match is perfect, then reaches with 100% vegetated catchments should score close to 1 for all sub-indices. In most cases, these reaches scored within the top condition band. If they were outside the top band, the gauging station used to create the flow was deemed unsuitable. The table below displays results for some of the reference sites. This shows that gauges such as 701002 are unsuitable for use, and inspection of the data showed they were of poor quality (quality codes indicated data were often estimated).

SWMA	Reach	LF	HF	PZ	CV	SP	FSR	% veg	Indicator gauge
Warren	6071101	1.0	0.8	0.9	1.0	0.8	**0.9**	97	606002
Warren	6071107	1.0	0.8	0.9	1.0	0.8	**0.9**	93	606002
Greenough	7010321 (lower)	1.0	1.0	0.0	0.9	0.6	**0.7**	100	701002
Greenough	7010333 (upper)	1.0	0.7	0.0	0.9	0.5	**0.6**	100	701002
Greenough	7010473 (upper)	1.0	1.0	1.0	1.0	1.0	**1.0**	100	701007
Greenough	7010477	1.0	0.9	1.0	1.0	1.0	**1.0**	100	701007
Shannon	6061120	1.0	1.0	0.9	1.0	0.9	**0.9**	100	606001
Shannon	6061139	1.0	1.0	0.9	1.0	0.9	**0.9**	100	606001
Shannon	6061140	1.0	1.0	0.9	1.0	0.9	**0.9**	100	606002
Collie	6120826	1.0	1.0	0.9	1.0	1.0	**1.0**	96	612014
Collie	6120842	1.0	1.0	0.9	1.0	1.0	**1.0**	96	612014
Albany	6021024	1.0	1.0	0.8	1.0	0.7	**0.9**	100	615016
Albany	6021025	1.0	1.0	0.8	1.0	0.7	**0.9**	100	615016
Albany	6021028	1.0	1.0	0.7	1.0	0.9	**0.9**	100	602001
Albany	6021036	1.0	1.0	0.7	1.0	0.9	**0.9**	100	602001
Albany	6021502	1.0	1.0	0.8	1.0	0.9	**0.9**	100	601001
Albany	6021929	1.0	1.0	0.6	1.0	0.9	**0.9**	100	602001

Sensitivity analysis

The appropriateness of the FSR's general principles is supported by its use in a number of river health monitoring programs (e.g. ISC; a similar version for the SRA; the wet-dry tropics FARWH trials applied to the Ord and Darwin rivers) and as a recommendation in the FARWH guidelines (NWC 2007b). Therefore, sensitivity analysis for the SWWA-FARWH trials was primarily targeted towards applicability to SWWA systems.

To test the FSR's sensitivity, a number of scenarios were assessed – focusing on the attributes used to calculate reference (clearing and dams). These were:

1. Effects of clearing (using different levels of existing vegetation 8%, 18%, 68%)
2. Effects of clearing in various rainfall zones (mean annual rainfall 400, 600, 800 mm)
3. Effects of clearing in catchments of different size (103, 326, 956, 1866 km^2)
4. Effects of reservoirs under different clearing scenarios
5. Impact of farm dams

As can be seen above, the treatments used to test each scenario do not represent a standard linear scale (e.g. vegetation was assessed at 8%, 18% and 68% vegetative cover), as treatment values were based on actual reaches assessed within the SWWA-FARWH trials.

For scenario 1 (effects of clearing), the response of the FSR and each of its components to vegetation clearing was assessed, using sites with different vegetation covers (current percentage). Sites were otherwise standardised and chosen within the same mean annual rainfall zone, with approximately equal catchment areas (324 km^2 to 398 km^2). FSR results are shown below (Figure 23).

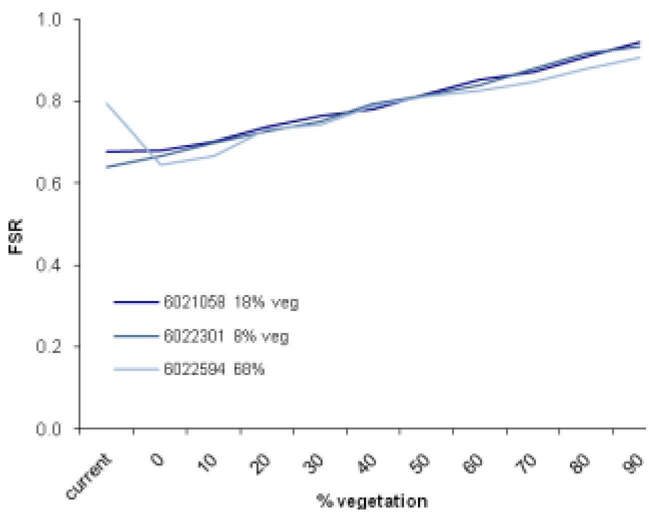


Figure 23 Effects of clearing on FSR scores in catchments with different percentages of vegetation cover

The pattern observed in the above figure was expected, given that hydrological stress should reduce with more vegetation present in the catchment. The response of the FSR is further validated as no difference was seen between sites with different starting levels of clearing, as the FSR is based on a reference condition of 100%.

Analysis of the individual FSR components for reach 6021058 (currently 18% vegetated) is shown in Figure 24. The *LF* component appears to be non-responsive to clearing, whereas the *PZ* component changes significantly.

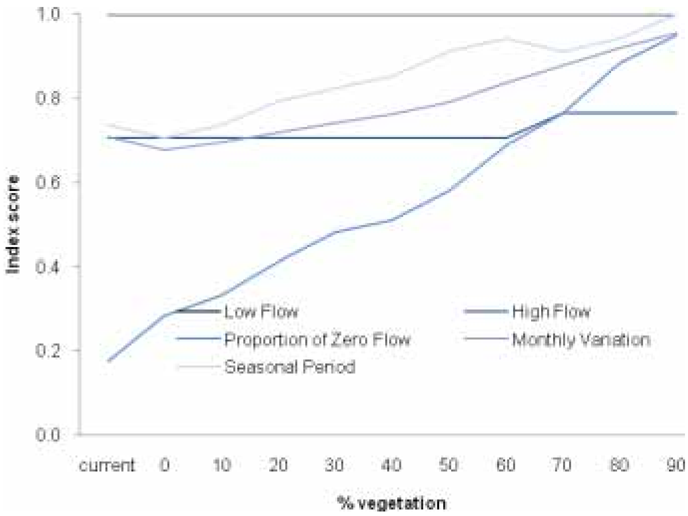


Figure 24 Variation in FSR components due to vegetation clearing

The difference between the *LF* and the *PZ* is that the *LF* indicates a change in the magnitude of the low flow while the *PZ* indicates a change in the duration of no flow.

In this example the *LF* remained at 1 despite changes in clearing. This is because the current 91.7% and 83.3% exceedance flows are both 0 ML. The catchment is mainly cleared (18% vegetation) and while increasing the extent of vegetation would normally lower the magnitude of flow, this is not possible in this case as the flow is already zero.

The *PZ* increased almost linearly with increasing vegetation cover. As more of the catchment is cleared, the rainfall:runoff ratio generally decreases (i.e. more runoff is produced for the same amount of rain). This leads to more flow and a corresponding smaller proportion of zero flow.

In scenario 2 (effects of clearing in various rainfall zones), three values for mean annual rainfall (400, 600 and 800 mm) were assessed against effects from clearing. The reaches used (representing the different rainfall values) had similar catchment areas and current vegetation extent. Results are provided in Figure 25 and show an increasing FSR as the percentage of vegetation increases. No obvious patterns are apparent between the different rainfall categories, which supports the requirement that the FSR not be biased by natural conditions of rainfall – making it applicable across SWWA.

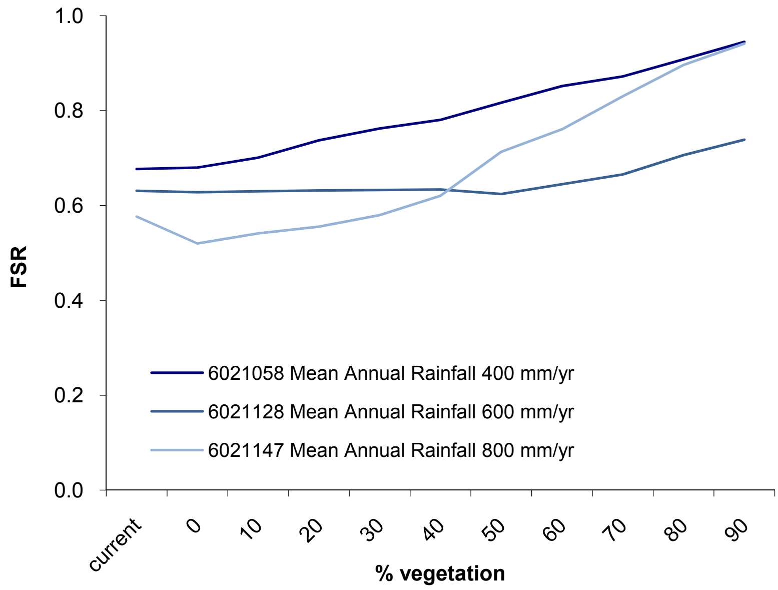


Figure 25 Effects of clearing on FSR scores in areas of different mean annual rainfall

For scenario 3, reaches with different catchment areas were chosen (constant mean annual rainfall and vegetation cover). No effect of catchment area was observed (Figure 26), further supporting the applicability across the diverse catchment sizes present in SWWA.

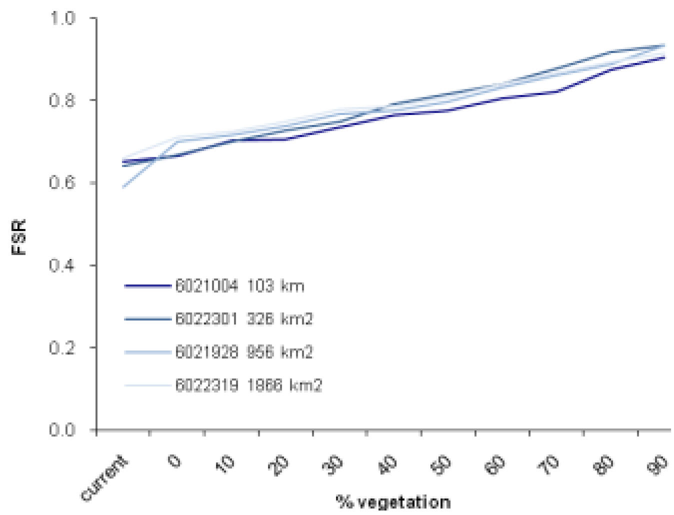


Figure 26 Effects of clearing on FSR scores in catchments of different size

In scenario 4, the possible effects of clearing and/or large dams on the FSR were assessed. Saint Mary River was chosen to run the scenarios, as this is a priority 1 Wild River in the Albany Coast SWMA, is in near-pristine condition and has a very high environmental value (Wild Rivers dataset, see Table 68); that is, the scenario is not obviously influenced by other anthropogenic effects.

Three conditions were investigated (see below) and are described in Table 16.

- A: no reservoir 100% vegetation

- B: with reservoir 100% vegetation
- C: with reservoir, 0% vegetation).

Table 16 FSR results for scenario 4

Condition description	LF	HF	PZ	CV	SP	FSR
Condition A no reservoir + 100% vegetation	1.0	1.0	0.9	1.0	0.9	1.0
Condition B with reservoir + 100% vegetation	1.0	0.0	0.9	1.0	0.9	0.8
Condition C with reservoir + 0% vegetation	0.8	0.5	0.6	0.9	0.6	0.7

The addition of the hypothetical reservoir in condition B reduced the extent of the high flow period, resulting in the *HF* component score dropping to zero. All other components remain unchanged. Although the catchment area is now a tenth of the original size, there is obviously some degree of catchment runoff remaining.

Clearing the catchment in condition C increases flow. Therefore the *HF* is slightly improved, scoring 0.5. There has also been a reduction in the scores for the *PZ, LF* and *SP* components: this is attributed to increased flow, decreasing the proportion of zero flow, increasing the low flows and widening the seasonal period. For further reference, Figure 27 illustrates the mean monthly flow for conditions A, B and C.

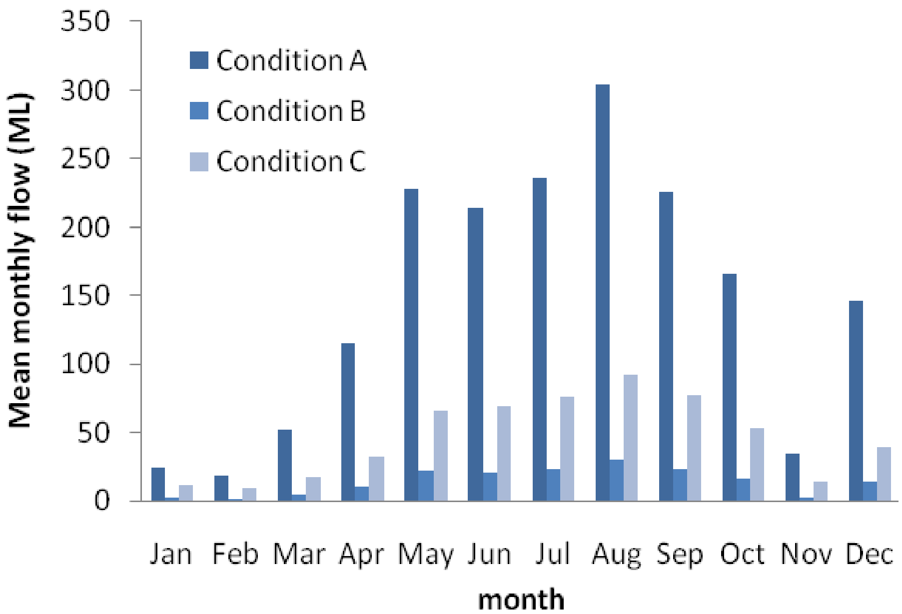


Figure 27 Mean monthly flow for conditions A, B and C

Condition C resulted in a score of 0.7, which is considered relatively healthy for effectively the worst-case scenario based on the attributes used to determine reference condition. Given this, it was decided to create a hypothetical zero flow condition for every month and run this through the FSR (condition D) to determine whether a zero score for the FSR could be obtained. This resulted in an FSR score of 0.3 and poor scores for all components apart from the *LF* (Table 17).

Table 17 FSR scores based on zero-flow conditions

Condition description	LF	HF	PZ	CV	SP	FSR
Condition D No flow	1.0	0.0	0.0	0.2	0.3	0.3

In the example above, the *LF* component scored well because this site had naturally low flow. Initially this result would indicate the *LF* is not viable for an assessment of hydrological change in SWWA, given many of our streams naturally have periods of low or zero flow. However, largely impacted sites do result in poor *LF* scores (Table 18) and reaches within high-rainfall zones and highly cleared catchments also scored lower in terms of the *LF* (Table 19) (note: high rainfall relates to permanent systems, thus the magnitude of the low flow exceedance is higher). Poor scores for the *LF* were also found in the farm dam investigation, see scenario 5.

Table 18 Highly impacted reaches showing poor scores for the low flow component

Reach ID	SWMA	Description	LF
6131420	Harvey River	Samson Brook, downstream of Samson Brook Dam	0.1
6120802	Collie River	Wellesley River, downstream of Wellesley diversion	0.1
6100902	Busselton Coast	Gynudup Brook, downstream of Gynudup bypass drain	0.0

Table 19 Reaches in high-rainfall zones with poor scores for the low flow component

Reach ID	SWMA	Description	LF
6031544	Denmark River	Seven Mile Creek – small catchment area (58 km^2), 40% vegetation cover	0.0
6021137	Albany Coast	Napier Creek – small catchment area (78 km^2), 21% vegetation cover	0.0

Scenario 5 examined the impact of farm dams on the FSR. Farm dam mapping data were available for this assessment for eight catchments, derived from previous studies by Sinclair Knight Merz (SKM 2007a; SKM 2008). These datasets describe a flow time-series for three conditions: current flow; no dams and current clearing; and no dams and no clearing. An example is shown in Figure 28. The FSR was applied to two of these datasets: current flow; and no dams and current clearing.

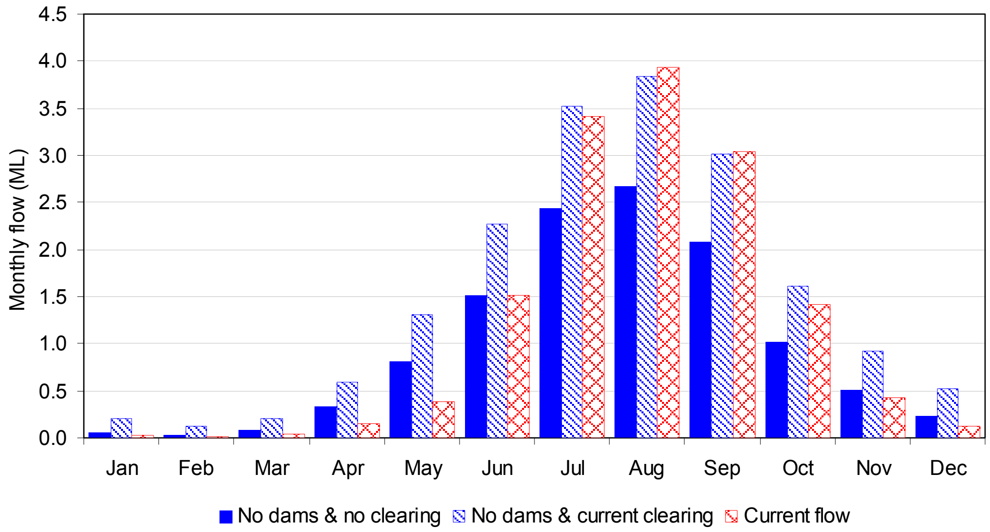


Figure 28 Impact of farm dams at Channybearup (DoW 2009b)

These datasets were chosen so that only the effects of the dams would be detected in the FSR, and would therefore advise whether the FSR was sensitive enough to pick up any changes. Results of this scenario are shown in Table 20.

Table 20 FSR illustrating effects of farm dams

Reach	LF	HF	PZ	CV	SP	FSR
Lower Collie	0.8	1.0	1.0	1.0	0.9	0.9
Capel River	0.5	0.9	1.0	0.9	0.9	0.9
Chapman Brook	1.0	1.0	1.0	1.0	1.0	1.0
Cowaramup Brook	0.9	1.0	0.7	0.9	0.7	0.8
Lefroy Brook	0.2	0.9	1.0	0.8	0.9	0.8
Margaret River	1.0	1.0	1.0	1.0	1.0	1.0
Wilyabrup Brook	0.5	0.9	1.0	0.9	1.0	0.9
Channybearup	0.4	0.9	1.0	0.8	0.8	0.8

The *LF* component was sensitive to these changes, and as this sub-index had been the least sensitive thus far, this was a significant discovery. Although the farm dam mapping is limited spatially within the south-west study area and thus cannot be used for assessing farm dam impact for the entire SWWA-FARWH, it supports the recommendation that the impact of farm dams be included in future works.

Finally, FSR results were analysed for relevance against the general expectations regarding hydrological stress in SWWA rivers (based on expert knowledge throughout the Department of Water). This was not an exhaustive process, but did show that results matched expectations, with the areas considered relatively pristine scoring well and those known to be heavily altered scoring poorly (see the final results in the next section).

Hydrological Change index and FSR components reach scores

The sensitivity of the *Hydrological Change index* and its components was further examined by analysing the final scores. The following section discusses hydrological changes occurring within SWWA and the ability of the index, and associated component indices, to detect these changes and therefore appropriately reflect health – at both the reach and SWMA scale.

Reach scores for the *Hydrological Change index* are given in Figure 29. Note: scores for all reaches are provided because the index was calculated remotely, rather than relying on field data.

The scores indicate some differentiation across SWWA; for instance, the Shannon SWMA shows the least impact compared with the others, pointing to increased hydrological stress in those SWMAs that have been cleared. One important finding is that no reach scores are in the bottom-two health categories (Figure 29), and further, when SWMA scores are calculated from the reach scores (see column 2 in Table 21) all SWMAs score within the top-two bands (‘largely unmodified’ and ‘slightly modified’ conditions). This finding reflects that hydrological value can still be found throughout SWWA, which is understandable given its brief history and low population.

Based on interrogation of data (discussed further below), most hydrological impacts in SWWA relate to increased flow due to clearing, which still offers ecological value.

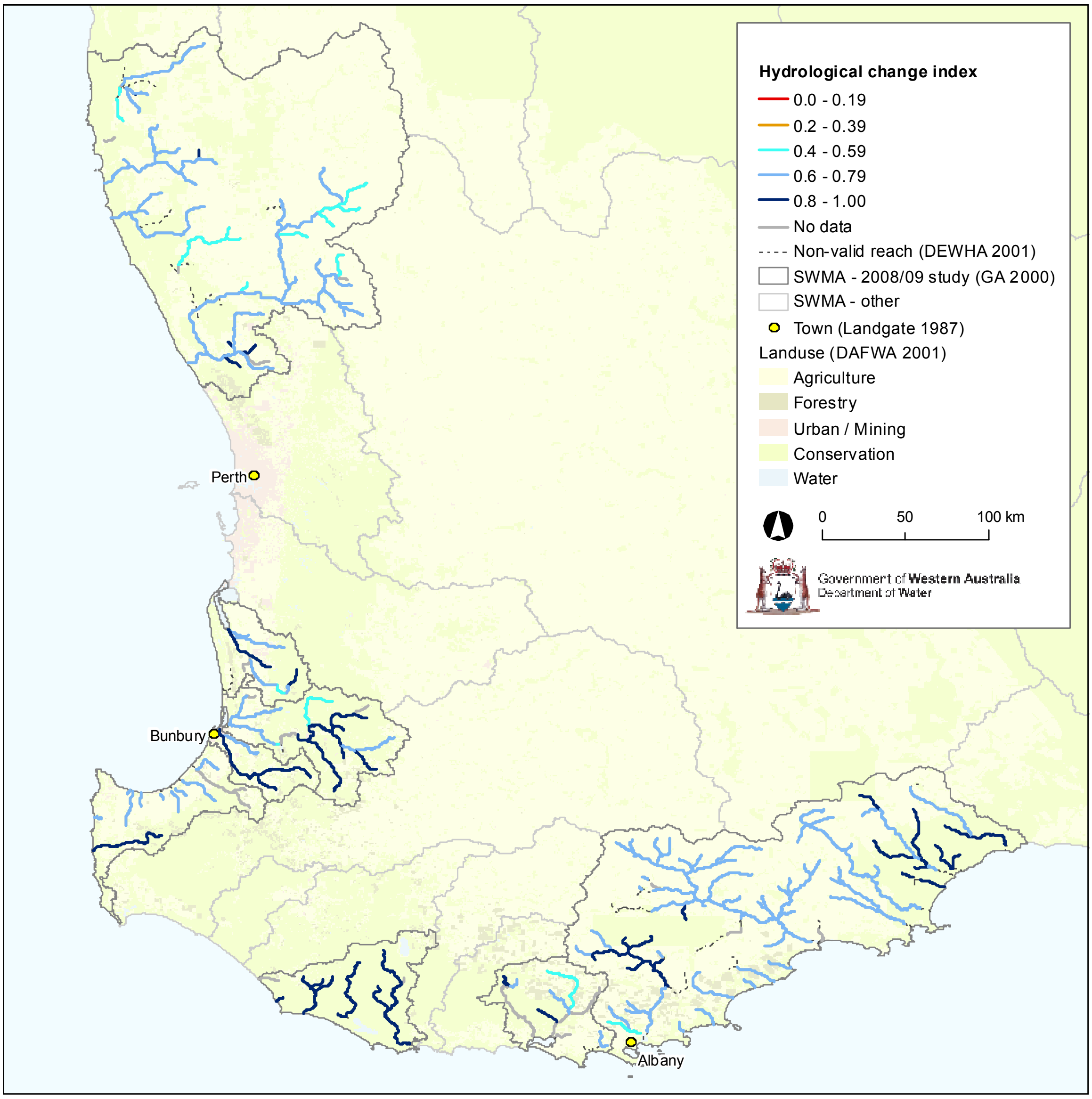


Figure 29 Hydrological Change index reach scores for SWMAs assessed during the SWWA-FARWH field trials (2008 and 2009)

When components of the FSR are aggregated to the SWMA scale a number of patterns emerge (Table 21). (Note: aggregation of components was done for sensitivity analysis and final scoring involved calculating the *Hydrological Change index* score for a reach before aggregation.) The *CV* and *SP* components show little differentiation at the SWMA scale, while *LF* saw one SWMA (Harvey River) falling into the 'moderately modified' condition band. The *PZ* and *HF* components highlight significant differences among the SWMAs. Five SWMAs scored in the 'moderately modified' band for *HF* whereas for *PZ* there were two in the 'moderately modified' and two in the 'substantially modified' bands (Table 21).

Table 21 Final scores for the Hydrological Change index and components of the FSR for SWMAs assessed within the 2008 and 2009 SWWA-FARWH trials

SWMA	HCI	LF	HF	PZ	CV	SP
Albany Coast	0.68	0.88	0.69	0.34	0.80	0.74
Denmark River	0.64	0.76	0.55	0.46	0.71	0.69
Shannon River	0.94	1.00	0.95	0.87	1.00	0.86
Busselton Coast	0.69	0.89	0.56	0.47	0.91	0.66
Preston River	0.84	0.79	0.68	0.90	0.91	0.88
Collie River	0.76	0.85	0.55	0.66	0.87	0.82
Harvey River	0.70	0.59	0.53	0.77	0.88	0.71
Moore-Hill Rivers	0.66	0.97	0.50	0.30	0.73	0.76

The individual reach scores that contribute to the values in Table 21 are provided in Figure 30.

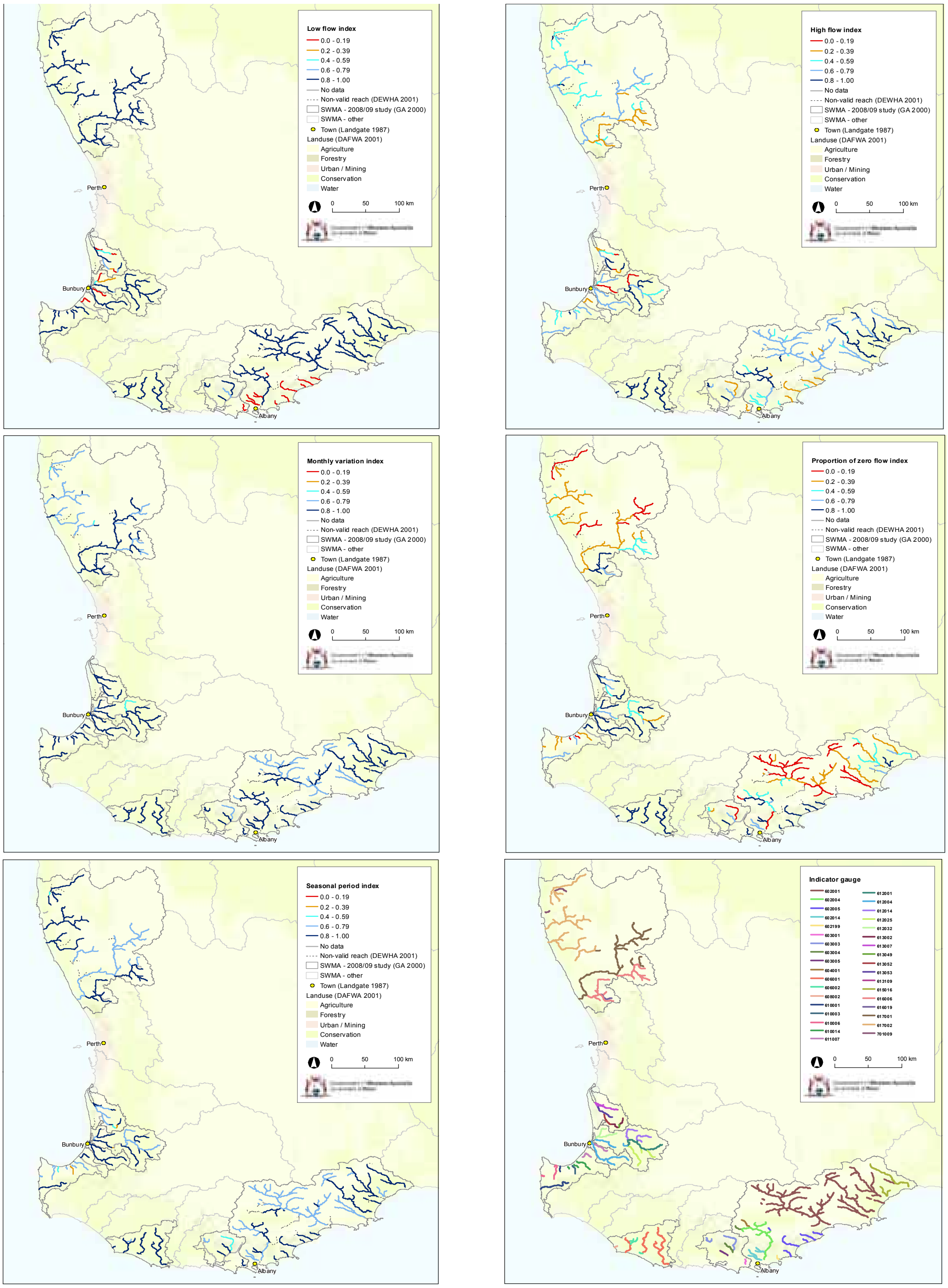


Figure 30 Component reach scores of the FSR: LF (top left), HF (top right), MV (middle left), PZ (middle right), SP (bottom left). Includes indicator gauges used to determine flow for all reaches (bottom right)

A number of interesting results are apparent in the component reach scores (shown in Figure 31): these are discussed below.

Low flow (LF) component results

- Harvey River SWMA result: **0.59 *LF component***

The following descriptions explain, using examples, reasons for the detected impact within the Harvey River SWMA.

Mayfield Drain (at the catchment's base) scored 0.1, attributed to its catchment being largely cleared (only 11% vegetation remaining). As a result, flows have increased, which has led to a change in the 91.7 and 83.3% exceedance being substantially larger than pre-impact conditions.

Samson Brook (towards the top of the catchment) scored 0.1, attributed to its location downstream of a water supply reservoir (Samson Brook Dam) which has altered its catchment area to 20% of the pre-impact area.

Harvey River SWMA (reach in the upper catchment) scored 0.1, due to the presence of Stirling Dam which has altered the catchment area to 27% of its original size.

- Albany Coast SWMA result: **0.88 *LF component***

Although a relatively healthy score was returned for the Albany Coast at a SWMA scale, a small area in its south-west corner showed significant signs of stress through the *LF component*. This cannot be attributed to the presence of dams (as there are none) or high rates of clearing, as in some cases more than 50% of the catchment is vegetated.

A number of factors may be contributing to this situation, however there is a strong correlation with rainfall:runoff ratios for the region (see figures 31 and 32).

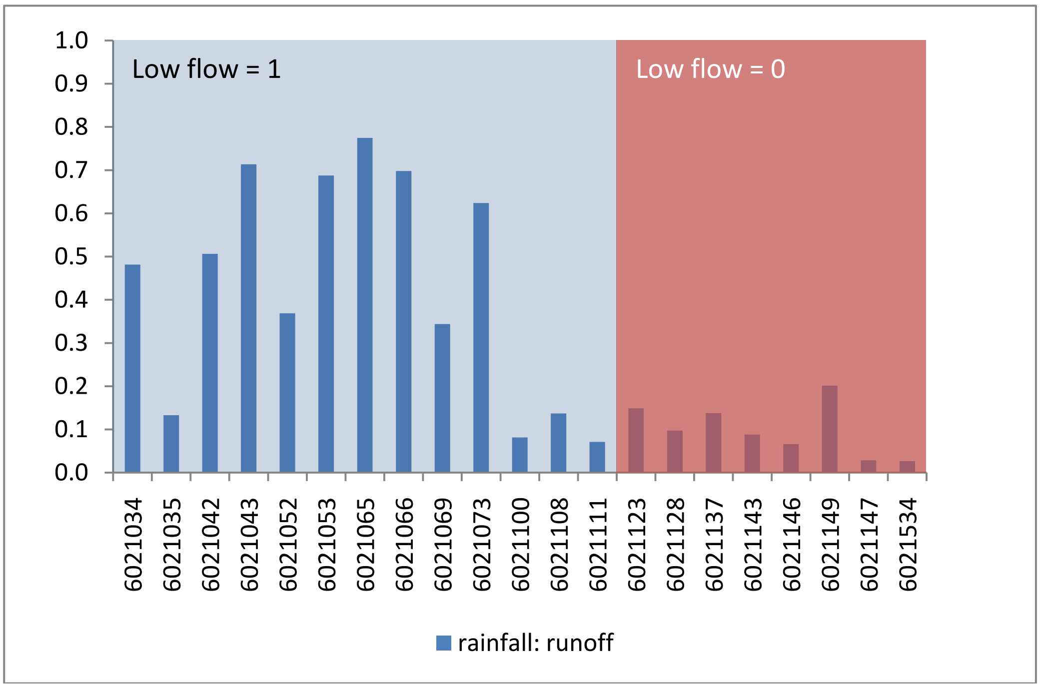


Figure 31 Rainfall:runoff ratios for reaches within the Albany Coast SWMA. Red area denotes reaches scoring zero for the low flow component, remaining reaches were 'largely unmodified'

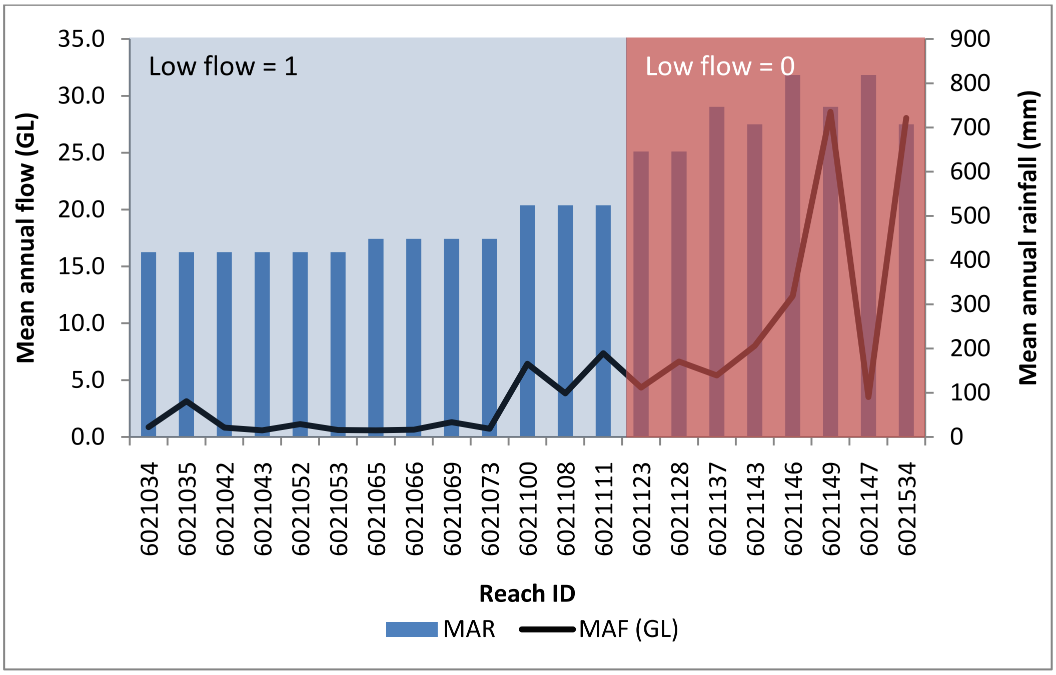


Figure 32 Mean annual rainfall and flow for reaches of the Albany Coast SWMA. Red area denotes reaches scoring zero for the low flow component. Low flow was not impacted in the blue area

The reaches within the Albany Coast SWMA which scored zero for the *LF component* (see top left graph in Figure 30) are those which tend to have smaller rainfall:runoff ratios (see Figure 31). These reaches are also within a higher rainfall area, with typically higher flow rates (Figure 32), indicating they are permanent river systems. These reaches therefore have more potential to have their low flow altered (with clearing having increased the magnitude of low flow). Conversely, the reaches that scored 1 are in the lower rainfall areas, with lower flow rates. There is less potential for impact to low flows in these reaches, as changes to land use would have had little effect on the flow rates due to the low rainfall.

The length of impacted reaches in the Albany Coast was not sufficient to reduce overall scores significantly (SWMA score for *LF component* = 0.88); however, if reach scores reduce further for these systems, or if an additional reach of average size was to become impacted, the SWMA score would drop a condition band.

High flow (HF) component results

At the SWMA scale, the *HF component* scores for Collie River, Harvey River, Denmark River, Moore-Hill Rivers and Busselton Coast all fell within the ‘moderately modified’ band.

For Collie River and Harvey River, this can be attributed to two reaches in each SWMA being in ‘severely modified’ condition due to their location downstream of water supply reservoirs (and therefore now having smaller catchment areas and smaller high flows than under pre-impact conditions).

For Denmark River SWMA, one reach (Hay River) scored poorly because it has a largely cleared catchment (70% cleared). The 8.3% exceedance flow at this site is five times higher than under pre-impact conditions (14 GL as opposed to 2.8 GL).

For Moore-Hill Rivers SWMA, a group of reaches in the southern part of the SWMA are all in ‘substantially modified’ condition, with most remaining reaches in ‘moderately modified’ or ‘slightly modified’ condition for the *HF component*. This is surprising, given the hydrological impacts are uniform across the study area. This may be an artefact of the indicator gauge used, as the data for most reaches in ‘moderately modified’ condition were from the same indicator gauge (see Figure 30, bottom right). It may also reflect the fact that this area of the SWMA behaves differently to the rest of it: the sites are typically on different branches and have a larger variety of land uses compared with the rest of the SWMA.

Albany Coast SWMA presents similar complexities, as was seen in the *LF component*, where a number of short coastal systems score in the ‘substantially modified’ band. Due to their relatively short length they do not greatly influence the overall SWMA score (this is a sensitivity limitation of large SWMAs in SWWA).

Proportion of zero flow (PZ) component results

At the SWMA scale, both Moore-Hill Rivers and Albany Coast scored within the ‘substantially modified’ band for the *PZ component*.

Most reaches within the Moore-Hill Rivers SWMA are of ‘substantially’ or ‘severely’ modified condition, apart from the southern area which is ‘largely unmodified’ or ‘moderately modified’. This means the hydrology in the southern area behaves differently, which could be due to a number of factors, including climate and rainfall patterns, soil type, slope of the catchment and connectivity of upstream waterways. It may also be an artefact of the indicator gauge used, as the data used for the majority of reaches in better condition – 'moderately' to 'slightly' modified and 'largely unmodified' – were from the same indicator gauge (see Figure 30, bottom right). It may also reflect the fact that this area of the SWMA behaves differently to the rest of the SWMA: the sites are typically on different branches and have a larger variety of land uses compared with the rest of the SWMA.

The reaches that scored poorly can be attributed to their highly cleared catchments, which now produce more flow and therefore shorten the period of zero flow. For example, in one tributary of the Moore River North Branch, the proportion of zero flow for the current condition is 0.5% compared with 54% for the pre-impact condition.

In the Albany Coast SWMA the Pallinup River area scored poorly, with reaches scoring in the 'severely' or 'substantially' modified bands. This relates to the proportion of zero flow for current conditions being five to six times less than pre-impact conditions.

The Harvey River and Busselton Coast SWMAs were also shown to be impacted, with causes similar to the Albany Coast and Moore-Hill Rivers SWMAs, but in more localised areas (among more hydrologically unimpacted reaches).

Comparing component scores and SWMAs

Comparison of reach scores across the different components of the *Hydrological Change index* show that different impacts are being detected, which supports the use of multiple components. All components were shown at one time or another to detect different things, therefore no redundant component indices were apparent within the index. There is also a general negative correlation between hydrologic impact and the proportion of vegetation remaining (Table 22). It should not be concluded, however, that a direct relationship with vegetation cover exists, given the proportion of remaining vegetation also correlates highly with agricultural land use in these areas – and therefore associated water resource use (dams).

Table 22 Proportion of vegetation (per cent) remaining in each SWMA assessed within the SWWA-FARWH 2008 and 2009 trials

SWMA	HCI score	Proportion of vegetation (%)
Moore-Hill Rivers	0.66	34
Albany Coast	0.68	40
Busselton Coast	0.69	50
Harvey River	0.70	51
Denmark River	0.64	54
Preston River	0.84	57
Collie River	0.76	74
Shannon River	0.94	91

Based on the relationship between impacts used in developing the FSR for SWWA (clearing and dams) and the *Hydrological Change index* scores, the index does appear to differentiate SWMAs appropriately; therefore inclusion in the FARWH is supported.

However, the *Hydrological Change index* was shown to be relatively insensitive to short-term changes (as examined in the sensitivity analysis in the previous section), which demonstrates that any users of the index at SWMA level must understand the degree of change able to be detected. This result is understandable given the FSR components were shown to respond individually to the various scenarios (e.g. effects of farm dams only produced an impact on the *LF component*). That is, when the components are combined for the index these specific changes are masked. This does not affect the conclusion that the index should be included in the SWWA-FARWH, however it does suggest that assessments need only be infrequent (discussed further later) and that management should assess hydrological impact at a component level to determine the nature and cause of impact.

Power analysis

As this sub-index was calculated for all reaches a power analysis was not conducted.

Data verification

A panel of hydrologists from the Department of Water's Water Science and Surface Water Assessment branches agreed on the overall approach to calculating the *Hydrological Change index*.

Verifying input data

All flow data have quality codes assigned (see Table 68). Quality relates to a number of factors, such as whether the rating curve (used to calculate flow from stage height) is appropriate (e.g. inaccuracies exist when data falls outside the experience of the rating curve) or the equipment being used is reliable. The Department of Water's Water Information Branch manages and checks the data. It also references and stores data appropriately and emphasises quality assurance.

The extent of vegetation was sourced from the most up-to-date dataset available on the Department of Water's internal GIS database (Native Vegetation Current Extent dataset, see Table 68).

Catchment boundaries and areas were sourced from the Hydrographic Subcatchments dataset (see Table 68), as these were the most spatially accurate. Basin areas for each reach were cross-referenced with the sum of each catchment area.

Calculating the FSR for each reach largely depends on an accurate catchment area corresponding to the reach in question. Where possible, Hydrographic Subcatchment boundaries were used in favour of the ARC reach catchment boundaries (known as 'Subcatch reach geog', see Table 68) because these had more useful attributes for FSR calculations (e.g. basin area). In some cases, Department of Water catchment boundaries were too coarse to reflect the reaches. If the Hydrographic Subcatchment boundaries were not accurate then the reach was not included in the analysis.

Rainfall and evaporation data has been sourced from the SILO patch point dataset available on the internet at <www.longpaddock.qld.gov.au/silo> (see Table 68).

Indicator gauges were chosen based on work from a previous study (SKM 2007).

Calculating reference condition

Calibration graphs and efficiencies from the FCFC processing were assessed for fitness; an example is shown in Figure 33. The calibration result aligns closely with gauged data, as indicated by the high mean-median correlation of 0.8099. The flow duration curves also match well, with deviation seen only in the very small flows (0.001).

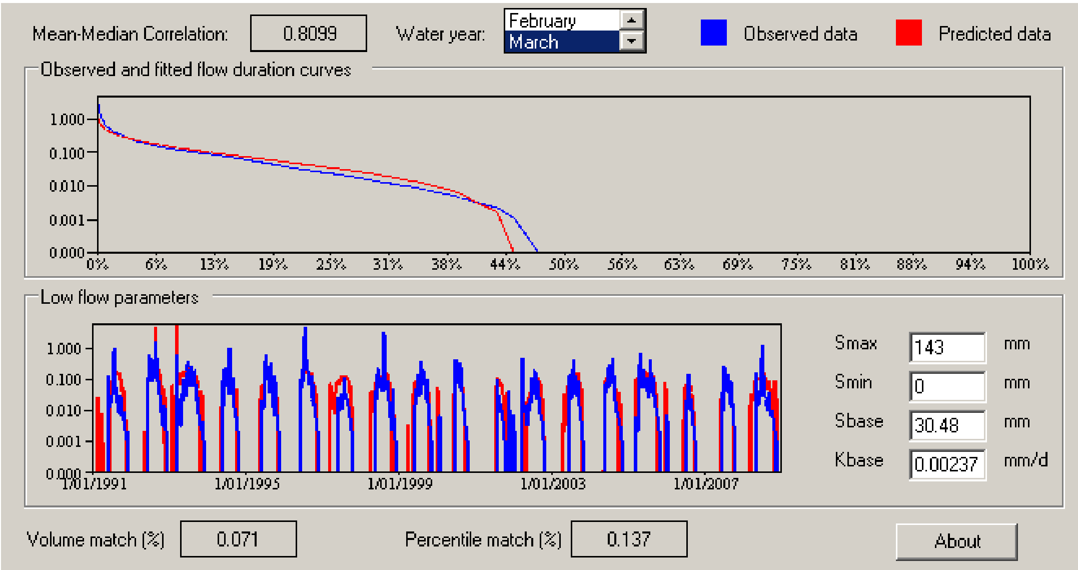


Figure 33 Calibration graph and efficiency for FCFC, referring to reach 9090940 within the Blackwood River SWMA

Figure 34 shows the deviation in the flow duration curves from current (7% vegetation – blue line) to unimpacted (100% vegetation – red line).

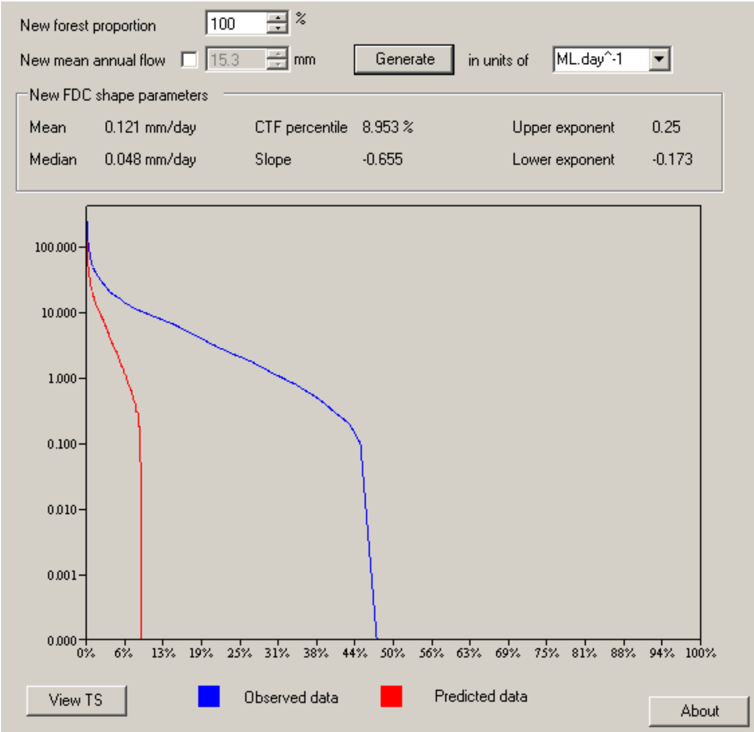


Figure 34 Flow duration curves from current to unimpacted condition based on FCFC calculations

Note: random verification of calculations was undertaken to ensure errors due to incorrect data entry or values outside the ability of the model were not included.

Frequency of new data regeneration

The FSR could be updated annually because it is reported at this time scale, but due to a number of factors (see below) a three- to five-year interval is suggested.

- Flow data are measured daily, although they go through a validation process before becoming available for use on the Department of Water's WIN/HYDSYS system. Thus there is a lag between data collection and their becoming available for use (between one to three years) and therefore annual updates may not be reasonable.
- In six of the SWMAs (Swan Coast, Preston River, Moore-Hill Rivers, Denmark River and Busselton Coast) the index was calculated for 2005 and 2008. Only slight changes were seen in a very small number of reaches, indicating the index is unlikely to change on an annual or bi-annual basis. Therefore, a period of three years or more would be a reasonable frequency of assessment.
- For reference, the ISC (Vic) measures hydrology every five years. During the period between 1999 and 2004 no major changes were reported at a statewide scale (Government of Victoria 2009).

Statistical analysis

The relationships between the components of the *Hydrological Change index* were examined using scatter plots and linear regression, to determine whether any redundancies existed. Within the index the *proportion of zero flow* was shown to have a moderate correlation with *monthly variation* ($r = 0.63$; $p = < 0.05$), *low flow* ($r = -0.53$; $p = < 0.05$) and *seasonal period* ($r = 0.46$; $p = < 0.05$). A moderate correlation existed between *low flow* and *high flow* ($r = 0.44$; $p = < 0.05$); and a low correlation between *monthly variation* and *seasonal period* ($r = 0.32$; $p = < 0.05$)

As described in the theme review, the components of the *Hydrological Change index* describe different aspects of hydrology, with each being able to change independently to the other. As such, correlations do not reflect redundancy.

Limitations

Limitations exist in the data in terms of both measurement and applicability, and the processes which use these datasets. Ultimately, the result of the FSR or any other type of hydrological disturbance index is reflective of the datasets from which they are derived. These issues are described below.

- Gauging stations record water level which is converted to flow. If a gauging station hasn't been rated many times then high flow events may be outside the rating curve, resulting in poor calculation of high flow events. Department of Water flow files have a quality code associated with every flow record, which indicates if this is the case.
- In ungauged areas indicator gauges are used to represent current conditions – if the indicator gauge is not a good match then the results returned will not be accurate.
- Unimpacted conditions were derived by removing the impact of clearing, large reservoirs and large diversions. Farm dams and abstraction have not been accounted for.
- Hydrological characteristics associated with natural streams are different to those of drains. Drain hydrographs tend to be flashier, with higher high-flows and quicker responses to rain events. In the current method the FSR has not picked up these changes – this is because the referential approach is used, whereby reference condition for a drain in a cleared catchment is reflective of a drain in a vegetated catchment, not a natural stream. Hydrological differences between drains and streams are obvious at a daily time-step, however when analysing monthly flow (the period at which the FSR is calculated) these differences are reduced. In the future reference condition should be calculated in such a way as to incorporate the difference between drains and streams, perhaps by developing a different method to define reference condition for drains.
- There is an obvious impact of climate change on hydrological regime and therefore river health, with reductions in rainfall in SWWA equating to a three- to four-time reduction in streamflow (Berti et al. 2004; Kitsios et al. 2008; Smith et al.

2009). In terms of the *Hydrological Change index*, reference condition has been developed based on current conditions without impacts. Reference condition was modelled using FCFC which used 15 years of rainfall data reflective of current climate, not pre-European climate.

- The FCFC did not always calibrate well, and therefore data derived from this process may not reflect unimpacted conditions in some areas; for example, some reaches in the Greenough River SWMA with 100% vegetation scored an FSR value of 0.7 – in these cases the gauge was deemed inappropriate for use.
- Current conditions are best represented if flow on the reach in question is measured at a daily time-step, without gaps, continuously for many years. In this study, a minimum of 15 years was required to perform the FSR calculations. The gauging station also needed to be operational to ensure the most up-to-date data and continuity for the future. These conditions greatly reduced the number of gauging stations available for use.
- For reaches in ungauged areas, or in areas without appropriate records, indicator gauges were used to provide a flow time-series. The flow from the indicator gauge was scaled to reflect the catchment area of the reach in question. Indicator gauges were chosen based on a spatial dataset generated during the Sustainable Diversion Limits study (SKM 2007b). If none of the three suggested indicator gauges were ideal, then the closest gauge meeting the criteria was used.

Hydrological Change index summary

The *Hydrological Change index* was included in the FARWH to measure the impact of the water regime (both surface and groundwater) on the functioning of the aquatic ecosystem (NWC 2007a). The index uses the referential approach, where reference is defined as current condition without impact from human activity. The reference condition for the SWWA-FARWH trials is modelled from current hydrological data removing the impact of vegetation clearing and reservoirs (identified as the major impacts on flow in SWWA). The model does not incorporate effects from farm dams or abstraction, therefore a certain degree of residual variation exists. This variation could not be addressed for the SWWA-FARWH trials due to insufficient data, but is a key recommendation for future work.

The *Hydrological Change index* was implemented using the Flow Stress Ranking (FSR) with each of the five components weighted equally.

Future

For future applications of the FSR to SWWA, the following changes are recommended:

- Higher accuracy is required for reach definition and corresponding catchment delineation. Catchment and basin areas for each reach are also required.
- When scaling flow for ungauged areas, scale the flow from a nearby streamflow gauge based on catchment hydrologic similarity measures such as area, mean

annual rainfall, evaporation and proportion of vegetation (current scaling was done by catchment area only). This would account for the fact that some catchments respond differently (in terms of their rainfall/runoff processes) to other catchments; that is, a 50% cleared catchment would have a different rainfall/runoff pattern than a 20% vegetated catchment.

- The impact of abstraction has not been directly taken into account. To model this, an integrated surface/groundwater model would be required, as well as the timing and volume of water extracted. Alternative proxy methods to measure the impact of abstraction would be to determine the number of abstraction points per km^2 in the catchment in question. A farm-dam density measure would also provide an indicator for surface water allocation.
- Account for the impact of farm dams. Eight catchments within SWWA have been modelled using the CHEAT program. Each of these catchments had a different *farm dam density* (measure of farm dam storage per catchment area). This modelling was able to determine the differences in flow caused by the presence of farm dams within the catchment. As a result of this modelling, each catchment has a time-series that relates to 'difference in average daily flow due to farm dams' as shown in Figure 35. Once farm dams are mapped, the *farm dam density* can be calculated and the corresponding curve can be applied to the existing daily or monthly data.
- Alternatively, an additional sub-index relating to *farm dam density* and *farm dam development* could be created once farm dams are mapped. See Appendix C for methodology on additional indices. Measures of *farm dam density* may also be considered proxy indicators for areas of surface water over-allocation.

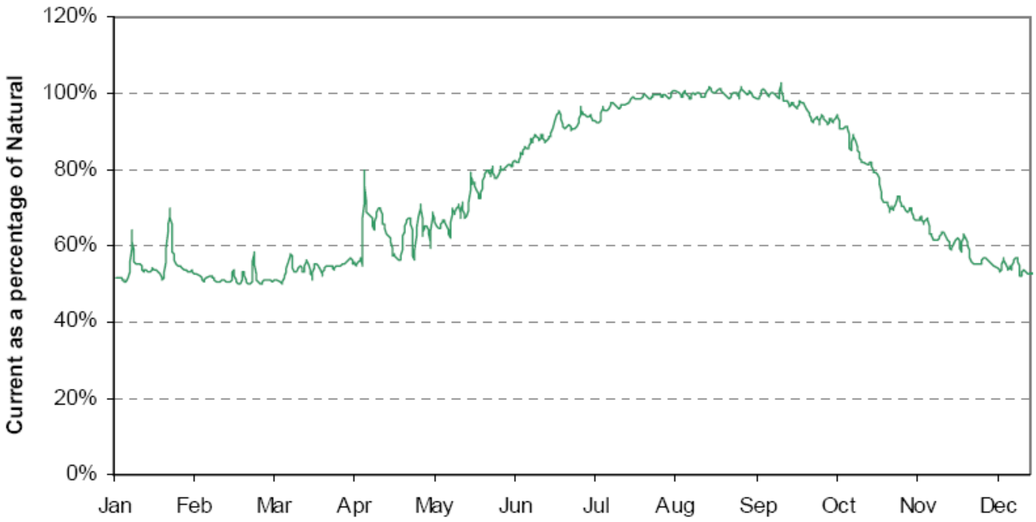


Figure 35 Difference in average daily flow due to farm dams (SKM 2007a).

4.3 Theme: Water Quality

Water quality encompasses a range of chemical and physical attributes that are important aspects of riverine habitat character and useful indicators of catchment and riverine transport and biochemical information processes. Assessments of water quality are conducted for a range of objectives, such as meeting drinking water standards or guidelines for use in irrigation. For the purposes of the SWWA-FARWH, assessments are made purely against ecosystem health.

Historically, water quality has been used as a surrogate for ecological health, reflecting its versatility in representing both pressure and response. However, in recent times it has become apparent that water quality alone is not enough to define health, especially due to factors such as the synergistic effects of multiple parameters and an inability to test for everything. Rather, it is primarily a diagnostic tool to infer causes of biological change or highlight impacts from catchment disturbance.

Based on the above attributes, water quality indicators have been employed as a component of river health assessment programs in other parts of Australia (e.g. ISC and EHMP) and around the world (e.g. EMAP and WFD). Water quality has also been shown to be effective in identifying changes in ecosystem function through a range of scales, from site-specific assessments to watershed-scale investigations (Mulholland et al. 2005).

Indicator selection

The most widespread water quality problems in SWWA are salinisation and eutrophication. These reflect the most prominent post-European-settlement land use changes: those of land clearing and agriculture. Low oxygen is another common problem, although its occurrence is primarily localised, sporadic and often temporary. Oxygen depletion can be in response to any number of causes, but is often a symptom of elevated nutrients (due to phytoplankton blooms and subsequent collapses). Temperature and turbidity changes are also key environmental indicators, being attributed to a range of biotic impacts in SWWA, and are typically due to clearing of riparian vegetation and streams becoming shallower as a result of sedimentation. These water quality issues were targeted during the first stage of indicator development for the SWWA-FARWH program and represented four of the six indicators that a 1998 NLWRA workshop identified as being of national importance (NWC 2007a). The other two indicators were pH (recorded but not scored, see review at the end of this section) and faecal coliforms (not a significant issue in SWWA).

The selection of suitable water quality parameters was heavily influenced by cost (labour, equipment, analysis), speed of assessment, ability to define reference and applicability to the broad scale required for the FARWH. For instance, parameters such as pesticides, hydrocarbons or metals are typically only relevant at specific sites, and this (coupled with high analysis costs) led to them being omitted.

Future development of the FARWH should assess additional parameters to target other significant, but less widespread water quality problems. This includes specific contamination arising from urban development and mining activities. This direction may only eventuate as a secondary targeted investigation following the broad-scale assessment reported here.

Of the parameters tested, six sub-indices were selected for scoring the *Water Quality index*, these were:

- total nitrogen (TN)
- total phosphorus (TP)
- turbidity
- salinity
- diel dissolved oxygen
- diel temperature

A number of parameters and associated indicators were identified for future testing, such as pH and sediment. The reasons these indicators were not incorporated into current scoring protocols are discussed at the end of this section. Some parameters have been included in field assessments due to the valuable interpretive information they provide. These include total oxidised nitrogen (nitrate and nitrite), ammonium nitrogen, dissolved organic nitrogen, soluble reactive phosphorus, pH, total alkalinity and true colour.

Existing data

A series of water quality programs are active across SWWA. The most extensive of these includes regular monitoring of the Department of Water's gauging station network and other fixed surface and groundwater sites. There are also numerous assessments tailored to specific locations and events. The department captures data across all of its monitoring programs within the Water Information Network (WIN) (see reference in Table 68). This data was available for use in generating *Water Quality index* scores and reference conditions (discussed in more detail later).

The ability to generate *Water Quality index* scores from existing data alone is currently possible through WIN for four of the trialled parameters: TN, TP, turbidity and salinity. However, this is limited spatially because coverage varies between SWMAs.

Due to the spatial limitations of data stored in WIN, data for the 2008 and 2009 FARWH field trials for all indicators except salinity were collected in the field using spot measurements (TN, TP, turbidity) and logged data over a 24-hour period (diel dissolved oxygen, diel temperature). Field data were also prioritised over WIN data for the SWWA-FARWH trials to allow direct comparison with other themes at the time of sampling, especially for interpreting biotic responses, which may reflect acute changes not detected in WIN data.

Salinity was scored using a combination of measured and modelled data, created by Mayer et al. (2005) (see Table 68 for Stream salinity status dataset). This dataset was cross-referenced against data collected in SWWA field trials to ensure correlation. Results of this comparison are given in the indicator reviews below.

Of the parameters trialled in SWWA-FARWH, salinity was the only parameter where modelled data already existed. Note: development of new models was outside the capacity of this project. Modelling for salinity was shown to be a valuable tool for the scale of assessment required for the FARWH and it is recommended this approach be trialled for other indicators in future. It should be noted that the use of modelling for future assessments would require regular calibration, and as such the parameters identified in the SWWA-FARWH should be recorded as part of any field assessment. Further, water quality data are valuable for interpretation of biotic response, which requires spatially and temporally specific data.

Note: SedNet (developed by CSIRO) was evaluated for use in modelling nutrients (and sedimentation for the Physical Form theme). Due to inaccuracies in the datasets required to generate modelled data using SedNet (gully erosion, bank erosion and hill slope erosion datasets) and the lack of time/resources available to regenerate these datasets, this was not pursued. Future work should look at this option.

Setting reference condition

Scoring bands for most indicators have been derived from expert opinion based on knowledge of SWWA river ecology, historical evidence and biotic tolerances – rather than from reference site data. The scoring bands were essentially standard values assigned to represent threshold conditions for ecosystem protection and followed the ecological niche theory (Shelford 1911).

The use of this approach was due to a lack of spatially and temporally sufficient data to capture expected natural variability (no reference sites).

The rationale for setting scoring bands varies for each indicator and is described in the relevant sections below.

Sampling methods

Sampling methods for all parameters (both for scoring indicators and those used as supplementary data) are described in the *Inception report – volume 2: SWWA-FARWH* (van Looij & Storer 2009b). Updated field sheets for recording field water quality data (superseding those published in the inception report) are provided in Appendix B.

Note: water quality assessment was limited by equipment, in that logged data was only available for dissolved oxygen and temperature. This limits confidence in spot measurements for parameters such as turbidity and nutrients (e.g. common pulses from runoff in agriculture and urban areas are likely to be missed). Parameters with a high diurnal flux, such as pH, were not included due to the inability to represent variability with single point measurements. In response to this limitation, improved water quality logging equipment (Eureka Manta 2-40 Multiprobe) was ordered before the 2009 spring sampling began. This equipment incorporated additional parameters (outside of dissolved oxygen and temperature) such as turbidity, pH and electrical conductivity, as well as a capability for longer deployment (two to three months versus 24 hours). Purchasing and shipping delays resulted in this technology not being available for testing as part of the main SWWA-FARWH trials, however results from follow-up trials are provided in the theme summary at the end of this section.

Indicator summaries

The following is a review of each of the indicators trialled for the SWWA-FARWH. Many of the general techniques, methods and procedures conducted in evaluating the sub-indices were common. As such, these are fully explained in the first sub-index review and referred to thereafter.

Sub-index: total nitrogen

Nitrogen is a fundamental element of primary production and can be a limiting agent in SWWA systems. This is a particularly applicable indicator given that eutrophication is one of the more common problems occurring in the region, due to widespread agriculture and associated fertiliser application. The situation is exacerbated by extensive clearing of fringing zone vegetation (reducing buffering capacity) and because systems are poorly equipped to deal with high nutrient concentrations due to their oligotrophic evolution.

It should be noted that elevated nitrogen concentrations in SWWA systems do not appear to reach toxic levels, but given the association with primary productivity and the related impacts from unnatural levels of algal growth, nitrogen remains a valuable indicator. Further, analysis of nitrogen concentrations is important in elucidating linkages between stream impacts and adjacent land uses, and as such has been used in numerous environmental impact assessment studies throughout the world (e.g. Bormann & Likens 1979; Swank 1988; Mitchell et al. 1996; Aber et al. 2003 – in Mulholland et al. 2005).

Scoring method and reference condition

There is no agreed approach to developing scoring protocols for total nitrogen (TN) in the FARWH documents.

Ideally, minimally disturbed reference sites would be used to determine natural TN concentrations, but this was not feasible for SWWA because suitable reference sites were not available due to large areas of clearing. While the catchments of some rivers are entirely uncleared (or nearly so), they do not provide suitable reference sites for other systems due to a range of factors including variability in rainfall gradient, geology, river form and function.

The use of predictor variables to determine reference condition was assessed, whereby existing data from the WIN database were compared against variables that were unlikely to change due to human impact (e.g. easting, northing, altitude and average maximum daily temperature). The premise was that relationships could then be used to predict the expected nitrogen concentrations for individual reaches. Data from August through to January was combined to test the validity of predictor variables, so that any effects from seasonality were reduced (as most systems in SWWA exhibit a flow-concentration relationship). No relationship with predictor variables was observed.

ANZECC and ARMCANZ (2000) guidelines were also consulted to determine suitability for assigning expected nitrogen concentrations to reaches. Two default trigger values were reported: one for lowland rivers (less than 150 m altitude) of 1.2 mg/L and one for upland rivers (greater than 150 m altitude) of 0.45 mg/L. Firstly, the distinctions based on altitude did not correlate with SWWA conditions (based on comparisons made against WIN data). Through assessment using three SWMAs, no obvious altitude strata was supported for Moore-Hill Rivers SWMA, and if anything a cut-off point of 25 m appeared more applicable to data taken from the Collie River and Albany Coast SWMAs (Figure 36).

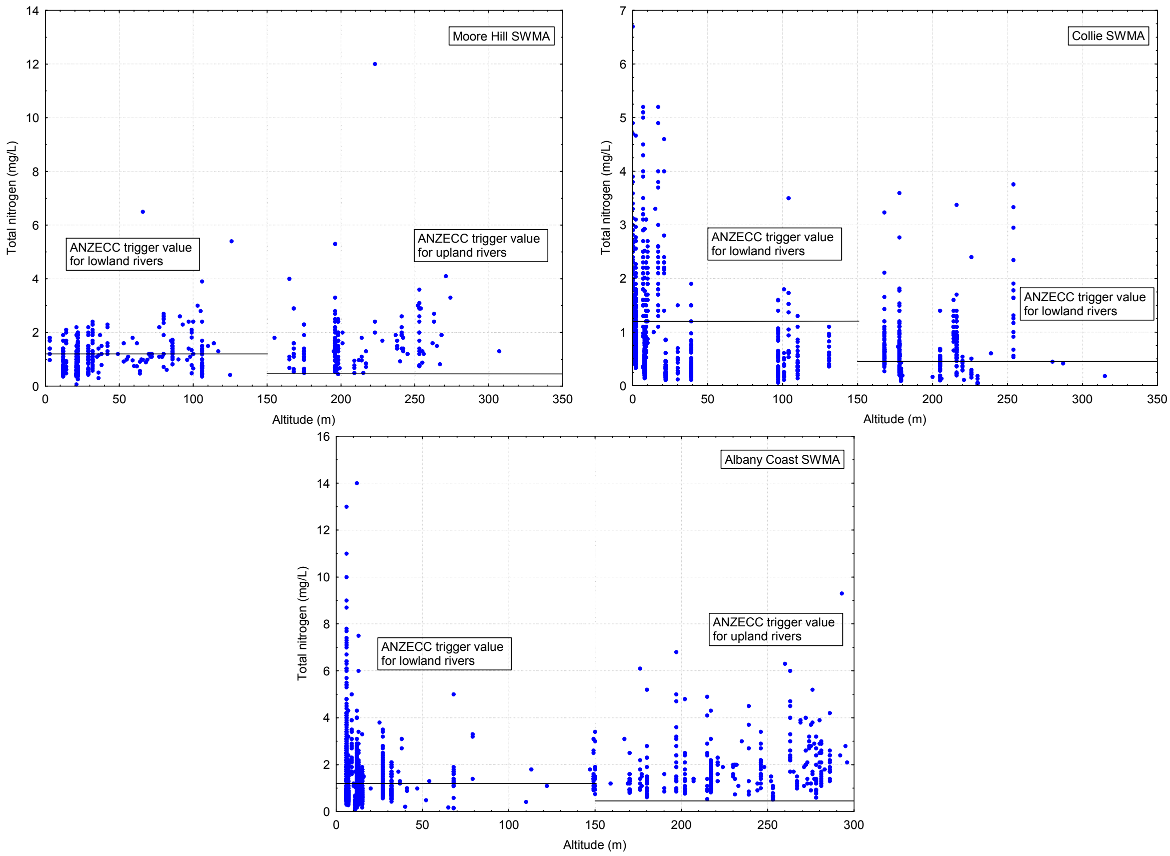


Figure 36 Total nitrogen versus altitude in the Moore-Hill Rivers, Collie River and Albany Coast SWMAs

Secondly, the trigger values reported did not fit any obvious impact scales as defined by land use. For instance, sites that would be considered close to reference (e.g. minimal clearing and no significant hydrological changes) returned nitrogen concentrations in excess of these values. As a general summary, Figure 37 shows a plot of nitrogen concentrations versus land use, highlighting that assignment of ANZECC trigger values does not accurately represent the data. Note: data in Figure

37 has not been 'cleaned'; for example; conservation areas that may have been defined only recently (and thus are potentially in an impacted state) have not been excluded. Figure 37 does support the inclusion of nitrogen for river health assessment, through the positive correlation with perceived impacts from land use.

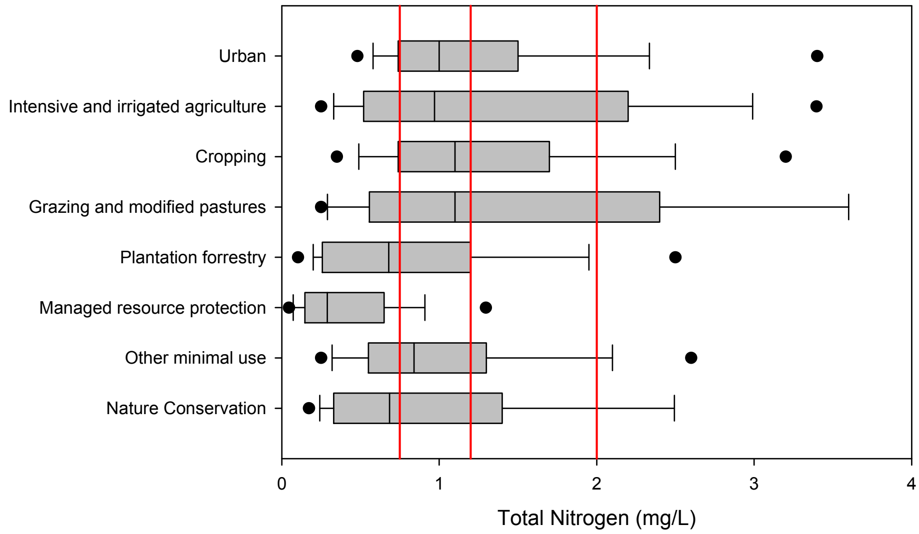


Figure 37 Total nitrogen concentrations for SWWA land uses (red lines indicate scoring bands for the SWWA-FARWH; central point is the median, box represents the 25th to 75th percentiles and whiskers the 10th and 90th percentiles)

An existing TN classification scheme developed for Western Australia was used to develop the scoring protocol for TN (DoW 2004). This scheme was developed by the Department of Water, based on all available TN data from WIN, to allow statewide comparisons of TN concentrations. The categories, definitions and associated FARWH scores are provided in Table 23. Comparison of these bands against impacts represented in Figure 37 aligns well.

Table 23 Total nitrogen categories and scores

TN concentration (mg/L)	TN category	FARWH score
< 0.75	low	1
0.75 – 1.2	moderate	0.8
> 1.2 – 2.0	high	0.6
> 2.0	very high	0.4

A zero score was not assigned because departure from reference is not finite and significant stream impacts (as represented by aquatic biota) were not correlated with a specific high nitrogen concentration. This assumption was supported by a number of sites in SWWA where high nutrient concentrations were recorded in areas with no obvious impacts on aquatic biota. Note: the significant health impacts that can be caused by nitrogen via indirect pathways (e.g. algal blooms) will be identified in other SWWA-FARWH indicators.

Note: modelled data does exist for some catchments (e.g. nutrient models have been created for a number of systems in SWWA, such as the Vasse-Geographe (Busselton Coast SWMA), Leschenault (Collie River and Preston River SWMAs) and Swan (Swan Coast SWMA) (Hall 2009; Marillier 2010; Kelsey et al. 2010) as well as projects underway in the Murray and Peel Harvey), however as these are spatially limited they were not adopted. Given inherent errors in water quality monitoring (capturing diurnal/seasonal/site variability), the investigation of modelling options for future assessment is recommended.

Sensitivity analysis

Sensitivity analysis was conducted as part of developing the Department of Water classification scheme (DoW 2004) and was used to set scoring bands. Figure 37 provides an overview of the ability of bands to represent impacts.

A number of scenarios were tested based on modelling data generated within the department. Table 24 shows the predicted increase in TN based on intensification of dairy farming (increased land or stock). For this scenario, the current SWWA-FARWH scores would move from 0.6 (‘slightly modified’) to 0.4 (‘moderately modified’ – the most severe category possible for this sub-index) for the associated catchment, which would appear to show a reasonable response in terms of impact.

Table 24 Results from dairy intensification scenarios on the Scott River, south coast of Western Australia (DoW 2009a)

Scenario	Current equilibrium TN mg/L	Modelled TN mg/L
Double stock	1.8	3.7
Double # dairies	1.8	2.3

The predicted nitrogen increases in the Swan-Canning area around Perth have also been modelled (Kelsey et al. 2010) based on forecast levels of urban development (Table 25). This table predicts a significant increase in nitrogen concentration based on proposed development.

Table 25 Average annual median total nitrogen concentrations following urban development proposed in the Metropolitan region planning scheme (subset of larger table in Kelsey et al. 2010)

Catchment	# new properties	Current TN mg/L	Modelled TN mg/L
Henley Brook	6063	1.2	2.07
Lower Canning	5596	1.8	2.07
Belmont Central	888	0.8	1.04
Blackadder	3437	0.8	1.57
Upper Swan	6993	1.2	3.07

In respect to the SWWA-FARWH scoring protocols, changes in Blackadder (0.8 to 1.57 mg/L) would change the site from 'largely unmodified' to 'slightly modified', and in Henley Brook (1.2 to 2.87 mg/L) from 'largely unmodified' to 'moderately modified'. Therefore, the FARWH scores will reflect urban pressure through the *Water Quality index*.

Sub-index scores

The final scores for the *total nitrogen sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 38.

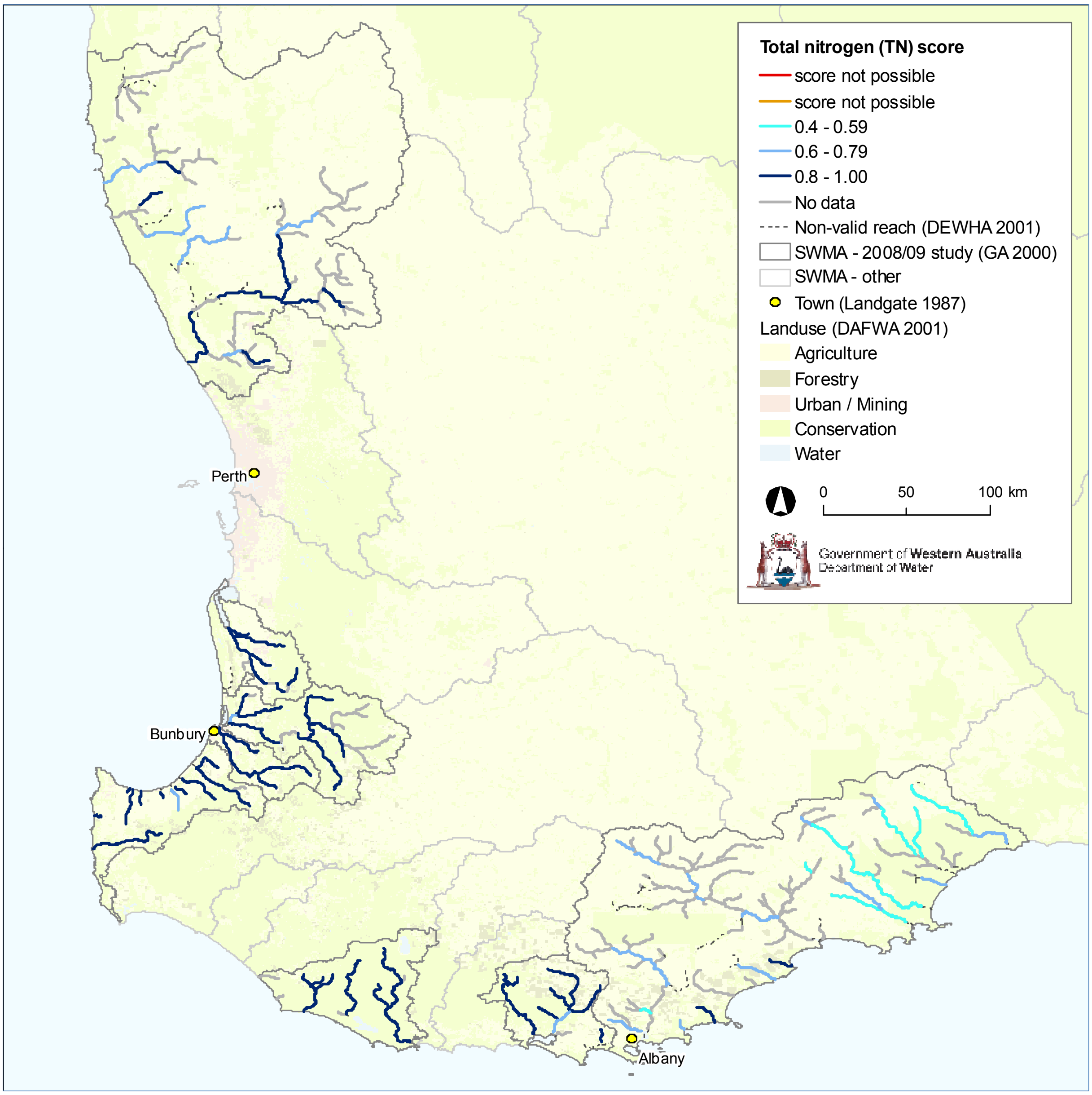


Figure 38 Total nitrogen sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

All possible SWWA-FARWH scores across the impact scale for TN were present within SWWA (based on scoring protocols, scores less than 0.4 are not possible). A general trend is apparent across SWWA, with nitrogen concentrations increasing in low-rainfall non-permanent river systems in the north (Moore-Hill Rivers SWMA) and east (Albany Coast SWMA). These SWMAs are dominated by extensive agriculture, with significant clearing of riparian zones and, in many cases, unimpeded access for livestock. Agricultural areas in the south-west corner of SWWA (which have lower nitrogen concentrations) have higher rainfall and typically more intact streamside vegetation.

As such, the *total nitrogen sub-index* appears to correlate well with expectations based on clearing, land use and hydrology.

Power analysis

Following power analysis it would appear the current sampling effort is reasonable, accounting for a 20% change in the mean or better. For some SWMAs sampling could be reduced, such as in Harvey River and Preston River (which showed little variability throughout the SWMA) and to a lesser extent in Albany Coast, Collie River and Moore-Hill Rivers. As time is not a limiting factor in terms of collection of data given that existing programs are in place to do this (piggybacking), the decision to reduce sampling effort is primarily a function of associated laboratory costs.

A table and graph depicting the results for the power analysis can be found in Appendix C.

Data verification and quality control

Entry of laboratory-analysed data was conducted by the National Measurement Institute (NMI) laboratory and WIN staff. As such, entry of data for TN, TP and turbidity (and supplementary parameters) followed strict data verification procedures for both groups.

All data underwent outlier analysis and none were found.

Further, to evaluate correlation all data collected were compared against long-term seasonally adjusted data held in the WIN database. This was to ensure that field data were within typical variability for each reach. The field data points generally fell within reach variability, however only 26 of 157 WIN sites (that had TN, TP or turbidity data collected during spring of either 2008 or 2009) were on the same reach as those tested in the field, and only five of these were exactly the same site; therefore assessments are insufficient to draw any firm conclusions.

Quality assurance and control measures are part of the standard practice for water quality measurements within the Department of Water, including regular analysis of both replicates and blanks – described in full in the inception report (van Looij & Storer 2009b). Quality assurance and control is also conducted by the NMI.

Frequency of assessment

In its current form (using field data), the *total nitrogen sub-index* is relevant for reassessment whenever new field data are collected, using comparisons against condition bands.

As water quality data can help with inferring causes of biological change, they should be collected in the field whenever new data is collected for the Aquatic Biota theme (also a required variable for AUSRIVAS macroinvertebrate sampling).

Water quality data alone are insufficient to define river health, therefore it is meaningless to collect them as part of a stand-alone, once-off sample (i.e. as per the general FARWH field sampling program of annually in spring). Such data can be useful if collected as part of a regular (e.g. every fortnight) and long-term (e.g. at least over five years) monitoring program, however this is beyond the scope of the FARWH.

Limitations

Collection of samples requiring laboratory analysis has three main limitations:

1 Costs associated with holding samples (refrigeration)

2 Logistical challenges associated with the need to return samples to the laboratory within specific holding times (versus the need to sample in remote locations and for extended continuous periods)

3 Laboratory analysis costs.

Water quality data analysed using mobile equipment are limited by the equipment's initial cost and any ongoing maintenance needs. In addition, field equipment to analyse TN/TP is less accurate than laboratory analysis and is time consuming.

All water quality data used for the SWWA-FARWH are limited by the inherent errors of single time point-sampling and can therefore be influenced by natural variations in concentrations. Further, pulses are unlikely to be sampled given their short duration.

Finally, the current scoring methods for nitrogen (and phosphorus, see below) do not take into account whether nutrients are limiting. This is a recommendation for future investigation, where weighting could be employed for limiting elements.

Sub-index: total phosphorus

Information relating to data sources, data collection methods, data coverage and modelling options is unchanged as was reported for the total nitrogen sub-index. *Refer to that review for a more detailed description than has been provided in the following section.*

In SWWA systems phosphorus concentrations have not been recorded at a level considered directly toxic to aquatic biota. However, due to the effect of nutrient releases from extensive agriculture (among other land uses) in systems that have evolved in nutrient-poor environments, the subsequent impacts of nutrients (e.g. due to phytoplankton proliferation) can be significant. As such, phosphorus is an important inclusion in a SWWA river health assessment.

Scoring method and reference condition

The approach taken to determine reference condition for the *total phosphorus sub-index* scores was the same as that used for the *total nitrogen sub-index*. The resulting categories and scores are provided in Table 26.

Table 26 Total phosphorus concentrations, categories and scores

TP concentration (mg/L)	TP category	FARWH score
< 0.02	low	1
0.02 – 0.08	moderate	0.8
> 0.08 – 0.2	high	0.6
> 0.2	very high	0.4

Sensitivity analysis

The approach to sensitivity analysis for the *total phosphorus sub-index* was the same as that used for the *total nitrogen sub-index*.

In terms of the relationship between phosphorus levels and land uses, Figure 39 provides a reasonable overview of the ability of scoring bands to represent impacts.

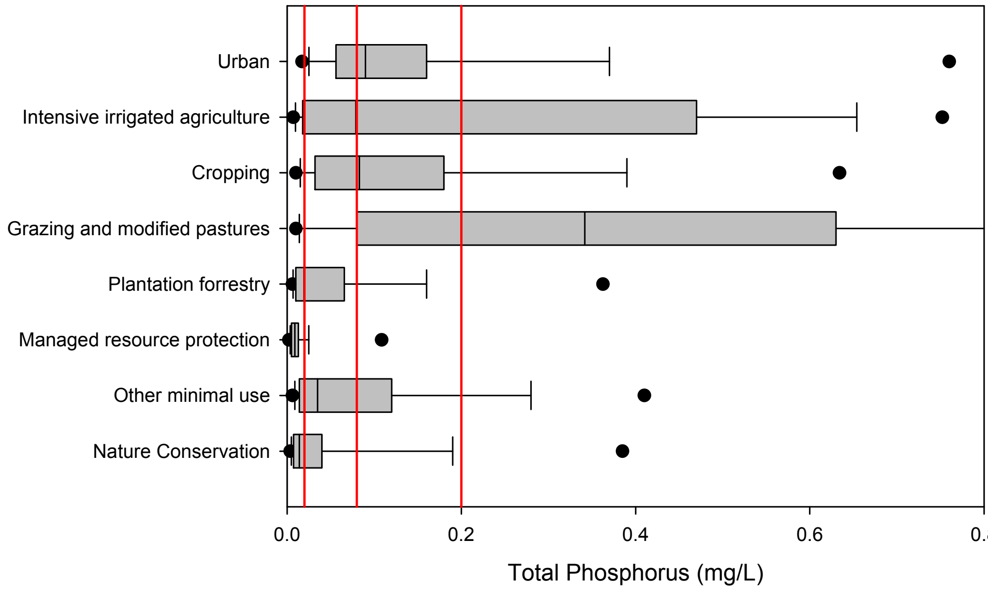


Figure 39 Comparison of phosphorus concentrations to land uses for SWMAs assessed through the SWWA-FARWH trials (red lines indicate scoring bands for SWWA-FARWH; central point is the median, box represents the 25th to 75th percentiles and whiskers the 10th and 90th percentiles)

A positive correlation between total phosphorus (TP) and perceived impacts from land use is apparent, which supports the relevance of this sub-indicator to reflect catchment condition.

Further, analysis of the sensitivity in scoring bands against urban development was assessed using data generated from nutrient models prepared by the Department of Water (Kelsey et al. 2010). These models examined predicted increases in phosphorus if urban development was completed in those areas currently zoned as ‘future urban’ within catchments of the Swan and Canning rivers. Changes in TP concentrations were reflected by FARWH scores; for instance, a change of 0.15 to 0.23 mg/L of TP in the Saint Leonards catchment results in a move from the ‘slightly modified’ to the ‘moderately modified’ band (equating to 2600 new residences) (see Table 27).

Table 27 Average annual median total phosphorus concentrations following urban development proposed in the Metropolitan region planning scheme (subset of larger table in Kelsey et al. 2010)

Catchment	# of new residences	Current TP mg/L	Modelled TP mg/L
Henley Brook	6063	0.31	0.65
Lower Canning	5596	0.17	0.21
Belmont Central	888	0.07	0.08
Blackadder	3437	0.04	0.05
Saint Leonards	2600	0.15	0.23
Upper Swan	6993	0.07	0.08

Sub-index scores

The final scores for the *total phosphorus sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 40.

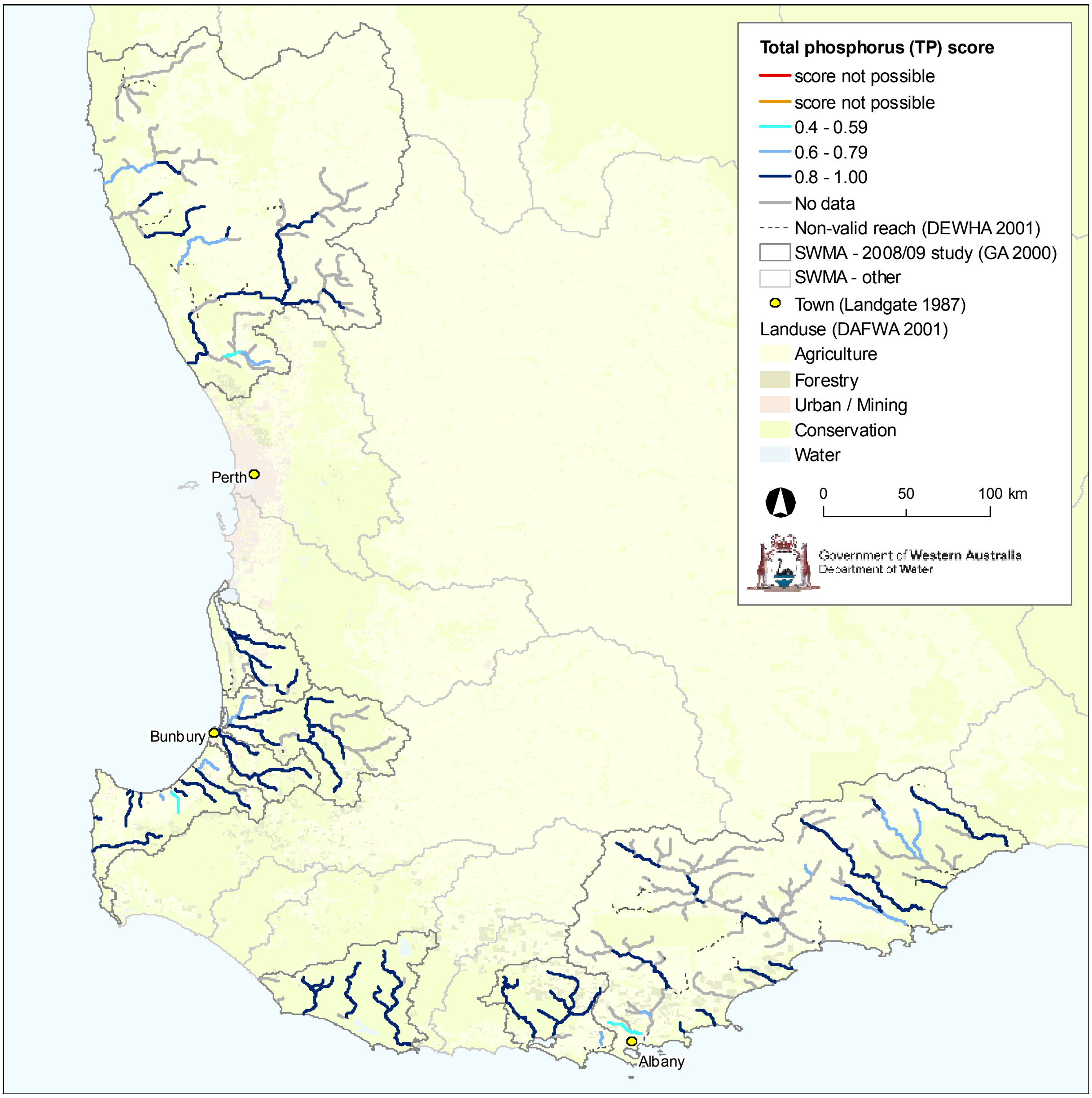


Figure 40 Total phosphorus sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

TP concentrations were relatively low across SWWA ('largely unmodified' band), based on the categories assigned by the SWWA-FARWH. There were some localised systems with elevated phosphorus concentrations, falling into the 'moderately modified' band. It is important to note that reaches scoring in the 'moderately modified' category are considered to have very high TP concentrations based on the Department of Water's classification system (DoW 2004). The 'substantially' and 'severely modified' condition bands do not exist for this sub-index.

As the *total phosphorus sub-index* showed differentiation across SWWA – with no obvious correlation to natural features – it would appear it is responding to localised impacts, and is thus worthy of remaining in the SWWA-FARWH.

Power analysis

Adequate power in the current sampling effort is supported, with around 20% of variation explained with the number of samples collected. If increased efficiency was required the effort could be reduced in some SWMAs; for example, almost 50% fewer sites could be sampled in Albany Coast. Note: in some SWMAs, such as Busselton Coast, the required number of reaches to describe even 20% change is not possible given the number of existing reaches; therefore all reaches should be sampled.

A table and graph depicting the results for the power analysis can be found in Appendix C.

Data verification and quality control

The approach to data verification and quality control for the *total phosphorus sub-index* was the same as that used for the *total nitrogen sub-index*.

Frequency of assessment and limitations

The potential frequency of reassessment/scoring (based on generation of new data) and indicator limitations are the same as those for the *total nitrogen sub-index*, see associated review.

Sub-index: turbidity

Turbidity, whether biotic or abiotic, provides an important link with primary productivity and community dynamics (e.g. predator/prey interactions) through its influence on light penetration. High levels of turbidity have the potential to smother benthic organisms and habitat, affect fish due to mechanical and abrasive effects on gills (reducing oxygen uptake) and alter the prey/food selection of aquatic biota due to impacts on cost/benefit ratios due to increased searching in poor visibility, and altered water temperature (Storer 2005). The additional impacts often associated with unnaturally high bioturbidity (algal blooms) are assessed within other indicators (e.g. dissolved oxygen). Therefore, distinction between the turbidity types is not required here.

The *turbidity sub-index* was assessed using laboratory-analysed spot measurements. This limited the number of reaches able to be assigned a turbidity score because many reaches were not sampled. At present this is the only option for turbidity assessment given that no suitable modelling approaches are available, and WIN data are not spatially and temporally sufficient. SedNet was assessed as a potential option for modelling but was not supported (see review at the start of this section).

Scoring method and reference condition

The approach taken to develop the *turbidity sub-index* scores was the same as the *total nitrogen* and *total phosphorus* sub-indices. The resulting categories and scores are in Table 28. Note: a zero score was not assigned as it was felt this was not relevant to turbidity. Even at very high turbidity levels a system will continue to have ecological value and cannot be defined as 100% departure from reference.

Table 28 Turbidity levels, categories and scores

Turbidity (NTU)	Turbidity category	FARWH score
< 5	Low	1
5 – 10	Moderate	0.8
> 10 – 25	High	0.6
> 25	very high	0.4

Sensitivity analysis

The methods and results for the *turbidity sub-index* sensitivity analysis were the same as those employed for the *total nitrogen sub-index*, see associated review.

Turbidity levels were assessed against land use to elucidate the sensitivity of scoring bands versus perceived impacts (Figure 41). The relationship supported the scoring bands.

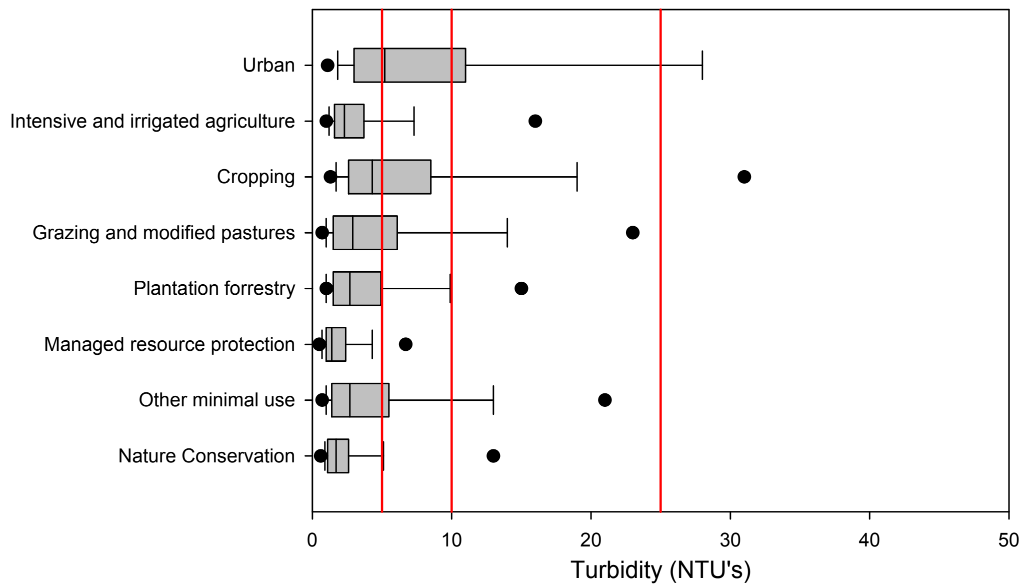


Figure 41 Turbidity levels with corresponding SWWA land uses (red lines indicate scoring bands for SWWA-FARWH; central point is the median, box represents the 25th to 75th percentiles and whiskers the 10th and 90th percentiles)

Sub-index scores

The final scores for the *turbidity sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 42.

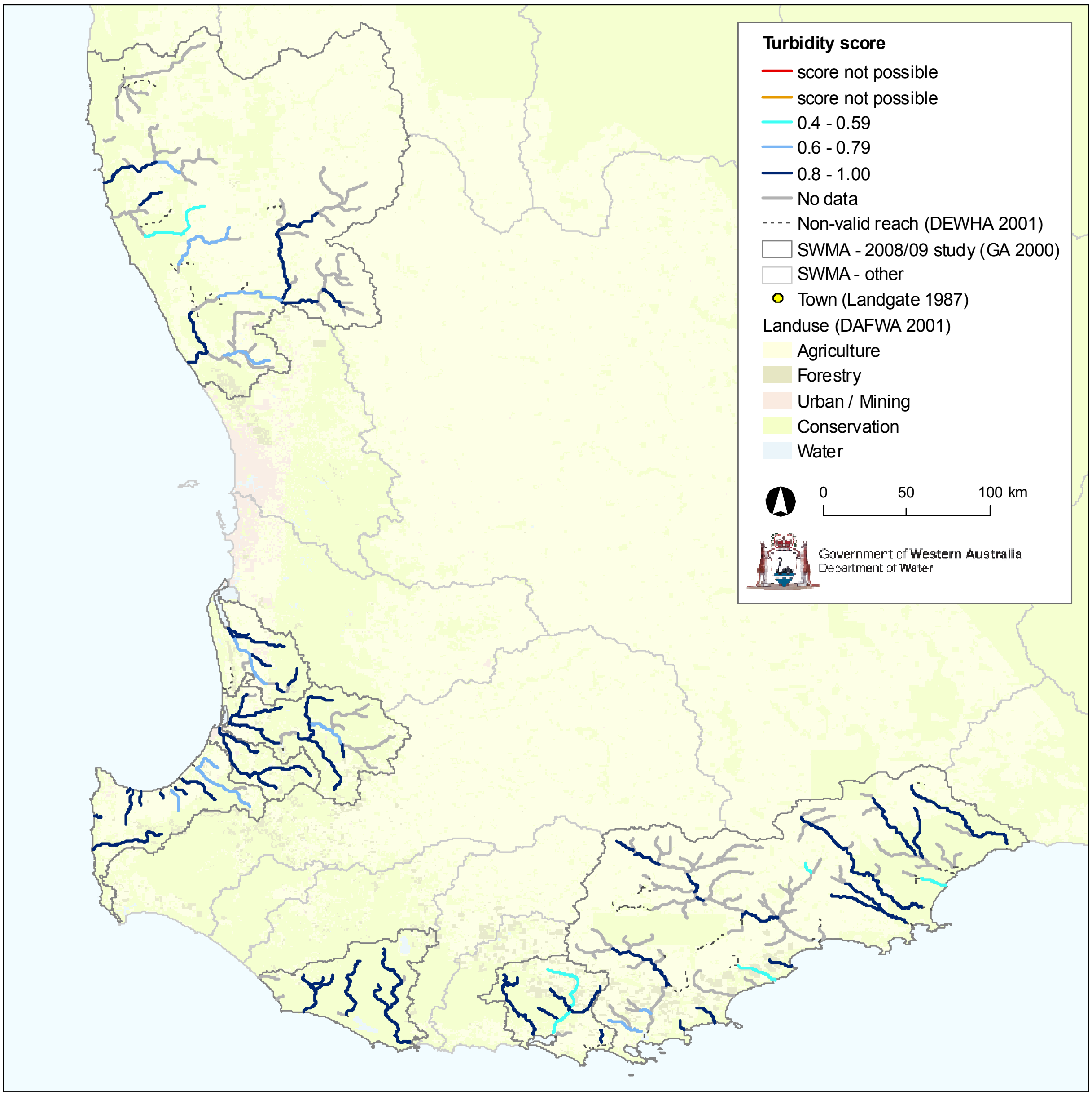


Figure 42 Turbidity sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Turbidity was elevated in a number of areas, although a regional pattern was not apparent. As such, turbidity did not appear to be related to natural features. While turbidity did not present as a serious issue for SWWA (most reaches scoring as ‘slightly modified’ or ‘largely unmodified’), the scores showed sensitivity to something other than natural features, which supports the inclusion of turbidity in future. Note: there was no correlation with generally associated impacts; for example, erosion or loss of fringing zone, and as such further investigations into causes are required.

Power analysis

High variability, especially for the SWMAs assessed in 2009, suggests that all reaches should be assessed. Note: the use of logged data in future – to reduce variability due to natural diurnal patterns – may reduce the required sampling effort.

A table and graph depicting the power analysis results can be found in Appendix C.

Data verification and quality control

The approach to data verification and quality control for the *turbidity sub-index* was the same as that used for the *total nitrogen sub-index*.

Frequency of assessment and limitations

The potential frequency of scoring (based on generation of new data) and limitations of the *turbidity sub-index* are the same as those of the *total nitrogen sub-index*, see associated review.

For the SWWA-FARWH trials turbidity was measured by laboratory analysis of water samples collected in the field. After the successful trialling of newly purchased water quality loggers, in future turbidity will be logged with dissolved oxygen, temperature, electrical conductivity and pH (see review of trials in the theme summary at the end of this section). In addition, because turbidity is a required variable for the AUSRIVAS macroinvertebrate model, water samples for turbidity will continue to be collected in the field to confirm the accuracy of logged data and in case of equipment failure.

Sub-index: salinity

Salinity is well-supported as an indicator of river health: it is easy to measure (low cost, accurate and rapid) and is a direct response measure of land use. Salinity can affect aquatic biota directly through specific tolerances (particularly due to effects on osmoregulation) and indirectly via the relationship with concentrations of other parameters (changing chemical equilibria and solubility of some minerals due to altered portions of anions and cations). Further, salinity can present a physical barrier to aquatic biota (Storer & Norton, in press) and also to movement of oxygen from surface waters to benthos (Nielsen et al. 2003), with obvious secondary ramifications.

Scoring method and reference condition

There is no agreed approach to developing scoring protocols for salinity in the FARWH documents. The issue of limited reference sites for SWWA has previously been discussed. An extensive review of the literature to determine historical conditions found conflicting information, with some reports suggesting that all or parts of some rivers in SWWA were naturally brackish or salty (Hargraves 1863; Bleazby 1917; Bennett & McPherson 1983; Schofield et al. 1988) and others that all rivers were once fresh (Mayer et al. 2005). The evidence does seem to suggest that rapid salinisation occurred after European disturbance as a result of rising groundwater levels due to extensive clearing (Schofield et al. 1988). For example, Bleazby (1917) noted rising stream salinity in areas where trees had been cleared, whereas in adjacent vegetated catchments salinity remained low.

Mayer et al. (2005) suggest that forested catchments may make appropriate reference sites for salinity. They define forested catchments as those with less than 4% of their native vegetation cleared. Most of the SWWA catchments fitting this description are in the high-rainfall zone (greater than 900 mm of rainfall annually) and are thus not necessarily good reference sites for low-rainfall areas. However, the evidence seems to suggest that streams in forested catchments in lower-rainfall areas were also once fresh. Both the Canning and Mitchell rivers, for example, lie in areas of less than 900 mm annual rainfall and are fresh (Mayer et al. 2005).

Due to the conflicting evidence it is difficult to determine what the reference condition for salinity would be. Certainly most systems would have been less salty than they are now, but whether they would be naturally brackish or totally fresh is not possible to determine.

Ecosystem tolerance to salinity was then investigated and is summarised in Table 29. Information is based on Australian examples only.

Table 29 Summary of salinity tolerances in the literature

Salinity levels (mg/L TDS)	**Reported tolerance levels for aquatic species**	**Reference**
62 to 156	Recommended trigger value for upland and lowland rivers in SWWA.	ANZECC & ARMCANZ 2000 (trigger values)
800	Macroinvertebrates: adverse effects for the most sensitive species starts to occur.	Bailey & James 2000
1000	Macroinvertebrates: adverse effects (e.g. osmoregulatory function starting to fail). Insects are usually quite tolerant, however stoneflies, mayflies and caddisflies are more sensitive.	Hart et al. 1991, Hart et al. 1989
> 1000	Direct adverse effects become apparent in Australian river and wetland ecosystems. Below this salinity freshwater ecosystems are subject to little stress.	Mayer et al. 2005, Hart et al. 1991, Nielsen et al. 2003
1000–2000	Submerged macrophytes: sensitivity and some lethal effects (e.g. a decline in growth and suppressed reproduction) (Victorian study).	Hart et al. 1991, Hart et al. 1989, James & Hart 1993
2000	Macroinvertebrates: lethal effects (Victorian study).	Bacher & Garnham 1992
< 2000	Microinvertebrates: lethal effects (NSW wetlands).	Nielsen et al. 2003
3000	Riparian vegetation, e.g. adverse effects for species such as *Eucalyptus, Melaleuca* and *Casuarina* (e.g. seed germination decreases).	Hart et al. 1991, Hart et al. 1989
> 3000	Species reduction in freshwater algae, plants and macroinvertebrates.	Hart et al. 1991, Hart et al. 1989

Salinity levels (mg/L TDS)	Reported tolerance levels for aquatic species	Reference
4000	Freshwater aquatic plants: upper tolerance level.	Nielsen et al. 2003, Brock 1981
5000	Gastropods – majority only occur at salinities below this concentration. Oligochaeta – majority only occurred below this concentration.	Rutherford & Kefford 2005*
8800	Adult fish: most tolerate to this level.	James et al. 2003
10 000	Freshwater fish: tolerate salinity to this concentration. Larval fish are more sensitive than adults and eggs more tolerant than larvae: e.g. some juvenile fish in the Murray-Darling Basin only tolerate a maximum 5000 mg/L. Examination of 491 freshwater WA Wheatbelt invertebrates showed that 76% of freshwater species were collected at salinities below this level.	Hart et al. 1991, Hart et al. 1989, James et al. 2003 Pinder et al. 2005: unpublished data in Halse et al. 2003
5000–10 000	Trichoptera: majority only occurred below this concentration	Rutherford & Kefford 2005*
7000–13 000	General tolerance limits for freshwater fish species (Southern Victoria and Murray-Darling River System).	James et al. 2003, Bacher & Garnham 1992
10 000	Few Dipteran species found above this level (WA Wheatbelt). Diversity of macroinvertebrates in saline lakes decreased rapidly above this level (Western Victoria). Waterbirds – species richness increased below this level (WA Wheatbelt)	Pinder et al. 2005, Williams et al. 1990
~15 000	Acute tolerance level for western minnows and pygmy perch from Blackwood River (WA). **	Beatty et al. 2008
15 000	Odonata – majority only occurred below this concentration.	Rutherford & Kefford 2005*
15 300	Most WA species of waterbirds are found below this level.	Goodsell 1990

**Rutherford & Kefford (2005) re-examined a large field monitoring dataset from Victoria and South Australia that provided estimations on the maximum field distribution of macroinvertebrates. Data given may not include all species from that order.*

*** New data (collected immediately after the FARWH trials) from the two sites on the Avon River (Western Australia) in June 2010 found western minnows in salinities up to ~25 000 mg/L TDS. The FARWH sampling also collected one individual western minnow in a river in the Albany Coast SWMA with 28 000 mg/L TDS, however they were mostly found below 20 000 mg/L TDS.*

Due to limited specific studies on SWWA species, specific tolerance limits cannot be confirmed. It should also be noted that for SWWA, an area of possible historic salinisation, many macroinvertebrate families could occur in rivers of higher salinities than presented above (typically eastern Australian studies) – with evidence of macroinvertebrates adapting to increased salinity (Penn 1999; Kay et al. 2001).

With this in mind, the biological evidence was deemed sufficiently consistent and supportive of local knowledge (regional Department of Water staff) such that this method was supported as the benchmark for scoring the *salinity sub-index* using modelled and measured data as described below.

While spot measurements of electrical conductivity were taken in the field (for interpretation across themes), an existing dataset combining measured and modelled salinity data were used to assign scores. This was due to superior coverage and data being generated at reach level rather than at individual sites. This dataset was developed by the Salinity and Land Use Management Branch of the Department of Water through a large-scale project classifying streams by salinity in SWWA (Mayer et al. 2005). This project used data from a number of sources, with a preference for gauging stations with long-term continuous datasets (a minimum of 10 years). The REG6 model (since updated to the REG75 model) was used to estimate salinity for those streams where there were no available salinity data. The average flow-weighted salinity for the period between 1985 and 2002 was presented.

Reaches used in the salinity mapping exercise described above were generally much shorter than those used for the FARWH, resulting in numerous classifications for some FARWH reaches (up to 50 per reach). In all cases there was one classification that was more common than the others, and as such the mode of the classification categories was used as the FARWH reach classification.

The associated scoring bands developed from the dataset described above were designed using the precautionary approach, on the basis that we are attempting to protect sensitive species (see Table 30). The salinity categories listed in Table 30 were those used by the salinity dataset (only these categories were provided).

Table 30 Salinity bandings, categories and scores

Salinity (mg/L TDS)	Category (from Mayer et al. 2005)	FARWH score	Species tolerances
< 500	Fresh	1	Low-level impact to macroinvertebrates
500–1000	Marginal	1	Low impact to macrophytes towards upper level
1000–1500	Marginal-brackish	0.9	Sensitive macroinvertebrates affected
1500–3000	High-brackish	0.8	Effects to fringing vegetation. Lethal effects to some species of micro/macroinvertebrates
3000–7000	Low-saline	0.5	Loss of species (algae, macrophytes, sensitive fish, and micro/macroinvertebrates e.g. oligochaetes/gastropods).
7000–14 000	Mid-saline	0.2	Loss of less sensitive fish species
14 000–35 000	High-saline	0	Marron (particularly insensitive to salinity) are lost around 17 000 mg/L
> 35 000	Brine (seawater)	0	

The defined bands above are purposely coarse, as finer-scale bands are both difficult to determine and would not be encompassing of all aquatic biota (as tolerances differ greatly with both species and life stage (e.g. Halse et al. 2003)).

Sensitivity analysis: sub-index scores

The final scores for the *salinity sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 43. Note: salinity scores are available for most reaches as these were calculated using an existing dataset that comprised both measured and modelled data.

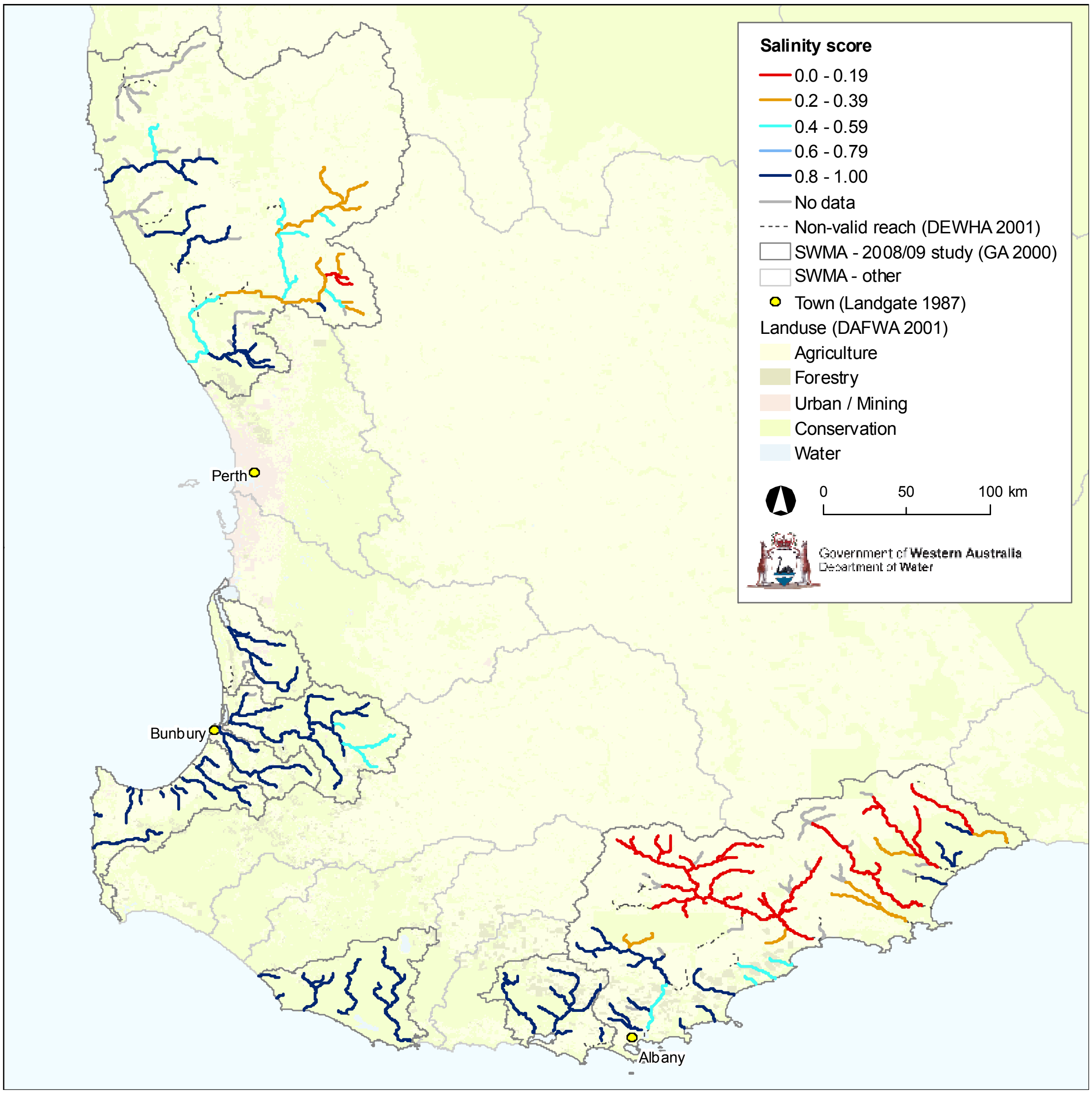


Figure 43 Salinity sub-index scores for reaches in SWMAs assessed in spring 2008 and 2009 within the SWWA-FARWH trials

Of all the *Water Quality index* sub-indices, the *salinity sub-index* scores exhibited the most significant impacts, with many reaches presenting as ‘severely modified’ (primarily in the Albany Coast SWMA) and a number as 'substantially modified' (including much of the Moore River in the Moore-Hill Rivers SWMA). Salinity effects are correlated with the lower-rainfall areas of SWWA, as well as areas dominated by seasonal, intermittent and ephemeral systems. These areas also have widespread agriculture and are often extensively cleared (including much of the riparian vegetation).

Note: there is evidence that a number of these systems, primarily in the eastern third of the Albany Coast SWMA, may have been naturally saline. However, there is also evidence against this theory and a general understanding that salinity would have significantly increased during the past 100 years regardless of the original state. Based on the experience of FARWH field officers and Department of Water regional staff, these suggested impacts are a reasonable assessment – and support that significant restoration work is required in these areas.

Power analysis

As this sub-index was calculated for almost all reaches a power analysis was not conducted.

Data verification and quality control

Before salinity data from the salinity dataset were used, data verification was conducted by comparing the data against point data collected during the 2008 FARWH field trials, as well as other available data from WIN. In all cases a good relationship was found. Data verification was also conducted in creating the salinity dataset, see summary in Mayer et al. (2005).

Frequency of assessment

As salinity has been shown to change relatively rapidly, reassessment/scoring should be done after generation of any new data. The data from the salinity dataset were generated from average flow-weighted data (measured and modelled) for the period 1985 to 2002; as such, if a comparative assessment were to be conducted, this process would need to be recreated with new information. At this stage it is unknown whether this data will be updated.

Assessments could be made based on newly generated field data and the scoring bands provided here. However, a limitation is that salinity is usually obtained from spot samples, which can misrepresent conditions given potential variability. To overcome this, salinity could be logged for weeks or months (along with pH, dissolved oxygen, temperature and turbidity).

As per TN, TP and turbidity it is recommended that salinity (i.e. electrical conductivity) be collected whenever data is collected for the Aquatic Biota theme.

Limitations

Because the reach definition used in the salinity dataset differs to that used for the FARWH, 100% coverage of all the FARWH reaches is not achieved. There was 81%

coverage of the reaches for Moore-Hill Rivers SWMA, 85% for Albany Coast SWMA, 95% for Collie River SWMA and 100% for Denmark River, Shannon River, Busselton Coast, Preston River and Harvey River SWMAs. Additionally, data are not current (1985–2002 mean flow-weighted salinity used). Note: the decision to use this data was based on a wider spatial coverage being deemed more beneficial than using current FARWH or WIN data.

Sub-index: diel dissolved oxygen

Dissolved oxygen affects aquatic biota directly through oxygen availability for respiration, and indirectly through biochemical processes (Bott 2006; ANZECC & ARMCANZ 2000). Oxygen levels outside of tolerance ranges can have both acute (e.g. mortality) and chronic (e.g. growth) effects, depending on extent and duration. Low oxygen levels can also increase the release of nutrients and some metals from sediments, in turn influencing stream health.

Note: oxygen is dependent on temperature, salinity, biological activity and rate of transfer from the atmosphere, therefore data interpretation requires an understanding of the behaviour of these elements within an ecosystem.

Scoring method and reference condition

As there was a lack of ‘pristine’ or minimally disturbed reference sites with which to determine scoring, the literature was used to determine suitable bandings. A lower cut-off (zero score) of 2 mg/L was selected because in a number of documents this is given as the limit below which aquatic fauna and ecosystem processes are severely affected, with both fish and macroinvertebrate mortality common (ANZECC & ARMCANZ 2000; Davies 1995; Davies et al. 2004; Waterwatch Australia Steering Committee 2002).

In determining the upper limit, or the minimum level of oxygen required before any risk of adverse effects is suggested, the following sources were considered. The ANZECC guidelines recommend a default trigger value of 80% saturation for lowland rivers and 90% saturation for upland rivers, which equates to approximately 6 mg/L (ANZECC & ARMCANZ 2000). Hunt & Christiansen (2000) state that concentrations below 5 mg/L will start to have an impact on fish, with most species actively moving away to more oxygen-rich waters. They further define ‘clean’ water as having a dissolved oxygen concentration greater than 6.5 mg/L (Hunt & Christiansen 2000). The Waterwatch Australia Steering Committee (2002) states that a minimum of 5 to 6 mg/L is required for fish growth and activity. An upper limit of 6 mg/L was therefore selected.

Four additional bands between the upper (6 mg/L) and lower (2 mg/L) limits were assigned by an even distribution: 2–3 mg/L, 3–4 mg/L, 4–5 mg/L and 5–6 mg/L (creating six bands in total, see Table 31).

Note: the selection of bands is particularly challenging because the oxygen tolerances of aquatic biota vary considerably depending on species (especially between warm- and cold-water species), life stages and with different life processes (feeding, growth, reproduction) (ANZECC & ARMCANZ 2000); as such banding was kept relatively coarse.

As no appropriate models were available to determine diel dissolved oxygen concentrations, field-based data were measured. Twenty-four-hour dissolved oxygen readings were collected at 10-minute intervals at each site sampled using the open water (whole stream) method. For a detailed data collection method, see the approach used for the River Health Assessment Scheme (RHAS) (Galvin et al. 2009).

Scoring dissolved oxygen involved determining the proportion of time it was recorded in each of the bands over the 24-hour monitoring period, with each band being assigned a weighting.

Table 31 Dissolved oxygen concentrations, bands and weighting scores.

Band	DO concentration (mg/L)	Weighting score
Band 1 (B_1)	> 6	1
Band 2 (B_2)	> 5 to 6	0.8
Band 3 (B_3)	> 4 to 5	0.6
Band 4 (B_4)	> 3 to 4	0.4
Band 5 (B_5)	2 to 3	0.2
Band 6 (B_6)	< 2	0

If more than 25% of the 24-hour data were below 2 mg/L the site was assigned a score of zero. Through comparisons against aquatic biota, sites experiencing oxygen levels above 2 mg/L for more than 75% of the time were shown to support native species, whereas sites with oxygen levels below 2 mg/L more than 25% of the time had no fish or were populated by air-breathing exotic species only. The expectation is that sites that reach less than 2 mg/L for short periods (less than 25% of the time) would have nearby refugia to sustain populations. Outside of this rule, the overall score for sites was calculated using Equation 5 below.

Equation 5 $$DO = (1.0 \times B_1) + (0.8 \times B_2) + (0.6 \times B_3) + (0.4 \times B_4) + (0.2 \times B_5) + (0 \times B_6)$$

Where: DO = the diel dissolved oxygen sub-index score for the site; B_1 = proportion of time spent in band 1; B_2 = proportion of time spent in band 2, and so on.

Other Australian states suggest the use of percentiles to score current data against reference conditions; for example; 75th and 80th percentiles are used in Victoria (ISC) and the Northern Territory (FARWH trials) respectively. Notwithstanding ongoing debates in the literature about the validity of percentiles for ecological studies, this was not investigated because reference sites were not defined for SWWA.

Sensitivity analysis: sub-index scores

The final scores for the *diel dissolved oxygen sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 44.

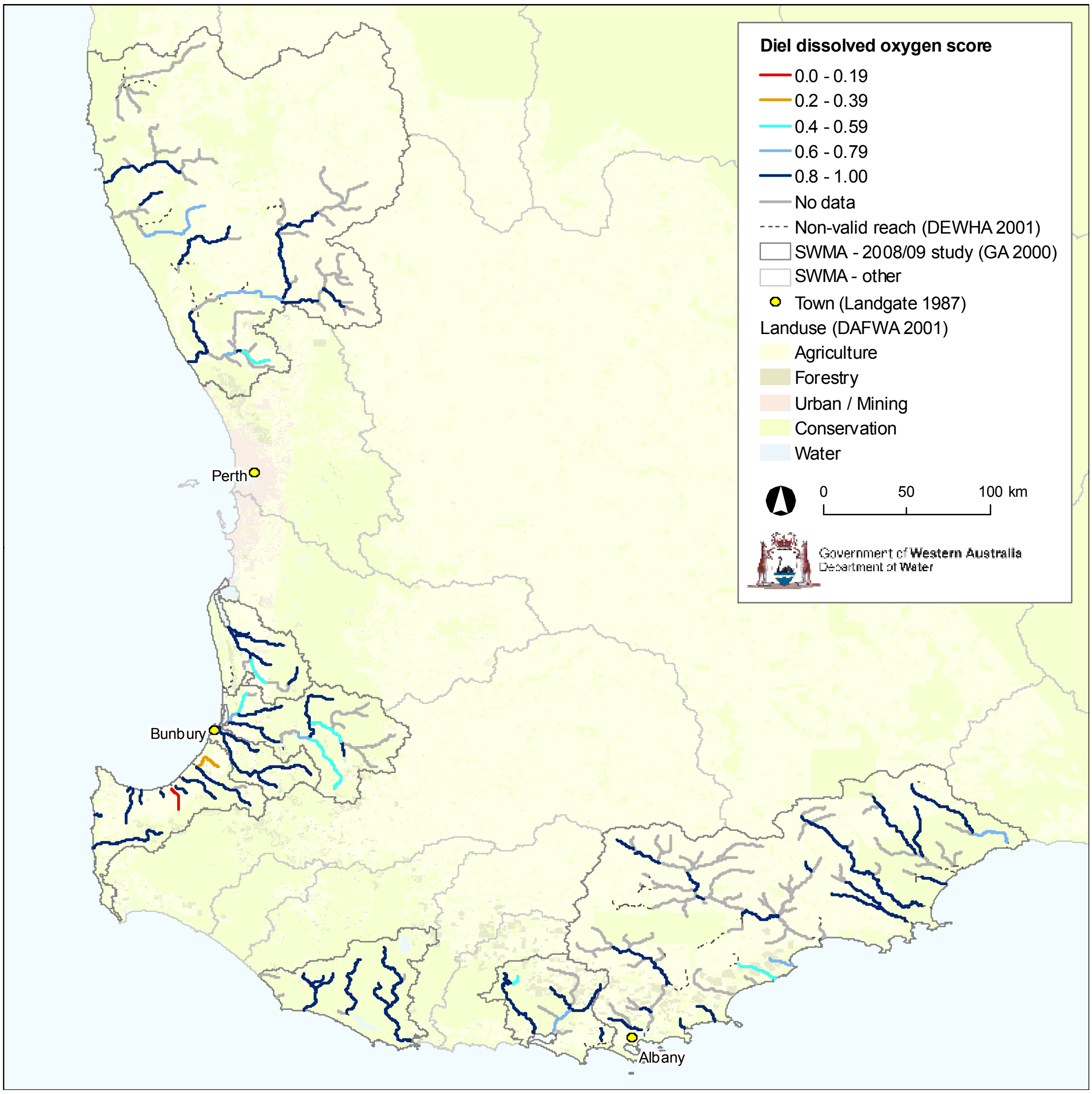


Figure 44 Diel dissolved oxygen sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Diel dissolved oxygen appeared to be within a relatively healthy range across SWWA, with a few localised exceptions. These exceptions were south of Bunbury, where two reaches scored as 'substantially' and 'severely' modified. These results correlated with poor fringing zones and macroinvertebrates, elements of hydrological change scores, and phosphorus and turbidity impacts. Field observations recorded anaerobic-smelling sediments.

The differentiation in dissolved oxygen scores supports ongoing use for the SWWA-FARWH, as it appears to be detecting impacts not associated with natural variability (given that impacted reaches occur within otherwise healthy regions). Further, dissolved oxygen is a good interpretative indicator for aquatic biota.

Power analysis

Power varied depending on the SWMA being assessed, therefore the general rule would be to sample all reaches. However, sites can be reduced for Harvey River, Preston River, Shannon River and Albany Coast SWMAs if required. If assessments are being conducted in conjunction with aquatic biota, then dissolved oxygen is recommended regardless of the power analysis results to inform responses.

A table and graph depicting the power analysis results can be found in Appendix C.

Data accuracy and verification

Field data was verified by comparing the diel dissolved oxygen curve of the two probes deployed and field notes (made if the pump malfunctioned, the probes shifted in the housing or became smothered in debris etc.). If one probe showed an erratic curve (based on best professional judgement) or the data was deemed unsuitable (based on field records), then only data from the other probe was used.

Frequency of assessment

As field data were used for this indicator, assessment frequency is governed by additional sampling. As dissolved oxygen is also necessary for interpreting aquatic biota dynamics, it should be included with any associated sampling.

Limitations

The difficulty in assigning bands to dissolved oxygen stems from the need to capture relevance across a wide range of species and systems – a limitation of a broad-scale assessment. But given this assessment is broad-scale, such a level of scoring is relevant. In future, it may be possible to tailor scoring bands to specific areas based on the communities present, although this would still require more detailed information on tolerance limits for SWWA species.

Collecting field data requires two site visits (separate days for deployment and retrieval of water quality loggers). The initial outlay can be costly, while field set-up is time consuming and the equipment cumbersome. Note: new technology enabling equipment to remain in-system for longer periods (due to battery life and probe quality) has been trialled. This may negate some of these limitations – trials for this equipment are reviewed at the end of this section. However, as the loggers are expensive, deploying enough to achieve good spatial variability is not possible.

Use of current data is somewhat limited by the lack of a typical diel oxygen curve (to fit other potential indicators such as metabolism): this is discussed below.

Potential for use of oxygen data for metabolism indicator

The feasibility of calculating stream metabolic variables (GPP, respiration and P/R) was also investigated as a separate use of the diel dissolved oxygen data. Stream metabolism is a well-accepted stream health indicator at this level of assessment, where linkages between catchment-scale disturbances and stream gross primary productivity and total ecosystem respiration rates during some seasons have been shown (Houser et al. in press, in Mulholland et al. 2005).

The main difficulty with determining stream metabolism using the open-water method is calculating the re-aeration coefficient (rate at which atmospheric oxygen diffuses across the air/water interface). For the SWWA-FARWH, the night-time regression method of Young et al. (2006) and Kosinski (1984) was used to calculate the re-aeration coefficient, as all other methods require in-stream velocity measurements and/or the use of in-field tracer gases and light data, which were not measured.

The open-water metabolism calculation was found to be ineffective for the data collected, with calculations failing at more than 50% of sites (trial done on sites in the Moore-Hill Rivers, Albany Coast and Harvey River SWMAs). This was attributed to many sites not exhibiting the ‘typical’ night/day diurnal pattern (Roger Young pers. comm. 2009), with oxygen levels remaining relatively stable throughout the 24-hour monitoring period. This suggests low productivity, which appears as a natural condition of many SWWA systems. Two loggers were deployed at each site so there is high confidence in the collected data; as such, the lack of typical diurnal patterns is a true reflection of river metabolism, rather than an artefact of human or instrument fault. It was concluded that the current open-water method would not work for many of our systems.

Further, caution is suggested when using stream metabolism as an indicator of catchment-scale disturbance even within small regions. Local factors related to riparian vegetation (e.g. status and density, leaf phenology, quantity and quality of organic inputs), sedimentation and floodplain/channel hydraulics can have large effects on stream metabolism (e.g. availability of light) (Mulholland et al. 2005)

Sub-index: diel temperature

Water temperature has a strong relationship with both the structure and function of streams, influencing primary production, saturation of dissolved gases and metabolic rates of organisms (ANZECC & ARMCANZ 2000; Rutherford et al. 2004; Bott 2006). Thermal stress in aquatic biota has been reported in all life stages, including growth, reproduction, mobility, survival and migration. In addition, temperature is a cue for many related events, such as emergence in macroinvertebrates, reproduction of lotic plants or onset of courtship behaviour and spawning in fish (e.g. Bott 2006). Temperature has also been linked with modification of chemical toxicity (ANZECC & ARMCANZ 2000).

Temperature is a useful inclusion in river health assessment due to its ramifications for biotic health and direct relationship with a number of stressors. For example, a strong correlation exists between increasing temperature and loss of riparian vegetation (Smith et al. 2001). Temperature changes due to loss of riparian vegetation are particularly noticeable in smaller systems (characteristic of the SWWA landscape), with marked increases in both water temperature and range. Davies et al. (2004) reported a 10°C increase in temperature in streams due to riparian clearing and a resultant reduction of oxygen concentration by 2.5 mg/L.

Scoring method and reference condition

While information is abundant on the lethal and sub-lethal effects of temperature on individual species, only limited information is available for SWWA species or whole-of-ecosystem effects. Additionally, many of the studies are laboratory based so it is difficult to know how this translates to actual field conditions.

A lack of suitable minimally-disturbed reference sites in SWWA for developing reference condition also makes it difficult to accurately score temperature effects. Natural temperatures in streams will vary across SWWA; for example, waterways in the Moore-Hill Rivers SWMA are expected to be significantly warmer than those in south coast SWMAs. Water temperature gradients across SWWA are seen across variations in latitude, altitude, vegetation types (e.g. open canopy in the north, east and inland) and rainfall (among others).

As such, in the SWWA-FARWH trials no attempt was made to develop a banding system similar to that used for dissolved oxygen. Instead, the change in temperature over the 24-hour period was trialled, with changes of less than 4°C being considered acceptable and changes greater than 4°C being considered unacceptable. This is the same approach used by the EHMP in Queensland (South East Queensland Healthy Waterways Partnership Office 2009). This value is supported by Cox & Rutherford (2000) who showed that when temperature varied diurnally by ± 5°C, a 50% mortality could be expected. This is calculated as the difference between the 95th and 5th percentiles to reduce the effect of any outliers. Table 32 summarises the scoring.

As there are no appropriate models for determining diel temperature levels, field-based data were used throughout the SWWA-FARWH trials to obtain the diel range. Temperature was logged at 10-minute intervals over 24 hours at each of the sites sampled (from the same probe used to collect oxygen data).

Table 32 Diel temperature sub-index scoring

Diurnal range	FARWH score
< 4 °C	0.8
> 4 °C	0.4

The use of maximum temperatures and other indicators will be discussed at the end of this section.

Sensitivity analysis

While the scoring of this sub-index is currently coarse, the continued collection of data will allow a more robust scoring method to be constructed in the future, where scoring protocols tailored to specific regions should be attempted. Scores for diel temperature ranges were compared against land use and land clearing. The results showed distinct trends, as is highlighted in figures 45 and 46.

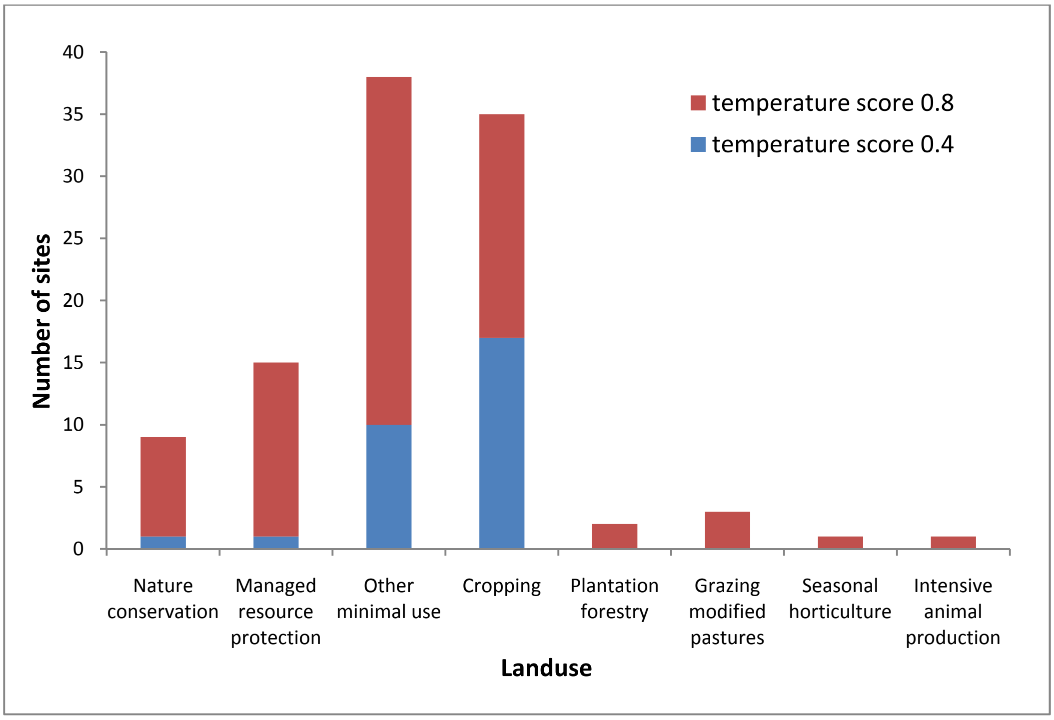


Figure 45 Comparison between diel temperature range scores and land use

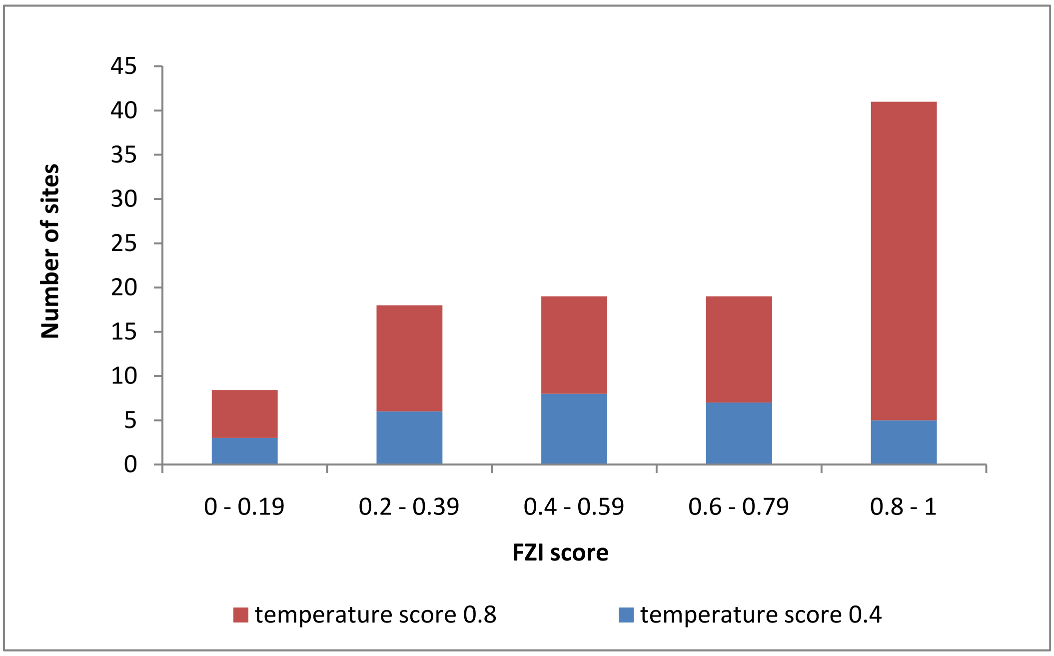


Figure 46 Diel temperature range scores compared with Fringing Zone index score

In Figure 45 it is apparent that sites with ‘good’ temperature ranges (<4 °C, FARWH score = 0.8) are mostly in the lower-impact land use categories. Interestingly, in Figure 46 little relationship between the *diel temperature sub-index* scores and *Fringing Zone index* scores are evident, with the exception of sites falling within the ‘largely unmodified’ category for the *Fringing Zone index*, which are primarily within the good temperature range. A number of explanations for the varied results are possible: in part they could be due to riparian zones being intact in areas that are otherwise cleared. However, near-optimal vegetation primarily returns water temperature in the 'good' zone, which is expected. This suggests that intact vegetation is important for good temperature ranges (as defined by the range designated here), however regardless of clearing, temperature is driven by land use factors, which may suggest a more subcatchment-related effect (note: this includes effects of clearing at the subcatchment scale). The relationship between temperature and land use does suggest there is value in assessing temperature, but diel range alone may be insufficient. Additional sub-indices were trialled and are reviewed towards the end of this sub-index summary.

Sub-index scores

The final scores for the *diel temperature sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 47.

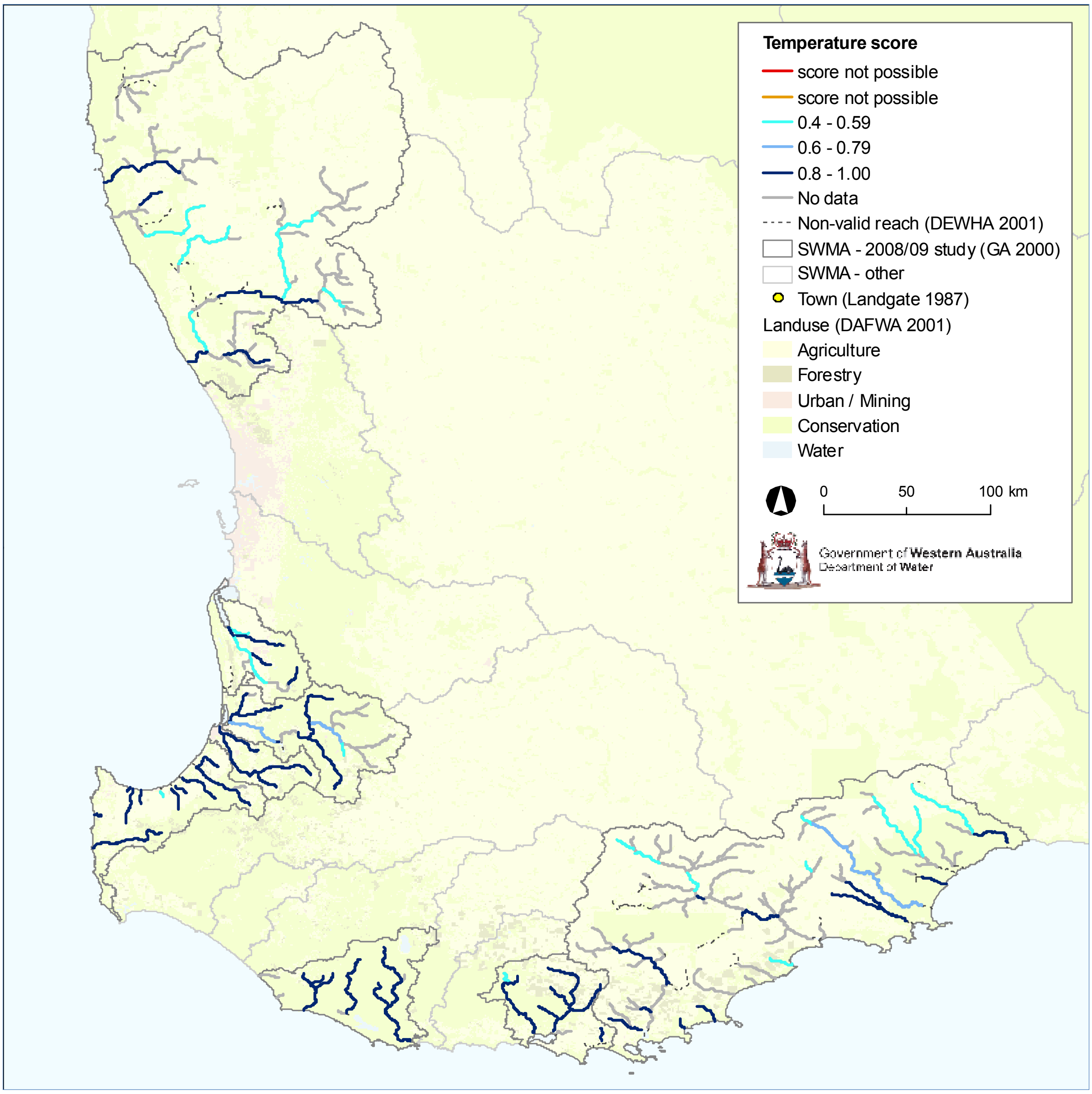


Figure 47 Diel temperature sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Diel temperature provided a relatively coarse indicator of impact, given there were only two possible scores based on range alone. Temperature scores did correlate with reaches in north and east SWWA – tending to return the lower score – which is understandable given systems in these areas are typically shallower (than the south-west corner) and have a tendency to dry over summer. Systems in these areas are also dominated by shrubland (compared with taller forest in the south-west corner) and are thus less influenced by shading. However, in saying this, ranges used to score temperature were based on expectations for all systems in the area and similar temperature problems were observed within other SWMAs. Furthermore, the SWMAs to the north and east are generally more extensively cleared than other systems, including greater impacts to fringing vegetation.

Diel temperature scores correlated well with the expectations of local environmental managers and showed differentiation at a SWMA scale, therefore inclusion in the SWWA-FARWH is supported.

Power analysis

With the exception of Preston River and Shannon River SWMAs, all reaches need to be assessed so that appropriate power is returned.

A table and graph depicting the results of the power analysis can be found in Appendix C.

Data verification and quality control

Temperature data collected in field showed a high degree of accuracy. Less than 1°C difference between replicate probes was seen, and the data relationship over the 24-hour logged period showed little noise.

This highlights the accuracy over 24 hours, but it is difficult to draw any conclusion about the relationship to seasonal variability. In future the new Eureka Manta 2-40 Multiprobe could be used to log temperature over a longer period.

Frequency of assessment

As per the other water quality parameters it is recommended that diel dissolved oxygen be collected whenever data is collected for the Aquatic Biota theme.

Limitations

Current water temperature ranges were not based on Western Australian data. Associated limitations centre on the difficulty in assigning more sensitive scoring bands, which is a function of understanding natural seasonal variability and reference conditions for SWWA systems, including biotic tolerances.

Collecting field data requires two site visits (separate days for deployment and retrieval of water quality loggers). The initial outlay can be costly, while field set-up is time consuming and the equipment cumbersome. Note: new technology enabling equipment to remain in-system for longer periods (due to battery life and probe quality) has been trialled. This may negate some of these limitations – trials for this equipment are reviewed at the end of this section. However, as the loggers are expensive, deploying enough to achieve good spatial variability is not possible.

Other potential temperature indicators

Temperature thresholds were investigated as an alternative or additional sub-index to diel range. Tolerances to maximum temperature were evaluated based on Davies et al. (2004), in which it was suggested that tolerance limits of species being exceeded for more than eight hours was 'intolerable'. This followed reported tolerances of 21°C and 29°C for cold and hot climates respectively. Analysis of field data found that sites from only one SWMA exceeded the eight-hour tolerance levels, with these sites showing no obvious correlation with impact. However, there was a correlation with sampling time, with these sites being sampled in mid-summer (due to sampling logistics it was not possible to sample this SWMA in spring). The maximum being exceeded suggested tolerance levels were more correlated with ambient temperature than impact. Furthermore, sites with an almost complete loss of vegetation and high degree of sedimentation (resulting in reduced stream depth) showed no obvious increase in temperature. As such, this indicator was not pursued.

Future assessment of this indicator is warranted with more data; that is, the tolerance levels require adjustment. The original tolerance limits were assigned based on data from only 14 sites and for only four macroinvertebrate species representing Odonata, Trichoptera and Ephemeroptera.

Water Quality index summary

Integration follows a variation on the methodology recommended in the FARWH documentation (NWC 2007a). The SWWA-FARWH assigned sub-indices as either ‘primary’ (salinity and dissolved oxygen) or ‘secondary’ (TN, TP, turbidity and temperature), with separate weightings applicable. Sub-indices were split based on the impact they were likely to have on stream function. This differentiation was made because extremes of salinity and dissolved oxygen (primary sub-indices) have been shown to exhibit a significant effect on aquatic biota, with mortality a likely end-point. High levels of TN, TP and turbidity (secondary sub-indices) will have an impact on aquatic biota, but the effects will be more chronic and generally non-fatal. Further, increases in nutrient levels are often coupled with an increase in productivity (up to a certain point), which further complicates scoring impact.

Note: although temperature can also be considered a primary sub-index (given that extremes will produce mortality in species), it was not included as such for scoring purposes. This is predominantly due to uncertainty about the temperature levels that would reflect different degrees of system impact. That is, given current data and understanding of ecology, temperature scores were only designed to add to the general story rather than be held up as a stand-alone representation of health. As such, temperature was included as a secondary sub-index.

For integrating the Water Quality sub-indices, the average of the four secondary sub-indices (TN, TP, turbidity and diel temperature range) was calculated. A precautionary approach was then used, where the worst score out of the three elements – two primary sub-indices (salinity and DO) and the average of the secondary sub-indices – was selected as the overall *Water Quality index* score

Equation 6

$$WQI = worst\ score\ of: (average\ of\ 2^{o} sub\ indices) or\ (salinity) or (diel\ DO)$$

Where: WQI = Water Quality index score; average of 2^0 sub-indices is the average of the TN, TP, turbidity and temperature sub-index scores; salinity is the salinity sub-index score; and diel DO is the diel dissolved oxygen sub-index score.

Scenario testing was conducted to assess this integration method. If the reach score was calculated by taking the lowest score of all the sub-indices (with one or all of the secondary indicators scoring 0.4 and the two primary indicators scoring 1) the overall reach score would not change despite the number of secondary indicators that scored 0.4 (see example in Table 33).

If, however, the current integration method is used the score would drop depending on how many secondary indicators received a low score (Table 33). For example, if TN was 0.4 and the other secondary and primary indicators had the highest-possible score the overall reach score would be 0.8 (rather than 0.4). This seems fair because if only one secondary indicator is poor, then it will probably not have a large overall impact on river health.

Table 33 Reach scores under the current scoring integration method and the scenario scoring integration method

TN score (0.4–1)	TP score (0.4–1)	Turb. score (0.4–1)	Temp score (0.4 or 0.8)	Mean of TN, TP turb and temp	Salinity score	DO score	Current scoring method*	Scenario scoring method#
0.40	1.00	1.00	0.80	0.80	1.00	1.00	0.80	0.40
0.40	0.40	1.00	0.80	0.65	1.00	1.00	0.65	0.40
0.40	0.40	0.40	0.80	0.50	1.00	1.00	0.50	0.40
0.40	0.40	0.40	0.40	0.40	1.00	1.00	0.40	0.40

** precautionary approach; # lowest score of all sub-indices*

Aggregation to the SWMA scale follows the methodology recommended in the FARWH documentation (NWC 2007a), where reach scores are aggregated to the SWMA score by calculating the length-weighted average of all the reach scores.

Where more than one site was sampled per reach, the *Water Quality index* score was calculated individually for each site and then the resulting scores averaged to produce one index score per reach.

Water Quality index scores

The final scores for the *Water Quality index* for reaches assessed during the 2008 and 2009 field trials are shown in Figure 48.

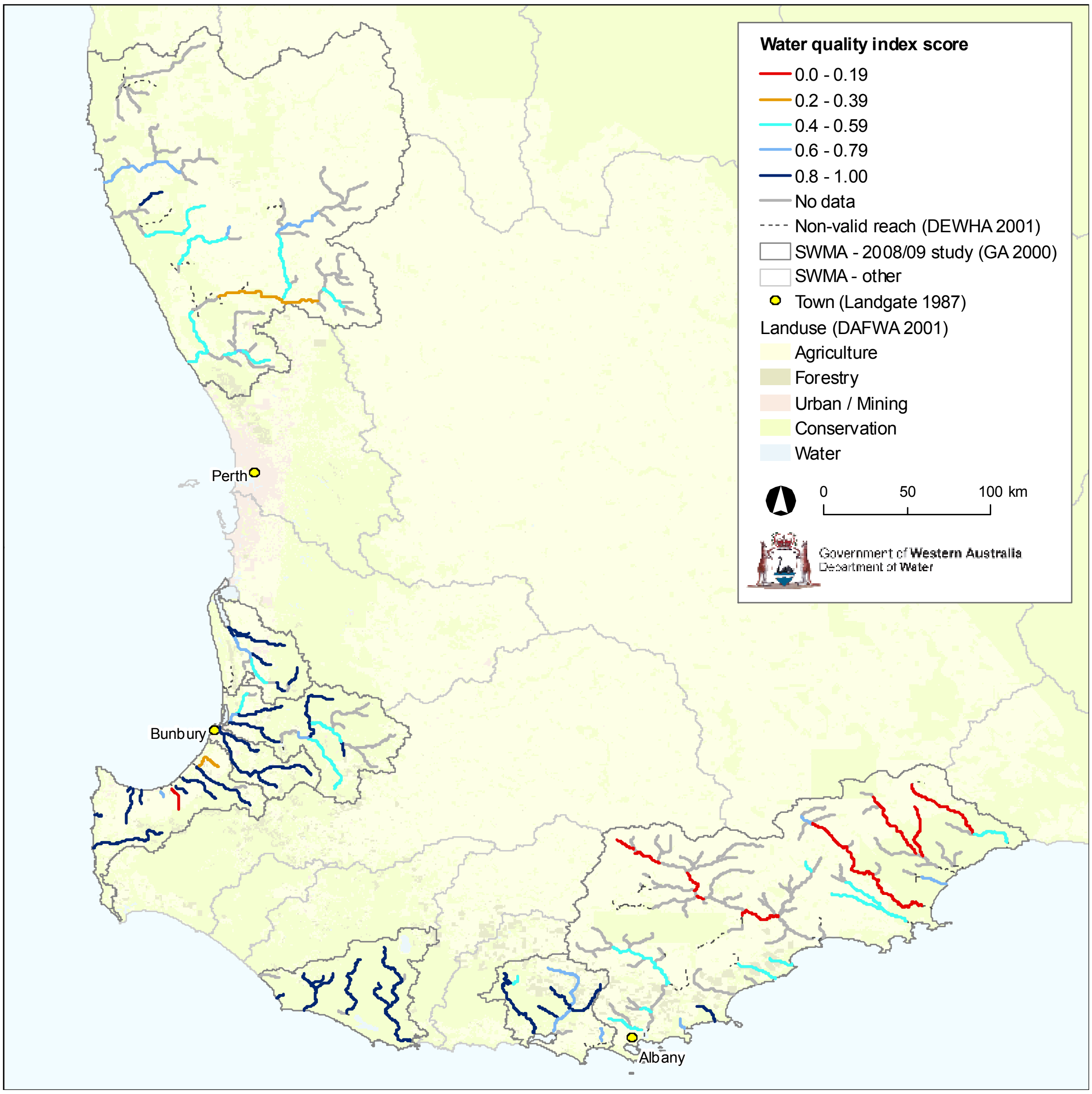


Figure 48 Water Quality index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

The overall results for the *Water Quality index* provide a good indication of the generally expected water quality impacts across SWWA. In the Moore-Hill Rivers SWMA (north of Perth), water quality is typically within the 'moderately modified' band. Salinity has the most notable effect – reducing overall scores in the mid to upper reaches of the Moore River. Water quality is relatively good in the SWMAs surrounding Bunbury (Harvey River, Collie River, Preston River and Busselton Coast), with a couple of reaches showing 'substantial' to 'severe' modifications, primarily due to low dissolved oxygen and high diurnal temperature ranges. The Shannon River SWMA, and to a slightly lesser extent the Denmark River SWMA (west of Albany), exhibit good water quality across all parameters, which is expected given the low level of clearing in these areas. On the other hand, the Albany Coast

SWMA displays significantly impacted water quality. This is due to salinity in the east and nitrogen, temperature and to a lesser extent turbidity across the entire SWMA.

It should be noted that management priorities cannot be set for the *Water Quality index* at the SWMA scale: given the precautionary approach and the data used to generate the index, this would only target salinity problems. The index should be viewed as interpretive, whereby management priorities are set on other values (such as protecting biodiversity) and used to highlight specific impacts to be addressed.

Given the *Water Quality index* receives a contribution from all sub-indices, there is strong support for including all associated data in future FARWH assessments.

Statistical analysis

The relationships between the indicators of the *Water Quality index* were examined to determine whether any redundancies existed. The *salinity sub-index* was identified as having a moderate correlation to both the *diel temperature* ($r = 0.43$; $p < 0.05$) and *total nitrogen* ($r = 0.55$; $p < 0.05$) sub-indices.

A significant, high correlation was also identified between *total nitrogen* and *total phosphorus* ($r = 0.60$; $p = < 0.05$).

As each sub-index has the ability to respond independently to any number of conditions, these correlations did not equate to redundancies.

Limitations of the Water Quality index

All sub-indices were designed for flowing systems and, as such, are not applicable for systems that are dry or a series of unconnected pools at the time of sampling.

There are general limitations regarding collection of single-point data, along with logistics such as sample storage in the field, acceptable holding times before analysis, data collection and analysis costs (described in the sub-index reviews).

A number of sub-indices, especially *diel temperature* and *diel dissolved oxygen*, require improvement of their scoring bands. This needs further work to develop better underpinning knowledge of aquatic biota tolerances.

In terms of WIN data, spatial and temporal limitations exist (as discussed).

For salinity data, future statewide monitoring data is dependent on whether and when the current dataset will be updated.

Improving methods: new water quality monitoring equipment

As mentioned in the summaries above, dissolved oxygen and temperature were recorded over 24 hours, which was far superior to the point data collected for TN, TP and turbidity, but still limited in terms of capturing natural variability and potential pulses. Selection of equipment was based primarily on cost efficiencies, but this limited deployment time to 24 hours. There was also an ongoing maintenance requirement: the membrane-based oxygen probes needed replacing regularly, as did the pumps for ensuring water was flowing over the membranes (every few months). In some cases, failure of pump or membrane resulted in lost data or data-drifting, which justified the use of replicate systems. Further, pumps and probes were relatively heavy (~10 kg), which was problematic for deployment in areas a long distance from the drop point and often over difficult terrain.

To address these limitations, new equipment (the Eureka Manta 2-40 Multiprobe) was trialled – incorporating optical dissolved oxygen sensors (no membranes) along with temperature, turbidity, electrical conductivity and pH probes. The new probes were reported to remain effective in long-term deployments (weeks to months), which would provide more useful data, especially for the more-variable systems (e.g. urban and agricultural). The new technology demonstrated a good response in all parameters, where typical curves were produced and little noise or obvious drift was apparent. Dissolved oxygen data from the new water quality equipment were compared against data collected using the previous TPS probes, deployed at the same site over 24 hours. Results demonstrated that oxygen concentrations were well correlated between both sets of equipment, but there was a standard error – with TPS concentrations being consistently lower than the Manta's (around 1 mg/L, see Figure 49). This requires further analysis, although it may suggest the TPS systems are hampered by the housing required to protect the membrane from clogging (dissolved oxygen housing and general set-up methods are described in detail in the *Inception report – volume 2: SWWA-FARWH* (van Looij & Storer 2009b)).

Note: due to manufacturing and transport delays this technology could not be tested as part of the larger SWWA-FARWH trial.

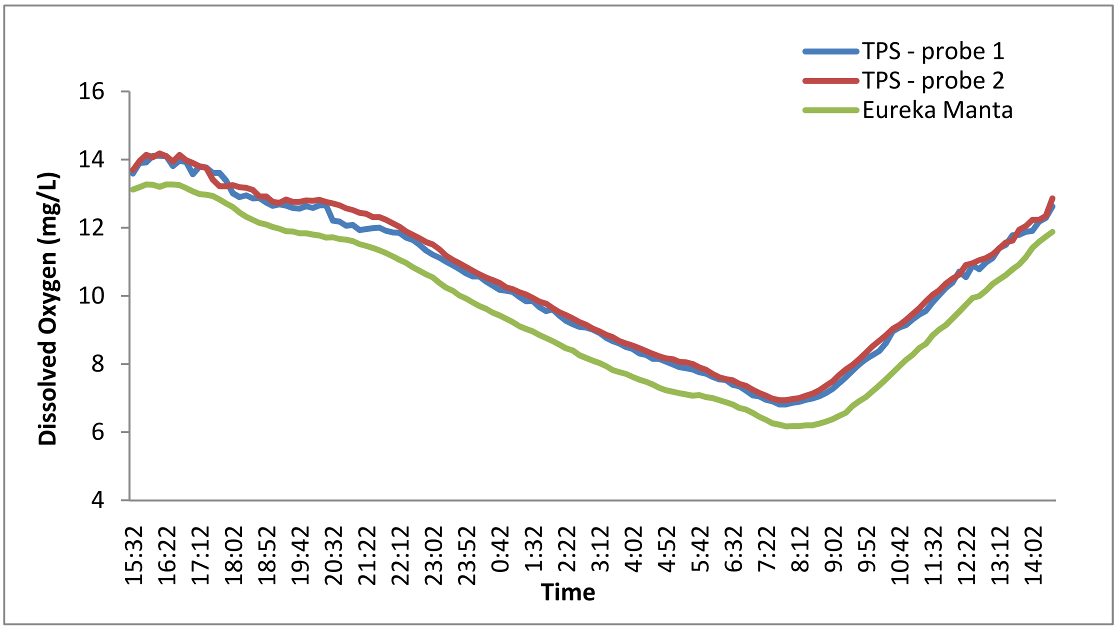


Figure 49 Comparison of the TPS probes and the new Eureka Manta Multiprobe dissolved oxygen data

Other indicators

Stream metabolism

Stream metabolism appears to be a useful indicator in other systems. As such, future trials should target collection of light data to enable calculation of metabolism for methods that may be applicable to the atypical dissolved oxygen curves encountered.

Carbon

Organic carbon is ecologically important as a basis for all life; it strongly influences food webs. Scoring protocols for carbon is a future recommendation, but are not being examined as part of the SWWA-FARWH trials.

Sediment

Sediment indicators were not targeted in the SWWA-FARWH trials because few data exist, there are no established indicators and it was generally outside the immediate knowledge base of the project team. Note: sediment indicators were not recommended as part of the reported FARWH protocol for rivers (NWC 2007a), but were rather a recommendation for wetland assessment.

Although not currently included in the SWWA-FARWH, the evidence does suggest that valuable sub-indices could be derived from sediment for a range of aspects, although the costs associated with data collection and analysis may be greater than ideal. Sediment indicators have been shown to provide valuable chemical (relating to nutrient cycling, buffering, toxicant analysis), physical (stability and support, habitat) and biological (biodiversity, nutrient cycling, filtering) information, which has a strong capability for linkage with management. Further, sediment indicators are capable of being measured accurately and correlate well with environmental conditions, see <www.soilquality.org>, with samples typically not deteriorating to the extent seen in water (certain parameters). It is also well known that most contaminants in streams are contained within sediments (e.g. Nice et al. 2009).

Investigation of potential sediment indicators is recommended for future trials.

pH

Changes to pH have been shown to have deleterious effects on aquatic biota due to interference with ionic balance and respiratory efficiency in both fish and invertebrates. Further, pH has been linked to a number of fish kills (Storer 2005).

pH varies naturally within and between systems, often depending on catchment lithology (e.g. geology) as well as associations with other parameters (e.g. salinity). Natural levels of pH are typically reported between pH 5 (tannin-stained streams) to more than pH 9 (alkaline headwaters). As such, appropriate system-specific reference data are required. Because this is not available for most SWWA systems, pH was not included as a sub-index at this stage. Further, as spot measurements were taken, pH would not be a robust parameter due to an inability to represent the natural diurnal range. Note: Eureka Manta probes have the capability to log pH and this indicator will be tested in the future.

As pH is correlated with a number of serious impacts, such as water leaching from exposed rock and tailings from coal mining activities and exposure of acid sulfate soils, it is highlighted as an indicator for future investigation. Note: ammonia and heavy metals can increase in toxicity due to low pH.

4.4 Theme: Physical Form

The purpose of the *Physical Form index* is to 'assess the state of local habitat and its likely ability to support aquatic life' (NWC 2007a). Habitat is defined as the physical environment in which an organism or community usually occurs (WRC 2000; Pen 1999); for example, oligochaetes (segmented worms) are found in soft organically-rich sediments while philoreithrids (a family of stick caddisflies) occur among pebbles and rocks (Gooderham & Tsyrlin 2003). This is also important at a life-stage scale; for instance, spawning habitats of freshwater cobbler and western pygmy perch (endemic SWWA fish species) are sandy benthos and macrophytes respectively (Tim Storer pers. comm. 2010).

Due to the intrinsic link between an organism and its preferred environmental conditions, the availability, quality and diversity of habitats within a river system affect the characteristics of the biological community (Maddock 1999; Boulton & Brock 1999). Evaluating physical habitat is therefore an important component of any health assessment (Maddock 1999), and provides valuable information about pressures affecting the biota within a river system.

Elements required to represent the theme

Aquatic habitats occur at a range of scales, from a microhabitat under a particular log to a macrohabitat such as a pool or riffle and, at the broadest scale, to the entire river system. Each habitat can comprise a number of components that perform different ecological functions, and which are influenced by a range of contributing factors (Table 34). The complex interactions between human activity, habitat and consequences for aquatic biota are summarised in Figure 50.

Table 34 Components of habitats, their ecological functions and factors contributing to habitat (compiled from Maddock 1999; WRC 2000; Pen 1999)

Microhabitat – immediate surrounds of organism		
Component	**Ecological function**	**Factors contributing to habitat**
Bed substrate (e.g. sand, stones, pebbles, leaf litter)	Shelter from predators, sunlight/heat and high flows Food source Hyporheic/burrows	Bed and bank geology/soil type Erosion/deposition – influenced by bank stability, flow regime
Large woody debris	Shelter from predators, sunlight and flow Slow flow velocity providing areas of varied flow Substrate material	Bank vegetation River 'training' programs (including clearance of woody debris)
Macrophytes	Shade from predators, sunlight/heat and	Bed substrate

Microhabitat – immediate surrounds of organism		
Component	**Ecological function**	**Factors contributing to habitat**
	high flow Food source Substrate material	Water quality Flow velocity
Bank vegetation	Shelter from predators, sunlight/heat and flow Substrate material Food source	Geology Climate Land use Flow regime
Flow velocity	Aquatic biota are adapted to different flow conditions	Flow volume Channel slope shape
Oxygenation	Aquatic biota are adapted to different oxygen levels	Flow volume and velocity Morphology Bed substrate
Macro or mesohabitat – morphological features		
Habitat type	**Ecological provision/influence**	**Factors contributing to habitat**
Riffle, cascade or rapid	Highly oxygenated water (microhabitat) Currents can provide supply of food for filter feeders Shallow water	Geology Flow volume and velocity Erosion/deposition
River pool	Deep water Shelter for large species Refugia for aquatic biota which are less tolerant of drought	Geology Flow volume and velocity Erosion/deposition
Run or low-flow channel, including meander	Slower flow (microhabitat) Sediment deposition (microhabitat)	Geology Flow volume and velocity Erosion/deposition
Reach or system habitat		
Habitat	**Ecological provision/influence**	**Factors contributing to habitat**
Flooded zones	Nursery areas for juvenile fish	Flood controls (levee banks, drains)
Passage through system	Breeding areas for migratory fish	Natural and anthropogenic barriers

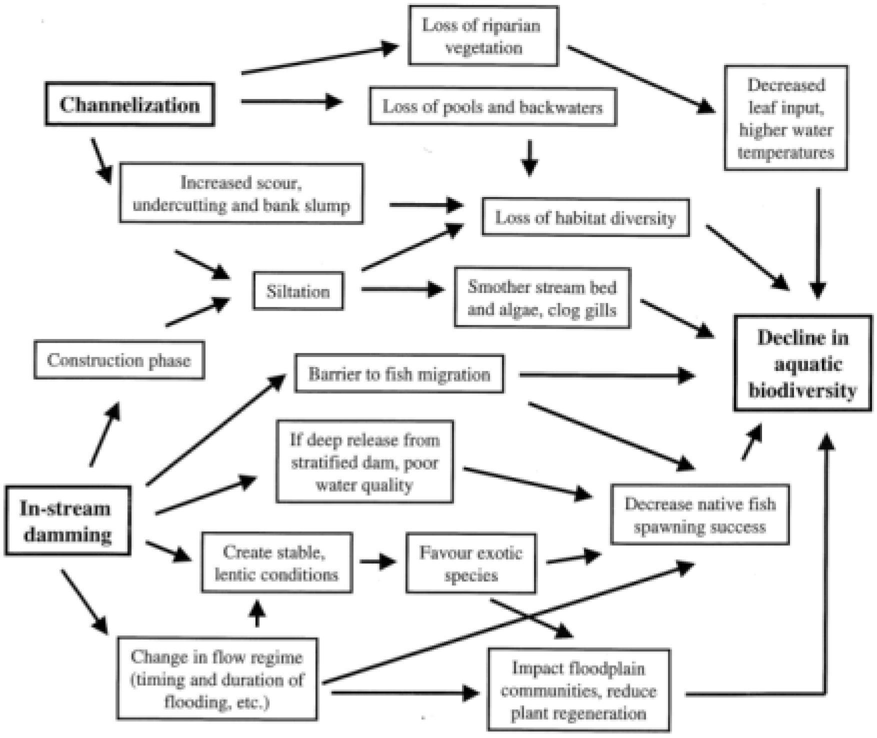


Figure 50 Interactive effects of channelisation and dams on the diversity of native aquatic life (Boulton & Brock 1999)

The scale of river health assessment will influence the scale of habitat being assessed, and thus determine the elements of the assessment and the methods used (Maddock 1999). For example, the assessment of a potential site for river restoration might include observations about bank and streamside vegetation, stream shade, bank stability and erosion, and a diversity of morphological features (WRC 1999). While invaluable for site-scale assessment of river health, this approach would be logistically challenging and data intensive if applied to a river-system-scale assessment. For the SWMA-scale assessment of physical form required for the NWI baseline and monitoring, quantification of macrohabitats and reach/system habitats are more appropriate.

Sub-indices

Three sub-indices have been developed, which combine to form the *Physical Form index*:

- *longitudinal connectivity sub-index* – availability of system habitat
- *artificial channel sub-index* – presence of macrohabitats
- *erosion sub-index* – impact on microhabitats.

In addition, several other sub-indices were investigated (discussed later).

Sub-index: longitudinal connectivity

The *longitudinal connectivity sub-index* provides a measure of the anthropogenic barriers to movement within each reach, which can be combined to evaluate the availability of the whole river system as habitat for fish and crayfish.

Fish and crayfish move through river systems for a number of reasons including feeding, avoidance of predators, migration for breeding/spawning, migration to nursery areas or new territory, movement to seasonal habitats and colonisation (Storer & Norton, in press). Anthropogenic and natural barriers can restrict these movements, leading to increased competition for food and microhabitats, increased predation and interruption of natural breeding/spawning cycles (Fairfull & Witheridge 2003). In addition, segregation of a population into localised groups can affect the genetic diversity of a group and its resilience to predation and environmental changes (Storer & Norton, in press).

The *longitudinal connectivity sub-index* was included within the *Physical Form index* in recognition of the importance of these impacts on the ecology of river systems in SWWA, and because it evaluates system habitat at an appropriate scale for a SWMA-based health assessment.

The *longitudinal connectivity sub-index* is recommended as a potential sub-index in the FARWH (NWC 2007b). A similar desktop-based approach is used in the Victorian ISC (White & Ladson 1999), wet/dry tropical FARWH (Dixon et al. 2009) and Tasmanian River Condition Index (TRCI) (NRM South 2009).

Scoring and reference condition

A number of anthropogenic structures exist within river systems that have the potential to prevent movement of fish/crayfish, including dams, weirs, flow gauging stations, fords and culverts. The extent to which a structure forms a barrier to fish/ crayfish passage depends on a combination of factors including the structure's size and the flow regime of the watercourse, which together determine how frequently the structure 'drowns out' the species present, their migration patterns and the location of the structures in relation to those patterns (NWC 2007b). In addition the barriers in neighbouring reaches can also affect fish/crayfish within a reach; expert advice suggests that species would be affected up to 20 km away from a barrier (NWC 2007b).

Unfortunately data for SWWA are insufficient to evaluate each structure individually based on the combination of these factors. In lieu of this, a scoring protocol was developed based on the presence of structures within a reach and in neighbouring reaches.

Structures have been grouped into four categories, forming separate components (Table 35). This approach has been taken so the impact of the four structure types can be presented and interpreted separately, and to allow for revision of the scores and scoring protocol as the data quality for each group improves.

Table 35 Longitudinal connectivity sub-index scoring protocol

Score	Major dam component	Minor dam component	Gauging station component	Road and rail crossing component
0.00	Present on reach			Not applicable
0.25	Present within 5 km of start/end of reach			≥ 2/km (high density)
0.50	Present between 5 and 20 km of start/end of reach			1 – < 2/km (moderate density)
0.75	Present between 20 and 40 km of start/end of reach			> 0 – < 1/km (low density)
1.00	Present at > 40 km of start/end of reach			0/km

For the major dam, minor dam and gauging station components the scoring protocol comprises five scores relating to proximity of structures to a reach (Table 35). Distance thresholds were selected based on expert opinion:

- the FARWH suggests taking a precautionary approach, applying reduced scores up to 40 km away from a barrier (NWC 2007b)
- species would be affected up to 20 km away from a barrier (Lintermans, O'Brien, Kennard, pers. comm. cited in NWC 2007b)
- native SWWA fish/crayfish species are generally small bodied and most can complete life cycles within relatively short ranges entirely within the freshwater environment (potadromous). (It is therefore reasonable to assume that smaller distances than reported in other Australian studies still represent value (Tim Storer pers. comm. 2010). Consequently, a threshold value of 5 km was selected to represent this value, although it is acknowledged that further study is required to validate this distance.)

The *road/rail crossings component* is based on the potential for obstruction of biota passage at each point – where a road or railway crosses a watercourse. The structure that occurs at each crossing differs (from fords and culverts to weirs and bridges), and it is acknowledged that the effect on aquatic biota passage varies considerably. It is not currently possible to identify the type of structure at each crossing in SWWA so the sub-indicator has been designed to give an indication of the density of potential barriers rather than quantify actual barriers to the passage of aquatic biota. The scoring protocol comprises four categories of density indicated by the number of crossings per kilometre of reach (Table 35). A score of zero has not been assigned because this would imply an absolute impact whereas the data currently available for this sub-indicator are only indicative in nature.

The scoring protocol for all four components uses an assumed reference condition of 'no artificial barriers to aquatic biota passage in pre-European times'.

The component scores are integrated into a *longitudinal connectivity sub-index* score by applying weightings, summing the weighted scores and range standardising the sum to between 0 and 1 (Equation 7).

Equation 7

$$LCSI = \frac{((MiD \times w) + (MnD \times w) + (GS \times w) + (RRC \times w) - (minimum\ possible\ score))}{(maximum\ possible\ score) - (minimum\ possible\ score)}$$

$$LCSI = \frac{((MiD \times w) + (MnD \times w) + (GS \times w) + (RRC \times w) - 0.06)}{2.50 - 0.06}$$

Where: LCSI = longitudinal connectivity sub-index; w = weighting; MjD = major dam component; MnD = minor dam component; GS = gauging station component, RRC = road/rail crossing component.

Note: range standardisation process uses the theoretical minimum (in this case 0.06) and maximum (in this case 2.50) possible score (i.e.) calculated from theoretical scenarios, not from actual scores in the trial SWMAs.

Weightings were assigned to components based on two factors: assumed potential for impact and confidence in source data (Figure 51). The greatest weighting was assigned to major dams, with reduced weightings assigned as confidence and potential for impact declined. In future it may be possible to revise the weightings, basing them on confirmed locations and quantification of impacts on fish passage.

Missing data

The scoring protocol has been designed for data available in SWWA (see *Data sources* section below) so it has been possible to calculate all four component scores for each reach, but if data were insufficient in the future it is recommended the minimum requirements for calculating the *longitudinal connectivity sub-index* are the *major dam* and *minor dam* components. The other structures – gauging stations and crossings – carry a much lower confidence in terms of potential for barrier impacts.

Major dam *w* = 1.0	**Minor dam** *w* = 0.75	**Gauging station** *w* = 0.5	**Road/rail crossing** *w* = 0.25
CONFIDENCE IN DATA →			
Actual structure, mapped and some registered.	Actual structure, mapped although some duplication occurs. Data cleansing required.	Potential structure, not all stations have structure which could restrict passage. Ground-truthing required.	Potential structure, each intersection between road/rail and watercourse will vary, extensive ground-truthing required.
POTENTIAL FOR IMPACT →			
Permanent barrier, year-round impact.	Permanent barrier, with potential to drown out in extreme flow events.	Seasonal barrier, very likely to drown out in high flow.	Seasonal barrier, structures are either likely to drown out in high flow (e.g. drops from culverts) or are partial barriers (e.g. culverts may only be restrictive to some species (e.g. those less tolerant to increased flow velocity or darkened conditions).

Figure 51 Potential for impact, confidence level and associated weightings for the four barrier types used in the longitudinal connectivity sub-index

Data sources

For the 2008 and 2009 assessment the *longitudinal connectivity sub-index* was calculated using data from the Fish Barriers Database (DoW unpublished, see Table 68) – a spatial database of potential and actual barriers to fish passage in Western Australia. It is designed to inform waterway managers to help them plan and prioritise the installation of fishways (Norton & Storer 2010).

Features in the database have been drawn from a number of different sources that were mapped at a range of scales to suit the purpose of the originating dataset. Consequently the features do not necessarily align closely with mapped watercourses including the Reconstructed Reaches (see Table 68). To overcome this spatial mismatch, all features within 200 m of each reconstructed reach were selected, including those falling on tributaries of reaches. This can be justified from an ecological perspective as SWWA native fish species such as *Galaxias occidentalis* (western minnow) and *Bostockia porosa* (nightfish) migrate from main channels to small tributaries to spawn (ARL 2005).

Note: trials of different buffer widths were conducted; 200 m was found to be the most appropriate width for selecting features related to a reach.

Once barrier types and locations were plotted, each reach was then scored according to the proximity of the various barrier elements (major and minor dams, gauging stations and the intensity of road/rail crossings per kilometre of reach). Note that proximity analysis included:

- structures both upstream and downstream of each reach to reflect the impact of barriers on both potadromous and diadromous species (e.g. SWWA contains both anadromous and catadromous species, such as *Geotria australis* (pouched lamprey) and *Galaxias maculatus* (common jollytail) respectively)
- barriers on tributaries, to reflect the impact of barriers on genetic diversity and subsequent resilience (see introduction to *longitudinal connectivity sub-index*).

Data verification

The Fish Barriers Database was created in late 2009 and to date only a limited number of features have been verified through ground-truthing. It is anticipated that verification will occur as fishway projects are initiated across Western Australia.

Data frequency

The department aims to update the Fish Barriers Database on an ad-hoc basis as ground-truthing information becomes available. As such it is unlikely that change over a short time period (e.g. one year) will be detectable in the sub-indicator scores. It is therefore recommended that this sub-index be recalculated at five-year intervals.

Sensitivity and scenario testing

The scoring protocol was tested to ensure the full range of scores between 0 and 1 could be obtained (given there are known examples of SWWA systems ranging from completely disconnected to unimpeded by artificial barriers), that they aligned with the condition bands recommended by the FARWH (NWC 2007a) and that they responded sensitively to change.

By using range standardisation during the integration process (Equation 7) it is possible to obtain the full range of scores using the *longitudinal connectivity sub-index* (Table 36). The scores align with the FARWH condition bands and were shown to respond practically. That is, scores follow an impact scale based on length of connected section of waterway. There are instances where scores may not reflect specific impacts; for example, anadromous species may be significantly affected by a dam in the lower catchment (restricting access to upper catchment spawning grounds), however the scores for reaches upstream will not reflect this impact (though the *fish/crayfish sub-index* may detect their presence). Obviously, where specific impacts are understood (such as example above) scores can be tailored appropriately.

Table 36 Example scenarios of the longitudinal connectivity sub-index, showing the full range of scores possible

Scenario	MiD score	MnD score	GS score	RRC score	LCSI score*
A. Worst case – all structure types on reach, crossings ≥ 2/km	0.00	0.00	0.00	0.25	0.0
B. Structures within 5 km, crossings ≥ 2/km	0.25	0.25	0.25	0.25	0.2
C. Structures within 20 km, crossings 1–1.99/km	0.50	0.50	0.50	0.50	0.5
D. Structures within 40 km, crossings 0.01–0.99/km	0.75	0.75	0.75	0.75	0.7
E. No structures, no crossings on reach	1.00	1.00	1.00	1.00	1.0

*Where: MiD = major dam component; MnD = minor dam component; GS = gauging station component; RRC = road and rail crossing score; LCSI = longitudinal connectivity sub-index * Note: sub-index scores are integrated using Equation 7. Sub-index scores are calculated to two decimal places, but final indicator scores are rounded to one decimal place as recommended by the FARWH (NWC 2007a).*

Scenario testing confirmed that scores are sensitive to change. For example, if a major dam is built on a reach which previously had no structures (pristine) the score would change from 1 (‘largely unmodified’ category) to 0.59 (‘moderately modified’ category). Note that sensitivity to future change may be influenced by verification of data in the Fish Barriers Database (see *Limitations* section). Table 37 also highlights that scores correlate well with assumptions about the degree and severity of impact of the various structures: from major dams (greatest general impact) through to road/rail crossings (least impact and confidence in data).

Table 37 Examples of scenario testing for sensitivity to change

Scenario	MiD score	MnD score	GS score	RRC score	LCSI score
Reach with no structures	1	1	1	1	1.00
Reach with high-intensity road/rail crossings	1	1	1	0.25	0.92
Reach with one gauging station	1	1	0	1	0.80
Reach with one minor dam	1	0	1	1	0.69
Reach with one major dam	0	1	1	1	0.59
Reach with one major and one minor dam	0	0	1	1	0.28
Reach with one major dam and one gauging station	0	1	0	1	0.39
Reach with one major and one minor dam and one gauging station	0	0	0	1	0.08

Final reach scores

The *longitudinal connectivity sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 52. The lowest scores occurred in the Harvey River and Collie River SWMAs, which matched expectations based on the level of development for agriculture and drinking water sources (which is higher in these SWMAs than others in the study area). They have a number of major dams, minor dams and associated gauging stations, plus an extensive network of roads.

In the Collie River SWMA there are four major dams located on four out of the 20 reaches (Harris Dam, Wellington Dam and Wellington Pipehead Dam on the Collie River, and Beela Dam on the Brunswick River), plus a number of minor dams (on 14 reaches) and gauging stations (also on 14 reaches). These reaches, and the reaches upstream and downstream of them, received low scores due to the impacts of these actual and/or potential barriers to fish migration. In addition, half of the reaches had a medium to high intensity of road/rail crossings, further reducing the reach scores.

In the Harvey River SWMA there are four major dams located on four of the 14 reaches (Harvey Dam, Stirling Dam, Samson Brook Dam and Samson Brook Pipehead Dam), plus a number of minor dams (on eight reaches) and gauging stations (on six reaches). In addition six of the 14 reaches had a medium intensity of road/rail crossings, further reducing the reach scores.

By contrast the reach scores for all other SWMAs assessed were moderate to high (0.4 to 1.0) with the exception of the lower Denmark River (reach 60315402) which has a major dam (Denmark Dam) plus a minor dam and a gauging station. While minor dams, gauging stations and road/rail crossings occur in all of these SWMAs, the absence of major dams resulted in higher reach scores than those occurring in the Collie River and Harvey River SWMAs.

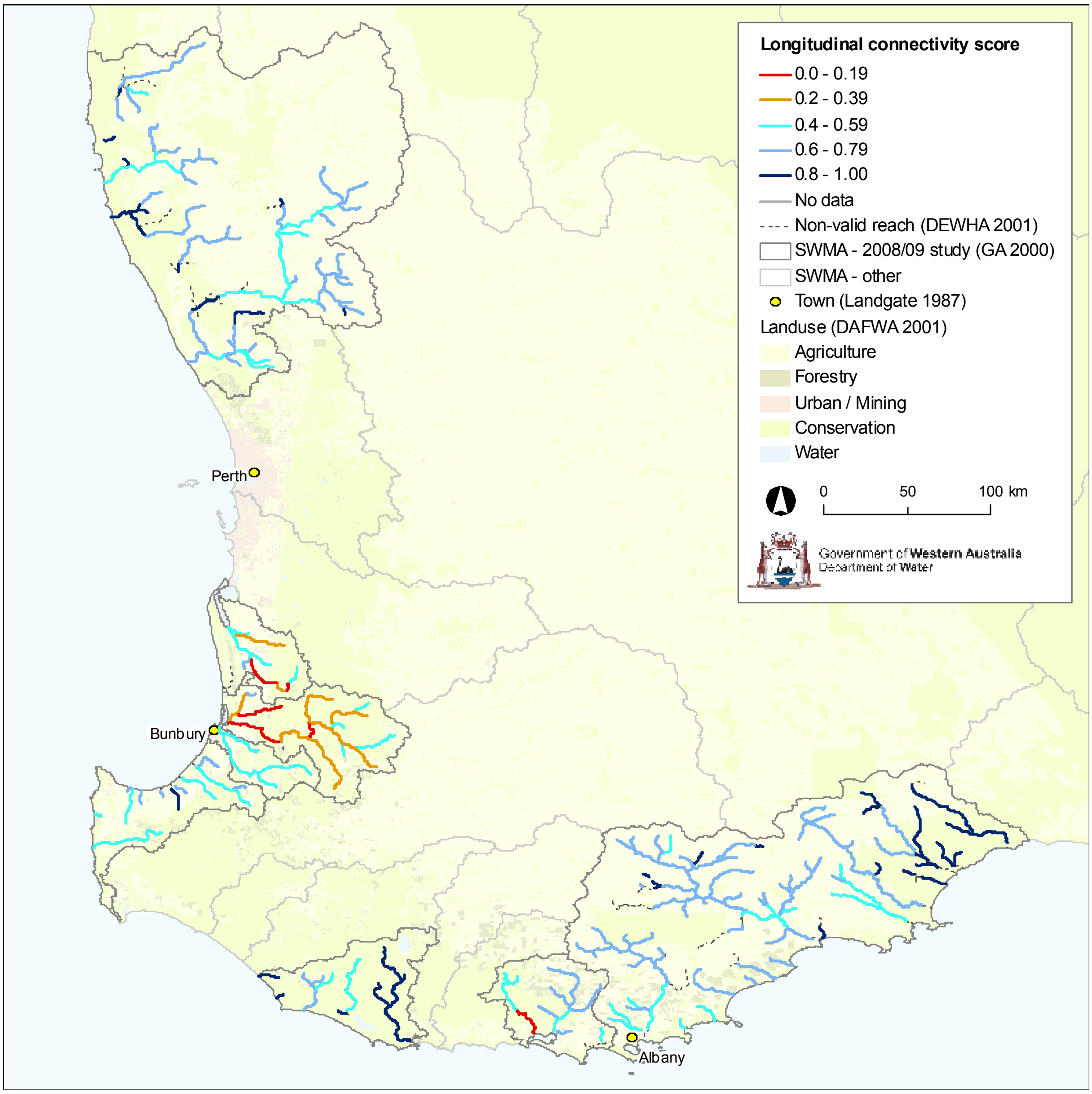


Figure 52 Longitudinal connectivity sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Power analysis

As this sub-index was calculated for all reaches a power analysis was not conducted.

Limitations

The Fish Barriers Database is currently at a pre-publication stage of development, and to date only limited data cleaning has occurred. It is acknowledged that because various sources have been used to create the features in the database, duplicate features have occurred representing the same potential barrier. Consequently the *longitudinal connectivity sub-index* scores for the 2008 and 2009 assessments are an over-estimate of the presence of barriers on reaches, and should be seen as indicative scores at this stage. Despite this, it is preferable to include an indicative score in the overall *Physical Form index*, rather than exclude it completely, to acknowledge the impact of barriers on the ecology of rivers. Further, any duplication should typically be a standard error across SWMAs, thus no significant bias is expected.

As data verification progresses it is likely the number of confirmed barriers will be lower than the number of potential barriers currently in the database, leading to improved sub-index scores, hence caution should be applied when making temporal comparisons between 2008 and 2009 and future scores. To reiterate, the barrier data used in the SWWA-FARWH scoring protocols are indicative of barrier density and thus of potential impact: the data should not be viewed as related to actual barriers or used for other purposes without a thorough understanding of the data generation methods.

The FARWH applies to freshwater rivers, hence the Reconstructed Reaches (see Table 68) dataset excludes estuarine portions of reaches. This limits the *longitudinal connectivity sub-index* in that barriers on estuaries are not included in the scoring; hence their impact is not included.

Recommendations for future development

It is recommended that:

- the *longitudinal connectivity sub-index* scoring protocol be reviewed as verification and ground-truthing of the Fish Barriers Database progresses (The protocol has been designed to accommodate data about potential barriers, but as more data about actual barriers are gathered, a revised protocol may be more appropriate.)
- the data analysis method be reviewed in the future as data resolution improves (In the 2008 and 2009 trials all structures within 200 m of a reach were selected for analysis, however if features in the Fish Barriers Database are re-mapped at a finer spatial scale (via ground-truthing) and reaches are redefined at a finer spatial scale, it may be possible to select only those structures which actually fall on a reach. Alternatively, all barriers within a subcatchment may be targeted regardless of assessment reach to reflect the importance of tributaries for the life-stages of most SWWA species (Tim Storer pers. comm. 2010).)
- any new research into impacts of different types of barriers be reviewed and used to revise the proximity distance rules and weightings accordingly
- the desktop analysis method be developed further to include barriers on estuarine portions of reaches.

Other indicators investigated

No other indicators were investigated for the *longitudinal connectivity sub-index*.

History

The *longitudinal connectivity sub-index* is broadly based on the methods recommended in the FARWH (NWC 2007b), with modifications to suit the data available in SWWA. The sub-index was divided into four components to accommodate the nature of the Fish Barriers Database, which is more detailed than the Wild Rivers data (Wild Rivers Impoundments layer, see Table 68) used in the Assessment of River Condition (ARC) (NWC 2007b). In addition the ARC allocated scores to river links then combined them to reach level, however river links are not mapped in SWWA – hence the scoring method was developed for use at the whole-of-reach scale.

Sub-index: artificial channel

The *artificial channel sub-index* was developed to provide an indication of the absence of macrohabitats within a reach. The presence of macrohabitats – such as riffles, pools and runs – are important to a river system's ecological health because they provide a diversity of environments for both plants and animals (Pen 1999). Riffles, for example, are characterised by swift-flowing turbulent water that is well oxygenated. Macroinvertebrate filter-feeders such as Simuliidae (blackfly larvae) use the supply of food in the turbulent water, and in turn provide a food source for fish species (Pen 1999; WRC 2000). The ecological functions of macrohabitats are listed in Table 34.

These morphological features are not currently mapped in SWWA, so it is not possible to assess the presence of these features on a scale suitable for a SWMA-based assessment of river health. However a spatial dataset of artificial watercourses is available. This can be used as a proxy for the absence of features based on the observation that artificial watercourses (canals, drains etc.) are generally straight, have uniform width and depth, and therefore lack the characteristics of riffles, pools, meanders etc.

Note: it is acknowledged this dataset does not include information about watercourses known to be modified at periodic intervals (e.g. via dredging for management purposes) but are not actually classified as 'canal', see *Limitations* and *Recommendations* section for further information.

The *artificial channel sub-index* was developed in SWWA for the Swan-Canning RHAS as a site-scale measure of channel straightness (Galvin et al. 2009), and was subsequently adapted for the SWWA-FARWH to provide a reach-scale assessment of macrohabitat loss. The TRCI includes 'sinuosity' as a component of its physical form sub-index (NRM South 2009), following similar principles.

Scoring and reference condition

Artificial channel sub-index scores are calculated on a linear scale based on the percentage of reach length mapped as 'artificial watercourse' (Table 38). The scoring protocol uses an assumed reference condition of 'no artificial watercourses in pre-European times'.

Table 38 Examples of scores obtained using the artificial channel sub-index scoring protocol

Reach characteristics	ACSI score
100% of reach length mapped as artificial watercourse	0.0
50% of reach length mapped as artificial watercourse	0.5
0% of reach length mapped as artificial watercourse	1.0

Data sources

For the 2008, 2009 and 2005 assessments the *artificial channel sub-index* scores were calculated using data from the Hydrography theme of the GEODATA TOPO 250K Series 3 (see Table 68). This was the most recent 1:250 000-scale topographic mapping dataset available when the desktop analysis was conducted (the dataset was published in 2006).

Within the dataset rivers and streams are mapped as:

- watercourse line: a natural channel along which water may flow from time to time
- canal line: an artificial watercourse conveying water for inland navigation, irrigation or drainage purposes.

The length of a reach mapped as 'canal' was expressed as a percentage of the total length of the reach, based on the total length of valid reach mapped in the Reconstructed Reach dataset (see Table 68), which was generated from 1:250 000 topographic mapping data.

Data verification

Data in the GEODATA TOPO 250k Series 3 has been verified by Geoscience Australia to meet standard positional and attribute accuracy specifications (Geoscience Australia 2006). The digitisation of a feature as a 'canal line' is based on visual identification of a straight watercourse, but must also be confirmed by reference material sourced from local and state governments and other mapping agencies (Shane Crossman pers. comm. 2010).

The occurrence of 'canal line' features on reaches has been ground-truthed against data collected in the 2009 field trial. Of the 42 sites sampled on valid reaches in 2009, the field observations were consistent with the topographic data at 40 sites. For the remaining two sites the percentage of the associated reach classified as canal was < 15% and the field sites fell in locations classified as 'watercourse'.

Data frequency

The national 1:250 000 topographic mapping data are updated and republished at irregular intervals (series 1, 2 and 3 were published in 1994, 2003 and 2006 respectively); as such, this indicator is only worth recalculating when new data is released.

(Note: the Series 3 data have been incorporated into the Australian Hydrological Geospatial Fabric (Geofabric) products published in October 2010.

Sensitivity and scenario testing

The scoring protocol was tested to ensure the full range of scores between 0 and 1 could be obtained, that they aligned with the condition bands recommended by the FARWH (NWC 2007a) and that they responded sensitively to change.

The *artificial channel sub-index* scoring protocol generates a linear score taken directly from the percentage of the reach length mapped as 'canal line'. The percentage can fall between 0 and 100%, therefore the full range of scores between 0 and 1 can be obtained, and they correspond to the FARWH condition bands. For example, a reach comprising 50% artificial channel will score 0.5, which falls into the 'moderately modified' condition band.

Any future changes to the mapped status of a watercourse will translate directly to a change in score. For example, if 1 km of a 10 km reach currently mapped as 'natural watercourse' was straightened, dredged and reshaped to function as a drain (and these changes were reflected in future topographic mapping datasets) the score for this reach would reduce from 1.0 to 0.9; hence the scoring protocol is sensitive to change.

Final reach scores

The *artificial channel sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 53. The results follow a similar pattern to the *longitudinal connectivity sub-index* scores, with the lowest reach scores occurring in the Harvey River and Collie River SWMAs. One reach in the Busselton Coast SWMA also had a low score (0.3).

The reaches with low scores (0.0 to 0.3) occur at the downstream end of river systems in areas of low topography (on the Swan Coastal Plain) which are heavily used for agriculture and therefore require drainage to reduce flooding of paddocks and properties. Consequently, a large proportion of these reaches (> 60% of the reach length) comprised artificial channel.

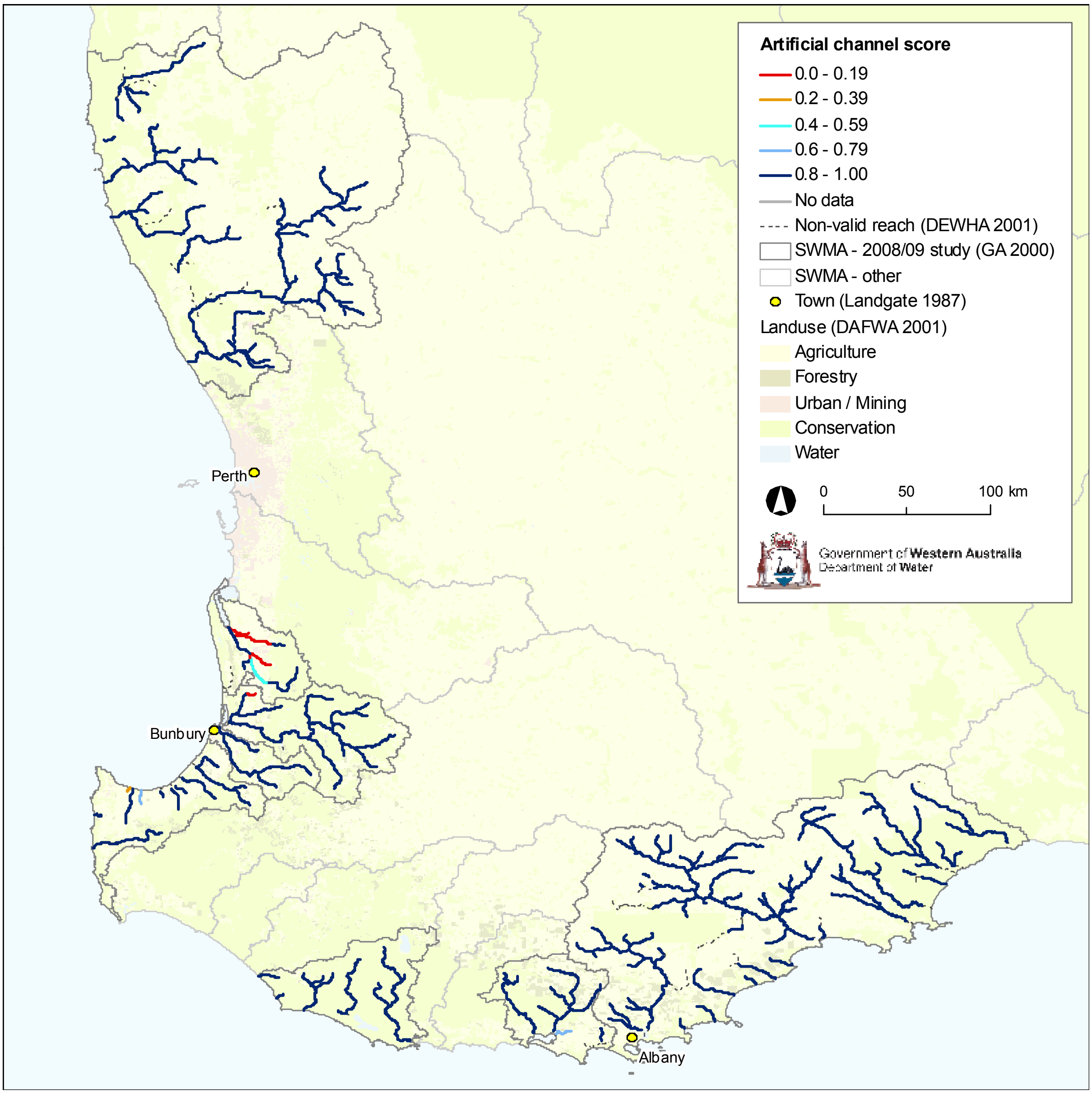


Figure 53 Artificial channel sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Power analysis

As this sub-index was calculated for all reaches a power analysis was not conducted.

Limitations

1:250 000-scale topographic mapping data are a 'model' of features on the earth's surface – they provide a generalisation of the features rather than a true record of each individual feature. It is produced for cartographic purposes, and is not designed for analytical interrogation (Shane Crossman pers. comm. 2010). The *artificial channel sub-index* scores obtained using this data should therefore be treated as indicative rather than absolute. Despite this limitation, the GEODATA TOPO 250k Series 3 dataset was selected from a number of others because it is consistent across the whole study area, is mapped to national standards and is the best data available for SWWA.

It is acknowledged the GEODATA TOPO 250k Series 3 data do not represent watercourses known to be dredged at periodic intervals but are not actually classified as 'canal'; for example, the Collie River near the Collie townsite. Data on dredging and other management activities are not collected in a single database or dataset. It may be possible to obtain information from individual local management authorities, but investigating this was beyond the scope of the project.

The FARWH applies to freshwater rivers, hence the Reconstructed Reaches (see Table 68) dataset excludes estuarine portions of reaches. This presents a limitation for the *artificial channel sub-index* in that canals within estuarine portions are not included in the score.

Recommendations for future development

It is recommended that:

- if suitable data mapped at a finer scale (< 1:250 000) become available in the future (e.g. within the current Bureau of Meteorology's Australian Hydrological Geospatial Fabric (Geofabric) project) the data source and scoring protocol be reviewed and adapted to make use of this data
- the possibility of obtaining information about management activities from local authorities be investigated, and if it is feasible to obtain the data, the scoring protocol be amended accordingly.

Other indicators

No other indicators were investigated for the *artificial channel sub-index.*

History

The channel pattern indicator used in the first-round trial was developed based on the channel pattern indicator in the Swan-Canning RHAS, in which field observations and GIS data were used to categorise a site as either 'river like' with meandering bends or 'drain like' with straight form, possible sharp bends and stabilised with man-made structures. The categories were given ratings of 4 and 0 respectively (on a scale of 0 (very poor condition) to 4 (excellent condition) (Galvin et al. 2009).

For the SWWA-FARWH trial the indicator was adapted to a reach-scale rather than site-scale indicator by assessing the channel pattern of the entire reach using GIS. In the first-round trial, scores were generated using the Hydrography Linear dataset (see Table 68) which is derived from topographic mapping captured at between 1:25 000 and 1:100 000 scale. Features in the dataset categorised as drain (major and minor), levee bank and supply channel were considered to provide evidence of channelisation, and the length of channelised reach was expressed as a percentage of the total reach length. Scoring was based on the percentage of the reach length which has been channelised (e.g. 100% channelisation would return a score of 0, 0% channelisation would return a score of 1) (van Looij et al. 2009).

For the SWMAs covered by the second-round trial, the Hydrography Linear dataset (see Table 68) was investigated but found to have inconsistencies in the attribution of features – drain (major and minor), levee bank and supply channel – in the relevant SWMAs. Alternative datasets were investigated and the GEODATA TOPO 250k Series 3 was selected as the best-available source of data.

In addition, the indicator's title was changed in the second-round trial (from channel pattern indicator to *artificial channel sub-index*) to better reflect its purpose – which is to assess the loss of macrohabitats within a reach.

Sub-index: erosion

The *erosion sub-index* provides a measure of current erosion and potential for future erosion (based on stabilising vegetation) occurring at a site, which is assumed to be representative of erosion along the reach in which the site is located.

It was included in the SWWA-FARWH in recognition of the ecological impacts of geomorphological processes on aquatic microhabitats. The FARWH recommends assessing this aspect of physical form via a bedload condition indicator calculated at a reach-scale using modelled data (NWC 2007b), however this was not feasible for the SWWA-FARWH trial (see review in *Other indicators* below). The *erosion sub-index* was developed as a proxy for sedimentation based on the assumption that erosion occurring in a reach will generate suspended sediment and possibly sediment deposition within the reach and/or downstream reaches.

Erosion and sedimentation are naturally occurring geomorphological processes, however an unnatural level of erosion and subsequent sedimentation can cause a number of significant ecological impacts. For example, suspended sediment causes turbidity in the water column, reducing light penetration and consequently reducing photosynthesis. It can also smother macrophytes and cause damage through abrasive forces, further reducing primary production. Suspended sediments can interfere with the filter-feeding of macroinvertebrates, clog the gills of fish and macroinvertebrates (Boulton & Brock 1999) (reducing respiration and potentially causing long-term problems due to physical damage) and decrease the effectiveness of species that hunt visually (reducing the cost/benefit relationship within the predator-prey dynamic, due to reduced detection lengths and increased searching and handling time) (Storer 2005). Sediment deposition fills interstitial spaces between stones, pebbles and rocks, reducing the availability and diversity of substrate habitats (Boulton & Brock 1999). Sedimentation can also fill pools and backwaters, reducing the availability and diversity of macrohabitats (Pen 1999).

River health assessment programs across Australia incorporate field-based erosion or bank stability indicators (Table 39). The methods and scoring protocols differ but essentially all indicators provide a measure of current erosion and/or potential for future erosion.

Table 39 Erosion and bank stability indicators used in river health assessment programs across Australia

River health assessment program	Indicator
Tasmania River Condition Index (NRM South 2009)	Bank erosion component: field observations of erosion scars are scored against expected erosion based on geomorphic benchmarks.
Victorian Index of Stream Condition (DSE 2006)	Bank stability indicator: field observations at three transects within site: bank profile (shape/slope), exposed roots and rating based on reference photographs/ descriptions.
Queensland Stream and Estuarine Assessment Program (Conrick et al. no date)	Bank stability indicator: field observations of location of instability, type of instability (eroding, aggrading, slumping), slope and shape, and factors affecting stability – used to calculate overall instability and susceptibility to erosion.
Queensland Ecological Health Monitoring Program (Conrick et al. 2008)	Bank stability indicator: field observations of percentage of bank that has experienced slumping (no details of observations available), scored against percentage of bank experiencing slumping at reference sites to give an observed/expected ratio.
Wet/dry tropical FARWH (Dixon et al. 2009)	Bank stability indicator: field observations of exposed soil, exposed tree roots, slumping, gullying, undercutting. Five indicators integrated by averaging.

Scoring and reference condition

For the 2009 assessment the *erosion sub-index* comprised two components: *erosion extent* and *bank stabilisation*. (Note that for the 2008 assessment the *erosion sub-index* scores were calculated using a different method, which was subsequently refined. The 2008 assessment method is described in the *History* section.)

Component: erosion extent

The *erosion extent component* assesses the extent of active and recently eroding surfaces on the left and right banks of a site (100 m). The extent of erosion features present (e.g. slumping, gullying, undercutting) were categorised into one of four bands for each bank, and assigned a nominal rating (Table 40). The rating for the left and right banks was averaged and range standardised (see Equation 8) resulting in a score between 0 and 1. The scoring protocol uses a reference condition of ‘no erosion or minimal naturally occurring erosion’ based on the literature (WRC 2002; Abernethy & Rutherfurd 1999).

Table 40 Erosion extent ratings

Extent of erosion (length of bank affected)	Rating
0 to 5%	4
> 5% to 20%	3
21 to 50%	2
> 50%	1

Equation 8 $$EES = \frac{\left(\frac{lbr+rbr}{2}\right) - min\ average\ rating\ possible}{(max\ average\ rating\ possible) - (min\ average\ rating\ possible)}$$

$$= \frac{\left(\frac{lbr+rbr}{2}\right) - 1}{4-1}$$

Where: EES = erosion extent score; lbr = left bank rating; rbr = right bank rating.

Note: the range standardisation process uses the theoretical minimum (in this case 1) and maximum (in this case 4) possible scores (i.e. calculated from theoretical scenarios; not from actual scores occurring in trial SWMAs).

Component: bank stabilisation

The *bank stabilisation component* provides a measure of the vegetation cover and complexity on the river banks, as an indication of how well the bank is stabilised and therefore how susceptible it is to future erosion.

Riparian vegetation helps to control bank erosion through binding and holding the banks together and by absorbing the force of flowing water (Pen 1999; Abernethy & Rutherfurd 1999). This valuable function can be lost or reduced when vegetation is cleared or becomes degraded (Rutherfurd & Ducatel 1994, cited in Pen 1999). Note: this is differentiated from vegetation indicators within the *Fringing Zone index*, as it only applies to bank condition, and only in terms of stability.

The percentage cover for each layer (shrubs, trees < 10 m, trees > 10 m) was categorised into one of five bands and assigned a nominal rating (Table 41). The ratings for all three layers for both left and right banks were added together (using an unweighted sum) and the total rating was range standardised to between 0 and 1 (Equation 9). The scoring protocol uses an assumed reference condition of '> 75% vegetative cover of shrubs and trees' (note that this was the highest rating in field observations).

The scoring protocol uses the percentage cover of shrubs and trees in the streamside zone (10 m) as a proxy for the presence or absence of complex vegetation (i.e. vegetation with multiple layers) with bank stabilisation properties. The scoring protocol does not distinguish between native and exotic trees because exotic species can contribute to bank stability (Abernethy & Rutherfurd 1999).

It is acknowledged that because groundcover is not used for scoring, a site with native groundcover but no trees or shrubs will get the same bank stabilisation score as one with grass groundcover. However, groundcover was excluded because the combined shrub and tree layers provided sufficient distinction between sites with complex vegetation and those without, based on results from a photograph verification exercise conducted by a panel of project officers (see *Limitations* section for details).

When applying the scoring protocol, operators are required to apply their professional judgement in areas where the assumed reference condition may not be applicable. For example, the vegetation at a bedrock-dominated site may naturally consist of a shrub layer with no trees, and hence it would be inappropriate to give the site a low score for bank stabilisation. In this case the percentage cover of the shrub layer alone would be used to generate the *bank stabilisation component* score.

Table 41 Bank stabilisation ratings

% cover of vegetation (shrub layer, tree layer < 10 m, tree layer > 10 m)	Rating
> 75%	4
> 50 to 75%	3
> 10 to 50%	2
1 to 10%	1
0%	0

Equation 9 $$BSS = \frac{(LBS+LBTi+LBTii+RBS+RBTi+RBTii)-(min\ total\ rating\ possible)}{(max\ total\ rating\ possible)-(min\ total\ rating\ possible)}$$

$$= \frac{(LBS+LBTi+LBTii+RBS+RBTi+RBTii)-0}{24-0}$$

Where: BSS = bank stabilisation score; LBS = left bank shrub rating; LBTi = left bank tree < 10 m rating; LBTii = left bank tree > 10 m rating; RBS = right bank shrub rating; RBTi = right bank tree < 10 m rating; RBTii = right bank tree > 10 m rating.

Note: the range standardisation process uses the theoretical minimum (in this case 0) and maximum (in this case 24) possible score (i.e. calculated from theoretical scenarios; not from actual scores occurring in trial SWMAs).

Integration

The *erosion extent component* and *bank stabilisation component* scores are integrated to calculate the *erosion sub-index* score by calculating an unweighted average (Equation 10).

Equation 10 $$ESI = \frac{EE+BS}{2}$$

Where: ESI = erosion sub-index; EE = erosion extent; BS = bank stabilisation

Missing data

To calculate a robust *erosion sub-index* score both components are required. If data are missing for one component it is recommended the *erosion sub-index* score is not calculated.

Data collection

The two components of the *erosion sub-index* are calculated from field-based observations of a sampling site (100 m in length).

Data for the *erosion extent component* were collected using the ‘banks and physical form’ section of the SWWA river health assessment field sheets (Appendix B). Evidence of erosion (e.g. undercutting, slumping, exposed roots, bare soil) was observed and the length of the affected left and right bank recorded in one of four bands (Figure 54). Note that data on the severity of erosion were also recorded in the field, but were not used in the scoring of the *erosion sub-index* (see *History* section).

BANKS AND PHYSICAL FORM

AMOUNT of erosion *Length of bank affected (%)*		
0 to 5%	**LB**	**RB**
>5 to 20%	**LB**	**RB**
21 to 50%	**LB**	**RB**
> 50%	**LB**	**RB**

SEVERITY of erosion, and bank stability	Circle	
Severe: LITTLE TO NO STRUCTURAL INTEGRITY Banks are predominantly bare. Significant sections of erosion (undercutting/slumping) on both outside bends and straight stretches (sediment deposits in river). Exposed roots obvious (where applicable), with significant loss of vegetation in eroding areas. Channel shape, bank shape and depth likely to change in near future.	**LB**	**RB**
High: POOR STRUCTURAL INTEGRITY Evidence of bank instability (undercutting/slumping); with signs of soil loss from banks, and possibly areas of sedimentation (i.e. sandbars or toes) and scouring. Some exposed roots (where applicable), with loss of vegetation in eroding areas. Erosion typically around outside bends.	**LB**	**RB**
Low-Moderate: GOOD STRUCTURAL INTEGRITY Banks relatively stable – exposed and superficially eroding bank (erosion doesn’t penetrate deeply into bank wall) or stabilised by only exotic grasses. Little likelihood of significant change to channel/bank shape, depth or loss of bank material in near future.	**LB**	**RB**
Minor: EXCELLENT STRUCTURAL INTEGRITY Banks stable and mostly intact (minor slumping, undercutting or bare banks expected naturally): stabilised by vegetation or bedrock.	**LB**	**RB**

Figure 54 Banks and physical form sections of the SWWA river health assessment field sheets (see Appendix B)

Data for the *bank stabilisation component* were collected using the ‘streamside zone vegetation’ section of the SWWA river health assessment field sheets (see Appendix B). The cover provided by the shrub and tree layers in the streamside zone (within 10 m of the bank) was observed along the left and right banks, and recorded as one of five bands of percentage cover (Figure 55). Note: for the second-round trial the streamside zone vegetation cover data were used as a surrogate for specific observations of bank vegetation, however in future the field sheets will be altered to include a section recording the vegetation characteristics on the bank itself (see *Recommendations*).

STREAMSIDE ZONE VEGETATION (FIRST 10m) - NATIVE AND EXOTIC VEGETATION

Percentage cover	0%		1 - 10%		10 to 50%		50 - 75%		> 75%	
	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB
Bare ground (not bedrock)										
Ground cover/grasses/sedges/rushes										
Shrubs (woody, multi-stem)*										
Trees < 10m										
Trees > 10m										

*Shrubs include Blackberry, Tea trees

Figure 55 Streamside zone vegetation section of the SWWA river health assessment field sheets (see Appendix B)

Data verification

Data from the field sheets were transferred to an Excel spreadsheet by one project officer and a randomly selected subset of data was checked by a second officer.

Data frequency

It is recommended that bank and physical form field observations are completed in late spring/early summer or autumn or when flows are low, to ensure maximum visibility of bank features. (Note: care must be taken to ensure that field operators differentiate between banks exposed due to erosion and those exposed due to low water levels). It is also recommended that bank and physical form field observations be completed in conjunction with streamside zone field observations and by the same team to reduce ambiguity between different field operators. If multiple assessments are conducted to assess temporal change in condition, it is recommended that field observations are made at approximately the same time of year as the initial observations, to avoid any influence of seasonal variability in vegetation cover and depth of exposed bank.

Erosion can occur both gradually (e.g. individual soil particles are dislodged by passing water) and rapidly (e.g. the undercutting or slumping of a bank during a high-flow event). The rate of change will depend on a number of factors which contribute to erosion, including existing erosion and bank stabilisation, geology, topography, geomorphic history, flow regime and climate (NRM South 2009). If the *erosion sub-index* is used to assess temporal changes at a site it is recommended the timeframe for repeating the assessment be tailored to the site in question. For example, if the site has a limited erosion extent and good cover of complex vegetation, repeat visits can be conducted infrequently (e.g. every five years). If the site has moderate erosion and moderate vegetation cover it may be susceptible to erosion and a more frequent sampling period (e.g. annual) may be appropriate to detect change.

Sensitivity and scenario testing

The *erosion sub-index* scoring protocol was tested to ensure the full range of scores between 0 and 1 could be obtained and that scores would respond sensitively to change. Scores were also tested against a range of scenarios to ensure the *erosion sub-index* scores complied with the condition bands recommended by the FARWH (NWC 2007a).

The *erosion extent* and *bank stabilisation* components are both range standardised to between 0 and 1. These scores are integrated by calculating an unweighted average (Equation 10), therefore a full range of scores between 0 and 1 can be obtained for the *erosion sub-index*.

Both components are calculated from field observations made within broad condition bands (tables 40 and 41). Temporal change in a site's condition will only be detected in component scores if the change is sufficient to result in a shift from one band to another. This suggests the *erosion sub-index* will only be sensitive to step-changes in condition, but this is considered to be an acceptable limitation. This is because more detailed field-observation bands can lead to greater operator variability and thereby reduce confidence in the field data and the resulting score.

A number of scenarios were created to ensure compliance with the FARWH condition bands:

- in a best-case scenario of a river in pristine forest with a natural level of erosion (Table 42, scenario A), the site would receive an *erosion sub-index* score of 1.0 which aligns with the FARWH category of 'largely unmodified' condition (score 0.8–1.0)
- in a scenario of a river in logged forest with some evidence of erosion (5–20% extent) and thinned vegetation cover (Table 42, scenario B), the *erosion sub-index* score is 0.71 which aligns with the FARWH category of 'slightly modified' condition (score 0.6–0.8).
- in a scenario of a river in agricultural land that has minimal erosion extent and no shrub or tree layer (Table 42, scenario C), the *erosion sub-index* score is 0.5 which aligns with the FARWH category of 'moderately modified' condition (score 0.4–0.6). (While this scenario is unlikely to occur – generally if the tree and shrub layer has been cleared erosion will be evident along the length of the site – the intention was to test the *erosion sub-index* scoring protocol to ensure it would adequately reflect all potential combinations of erosion extent and bank stabilisation.)
- in a scenario of a river with some erosion (21–50% extent) and a moderate shrub/tree layer (50–75% cover) (Table 42, scenario D), the *erosion sub-index* score is 0.5 which aligns with the FARWH category of 'moderately modified' condition (score 0.4–0.6). (Scenarios C and D illustrate that despite the different combinations of erosion extent and bank stabilisation, the resulting *erosion sub-index* scores are the same, and these combinations align with the FARWH condition categories.)
- in a worst-case scenario of a drain with eroded banks (> 50% extent) and no tree or shrub layer (Table 42, scenario E), the *erosion sub-index* score was 0 which aligns with the FARWH category of 'severely modified' condition (score 0–0.2).

Table 42 Scenario testing for erosion sub-index scores (assuming both banks are equal)

Scenario	Extent of erosion	Shrub % cover	Tree < 10 m % cover	Tree > 10 m % cover	Erosion extent score	Bank stability score	ESI score
A – river in pristine forest	0 - 5%	> 75%	> 75%	> 75%	1	1	1
B – river in logged forest	> 5–20%	50–75%	50–75%	50–75%	0.67	0.75	0.71
C – river with minimal erosion and no shrub/tree layer	0–5%	0%	0%	0%	1	0	0.5
D – river or drain with moderate erosion and reasonable shrub and tree layer	21–50%	50–75%	50–75%	50–75%	0.33	0.75	0.52
E – river or drain with extensive erosion and no shrubs/trees	> 50%	0%	0%	0%	0	0	0

Final reach scores

The *erosion sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 56. (Note: the 2008 assessment scores were calculated using a different field observation and scoring method compared with the 2009 assessment).

The reaches with the lowest scores (0.0–0.4) occurred in agricultural areas where the riparian vegetation had either been cleared or was highly disturbed (e.g. scattered trees, no shrub layer, groundcover dominated by exotic species). The 2008 assessment method did not include data on bank vegetation but a brief analysis of site photographs for all low-scoring sites suggested a similar pattern of vegetation disturbance occurred at most of these sites.

The exceptions to this pattern are the low-scoring reaches in the Shannon River and Denmark River SWMAs. These scores may be the result of field operator error (there was considerable discussion between operators before field observations were completed) or hydrological change in the river system causing changes in flow and consequent erosion. The pattern of low-scoring reaches in the Harvey River SWMA is similar to that for the *longitudinal connectivity sub-index* and the *artificial channel sub-index*, suggesting that erosion in this SWMA may be related to hydrological change as well as removal of riparian vegetation.

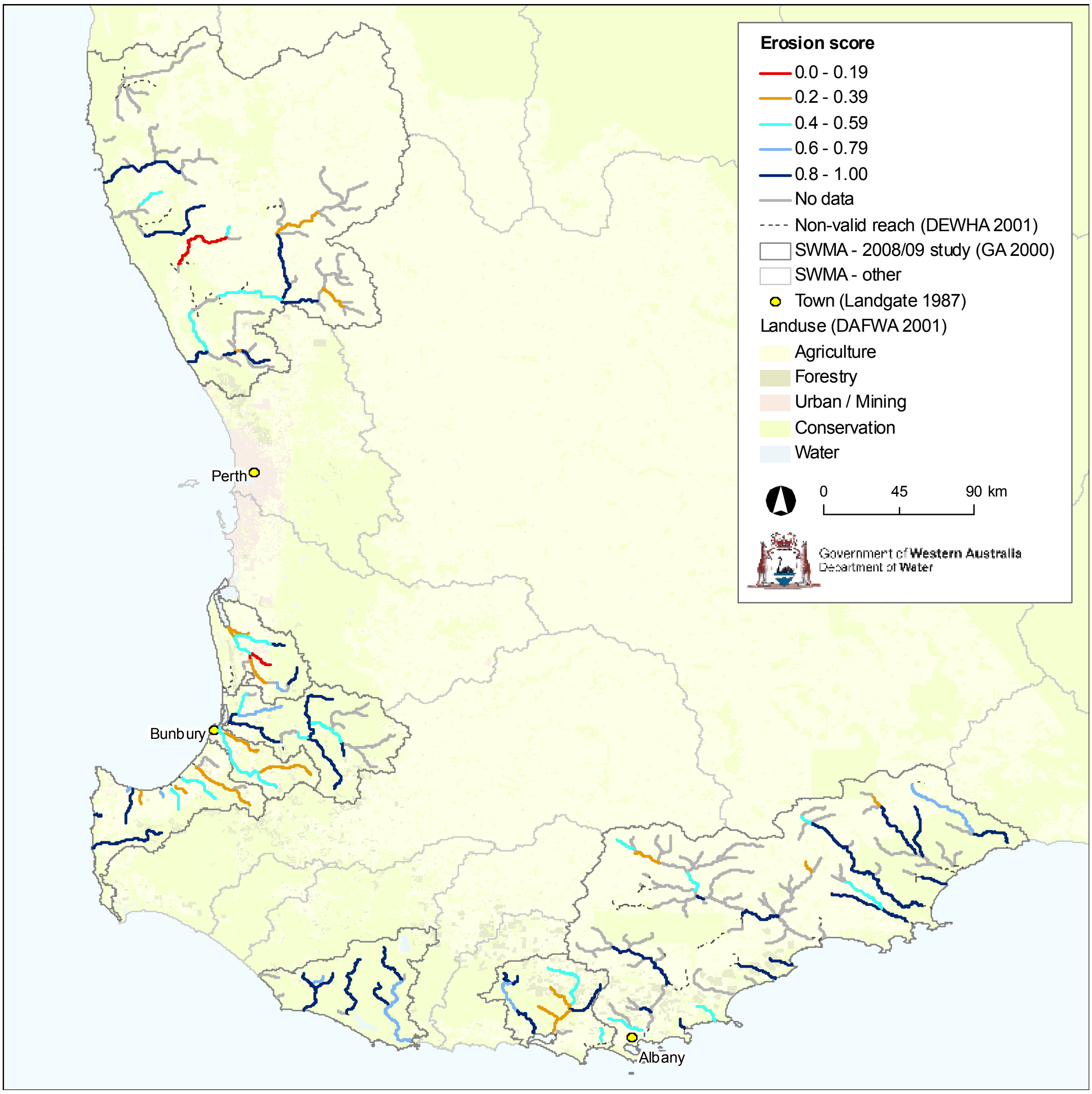


Figure 56 Erosion sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Power analysis

The number of samples required to detect a 10 or 20% change in the mean *erosion sub-index* score exceeded the number of reaches within every SWMA assessed in 2008 and 2009.

A table and graph depicting the results for the power analysis can be found in Appendix C.

Limitations

The *erosion sub-index* data collection methods and scoring protocol have several limitations. See the *Recommendations* section for a discussion on how to improve these aspects.

Field observations

Field observations about erosion extent and streamside vegetation cover are subjective and therefore prone to operator variability. While each operator was trained in the field, and field sheets were generally completed by two or more operators, some variability still occurs. It was not possible to quantify the degree of variability within the timeframe of the SWWA-FARWH project (see *Recommendations* section).

A subset of the 2009 streamside vegetation cover observations was verified by a panel of project officers who checked the *bank stabilisation component* score against a selection of photographs of the sites. Of the 19 sites verified, the field score and photograph grouping fell into the same FARWH condition band for nine sites; for five sites they varied by one category; and for five sites they varied by two categories. Further verification against a wider range of site photographs suggested the mis-matches were caused by the use of unrepresentative photographs in the verification process rather than by operator error in the field.

The *bank stabilisation component* scores were calculated from streamside-zone vegetation observations. The streamside zone is defined as the 10 m adjacent to the bank, therefore observations are not specific to the bank itself. However verification with photographs suggested these data provided a good indication of the vegetation on the bank itself, and were thus deemed a suitable surrogate for bank vegetation observations. Recommendations for improving these data are made in the section below.

Reference condition

The scoring protocol uses an assumed reference condition of '> 75% cover of shrubs and trees (< 10 m and > 10 m)' as a proxy for the presence of complex vegetation that provides bank stabilisation. It is therefore based on the expectation that shrubs, trees < 10 m and trees > 10 m will occur naturally at every site.

It is acknowledged this assumed reference condition may not apply across the whole study area (e.g. in areas where shrublands and sedgelands may have been the dominant natural vegetation type) but there is no comprehensive dataset that describes the vegetation cover of each layer (tree, shrub and ground) for pre-European times. As such it was not possible to derive a site-specific reference condition for shrub and tree cover for this indicator within the timeframe of the SWWA-FARWH project (see *Recommendations* section below). In lieu of this data, field operators should use judgement based on knowledge of vegetation existing at the site.

Recommendations

Field observations

Erosion severity was not used in scoring because of operator variability detected during photo verification (see *History* section below) – hence the *bank stabilisation component* was developed as a proxy. It is recommended the erosion severity observations be re-trialled using a series of separate observations about evidence of erosion, such as gullying, exposed soil, exposed tree roots, slumping and undercutting. Scores for these separate observations could then be combined to calculate an erosion severity score. This approach is used in the Tropical Rapid Appraisal of River Condition (Dixon et al. 2006).

It is also recommended that testing be undertaken during field trials to measure operator variability and field sheets be modified to reduce variability wherever possible.

Reference condition

It is recommended that a regional reference condition be created for the percentage cover of shrub and tree layers in pre-European times. To date no comprehensive dataset exists, however it may be possible to construct one based on the literature about current vegetation communities. This was not completed for the 2008 and 2009 assessment because it was beyond the timescale and resources of the SWWA-FARWH project.

Other indicators

No other indicators were investigated for the *erosion sub-index*.

History

This section has been included to aid future developers of the river health assessment program for SWWA. The following methods were trialled during development of the SWWA-FARWH, and although most appear an obvious inclusion, due to a range of limitations they did not sufficiently reflect health.

The *erosion sub-index* was developed during the first-round trial of the FARWH in SWWA, although it was named the sedimentation index in recognition of its use as a proxy for modelled sedimentation data. Observations about the severity of erosion were made in the field and translated directly into five scores (Table 43).

Table 43 Field assessment and scoring of erosion in the first round of trials

Category	Description	Score
Stable	Very few eroding banks, none of which are at the toe of the bank; continuous cover of woody vegetation; gentle slope; very few exposed roots of woody vegetation; erosion resistant soils.	1
Limited erosion	Some isolated bare eroding banks, though generally not at the toe of the bank; cover of woody vegetation is nearly continuous; few exposed roots of woody vegetation. Bank not vertical or undercut.	0.75
Moderate erosion	Some bank instabilities that extend to the toe of the bank (which is generally stable); discontinuous woody vegetation; some exposure of roots of woody vegetation. Bank may have gentle or vertical slope.	0.5
Extensive erosion	Mostly unstable toe of the bank; may be vertical bank with toe. Little woody vegetation; many exposed roots of woody vegetation.	0.25
Extreme erosion	Unstable toe of bank; no woody vegetation; very recent bank movement (trees may have recently fallen into stream); steep bank surface; numerous exposed roots of woody vegetation; erodable soils.	0

During the first-round trial field work, some operator variability was noted anecdotally (although this has not been quantified to date), with a lack of continuity caused by confusion between severity and extent of erosion. For example, a tall bank with an isolated area of slumping would be categorised as extreme, while a short bank with continuous undercutting would be observed as limited erosion.

In recognition of this inconsistency, the field sheets for the second-round trial were amended to include separate observations about severity and extent of erosion (Figure 54). This improvement anecdotally reduced the operator variability at most sites.

During development of the scoring protocol within the second-round trial, several scoring options were investigated that assigned scores to the erosion extent and erosion severity, which were then integrated to form an overall indicator.

Option 1: erosion extent and erosion severity observations were assigned scores in four condition bands (Table 44). Scores for left and right bank erosion extent were averaged to give a site score; scores for left and right bank erosion severity were averaged to give a site score; the two scores were then averaged to give an overall *erosion sub-index* score.

Table 44 Option 1 scoring bands

Erosion extent	Score	Erosion severity	Score
0 to 5%	1	Severe	0
> 5 to 20%	0.75	High	0.25
21 to 50%	0.25	Low-moderate	0.75
> 50%	0	Minor	1

Option 2: as per option one except the extent and severity were averaged together to give a score for each bank, and then averaged to give an overall *erosion sub-index* score. This resulted in very similar scores to option 1.

Option 3: extent and severity observations were allocated a nominal value between 1 and 4 (Table 45). Values for left and right bank erosion extent were averaged to give a site value; values for left and right bank erosion severity were averaged to give a site value (X); the site values were added together to calculate an overall value for erosion; the site value was range standardised to give an index value of between 0 and 1 (Equation 11).

Table 45 Option 3 scoring bands

Erosion extent	Value	Erosion severity	Value
0 to 5%	4	Severe	1
> 5 to 20%	3	High	2
21 to 50%	2	Low-moderate	3
> 50%	1	Minor	4

Equation 11 $$Range\ standardised\ ESI\ score = \frac{X-(min\ value\ possible)}{(max\ value\ possible)-(min\ value\ possible)}$$

Where: X = sum of values for site erosion extent and site erosion severity.

Note: the range standardisation process uses the theoretical minimum (in this case 2) and maximum (in this case 8) possible scores (i.e. calculated from theoretical scenarios; not from actual scores occurring in trial SWMAs).

An initial review of the results for the 2009 assessment sites – calculated using option 3 – suggested the scores did not meet expectations in all cases. For example, several floodwater drains with trapezoid channels stabilised only by shallow-rooted annual grasses scored between 0.8 and 1. While this reflected the minor extent and severity of erosion at these sites, the potential for future erosion was felt to be significant due to the lack of complex vegetation stabilising the banks. In addition, a score of between 0.8 and 1 implies 'largely unmodified' condition according to the FARWH condition bands (NWC 2007a) and it seemed inappropriate for a watercourse with completely artificial physical form to achieve this score.

The erosion scores were reviewed further by a panel of project officers. Panel members were asked to assign photos of 20 sites of variable erosion extent and severity into five broad categories of bank condition. The panel scores were compared with the scores calculated using option 3: there was a close correlation between the field- and photo-based groupings in terms of erosion extent, but a mismatch between field- and photo-based groupings of erosion severity. Panel discussions highlighted that operator variability during field observations was the most likely cause of the mismatch. Consequently the severity observations were discarded and the *bank stabilisation component* was developed to give a measure of potential future erosion.

Physical Form index summary

Integration and aggregation of indicators

The three sub-index scores (*longitudinal connectivity, artificial channel* and *erosion)* were integrated into the overall *Physical Form index* using the standardised Euclidean Distance as recommended in the FARWH (NWC 2007b) (Equation 12). This integration technique is used where the sub-indicators measure different aspects of physical form, which are then brought together to estimate overall status (NWC 2007a).

Equation 12 $$PFI = 1 - \frac{\sqrt{(1-LCSI)^2+(1-ACSI)^2+(1-ESI)^2}}{\sqrt{3}}$$

Where: PFI = Physical Form index; LCSI = longitudinal connectivity sub-index; ACSI = artificial channel sub-index; ESI = erosion sub-index.

Reach-scale *Physical Form index* scores were aggregated to SWMA scores by calculating a length-weighted average of the reach scores as recommended in the FARWH (NWC 2007a).

Missing data

The *Physical Form index* is intended to provide a measure of the impacts of anthropogenic activity on habitats at three levels (whole-of-system habitat, macrohabitats and microhabitats) via the three sub-indices. If data were missing for one of the three sub-indices an overall *Physical Form index* score can be calculated from the two remaining sub-indices.

All required data were available for the 2008 and 2009 assessment. Missing data was an issue for the 2005 assessment, where reach scores could only be calculated for the *artificial channel sub-index*.

Sensitivity analysis

The scoring protocol was tested to ensure the full range of scores between 0 and 1 could be obtained and that scores would respond sensitively to change.

Each sub-index of the *Physical Form index* has been designed to ensure a full range of scores between 0 and 1 are obtainable. Integration using the standardised Euclidean Distance precludes the weighting of the sub-indices, therefore it is possible to obtain the full range of scores between 0 and 1 for the *Physical Form index*.

The *Physical Form index* score is sensitive to an increase or decrease of 0.1 or 0.2 in just one of the sub-index scores, suggesting it is sensitive to change (Table 46, scenarios A to E).

Table 46 Examples of sensitivity of Physical Form index scores to changes in the sub-index scores and relevance of Physical Form index scores to the FARWH scoring bands

Scenario	LCSI	ACSI	ESI	PFI
A – score of 1.0 for all three sub-indices	1.0	1.0	1.0	1.0
B – change of 0.1 in score for one sub-index results in a change of 0.1 for the PFI score	1.0	1.0	0.9	0.9
C – score of 0.0 for all three sub-indices	0.0	0.0	0.0	0.0
D – change of 0.1 in score for one sub-index does not result in a change for the PFI score (due to rounding to one decimal place)	0.0	0.0	0.1	0.0
E – further change of 0.1 for one sub-index results in a change of 0.1 for the PFI score	0.0	0.0	0.2	0.1
F – agricultural – dam on reach u/s (within 5 km), completely artificial channel, limited erosion but also limited stabilising vegetation	0.3	0.0	0.3	0.2
G – conservation – no barriers and low intensity of crossings, no artificial channel, limited erosion and good stabilising vegetation	0.9	1.0	1.0	0.9
H – drinking water catchment (headwaters) – dam within 20 km d/s, no artificial channel, some erosion and good stabilising vegetation	0.5	1.0	0.8	0.7

The *Physical Form index* also displays relevance when practical scenarios are tested against the FARWH scoring bands (Table 46, scenarios F, G and H). For example, a watercourse in an agricultural area that has been converted to a drain, cleared of tree and shrub vegetation, and has a dam on a neighbouring reach (within 5 km) receives a *Physical Form index* score of 0.2 which falls in the 'severely modified' condition band (Table 46, scenario F). A watercourse in a conservation area with no barriers within 40 km and a low intensity of road/rail crossings, no channelisation, limited erosion and good bank vegetation cover scores 0.9, which falls in the 'largely unmodified' condition band (Table 46, scenario G).

Final reach scores

The *Physical Form index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 57. Note that of the 234 reaches included in the 2008 and 2009 assessments, the *Physical Form index* scores for 60% of reaches were calculated using *artificial channel sub-index* and *longitudinal connectivity sub-index* scores only, as it was not possible to conduct field work for every reach. The remaining 40% of reaches were sampled and the *Physical Form index* scores were calculated using all three sub-index scores.

The Moore-Hill, Albany Coast and Shannon River SWMAs generally scored reasonably well. This reflects the small number of dams located on the rivers in these catchments as well as the relatively small number of road crossings present. While erosion was present in these catchments (and in some cases this was severe), only a relatively small proportion of reaches were assessed for erosion (as this required a field visit). Therefore, the generally good scores for the other two sub-indices resulted in a reasonable overall score.

The remaining five SWMAs all scored more poorly, with the Harvey River SWMA returning the lowest scores. These SWMAs have a higher density of road crossings and more dams present. Further, many reaches in the Harvey River SWMA have been modified into drains to help remove water from the agricultural areas.

The integration approach taken for the *Physical Form index*, using standardised Euclidean Distance, places the emphasis on the sub-index showing the greatest departure from reference condition. Consequently the reach scores for the *Physical Form index* scores follow a similar pattern to the *artificial channel sub-index* scores (Figure 53), although it should be noted that the reaches with a lower *Physical Form index* score also had a low score for one or both of the other sub-indices.

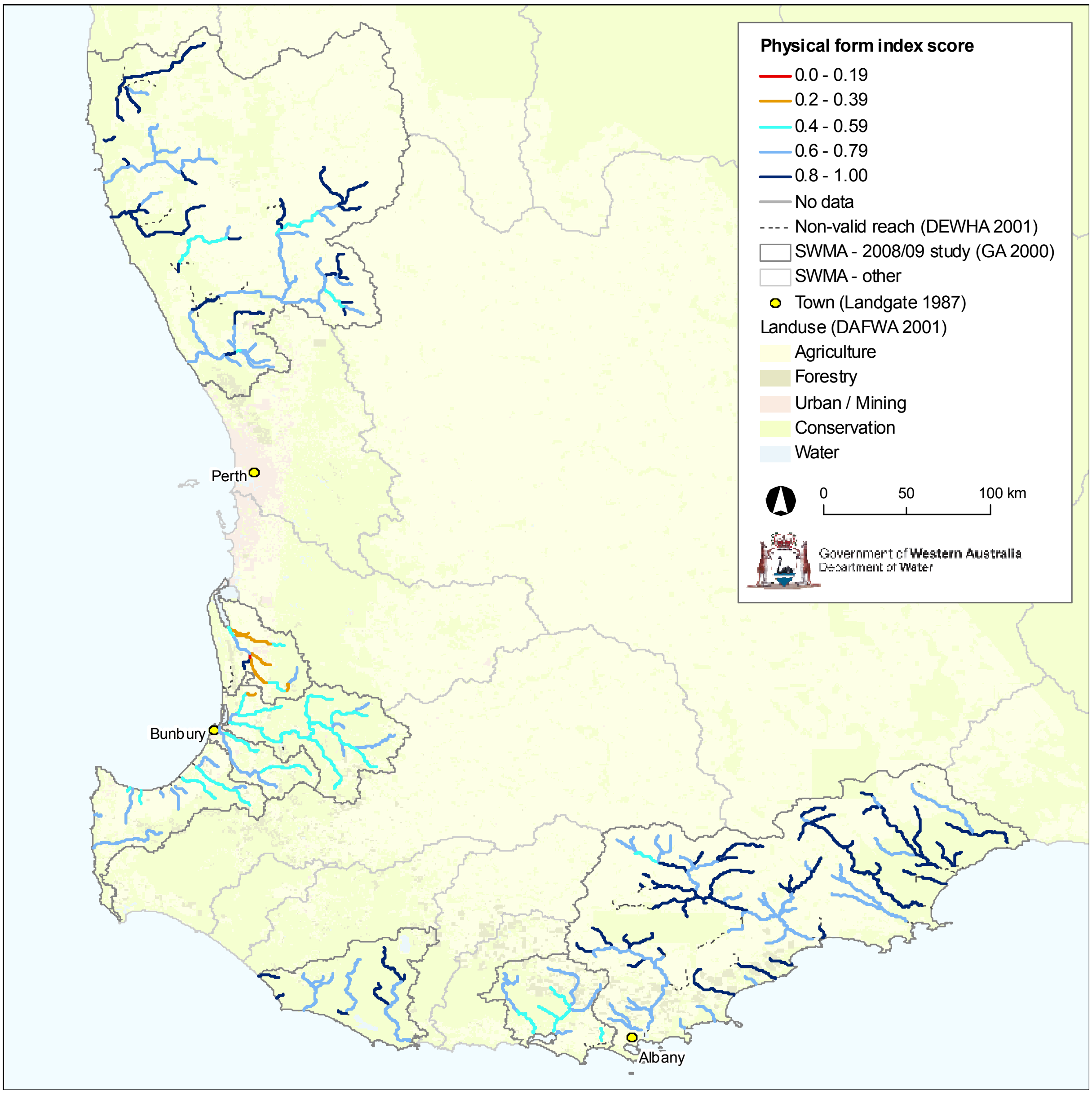


Figure 57 Physical Form index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Statistical analysis

The relationships between the indicators of the *Physical Form index* were examined to determine whether any redundancies existed. A significant low correlation exists between the *erosion* and *artificial channel* sub-indices (r = 0.38; p = < 0.05).

Despite a low correlation being observed it is likely some of the sites were highly correlated. This would be expected at sites that have been channelised and have unstable banks either due to poor vegetation or stock access.

Limitations of the Physical Form index

Limitations of the *Physical Form index* are primarily a function of the limitations of the sub-indices (refer to relevant sections). In addition, the *Physical Form index* does not include information on all possible habitat types (e.g. bed substrate, large woody debris, macrophytes etc.). This is not a limitation per se because the score represents the features intended, and should be interpreted accordingly; however, there is potential for the *Physical Form index* to become more reflective of habitat health as new indicators evolve.

Recommendations

It is recommended that:

- the scoring protocols for all three sub-indices use an assumed reference condition (In the TRCI reference condition has been defined by classifying rivers into different types according to valley setting, gradient and planform, adapted from the RiverStyles™ framework (Brierley & Fryirs 2005).)
- the possibility of defining geomorphic benchmarks for rivers in SWWA be investigated (In the TRCI geomorphic benchmarks were created for each river type documenting stream character, pre-European conditions and likely degradation processes. Examples of moderate or poor conditions for that particular river type are given to enable sites to be scored (NRM South 2009).)
- the methods and scoring protocols for the sub-indices be reviewed as data sources are verified (*longitudinal connectivity sub-index*), finer resolution data become available (*artificial channel sub-index*) or data collection methods are refined (*erosion sub-index*). (If new data become available it may be possible to add further sub-indices to evaluate additional habitat aspects, see the *Other indicators* section below.)

Other indicators

Several other indicators were investigated for inclusion in the *Physical Form index*.

Bed-load condition (sedimentation)

The FARWH recommends using an indicator of bed-load condition, based on sediment deposition modelled at a reach-scale using SedNet (NWC 2007a). The suitability of SedNet for use in SWWA was investigated, but expert opinion suggested that three of the input datasets (gully erosion, bank erosion, hill erosion) were not of sufficient quality to generate accurate results from the model, and that the model would need to be modified to include the impact of sediment from drains – which may be a significant source in Western Australia (Scott Wilkinson pers. comm. 2010).

Mapping the gully, bank and hill erosion in SWWA is a considerable task and was beyond the SWWA-FARWH project's scope and resources. In addition, SedNet takes between weeks and months to apply depending on the availability and quality of data (CRCCH 2005) and would require skilled officers, thus making it less accessible for future application than field-based indicators.

Field-based observations of sedimentation were included on the round-two (2009) field sheets but there was notable operator variability in the results, so the development of an indicator was not pursued.

Lateral connectivity

The FARWH recommends the inclusion of a lateral connectivity indicator to measure the impact of restricted floodplain connectivity on the health of a reach. The ARC 2005 used mapping of lateral barriers (levees) from the Wild Rivers project for NSW, Victoria and South Australia (NWC 2007b) (see Table 68). To date it has not been possible to source sufficient data on lateral barriers for SWWA so this indicator was not pursued. Note: there are lateral barriers in parts of SWWA; for example, sections of the Preston River are flanked by levees on both sides. However, the role of floodplains in south-west systems requires more research before data can be effectively integrated into river health analysis.

Farm dams

The *Inception report – volume 1: SWWA-FARWH* (van Looij & Storer 2009a) suggested the inclusion of an indicator based on the presence of farm dams in the catchment of a reach. Data sources for this indicator were investigated but found to be unsuitable for the whole study area. In addition, after considering the impact of farm dams on surface and stream flow it was decided that it was more appropriate to consider them within the *Hydrological Change index* (van Looij et al. 2009a).

4.5 Theme: Fringing Zone

The Fringing Zone theme encompasses the structural and floristic features and condition of the streamside zone (NWC 2007b). There is a distinct focus on the health of vegetation existing in a corridor either side of rivers and streams. For the SWWA-FARWH program, the size of this corridor has not been considered as a fixed element, but rather depends on the aspect of health under assessment. For instance, assessing the role of fringing vegetation as a buffer for runoff may require a corridor of more than 50 m from the bank, whereas the condition of riparian vegetation (e.g. in terms of shading attribute) may be limited to the first few metres from the streambank.

Fringing zone vegetation exists at the interface of aquatic and terrestrial environments and the interactions between these two adjacent ecosystems contribute to the complexity of structure and processes within riparian zones (Naiman & Decamps 1997). Fringing vegetation also influences the adjoining landscapes. For example, riparian vegetation relies on periodic inundation from the river, and itself has an influence on the movement of water across the landscape (Rutherfurd et al. 2004).

Fringing vegetation can affect river health in a number of ways: examples of these are summarised in Table 47 (adapted from the *Draft national indicator protocol:*

riverine (riparian) vegetation being developed by the River Health Contact Group (RHCG 2009)).

Table 47 Attributes of fringing vegetation (from RHCG 2009)

Shading
• Reduction of light for periphyton/phytoplankton and aiding in the prevention of algal blooms (Quinn et al. 1997; Roberts et al. 2004) • Moderation of temperature fluctuations (Rutherford et al. 2004) • Influences on photosynthetic activity through effects on both light and temperature
Providing a food source for native fauna
• Debris for detritivores (Wallace et al. 1997; Pusey & Arthington 2003) • Source of organic carbon (Sheldon & Thoms 2006; Bunn et al. 2006), with associated influence on trophic structure (DoW 2006)
Increasing bank stability
• Prevention of erosion (McKergow et al. 2003; Abernethy & Rutherfurd 1999)
Provision of habitat
• Habitat for water-dependent fauna (e.g. water rats, turtles, birds) (Price et al. 2004; DoW 2006) • Direct relationship with aquatic habitat; woody debris as structural habitat for fish (Pusey & Arthington 2003) and macroinvertebrates (Wallace et al. 1997) • Migration corridor for native fauna (e.g. crayfish, turtles) (DoW 2006)
Filtering of nutrient and sediments
• Buffer for inputs carried on overland flow (Naiman & Decamps 1997; Mayer et al. 2006); nutrients, pathogens, turbidity, waterborne spread of weeds (George et al. 1995; DoW 2006) • Interception of water before reaching watercourse; reducing rapid runoff from storm events • Removal (absorption) of nutrients (DoW 2006)
Physical barrier
• Deterring human/stock access (DoW 2006)

Given the strong reciprocal relationship between the health of fringing zone vegetation and both river health and level of catchment impact, it is a critical component of a river health assessment.

Indicator selection

A study commissioned by the NLWRA office, the *Riverine vegetation mapping scoping study* (SKM 2000), encompassed a review of riparian vegetation across Australia. This study recommended that the condition of riparian vegetation be measured in terms of the vegetated stream length, especially with respect to the abundance and continuity of tree cover and the presence of exotic species. Such an approach is supported within the FARWH guidelines (NWC 2007b) and was seen as particularly appropriate where clearing is the major threat to riverine vegetation (NWC 2007b). Clearing of native vegetation in SWWA is reported at approximately 81% and around 93% in the agricultural zone (Avon River SWMA) (DEC 2007).

The *Draft national indicator protocol: riverine (riparian) vegetation* (RHCG 2009) recommends several indicators of riparian vegetation (Table 48), which support and expand on those suggested above. This document also supports the need for methods to be referential, with a reference point equating to pre-European times (1750s), which is also a fundamental aspect of the FARWH (NWC 2007a).

Table 48 Attributes and possible components for assessing streamside vegetation (RHCG 2009)

Sub-indices	Attributes and possible components	Remote/field
Spatial integrity	• Width of riparian vegetation (as defined by inundation-dependent species) • Longitudinal continuity – continuous cover of dominant stratum along the channel • Connectedness of the riparian vegetation to other areas of native vegetation (riparian or terrestrial)	Remote sensing
Nativeness	• Percentage of non-native species • Abundance of non-native species in different strata • Presence and abundance of high-impact species	Field
Structural integrity	• Number of strata and/or life forms • Cover for each stratum	Field
Age structure	• Presence (or abundance) of different ages or stages	Field
Debris	• Presence (or abundance) of standing dead trees • Abundance of fallen logs • Percentage cover of litter	Field

For SWWA there is insufficient information to determine reference for a number of the components described above (see *Other indicators* section at the end of this theme review), however the *spatial integrity* and *nativeness* sub-indices were highlighted as particularly promising given data availability and their ability to be included in a rapid field-assessment method.

The specific indicators chosen for the SWWA-FARWH are described below.

Scoring method and reference condition

For the SWWA-FARWH, three components were trialled within two sub-indices. Other indicators (e.g. the NDVI or greenness index) that were investigated but not adopted are discussed later in this section. The chosen sub-indicators were:

1 *Extent of fringing zone*

a *fringing vegetation length*

b *fringing vegetation width*

2 *Nativeness* (extent of exotics)

This is similar to the approach of other river health programs in Australia (see Table 49), but techniques were simplified to reduce time taken for field assessments and maximise consistency of field officers' observations. This was also due to a current lack of ability in SWWA to define reference for structural complexity of fringing vegetation – and thus quantify impact at fine scales (to be addressed in future).

Table 49 Fringing zone assessments within the major river health programs existing in Australia

River health program	Fringing vegetation assessment	Comment
CFEV (Tasmania)	Vegetation context (tree assemblages)	Assessment of extent of vegetation remaining. Used modelled tree assemblages to provide vegetation context (statewide distribution of riparian vegetation not available). Model assumes pre-European conditions. Calculated (desktop) percentage area of natural vegetation remaining (based on specified tree assemblage or class) within a 50 m buffer on either side of the river. Score affected by presence of exotic willows.
TRCI (Tasmania)	Indicators: extent of vegetation, organic litter, logs, high-threat weeds, recruitment, canopy cover, number of species, cover, longitudinal continuity, large trees, patch size, neighbourhood, distance to core area.	The streamside zone assessment includes 13 components (see left). Of these components patch size, neighbourhood and distance to core area are assessed remotely, while the others are assessed in the field. Scores are calculated for each site by comparing observed values for each component to benchmark values specified for the vegetation type. Benchmarks have been developed for most vegetation communities that occur in Tasmania through the Tasmanian Vegetation Mapping Program (TASVEG).
ISC (Victoria)	Indicators: width, large trees, understorey, life forms, recruitment, longitudinal continuity, tree canopy, litter, logs, weeds.	The streamside zone assessment is based on a comparison between the current condition of a site (as represented by indicators on left) compared with its Ecological Vegetation Class (EVC) benchmark. EVC is a vegetation community defined by its plant species and location in the landscape. This is based on expected conditions without human impacts.
SRA (Murray Darling Basin)	Fringing zone not currently assessed. Proposed assessment for fringing zone in place.	Proposed channel-floodplain vegetation at two spatial scales. Tier 1: tracking catchment-scale changes in the extent and type of riverine vegetation relative to reference condition. Repeated every six years, mostly using satellite imagery. Tier 2: characterising vegetation at reach scale, based on field data. Indicators related to taxonomic composition and disturbance, nativeness/weediness, function (e.g. regeneration, crown coverage) and structure.
EHMP (QLD)	Fringing zone not currently assessed. Proposed assessment as part of the FARWH trials (see right)	Vegetation structure: identify and quantify relative proportion of Major Vegetation Group classes using remote sensing data and GIS. Compared against data from undisturbed structural conditions with guidelines values. Vegetation condition: quantification of the relative proportion of alien vegetation species using existing data and field observations (based on reference conditions). Longitudinal connectivity: per cent of foliage projected cover from existing remotely collected data (based on reference).

The scale at which fringing zone indicators are assessed varies from program to program and depends on the indicator, available data and the required management outcome.

For a reach-scale assessment (such as the FARWH) remote sensing is often recommended because GIS mostly enables the reach's entire length to be assessed. A loss of sensitivity can be associated with remotely sensed data (due to factors such as resolution (pixel size) and/or age of data) but they are not necessarily weaker than field-collected data, which has issues related to how much area can be covered and variability between field officers' interpretations. In addition, remote sensing options are typically significantly less costly (time, labour) providing appropriate datasets already exist. Field assessments are recommended when finer detail than can be obtained from most GIS layers is required. For instance, the presence of exotic species or information about vegetation occurring below the canopy requires field assessment.

The *extent of fringing zone sub-index* was assessed for an entire reach using remote sensing (GIS), whereas the *nativeness sub-index* was assessed at a field site (100 m). The rationale for specific methods is described in the sections below.

Note: structural elements outside of the upper-most canopy, such as understorey and shrub layers existing underneath the tree canopy, are not directly assessed within indicators selected for the SWWA-FARWH. However, aspects of these elements are included in the *nativeness sub-index* (see review). The justification for excluding these elements from direct assessments is covered in *Other indicators* at the end of this theme review.

Sub-index: extent of fringing zone

Both width and length components were calculated for the *extent of fringing zone sub-index*, which were assessed remotely for the entire reach.

A number of datasets were investigated to determine their suitability for scoring. Consideration was given to the datasets' spatial extent, their scale and update frequency. The Land Monitor Vegetation Extent datasets (see Table 68) were selected. These raster datasets are derived from Landsat 5 Thematic Mapper images and show the extent of perennial vegetation at a 25 m x 25 m pixel scale. They cover the agricultural area of SWWA, from Kalbarri to Cape Arid, and are updated annually by Landgate for the Land Monitor project (Furby et al. 2009).

To calculate the *extent of fringing zone sub-index* scores the Reconstructed Reaches dataset was used (see Table 68). Note: use of this dataset in preference to the ARC reaches was particularly applicable for the *extent of fringing zone sub-index* [see Summary Box 5].

Summary Box 5:

The decision to reconstruct the reach dataset was based on the observation that those presented in the ARC reaches dataset often did not overlie the actual location of streamlines on the ground. As there are vegetation corridors of varying widths along many SWWA streams, using the ARC reaches dataset would have underestimated the amount of vegetation present along the reaches. This is due to the coarsely-defined ARC reaches often falling in cleared agriculture or urban areas outside of the vegetation corridor.

Figure 58 shows an example of the disparity between the ARC reaches dataset, the 1:250 000 topographic mapping data and the actual stream location as shown by aerial photography. The disparity between the ARC reaches dataset and the actual streamline was measured in the order of a few kilometres in some areas.

Figure 58 Example of the disparity between the ARC reach dataset, the GEODATA TOPO 250K dataset and the actual streamline on the Brunswick River in the Collie SWMA

Component: fringing vegetation length

This component measured the percentage of the reach length that is vegetated (perennial vegetation only).

Longitudinal continuity, or the length of continuous vegetation without breaks of greater than 10 m, was initially intended to be used for the FARWH assessment. However, the best vegetation dataset available consisted of 25 m pixels and as such would not detect gaps of 10 m. Therefore, a simple indicator based on percentage of length of a reach that was vegetated (regardless of gaps) was developed. Note: other datasets were available with finer-scale resolution, but due to factors such as age of data or spatial coverage, they were not used. *Longitudinal continuity is a recommended indicator for future assessment when resolution of appropriate datasets is improved.*

To generate scores for the *fringing vegetation length component*, Land Monitor Vegetation Extent datasets for 2005, 2008 and 2009 (converted from raster to vector) (see Table 68) were used. The Reconstructed Reaches were clipped to the vegetation dataset and the length of perennial vegetation (expressed as a percentage of the total reach length) was calculated. Note: perennial vegetation includes trees, shrubs and groundcover combined (only non-perennial vegetation is excluded, such as exotic grasses). Reference condition (pre-European) was assumed to be 100% vegetation coverage. The associated score was calculated using Equation 13.

Equation 13: $FVLC = \frac{1}{100} \times percent\ of\ length\ vegetated$

Where: FVLC = fringing vegetation length component; 100% vegetated = score 1.0; 50% vegetated = score 0.5; 0% vegetated = score 0.0

Sensitivity analysis

Sensitivity analysis was primarily conducted by assessing scores against aerial photography and site descriptions, and looking at general correlations against knowledge of associated impacts (e.g. land use). Figure 59 displays scores for the *fringing vegetation length component*. Note: the 2008 reach scores (Albany Coast, Collie River and Moore-Hill Rivers SWMAs) were updated (from the first trials report, van Looij et al. 2009) using the 2009 Reconstructed Reaches and the 2008 Land Monitor perennial vegetation dataset.

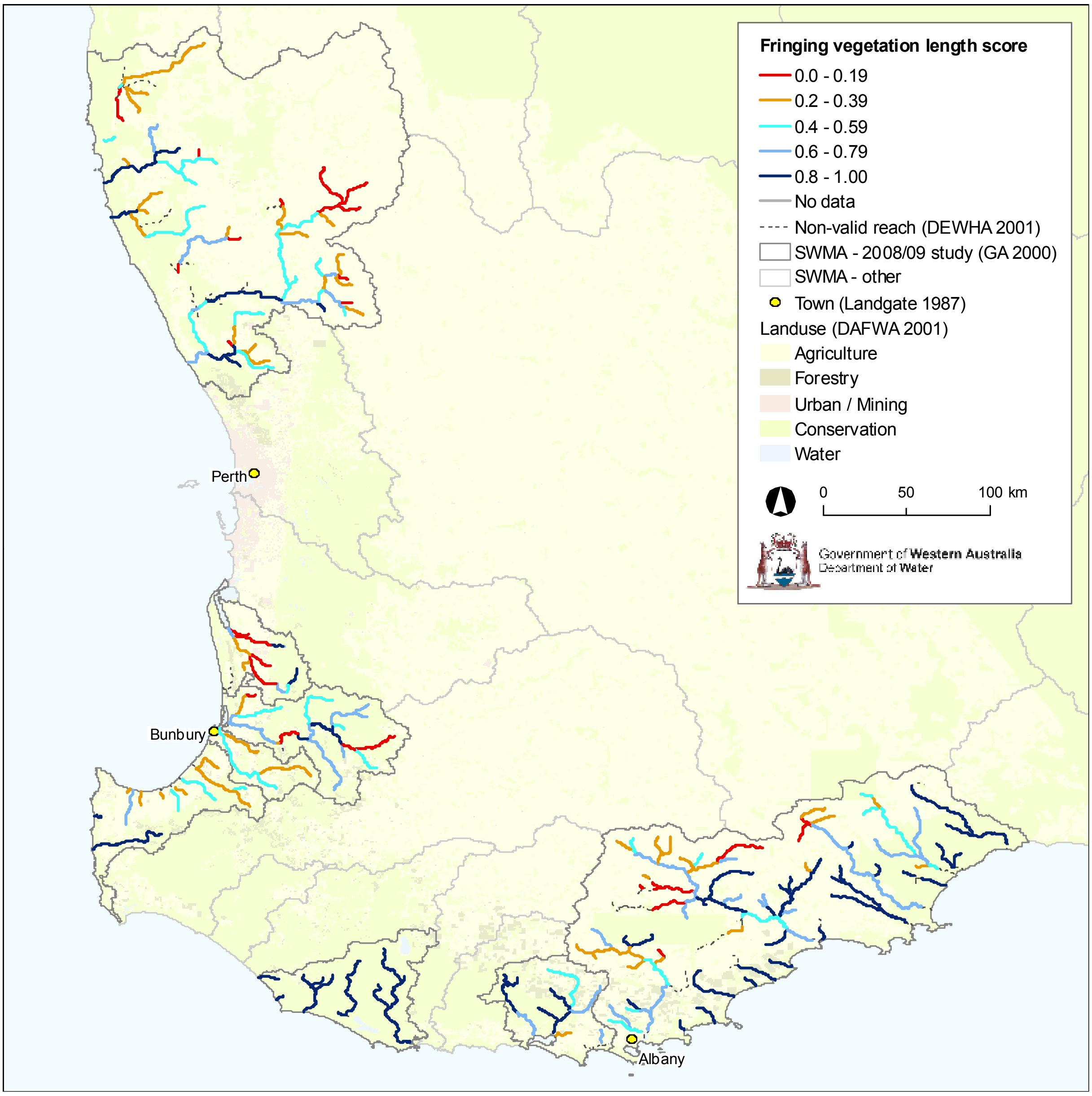


Figure 59 Fringing vegetation length component scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

The *fringing vegetation length component* scores showed impacts within the full scale scored against, with areas of 'severely' and 'substantially modified' vegetation (particularly in upper reaches) through to 'pristine' areas, particularly within the Shannon River SWMA. Furthermore, it does not appear this component is influenced by any natural condition feature (e.g. climate, land form, altitude) and as such is detecting anthropogenic impacts.

The scores depicted above were also shown to correlate well with expected associated impacts, such as land use. The SWWA-FARWH's final summary will expand on this relationship.

Based on the above, the *fringing vegetation length component* is strongly supported for future use in the SWWA-FARWH.

Power analysis

As this component was calculated for all reaches a power analysis was not done.

Frequency of assessment and limitations

These are discussed in the theme summary.

Component: fringing vegetation width

This indicator was initially intended to be used to score the riparian zone. This was revised and the scoring now relates to the fringing zone. This decision is due to the naturally expected differences in riparian vegetation width in SWWA, and no data on expected riparian widths [see Summary Box 6]. Further, as one of the key reasons to measure riparian width is to indicate stream buffering capacity against surrounding land uses, it was decided that measuring fringing zone width was more robust.

> *Summary Box 6*
>
> Riparian vegetation varies from very wide (typical of lowland rivers) and naturally narrow (less than 1 m in some headwater streams) to almost non-existent in some bedrock-dominated areas. Note: these are generalisations and could not be used with the current level of knowledge as appropriate strata.

The width of vegetation was compared against a reference condition of 100% coverage, based on the assumed pre-European condition. The vegetation data used for this assessment (Land Monitor Vegetation Extent 2007 datasets, see Table 68) include trees, shrubs and groundcover combined (only non-perennial vegetation is excluded, such as exotic grasses). This was measured against a standardised corridor width. Recommendations for appropriate buffer widths to minimise impacts from surrounding land use depend on management objectives (see Table 50); from this a precautionary approach was taken, with a 50 m width being selected.

Table 50 Assessments on recommended width of vegetation corridor required to protect river health

Width	Reference
Recommended minimum width: 5–10 m for most management objectives, up to 30 m for fish and terrestrial habitat	Price et al. 2004
Minimum 20 m	WRC 2000
20 m width criteria for verge vegetation score	WRC 1999
30 m for a ‘foreshore reserve’ (setback for residential subdivision)	WAPC 2002
10 m grassed and 10 m native veg	Askey-Doran et al. 1996
50 m critical minimum buffer zone	Roberts et al. 2009

Fringing vegetation width was measured from the Land Monitor Vegetation Extent datasets for 2005, 2008 and 2009 (see Table 68). These datasets show the presence or absence of perennial vegetation, but differences in vegetation structure (trees, shrubs) and in native or exotic species are not distinguished. Width was calculated by generating transects at 90º from the reach, extending 50 m from the reach line (generally the centre of the watercourse), spaced at 50 m intervals. Transects were clipped to the Vegetation Extent dataset and the width of transects adjacent to the reach were measured: this indicated continuous vegetation from the bank. From this the average width of vegetation was calculated.

This was then converted to a score out of one by dividing by 50 (the average width that would be obtained in a reference situation where no clearing of the fringing zone had occurred). See Equation 14.

Equation 14 $FVW = \frac{1}{50} \times \frac{(W_{T1} + W_{T2} + W_{T3} \ldots\ldots + W_{Tn})}{n}$

Where: FVW = fringing vegetation width component score; W_{T1} = width of fringing zone in transect 1; W_{T2} = width of fringing zone in transect 2 and so on. n = total number of transects in the reach.

From Equation 14:

- 50 m of vegetation = score 1
- 25 m of vegetation = score 0.5
- zero vegetation = score 0

Appropriate spacing between transects along a reach was considered. As the dataset being used has a 25 m^2 pixel size, a transect spacing of 25 m was selected as a minimum and the average vegetation width of a number of test reaches was calculated. This was repeated for spacings of 50, 100, 150, 200, 250, 500 and 1000 m to determine the most appropriate transect spacing. Figure 60 shows the average vegetation widths calculated using the different spacings for two reaches.

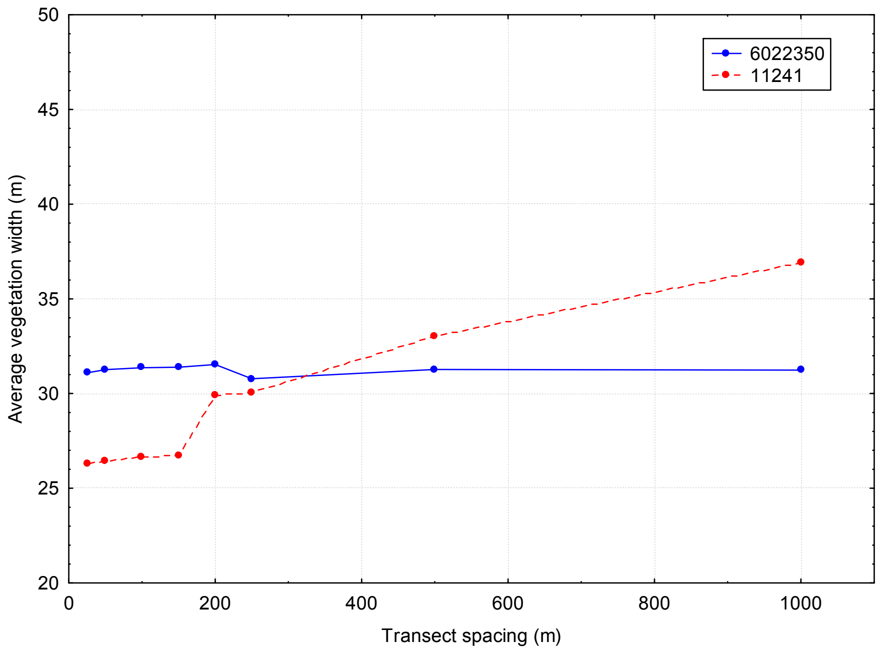


Figure 60 Average vegetation widths (to a maximum of 50 m) for different transect spacings in two reaches

As can be seen in Figure 60, transect spacings up to about 150 m give similar results. The computational time for calculating the average vegetation width varies very little between the transect spacings so this is not a limiting factor. A transect spacing of 50 m was selected for performing the final measurements based on these trial measurements and the observation that a spacing of 25 m led to duplication. This duplication occurs where transects fall near a sharp river bend: because transects are placed at a 90° angle to the river it is possible for transects to overlie each other where there is a bend in a river, resulting in the same area being measured twice (Figure 61). A transect spacing of 50 m reduced this duplication. Note: if field assessment is used to generate fringing vegetation data in the future, based on the above results a transect spacing of 50 m is also recommended in terms of both efficiency and accuracy.

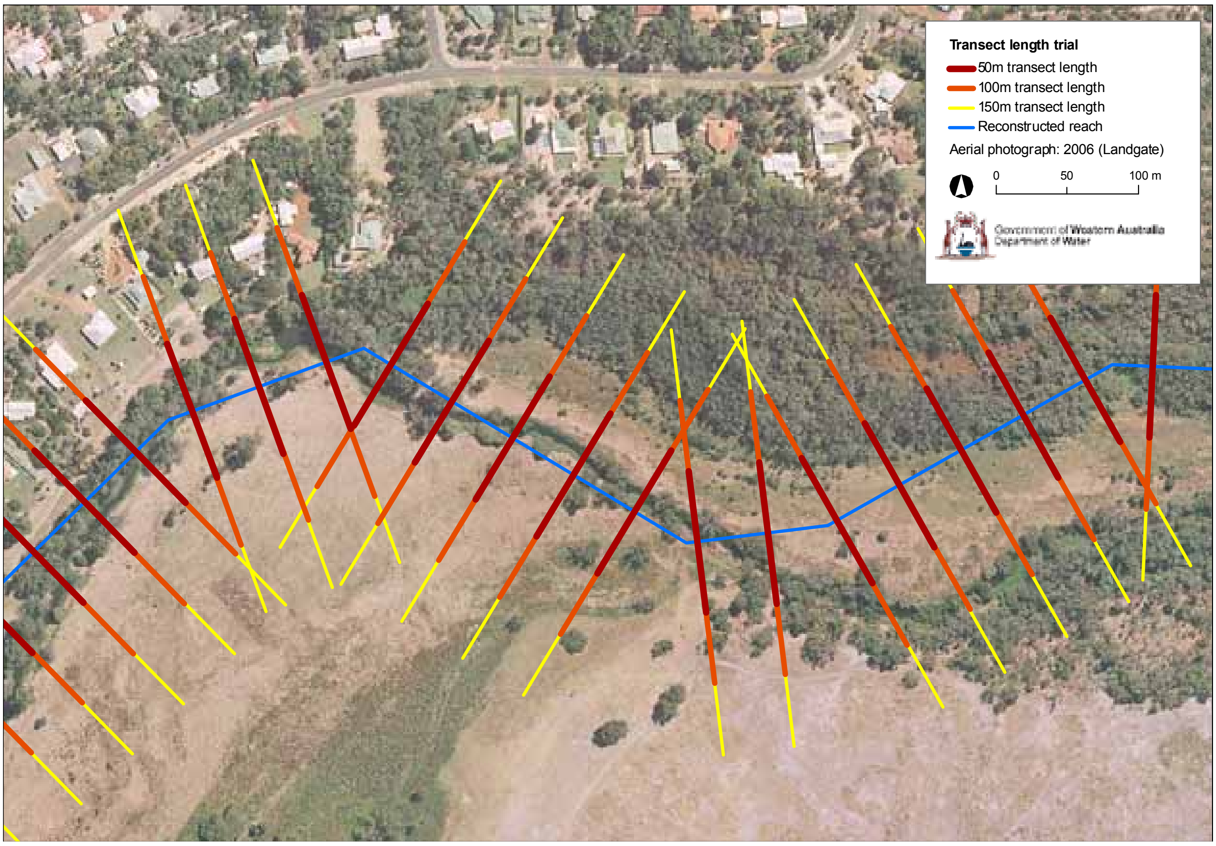


Figure 61 Potential duplication errors caused by overlapping transects (dependent on transect length and angle of curve of river bend)

Note: other river health programs, such as ISC and TRCI, use buffer widths dependent on river size. Although this approach is supported, it was not adopted because methods for the SWWA-FARWH use remote-sensed data and there is no dataset of river widths available for the study area. If data on the size of rivers become available in the future, the method could be adapted to incorporate different reference conditions for vegetation width.

Sensitivity analysis

Sensitivity analysis was primarily conducted through assessment of scores against aerial photography and site descriptions, and looking at general correlations against knowledge of associated impacts (e.g. land use). Figure 62 displays scores for the *fringing vegetation width component.*

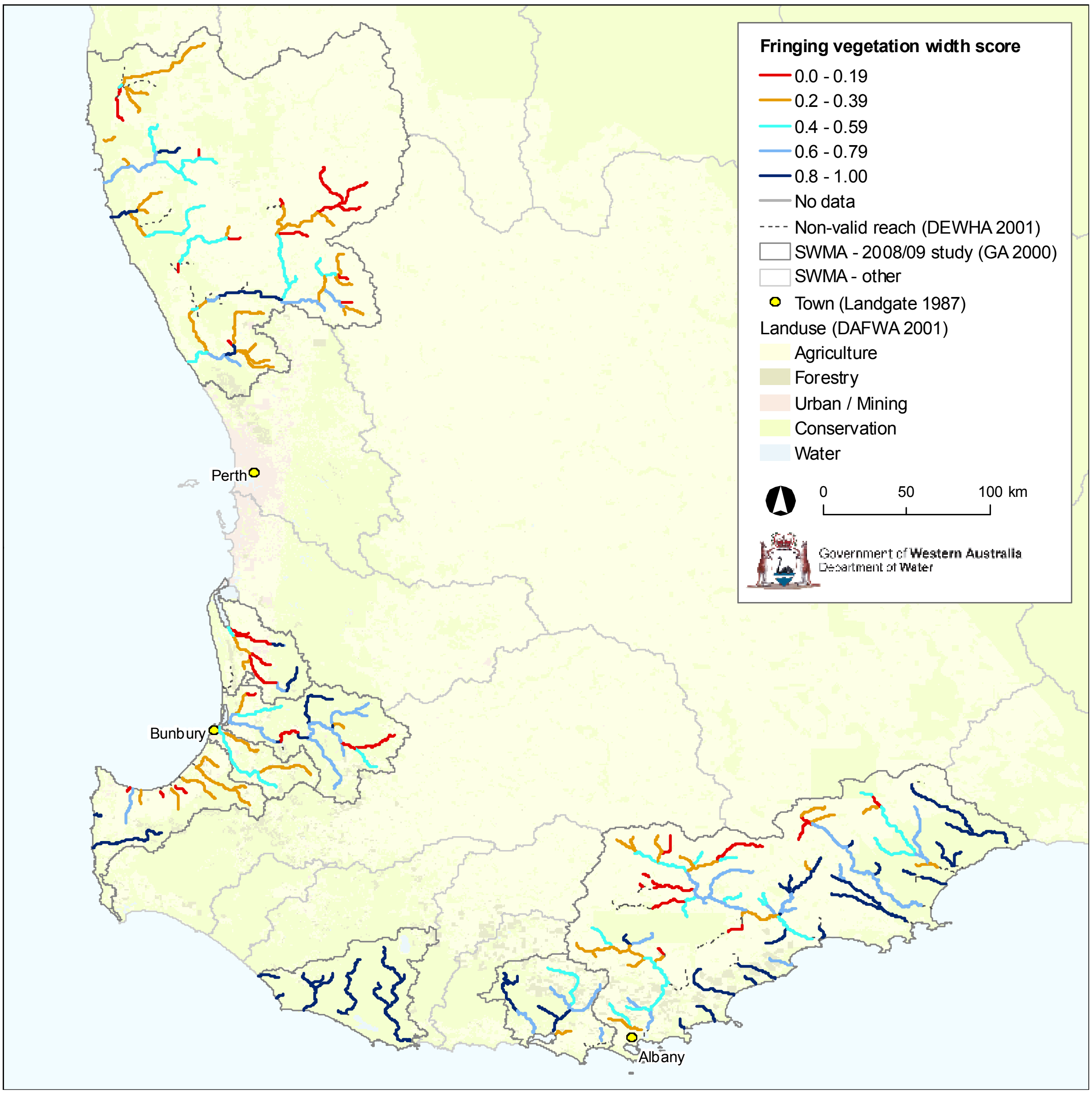


Figure 62 Fringing vegetation width component scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

The *fringing vegetation width component* scores showed impacts within the full scale scored against, with areas of 'severely' and 'substantially modified' vegetation (particularly in upper reaches) through to 'pristine' areas, particularly within the Shannon River SWMA. Furthermore, it does not appear this component is influenced by any natural condition feature (e.g. climate, land form, altitude) and as such is detecting anthropogenic impacts.

The scores depicted above were also shown to correlate well with expected associated impacts, such as land use. The SWWA-FARWH's final summary will expand on this relationship.

Based on the above, the *fringing vegetation width component* is strongly supported for future use in the SWWA-FARWH.

Note: the two components of the *extent of fringing zone sub-index* (width and length) showed strong correlation, however it was shown this did not reflect redundancy. This is explained further in the *Theme integration and aggregation* section later in this section.

Power analysis

As this component was calculated for all reaches a power analysis was not conducted.

Data verification

Documentation supplied with the Vegetation Change product describes the following accuracy issues with the data (Furby et al. 2009):

- Perennial vegetation mapping is based on the spectral signature of light being reflected from different types of land cover, which is detected by a satellite sensor. Classification of land cover types requires contrast between spectral signatures, and a certain density of vegetation is required to categorise an area as perennial vegetation; hence areas with sparse coverage of perennial vegetation (e.g. tracks, rocks, fire scars, salt-affected areas) may be classified as non-perennial cover.
- Areas of revegetation will not be classified as perennial vegetation until the density reaches a sufficient level; hence there is a lag in the detection of revegetated areas.
- Land cover with a similar spectral signature to perennial vegetation (e.g. persistent dark soil, lake fringes and changes from dry to wet lake surfaces) may be incorrectly classified. Data smoothing techniques are applied but some areas of error may remain.

An assessment of the Vegetation Extent data's accuracy compared with detailed aerial photography found the data's overall accuracy was 99% (Bryant & Wallace 2001).

Frequency of assessment and limitations

This is discussed in the theme summary.

Sub-index: nativeness

Analysis of the *extent of fringing zone sub-index* highlighted a significant gap in its ability to describe the health of the fringing zone. This was primarily seen in agricultural areas (typically sheep and cattle, and to a lesser extent cropping), where an intact (to semi-intact) tree-layer canopy masked a non-existent or exotic-dominated understorey (Figure 63).

Figure 63 Typical agricultural land use, where understorey is dominated by exotic grasses

To ensure this type of scenario was assessed appropriately a number of trials were conducted (explained below) and from these the *nativeness sub-index* was developed. Nativeness is an indicator of the proportion of exotic species in the groundcover (described in more detail later).

Note: exotics are a direct indicator of impact and were also shown to be a reasonable surrogate for native structural integrity. In field trials and scenario analysis, it was found that the percentage of exotics typically reflected the health of native groundcover and shrub layers. This finding is understandable given that invasive species take advantage of stressed systems (Storer et al. 2005).

Scoring and reference condition

To score the *nativeness sub-index*, exotics (percentage as a portion of total vegetation cover) were assessed in the field for a 100 m site (groundcover only was used for this indicator, but all layers were assessed in the field). Assessments were confined to a 10 m corridor on both banks.

The proportion of exotic cover was calculated for each bank and then an average was taken for the site. Note: if more than one site existed on a reach (small number of occurrences), then data were averaged. A reference condition of 0% exotics was used, and scores were based on percentage cover of exotic species within five bands (as described in the field), as follows:

Table 51 SWWA-FARWH bands used to score proportion of exotic species present in the river corridor (percentage in 10 m corridor)

Nativeness (% exotics as a portion of total vegetation)	SWWA-FARWH score
0%	1
1–10%	0.8
> 10–50%	0.6
> 50–75%	0.2
> 75%	0.1

No zero score was assigned, as a site with > 75% weeds would still provide some habitat and buffering capacity due to any remaining native species and/or the ability (although reduced) for exotic species to take on some of the role of the native vegetation. It is well reported that although grassy buffers are effective for trapping sediment and reducing water flow, native vegetation is recommended for riparian buffers as it can provide better levels of stream shade, habitat and natural inputs than exotic understorey (EPA 2001). However, natural and grassy filter strips can trap around 90% of the sediment movement from upslope (Price & Lovett 2002).

Sensitivity analysis

Based on field observations and post-hoc comparisons between sites using photographic evidence, it was apparent the extent of invasion of exotic plants followed an obvious pattern. This pattern reflects the nature of invasive species, where some systems (rare) have no non-native species (most likely because little human contact has occurred post-European settlement), some systems have limited exotics (where species have been introduced into systems with a resilient native population), and the remainder of systems are dominated by exotics, primarily grasses (typical of agricultural areas where native vegetation has been cleared). This pattern was represented by the bands assigned for the SWWA-FARWH, as is represented in the final scores for the *nativeness sub-index* (Figure 64).

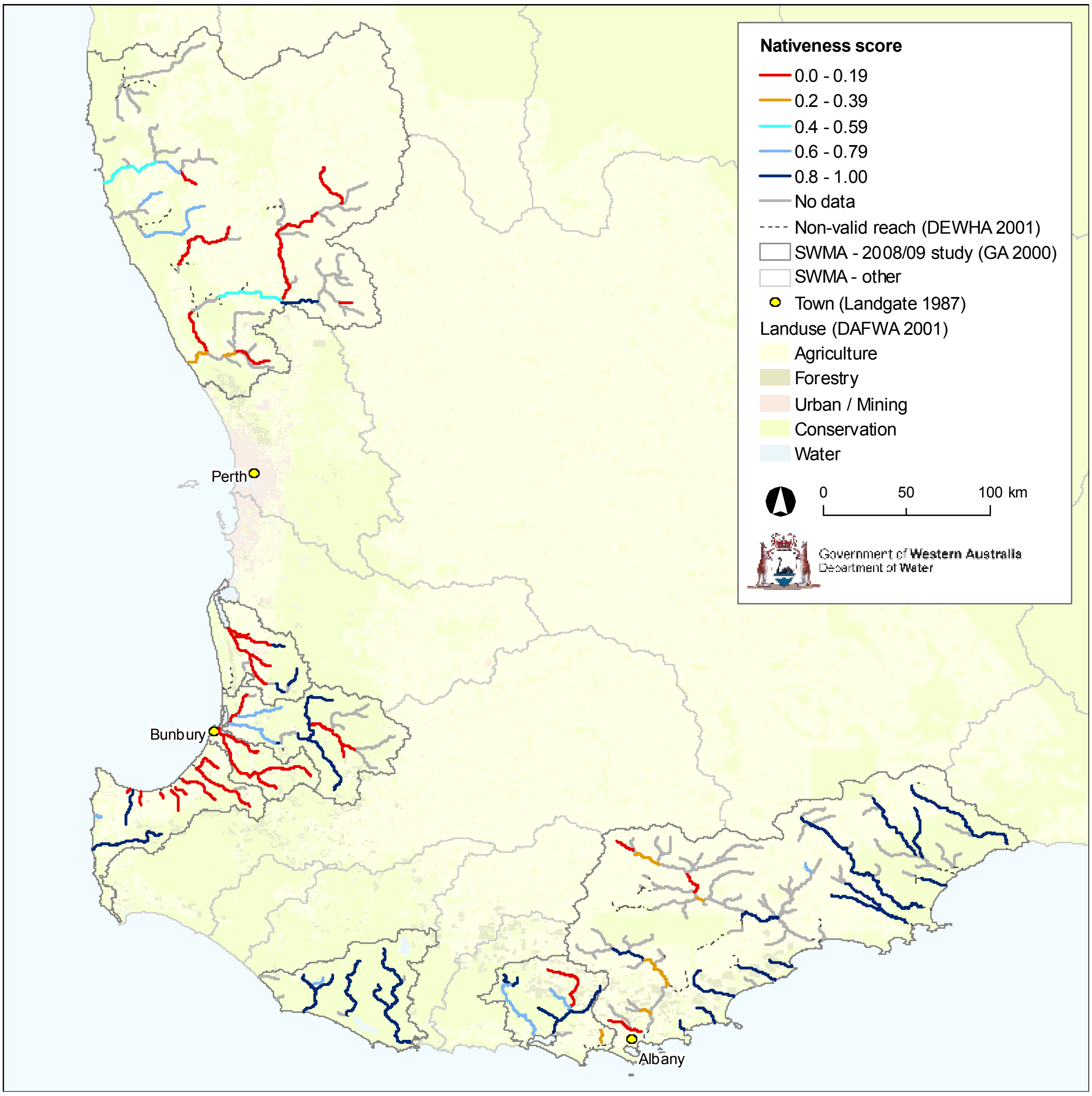


Figure 64 Nativeness sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials.

As Figure 64 shows, the *nativeness sub-index* score is dominated by extremes: either 'largely unmodified' or 'severely modified', which reflects the pattern discussed above. Note: the middle categories are mostly populated by systems in an intermediate phase, or where one bank of a river has been affected while the other remains protected (often due to different management actions depending on the landholder).

Nativeness sub-index scores were generally correlated with the *extent of fringing zone* indicators, yet there are many examples where an intact fringing zone (as represented by width and length components) has a high degree of impact identified by the *nativeness sub-index*. This follows observations made in a number of systems, where unconfined livestock has resulted in a complete loss of understorey (replaced by exotic grasses) while the upper canopy remains (see Figure 65).

Figure 65 Photographs of river corridors, where the understorey has been replaced due to clearing and/or foraging from livestock, yet large trees persist

The reaches described as 'severely modified' by the *nativeness sub-index* align well with the more intensive agricultural areas in the SWWA study area. In particular this is seen in irrigated regions, where access to drains has often resulted in the riparian zone's complete removal and its replacement with exotic grasses. The only exception is the Albany Coast SWMA's eastern area, where exotic species are not abundant even in cleared areas – due perhaps to climatic conditions and high salinity.

Based on how the *nativeness sub-index* provides differentiation across rivers within the study area, along with the increased level of information it provides over the *extent of fringing zone sub-index*, the *nativeness sub-index* is supported within the SWWA-FARWH protocol.

Power analysis

Power analysis requires that all reaches be assessed to represent the sample population for this sub-index. A table and graph depicting the results for the power analysis can be found in Appendix C.

Data verification

As this sub-index was based on field data, all information had to be downloaded from field sheets. This process was conducted by one project officer and double-checked by a second project officer via random selection of sites.

The correct assessment of extent of exotics was evaluated post-hoc through analysis of photographic evidence, including video. As was introduced above, the extent of exotics generally followed an obvious pattern and thus errors in field assessments were not found.

Frequency of assessment and limitations

This is discussed in the theme summary.

Fringing Zone index summary

Integration and aggregation

Integration of the *extent of fringing zone* and *nativeness* sub-indices is equally weighted, with the *extent of fringing zone* an unweighted average of length and weight components. For reaches not assessed in the field, the *Fringing Zone index* was calculated based on the *extent of fringing zone sub-index* only.

Analysis of the width and length component scores showed a strong correlation, as they are not mutually exclusive in terms of cause. However, the two components returned different scores in many cases, differentiating systems where narrow corridors of vegetation were protected (less impacted in terms of length) but beyond this the adjacent land was cleared (impacted width). As such, the strong correlation between components is not a reflection of redundancy. In saying this, due to the strong correlation, the two components were combined to indicate the overall extent, which could be compared against the degree of ‘nativeness’.

Aggregation to the SWMA scale is done by calculating the length-weighted average of all the reach scores, as per NWC (2007a).

Sensitivity analysis

Appropriate sensitivity of the individual components and sub-indices of the *Fringing Zone index* has been demonstrated (based on the national scale of reporting required for the FARWH) in the sections above.

Integration methods were also analysed to determine fitness against FARWH scoring bands. An internal expert panel ranked the overall health of fringing vegetation at 20 sample sites against results from scoring protocols under a range of possible weighting scenarios. The following review highlights the resulting site groupings based on equal weighting of sub-indices – the integration method chosen. Note: the panel assessment included 10 people, photographic evidence of each site, and instructions to place sites in order of impact to the riparian zone only.

Category: 'severely modified' condition (0.0–0.2)

Sites falling into this category should reflect an almost total loss of riparian structural integrity.

In SWWA, sites falling into this category were either totally impacted due to clearing and associated intensive (unfenced) agriculture or were part of maintained drainage networks. The example below (Figure 66) illustrates a typical drain site; that is, dominated (> 75% cover) by exotic species. In this case, the *extent of fringing zone sub-index* results in the site being placed in the appropriate category (as assessed by the expert panel). The *nativeness sub-index* is valuable in highlighting the benefits that the exotic grasses and watsonia provide, such as bank stabilisation, even though the remaining stability can be seen as temporary. In many cases, the banks of such drains are relatively free of erosion and offer some protection to runoff from catchments, thus should not score zero.

Fringing Zone index score: 0.05 (extent: 0.00, nativeness: 0.10)

Figure 66 Example photos of site with Fringing Zone index score of 0.05 – 'severely modified' condition

Category: 'substantially modified' condition (0.2–0.4)

For the SWWA-FARWH, this category was dominated by typical farming sites with a relatively dense but narrow riparian zone in terms of canopy. There is some structural intactness (i.e. mixture of shrubs and trees), with a significant invasion of exotic grasses from the surrounding agricultural area (see Figure 67 below).

Fringing Zone index score: 0.20 (extent: 0.29, nativeness: 0.10)

Figure 67 Example photos of site with Fringing Zone index score of 0.20 – 'substantially modified' condition

A number of sites where the immediate area bordering the river has been cleared, but with intact vegetation behind it, also sit in this category. This is seen in a number of managed drainage systems or where flood control measures have been undertaken (dredging). It is also common, to varying extents, in some of the more intensive recreational areas.

The second example (see Figure 68) is common of a river that is now more drain-like. Several large trees remain but the riparian zone is reduced and highly invaded by exotic grasses. In this case the riparian zone is slightly more stable than in the previous category and provides additional benefits due to organic material that is available to the aquatic environment (habitat and food).

Fringing Zone index score: 0.33 (extent: 0.57, nativeness: 0.10)

Figure 68 Example photos of site with Fringing Zone index score of 0.33 – 'substantially modified' condition

Figure 68 shows the *Fringing Zone index* scoring has become more sensitive (as determined by the expert panel) by adding in the *nativeness sub-index*. (Using the *extent of fringing zone sub-index* alone would see the site falling into the 'moderately modified' condition band – and close to the 'slightly modified' band.)

Category: 'moderately modified' condition (0.4–0.6)

Sites in this category appear to represent a transitional phase in condition. Depending on the level of management it is expected that sites in this category will improve or decline rapidly. This is expected because exotic species, with opportunity and without management, will rapidly dominate a site and their fitness (tolerance to light and temperature) will commonly prevent re-establishment of natives.

Sites in this category often display some degree of canopy loss and a significant invasion of the understorey by exotics.

The example below shows a site in 'moderate' condition. The site is fenced on both sides, providing a corridor of protection from livestock of around 10–15 m. As can be seen from the photo on the right, the structural integrity of the site is breaking down in some areas. This highlights an unsustainable fringing zone protection corridor.

Fringing Zone index score: 0.46 (extent: 0.71, nativeness: 0.20)

Figure 69 Example photos of site with Fringing Zone index score of 0.46 – 'moderately modified' condition

Category: 'slightly modified' condition (0.6–0.8)

Sites in this category typically have a near-pristine canopy (trees and/or shrubs), based on remotely sensed data used to generate the *extent of fringing zone sub-index*. Based on this sub-index alone they would be placed in the 'largely unmodified' band. However, the inclusion of the *nativeness sub-index* reduces the final *Fringing Zone index* score. This was viewed as appropriate by the expert panel, as it reflects the reduction in stability and loss of habitat and food diversity that would be provided to the aquatic environment.

The example below shows a common observation in SWWA systems where exotic grasses are gradually replacing understorey species – a situation that needs to be highlighted. The value of the *nativeness sub-index* in this situation does highlight a reduction in health, and stands out on interrogation of theme scores.

Fringing Zone index score: 0.77 (extent: 0.94, nativeness: 0.6)

Figure 70 Example photos of site with Fringing Zone index score of 0.77 – 'slightly modified' condition

<u>*Category: 'largely unmodified' condition (0.8–1.0)*</u>

This site has a pristine riparian zone with no exotic weeds. Note: sites naturally consisting of large areas of exposed bedrock have the potential for a reduced score, because the *extent of fringing zone sub-index* will pick this up as loss of canopy. Field officers need to be aware of this to adjust scores appropriately. In future, SWWA river systems require assessment for typology (including this scenario) to adjust reference conditions to account for these anomalies.

Fringing Zone index score: 1.00 (extent: 1.0, nativeness: 1.0)

Figure 71 Example photographs of sites with Fringing Zone index score of 1.00 – 'largely unmodified' condition

Site appearance not representing Fringing Zone index score

The *Fringing Zone index* appears to place sites into appropriate bands, as determined by the expert panel and general knowledge of reach conditions. However, in a few cases sites did not match expectations.

Figure 72 shows a site placed into the bottom category by the *Fringing Zone index* score, however photographic evidence would suggest it should be in a healthier category.

Fringing Zone index score: 0.14 (extent: 0.18, nativeness: 0.10)

Figure 72 Example photos of sites not matching Fringing Zone index score expectations

In these situations, the erroneous result appears related solely to the *extent of fringing zone sub-index* – due to this being assessed at a reach rather than site scale (the site is not necessarily representative of the extent of the fringing zone across the entire reach). This is certainly not a limitation of the *extent of the fringing zone sub-index*, as assessments are made at reach scales, however it does imply a limitation of the *nativeness sub-index* (due to field-based assessment), where field sites do not represent reach conditions. This finding is a typical challenge of any river health assessment and relates to the need to measure health at randomly selected sites across a reach over time.

As this is not applicable to a FARWH snapshot-style assessment, it is an unavoidable error.

Theme scores

The final scores for the *Fringing Zone index* based on the SWMAs assessed in the SWWA-FARWH trials are provided in Figure 73.

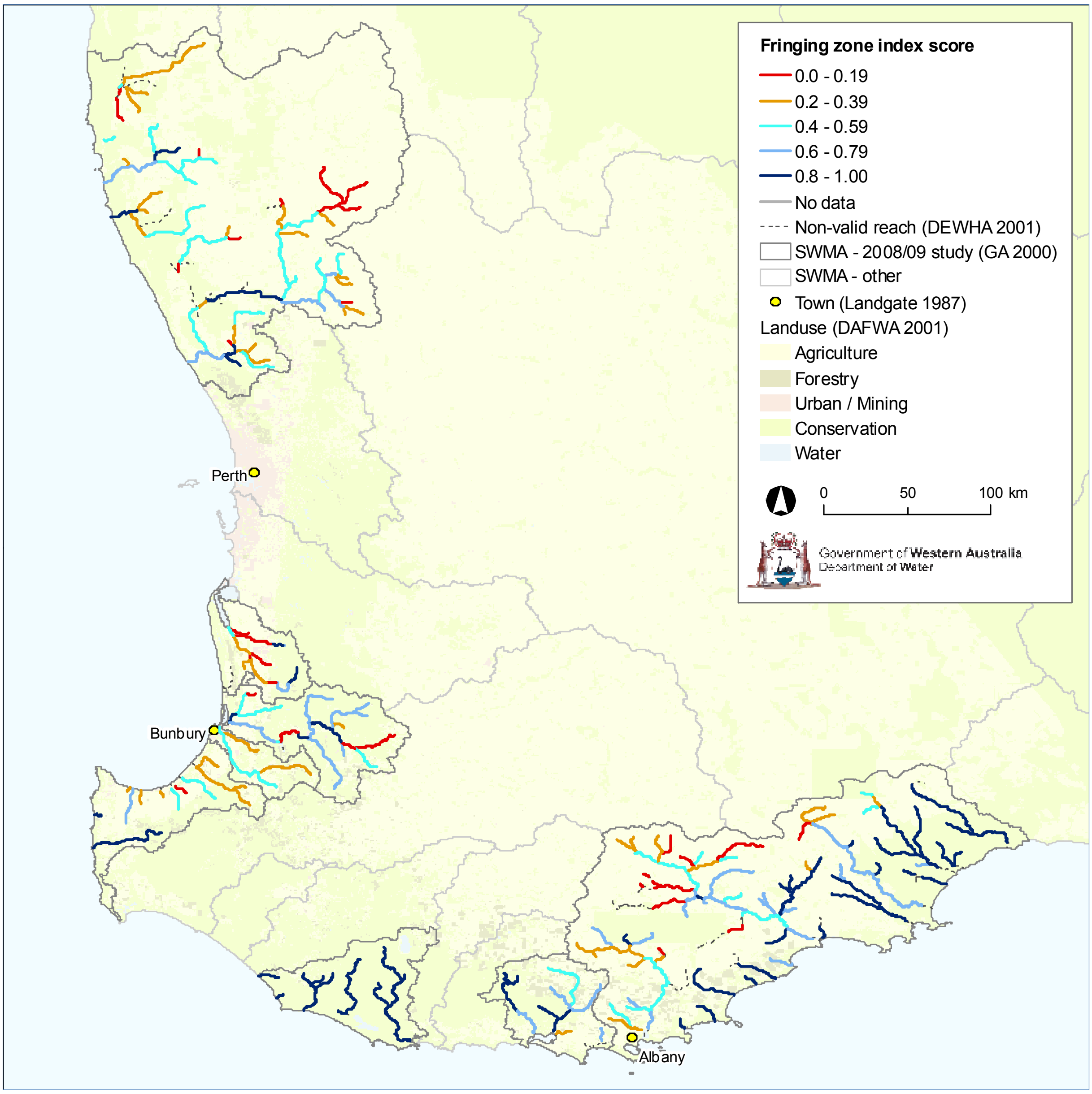


Figure 73 Fringing Zone index scores for reaches in SWMAs assessed in spring 2008 and 2009 within the SWWA-FARWH trials

The *Fringing Zone index* scores display an average of the *nativeness* and *extent of fringing vegetation* sub-indices, in that sites returning a ‘severely modified’ score have both a significantly reduced tree and shrub layer (both laterally and longitudinally) and a high proportion of exotic species.

The results represent the observations of field staff and the general understanding and knowledge of systems within the Department of Water, being highly correlated with land uses that typically result in tree removal and understorey clearing (livestock and to a lesser extent cropping). Urban development throughout SWWA (based on the SWMAs assessed) is relatively localised and would not contribute significantly to scores at this level of reporting.

The results support inclusion of the *Fringing Zone index* in the SWWA-FARWH, and more importantly highlight that vegetation clearing and the associated replacement by exotics is one of the most significant environmental stressors.

Frequency of data collection and assessment

Given the slow rate of change in the elements used to monitor riparian vegetation condition (outside of large developments or natural disasters such as fire), and the relative coarseness of scoring categories, frequent assessments are unnecessary in most cases.

This conclusion is echoed across most other river health programs; for example, the South African River Health Program monitors every two to three years. Further, the riverine (riparian) vegetation protocol developed by the River Health Contact Group for Australia-wide river assessments recommends a frequency of every five years (RHCG 2009).

However, since assessment of the *extent of fringing zone sub-index* is rapid, simple and cheap and the perennial vegetation datasets are updated every year, the riparian vegetation could be assessed every year. If the theme was to be assessed annually, its effectiveness at this temporal scale would need improving. Thus the resolution of the vegetation dataset would need to be finer to be sensitive enough to detect small changes. Obviously the continued inclusion of the *nativeness sub-index* requires field work.

Statistical analysis

The relationships between indicators of the *Fringing Zone index* were examined to determine whether any redundancies existed. The *extent of fringing zone sub-index* was identified as having a high correlation with its components: *fringing vegetation width* ($r = 0.98$; $p = < 0.05$) and *fringing vegetation length* ($r = 0.98$; $p = < 0.05$). Both components were also identified as being highly correlated ($r = 0.95$; $p = < 0.05$). Both components of the *extent of fringing zone sub-index* have been retained in the scoring because it can be demonstrated that each measures a different aspect of the riparian vegetation. It is possible for a site to score poorly in terms of riparian vegetation width and longitudinal length and vice versa. In addition, a site can score poorly in one of the components and better in the other; for example, vegetation in degraded systems can be narrow but still extend along the river length for a significant proportion.

Limitations of the Fringing Zone index

There were two main limitations to the *extent of fringing zone sub-index*.

The first limitation relates to errors associated with the reach dataset. The Reconstructed Reaches dataset was created using 1:250 000 scale topographic mapping. While this is a finer resolution than the ARC reaches (see Table 68), the dataset is still relatively coarse and does not always align closely with the location of watercourses on the ground. Consequently the width and length calculations are inaccurate in places. Underestimation also occurs in wide river systems, as reaches represent the centre of a watercourse and the vegetation is recorded as a distance from the centreline – thus any wetted area falling along the transect is calculated as un-vegetated.

To overcome these errors it is recommended the reaches be redefined at a much finer resolution so that they align closely with the location of watercourses (see reach definition within Section 3.2 for a more detailed review). Note: the error explained above is consistent across SWWA, therefore the limitation is non-biased and considered acceptable as long as scoring bands have a corresponding coarseness.

The second limitation was a result of the vegetation datasets used to determine widths and lengths. The datasets were chosen for their refresh rate (annually) and spatial coverage, but because they are raster images with a resolution of 25 m pixels there is an inherent limit to the sensitivity of the data; for example, small remnant patches of vegetation are not represented (vegetation cover is underestimated). Similarly, gaps in vegetation cover may not be detected (vegetation cover is overestimated).

The limitations described above are deemed acceptable at the scale of assessment the FARWH requires, and the information generated from the results aligns well with expectations. Yet in future new datasets should be assessed – ideally moving towards technologies such as Light Detection and Ranging data (LIDAR) (which may also allow assessment of understorey complexity).

A third limitation exists with the method for calculating width and length components, due to it resulting in an indication of total cover rather than where the cover lies. For instance, a 25 m vegetation corridor on both banks would score the same as a 50 m corridor on one bank and completely bare ground on the other. Given the scale at which the *extent of fringing zone sub-index* is assessed at, this is not seen as a significant limitation, but if finer-scale use is required in future, then this will need to be addressed.

Recommendations

See recommendations in previous sections.

Other indicators

A number of indicators were highlighted as important (e.g. Table 48) but not trialled due primarily to data availability for defining reference. The data required to assess these indicators (such as structural integrity and debris) were collected within the SWWA-FARWH field trials for future use if reference condition can be determined. Use of this data will require better spatial coverage to define the required benchmarks. The following information describes indicators with high potential for inclusion in river health assessments.

Greenness indicator

The Normalised Difference Vegetation Index (NDVI) (known as the greenness index) is derived from interpretation of satellite data and is based on the light wavelengths reflected by leaves in different stages of growth and senescence. It provides a measure of the density of green vegetation and can be used to identify areas of thriving vegetation and areas of vegetation under stress (e.g. due to lack of water) (Weier & Herring no date).

It is acknowledged the NDVI is a useful indicator of vegetation health, particularly in water-stressed catchments (Robinson 2010), but it was not possible to develop an indicator within the SWWA-FARWH project due to lack of time and staff with appropriate skills to analyse the data.

Stream shading

Shading is recognised as an important component of stream health. This was assessed within the SWWA-FARWH trials via canopy shots (fish-eye lens). However, based on the method used – where shots were taken from the stream's centre (Galvin et al. 2009) – a significant bias was observed depending on stream width. By an artefact of the method, wider systems were less vegetated (based on the stream-centre photo), while many small streams with little immediate streamside vegetation still registered reasonable health because the lens could detect vegetation in adjacent areas. This bias resulted in poor correlation against any of the obvious health factors.

Stream shading should be reassessed in future. Canopy shots from the bank may be more effective, although they are time consuming and thus may not be supported in a rapid assessment protocol.

Longitudinal continuity

As discussed above, longitudinal continuity was not assessed for the *Fringing Zone index* as it was inappropriate to measure gaps of ≥ 10 m in length using a dataset with a resolution of 25 m pixels. If data become available at a higher resolution it is recommended this indicator be investigated further.

Riparian indicators

As described previously, the riparian zone is not currently mapped for either current or pre-European times in SWWA. If a reference condition for this zone can be determined then a number of indicators relating to both nature and extent should be investigated.

Structural layers

Similar to the challenge of riparian zone classification is the need to determine reference for structural complexity of the fringing zone (trees, shrubs and groundcover). This information is readily collectable in field assessments but was not used because an appropriate benchmark could not be determined. Definition of reference was attempted by interrogation of the following datasets (see Table 68 for further detail):

- Vegetation – Pre-European Settlement (1788)

- Australia – Estimated Pre-1750 Major Vegetation Groups – NVIS Stage 1, Version 3.0
- Pre-European Vegetation

The Vegetation – Pre-European Settlement (1788) dataset only provided information on the percentage cover for the tallest (usually trees) layer unless the cover of this layer is < 10% at which point understorey is provided (Australian Surveying and Land Information Group 1990). The remaining two datasets do not provide any detail about the structural complexity of the vegetation complexes.

A literature review and expert consultation exercise was also conducted, and it was deemed that no reference condition was available for the expected cover of shrubs and groundcover. The highest level of information was confined to generalities; for example, the vegetation type 'Eucalypt Low Open Forests' provides a description of the forest understorey as exhibiting 'a wide variety of sub-forms, with understoreys ranging from low trees and shrubs to tussock grasses, or in some cases, bare ground' (Department of Environment and Water Resources 2007). As such, sufficient quality data is not available to determine the departure of current conditions, as assessed in the field.

A recommendation from this project is therefore the requirement to map and classify pre-European vegetation systems based on structural complexity.

4.6 Theme: Aquatic Biota

Aquatic biota is an important inclusion for river monitoring in SWWA. This is due to the ability of biota to reflect impact (discussed below), as well as the region being recognised as one of the world's 25 biodiversity hotspots, encompassing some of the richest and most threatened reservoirs of plant and animal life (Conservation International 2010).

Anthropogenic impacts and degradation of streams can affect the ability of an aquatic ecosystem to support natural diversity and maintain key ecological processes; damage to aquatic biota is often the end result of environmental degradation and pollution.

Biological criteria are an important inclusion in any environmental health assessment because they directly measure the condition of water resources, detect problems that other methods may miss or underestimate, and also provide a systematic approach for measuring the progress of aquatic environment improvement programs (Intergovernmental Task Force on Monitoring 1995).

The importance of aquatic biota is recognised around the world; for example, the United States EPA reports that chemical-based water quality programs alone are insufficient to identify and address all water quality problems and thus endorses the use of biological criteria. In meeting objectives of the US Clean Water Act (1977), the US EPA directs US states to incorporate biological criteria, with biological assessments currently adopted in a minimum of 20 states <www.epa.gov/bioindicators/html/biolexe.html>.

The Aquatic Biota theme has been included in the FARWH to measure the response of biota to changes in the aquatic environment (NWC 2007a). For the SWWA-FARWH, two sub-indices have been chosen: *fish/crayfish* and *macroinvertebrates*.

These sub-indices represent the unique aspects of SWWA systems and as such require tailored indicators to adequately represent dynamics [Summary Box 7].

The *fish/crayfish sub-index* includes measurements of fish abundance, community composition and presence of exotics. The *macroinvertebrate sub-index* describes the occurrence of macroinvertebrate genera/families at each site and incorporates measures of community composition.

The inclusion of multiple lines of biotic evidence is important in understanding ecological health. Fish and macroinvertebrates are often sensitive to different elements in the environment, and therefore have varied responses to disturbance.

Summary Box 7

SWWA rivers are distinguishable from many others around the world, including those found throughout Australia. This is due to a combination of factors such as climate, low topography and river beds being mostly sandy with few cobble-based riffle zones. This is highlighted by the high degree of endemism (e.g. endemic fish and crayfish species represent 80% and 100% of respective populations). Further, both fish and macroinvertebrates are depauperate, with typically less than seven fish species and around 20 macroinvertebrate families at any one site. All this relates to a need for indices tailored to SWWA, negating the use of most established indicators from around the world.

Other potential biota indicators, such as macrophytes, aquatic weeds, algae, microinvertebrates, water-dependent animals (e.g. water rats and frogs) and even terrestrial animals are identified as components of significant interest, however they were not included in the current assessment for a number of reasons. These are discussed in the theme summary at the end of this section.

Sub-index: fish/crayfish

Fish (fish and crayfish) are a direct measure of biological organisation, which along with vigour and resilience, make up the three key attributes of a healthy ecosystem (Costanza 1992; Haskell et al .1992). Fish provide an integrated measure of condition due to:

- direct sensitivity to water quality or general environmental change
- long-life (e.g. potential to highlight chronic or historical problems through changes in their population or community dynamics)
- mobility (e.g. representing wider system changes due to factors such as loss of connectivity or critical habitat destruction outside the immediate study area)
- position at the top of the food chain (reflecting a range of disturbances impacting on any level of the aquatic biological environment, including impacts that would

not affect fish directly, such as changes to macroinvertebrate communities). This includes trophic impacts such as bioaccumulation (where low-level contaminants would otherwise go undetected).

Due to these attributes, certain responses of individual fish or the responses within population and community dynamics can be associated with specific environmental impacts; therefore fish have the potential to be a powerful indicator of health.

Finally, fish are identifiable and valued by humans – including native (e.g. marron) and exotic species (e.g. trout) – and hence are a preferred means to communicate impacts to the community.

Sampling method

The aim of the sampling method for fish and crayfish is to obtain a species list based on standard effort, to collect all species present at a site, and to estimate abundance.

Details of the sampling procedures are provided in the *Inception report – volume 2: SWWA-FARWH* (van Looij & Storer 2009b). Two changes have been made to these procedures: trap numbers were halved and electrofishing was not employed. Trapping effort was assessed after the first round of trials and it was determined that species richness was represented by half the number of traps. Electrofishing was not used because it could not be applied effectively across the study area. Back-pack electrofishing was not successful in deep rivers and/or highly coloured environments. As SWWA has many naturally and heavily tannin-stained systems (typical across the south coast), coverage is significantly reduced.

Given sampling method has a significant bearing on catchability, a brief summary of techniques is provided. Fish are collected by fykes and box traps (large and small) set in the stream over a 24-hour period. Box traps were used for effectiveness in capturing crayfish species, and fyke nets for fish. Five small box traps (3 mm mesh) and five large box traps (2 cm mesh) were deployed per site. All fish/crayfish were identified, measured (total length for fish and total carapace length for crayfish) to the nearest 1 mm and sexed where possible. Observations relating to health and condition were also recorded, including reproductive condition (where visible), physical damage, disease and parasites.

Reference condition

Scoring the *fish/crayfish sub-index* is based on two components representing two key aspects of fish community dynamics, which relate to:

- expectedness
  - similarity in species composition of the observed native (non-exotic) assemblage of fish species to that predicted at a site under unimpacted or reference conditions (expected)
- nativeness
  - the proportion of fish species and abundance that consist of native fish, as opposed to introduced or ‘exotic’ fish.

Reference condition for fish and crayfish is the estimated fish assemblages (number and type of species and relative abundances) that would have prevailed now – in the absence of significant human disturbance.

The reference condition approach does not apply to particular sites or reaches, because habitat conditions vary and fish are likely to move between sites. Also, this level of information is not available. The distributions have therefore been based on subcatchments (see figures 74 and 75).

In SWWA it is not possible to directly measure reference condition via historical data or reference sites alone, hence reference was determined by combining evidence from previous research, museum collections, historical data and expert opinion. Data collected in the two field trials (2008 and 2009) were also used to inform reference condition, especially where there were no available data for sites having minimal impact (pseudo reference sites).

The datasets used in defining reference have each been cleaned and verified. Reference to these datasets has been provided in Table 68. The level of confidence in these datasets was generally high for all but one data source. Note: some data sources are being updated to improve accuracy, so future studies should contact the custodian directly. An example of the reference distribution created for the FARWH trials for two SWWA species is provided below (figures 74 and 75).

Figure 74 Reference distribution (subcatchment scale) for Galaxias maculatus, the common jollytail

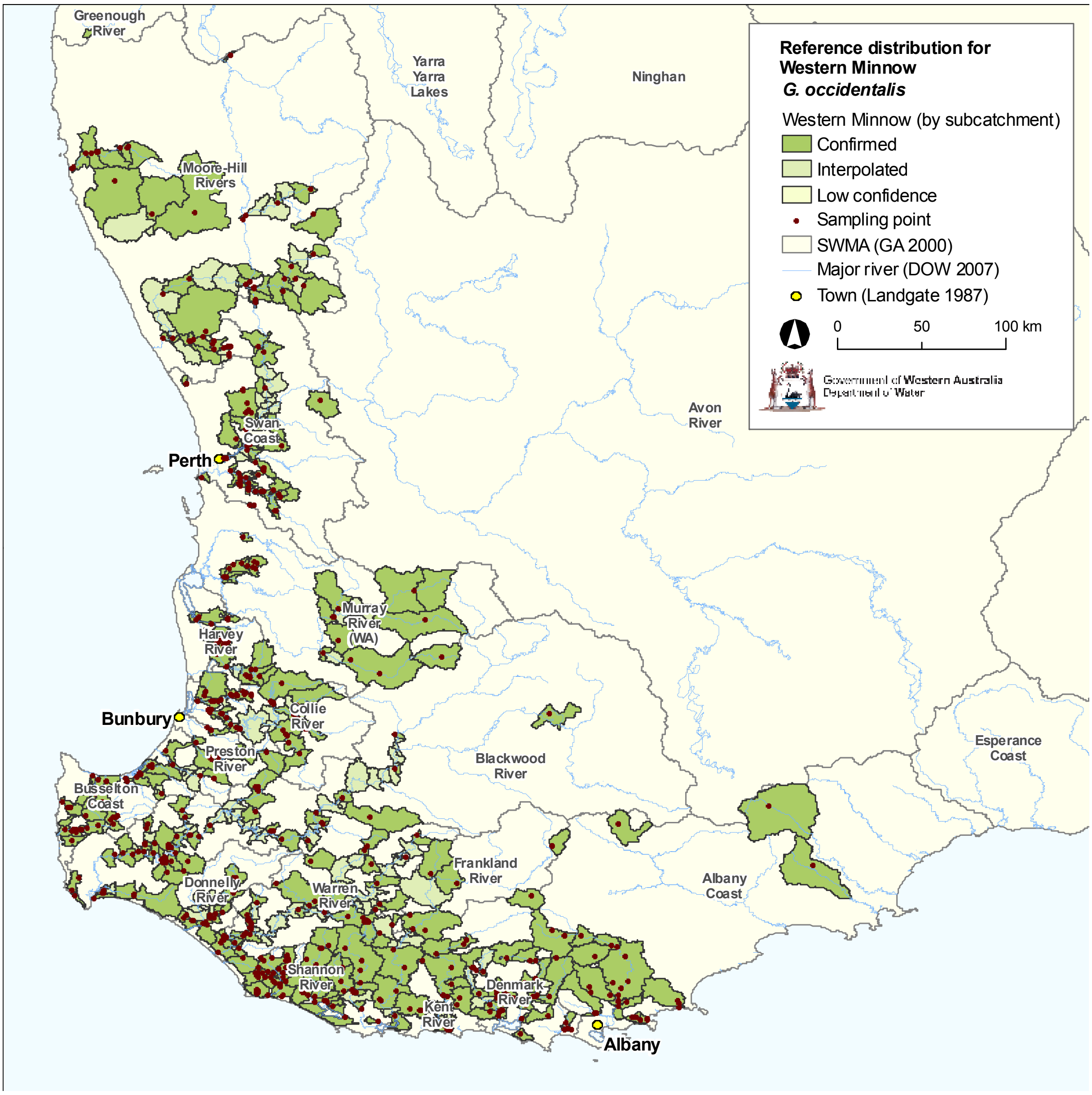


Figure 75 Reference distribution (subcatchment scale) for Galaxias occidentalis, the western minnow

The examples provided above highlight uncertainty in some of the data within the reference set. Within the FARWH trials, the two species above were not shown to inhabit the same system, which is understandable given they occupy a seemingly identical niche and would therefore compete in the same system. Further, the two species are very similar in appearance, which suggests the overlap in ranges seen above could be attributed to false identification in the previous records used to create the reference condition.

Missing data

Despite the numerous publications used to develop the reference database, substantial gaps in coverage for fish distribution remain. Rules were used predict reference in those areas, which are:

- *Interpolation:* where a species was previously recorded in upper and lower sections of a river system it was assumed the species would extend to the area between.
- *Extrapolation:* homogeneous systems adjacent to one another were assumed to have similar fish assemblages.

Fish assemblages recorded in lower catchment reaches were extended to reaches upstream if no obvious change in a system's form and function was apparent. Note: assessment of form/function only looked at elements as they would have appeared without human interference (e.g. elevation, geology, hydrology, vegetation types).

Where interpolation and extrapolation rules have been employed this has been designated in the final reference dataset (Expected distribution of freshwater fish and crayfish in SWWA, see Table 68), allowing delineation of actual versus assumed distribution. This includes distinguishing between interpolation and extrapolation, given that extrapolation is inherently more prone to error and therefore associated data have less confidence.

It is recognised that the rules in the fish/crayfish species distribution database could miss individual species occurrences, especially within or close to the limits of species ranges. Hence it was decided that any native fish/crayfish species found at a site in the SWWA-FARWH trials is deemed to be expected, and added to the expected species lists.

This has the inherent problem that current distribution due to translocation by humans will be counted in the reference condition. However, the presence of native SWWA species outside of a natural range is considered significantly less critical than the loss of a species within a natural range (which is the alternative). Note: in some instances extended ranges of species due to translocation have been recorded. This primarily relates to *Cherax cainii* (smooth marron), which has been introduced into rivers and dams since the early 1900s (Morrissy 1978). Where existing information exists it was accounted for in the reference database.

As discussed above, a reference dataset of expected fish distribution has been developed (see Table 68). This dataset incorporates attributes for each subcatchment – identifying whether expectations are based on actual or assumed data, the level of confidence based on the underpinning data sources, and whether the species is common or cryptic/rare. This last attribute aids interpretation based on catchability and is picked-up in the scoring protocols detailed below.

Scoring protocols

A number of methods (developed around the world) were trialled to score fish health. Methods not described here were either omitted or identified for future assessment (discussed at the end of this section).

One of the main differences between typical fish assessment methods and what was decided for representing SWWA systems was the effect of rare species. Many established methods for assessing river health exclude naturally rare species, as these species can confound scoring due to variability in chance of collection (versus impact-related reasons). Due to the low species diversity present in SWWA systems, the luxury of leaving out rare species cannot be afforded. For example: omission of rare species can change the number of expected species from 11 to 6. Attempts were made to incorporate all available species to increase the sensitivity of scoring protocols.

For reference, there are only 10 species of native freshwater fish (80% endemic) and 11 species of freshwater crayfish (100% endemic) present in the entire SWWA region. Note: five of the 11 crayfish species belong to the Engaewa family, primarily living in seepage areas or seasonally waterlogged areas (coastal flats, headwater seepages, peat swamps etc.) located in high-rainfall zones (DEC 2008). These species are not typically captured in rivers. There are also four estuarine fish species typically found in freshwater systems. At any one site it is rare to encounter more than six species and, in some areas, expected species richness may be as low as one.

The final scoring method chosen was based on the sustainable rivers fish index, a component of the Sustainable River Audit (SRA) protocols (Davies et al. 2008) developed for the Murray–Darling Basin. These methods were originally developed for the Index of Biotic Integrity in North America (e.g. Karr 1981) and the NSW River Survey (Harris & Gehrke 1997), and also adapted by the Tasmanian River Condition Index (TRCI).

This method was chosen because it enabled the weighting of individual groups of species depending on catchability. Through this, the high probability of not capturing certain species present in a system (due to low natural catchability) would not overweight scores, while still permitting their inclusion if captured. Based on scenario testing a number of minor modifications to metrics were made (discussed below).

Fish/crayfish sub-index component: expectedness

The *expectedness component,* as previously introduced, scores the observed species (captured through field sampling) with the species that are naturally expected. This indicator is divided into metrics that weight species depending on their catchability.

As previously introduced, certain species in SWWA naturally exist in low numbers in reference condition, so failure to capture them may be due to chance rather than a decline in river health. The *expectedness component* accounts for this by breaking down groups by catchability, achieved by using separate metrics to score different suites of species. Three metrics are used, these being the:

- O/E metric
- O/P_r metric
- O/P_s metric.

The **O/E metric** (observed/expected) only scores species commonly ‘expected’ at any one site; that is, species that if present have a high chance of being caught. Rare or seasonal species are not incorporated in either observations or expectations.

The **two O/P metrics** (observed/predicted) compare the native species predicted to have occurred in a subcatchment against the native species caught at the site. All species are included in the reference and observation lists, including both rare and seasonal species. Rare and seasonal species are assessed separately in the O/P metric to account for different expectations, these are:

- **O/P_r** – rare: species that naturally exist in low abundance within their distribution range, or do not readily enter traps/nets, hence their probability of capture is reduced. Further, when they are captured it is typically in low numbers.
- **O/P_s** – seasonal: species with a high probability of no capture due to seasonal migration or seasonal hydrological change such as seasonal river systems (presence is varied temporally). When caught these species are typically in large numbers.

The rare and seasonal taxa occurring in SWWA systems are listed in Table 52. Both *Lepidogalaxias salamandroides* (salamanderfish) and *Galaxiella nigrostriata* (black-stripe minnow) were not included in the scoring because they are mainly found in ephemeral pools, which the SWWA-FARWH protocol was not designed for. The burrowing crayfish (Engaewa) were also not included as they are not typically found in surface waters. Note: information on SWWA species’ biology has been compiled and is available from the Department of Water’s Water Science Branch.

Table 52 Seasonal, migratory and rare species

Migratory species	Seasonal species	Rare species
Tandanus bostocki (freshwater cobbler)	*Cherax preissii* (koonac)	*Nannatherina balstoni* (Balstons pygmy perch)
Geotria australis (pouched lamprey)	*Cherax crassimanus* (restricted gilgie)	*Galaxiella munda* (mud minnow)

This differentiation also allows more precise interrogation of data from final scores.

For scoring purposes, rare and seasonal species were separated to allow individual weighting. In response to expert opinion and subsequent scenario testing (discussed later), rare species were deemed more important as an indicator of system health than seasonal species and as such were weighted higher (double weighting).

Integration of the *fish/crayfish sub-index* components is discussed in more detail towards the end of this section.

Fish/crayfish sub-index component: nativeness

The *nativeness component* targets the establishment of exotic species.

Exotic species are an important component of river health assessment as an indicator of both symptom and cause of impact. Exotics typically have invasive qualities, with numerous attributes giving them a competitive edge over native species, such as superior breeding strategies (multiple cohorts per year or spawning earlier than native species, which afford offspring a competitive edge). Further, invasive species are often more tolerant to a range of environmental conditions (from habitat and food selection to water quality tolerances). It is this latter attribute that often results in a direct relationship between level of impact and extent of exotic inhabitation, in that native species are more likely to have reduced fitness compared with exotics under changing conditions. It is generally accepted that an otherwise unimpacted system will be highly resistant to the establishment of invaders due to the precise interplay between physical, chemical and biological environment (Storer et al. 2005).

Direct impacts from exotic species include predation, competition, habitat destruction, and introduction of disease/parasites.

The *nativeness component* involves integration of two metrics to account for the impact of exotic species, both in terms of abundance and diversity, these are:

- proportion of native abundance
- proportion of native species.

Scenario testing found that in this form the *nativeness component* did not differentiate systems with no fish versus systems with only exotic species. From this there are two possible directions (not including disregarding this artefact), which are:

1. Exotic species are considered worse than no fish, which would hold true against the strict definition of departure from reference, or
2. No fish is related to a higher impact than exotics alone.

The second option was chosen based on a number of examples from urban centres where high levels of contamination meant no life was supported. This is further supported in that situations where exotic species had out-competed native species to a point where the natives were absent – in an environment that would otherwise support them – were not seen.

This scenario was accounted for by modifying the original SRA scoring protocol to incorporate a lowest score of 0.05 for any system that has fish or crayfish (native or exotic) present. An automatic zero score is only assigned where no fish or crayfish are collected. Note: for flowing systems in SWWA fish are naturally expected on all occasions. This situation would change if the study area was extended to ephemeral systems, at which time the *fish/crayfish sub-index* would not be selected for scoring in the overall *Aquatic Biota index.*

Finally, it should be noted that regardless of the situation (exotics only or no fish) final scores will remain in the lowest scoring band. Therefore, the differentiation is primarily for interpretation.

Note: *Cherax cainii* (smooth marron) and other native species collected outside their reference range have not been included in the *expectedness* and *nativeness* score in these areas (still included in scoring in their natural range) because it was deemed improper to count them as either native or exotic in these regions. The presence of native species outside their natural distribution will continue to be recorded during field sampling, as the loss of these species from areas into which they have been introduced may have implications in future health assessments.

The *fish/crayfish sub-index* is summarised in Table 53 and describes the weighting associated with integration of the components.

Table 53 Components and scoring protocol for the fish/crayfish sub-index. Adapted from the sustainable rivers fish index of the Sustainable River Audit (Davies et al. 2008)

Component	Metric	Definition	Weighting
Expectedness Information on species richness relative to reference condition	Observed to expected ratio (O/E)	Compares the native species expected to occur in a site based on reference condition and the actual species collected. The total number of native species predicted to occur in the subcatchment is corrected downwards for species believed to be either rare or seasonal and unlikely to be caught in sampling.	0.25
	Observed to predicted ratio – rare (O/P_r)	Compares the native species predicted to have occurred (pre-European) in a subcatchment against the native species actually caught at the site. This metric includes the rare species.	0.17
	Observed to predicted ratio – seasonal (O/P_s)	A comparison of the native species predicted to have occurred (pre-European) in a subcatchment against the native species actually caught at the site. This metric includes the seasonal species.	0.08
Nativeness Information on proportions of abundance and species richness that are native rather than alien	Proportion native abundance	Proportion of individuals that are native species.	0.25
	Proportion native species	Proportion of species that are native species.	0.25

Expert rule, exotic species cap: where exotic fish are present in the absence of natives the site is automatically assigned a score of 0.05. Where no fish are present the site is assigned a score of 0.

Sensitivity analysis

Sensitivity analysis is complex and particularly critical for biological information. This is due to the range of impacts that may affect biotic response and the need for a clear demonstration of a reliable empirical relationship (consistent quantitative change) across a gradient of human influence.

To elucidate the ability of the *fish/crayfish sub-index* to reflect conditions, scoring methods were investigated for suitability using both data collected in the field and theoretical scenarios. A number of scenarios were assessed, targeting permutations of observed versus expected/predicted ratios of native species and varying proportions of exotic species or relative abundance. This process demonstrated that the scoring method assigned reasonable scores to the majority of scenarios tested, but highlighted no differentiation between systems devoid of all fish and crayfish and those which contained only exotic species. As described in previous text, this artefact was accounted for using a minimum score rule for systems able to support some life.

An example of the scenarios tested is given in Table 54, which was a part of evaluating the effects of rare and seasonal taxa on the *expectedness* indicator score.

Table 54 Scenario testing – rare and seasonal species

Scenario: Fish population comprising 4 common species, 2 rare taxa & 2 seasonal taxa					
Equation	**All species present**	**Lose half rare & seasonal taxa**	**Lose only rare taxa**	**Lose only seasonal taxa**	**Lose both rare & seasonal taxa**
$OE + [2(OP_{Rare})+(OP_{Seasonal})]/2$	1.00	0.90	0.87	0.93	0.80
$OP\ (_{Rare\ +\ Seasonal})$	1.00	0.88	0.63	0.88	0.75
$OP\ (_{Rare\ only})$	1.00	0.92	0.83	1.00	0.83
$OP\ (_{Seasonal\ only})$	1.00	0.92	1.00	0.83	0.83

As can be seen, in this example the results showed only minor changes in the scores observed and so were only likely to affect placement in condition bands in borderline systems. Yet the differentiation between species does allow some level of data interrogation without needing to source raw data. For example, not capturing seasonal species has been highlighted as less important than not capturing rare species.

Fish/crayfish sub-index scores

The final *fish/crayfish sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 76. Fish communities in the SWMAs assessed were shown to be similar to what would be expected under reference conditions, with most sites scoring as either 'largely unmodified' (0.8 to 1.0) or 'slightly modified' (0.6 to 0.79). These sites were typically dominated by native fish/crayfish species in terms of abundance and species richness. Exotic fish/crayfish species were encountered at some of the sites across SWWA (except in the most pristine areas, e.g. Denmark River and Shannon River SWMAs), however abundance was generally low.

The reaches with moderate scores (0.40 to 0.59) were typically located in agricultural areas where the riparian vegetation had either been cleared or was highly disturbed (e.g. scattered trees, no shrub layer, groundcover dominated by exotic species) and erosion was severe. One site located in the Harvey River's upper reaches (above the Stirling Dam) was the only exception. This site was located in a relatively pristine forest with little to no erosion. The fish assemblage consisted of one *G. occidentalis* (western minnow) individual and two *Salmo trutta* (brown trout) individuals. It is likely the extinction of other native species expected to occur here and very low abundance of *G. occidentalis* (western minnow) is due to the presence of *S. trutta* (brown trout) which are known to consume endemic fish and crayfish (Morgan et al 2004; Jenkins 1952; Pusey & Morrison 1989).

Three reaches scored in the ‘severely modified’ condition band (0.0 to 0.19). No fish were recorded at two reaches in the Albany Coast SWMA and only exotic fish/crayfish species were recorded at one reach in the Moore-Hill Rivers SWMA. All three sites are located in agricultural areas where the hydrological regime has been altered, the riparian vegetation is cleared or highly disturbed and erosion is severe. The sites in the Albany Coast SWMA are also affected by salinity.

Based on the results obtained from the two trials, the *fish/crayfish sub-index* is strongly supported for future use in the SWWA-FARWH.

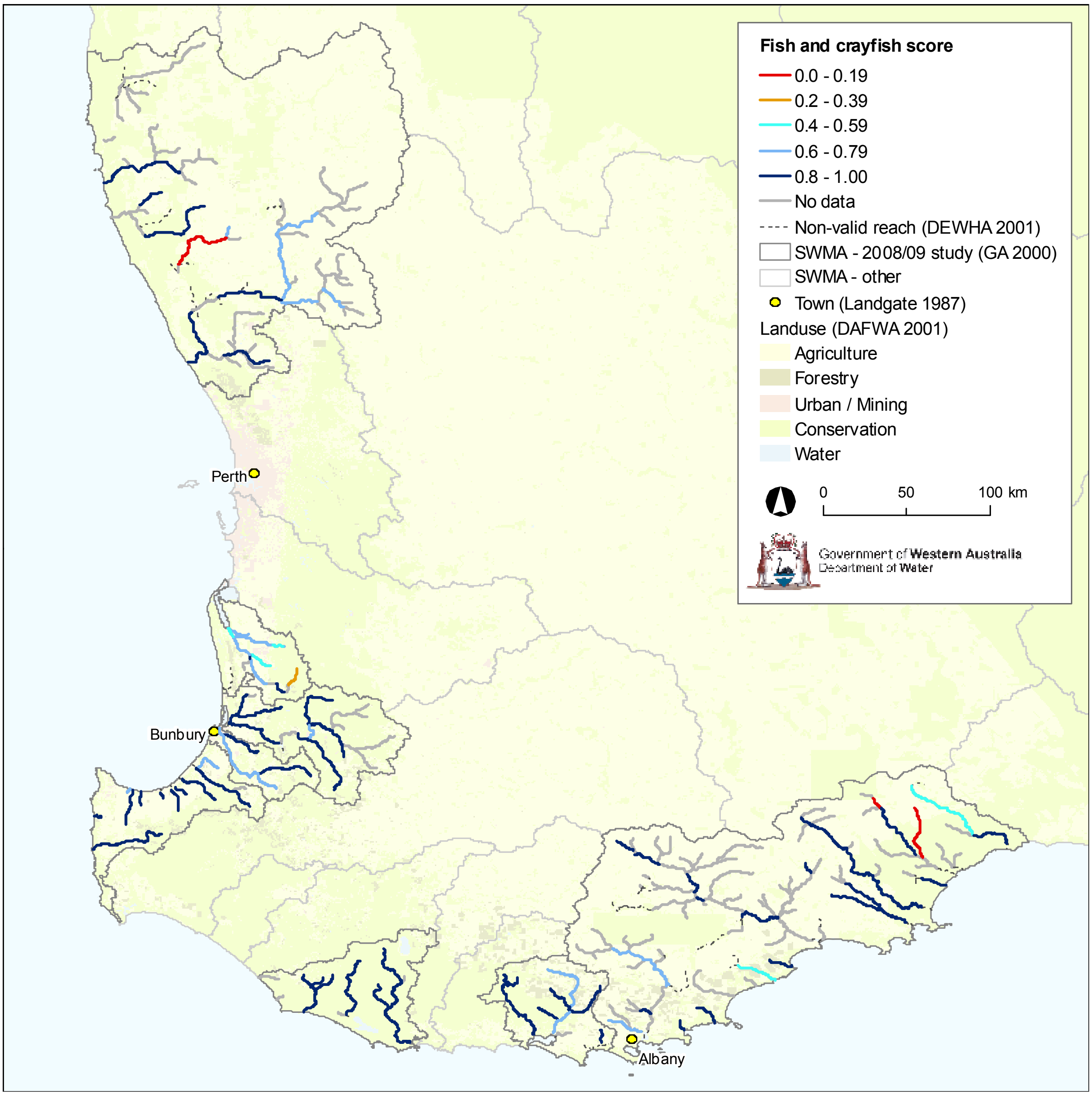


Figure 76 Fish/crayfish sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Power analysis

A table and graph depicting the results for the power analysis can be found in Appendix C.

Data verification

Data collected as part of the SWWA-FARWH field trials were verified using the following process: one staff member entering and double-checking data from field sheets and then a second staff member confirming entry by analysing a subset of sites chosen by random selection of sites and individual traps. Through this procedure, 1.8% data entry errors in abundance and species were corrected (based on 2008 data).

Data verification was a significant and intricate process for the development of reference condition. This involved checking all datasets against GIS layers to ensure points were correctly assigned to river lines, and also cross-referencing datasets to highlight when obvious identification errors were made.

Frequency

For SWWA-FARWH protocols, the frequency of generating new assessments is currently confined to spring (baseflow conditions), although is not impeded by anything other than sampling methods (cost, expertise). Spring sampling is not a pre-requisite for fish/crayfish sampling: in fact sampling in other periods is important for different levels of information. For instance, sampling in summer/autumn is more likely to highlight recruitment, given the breeding biology of SWWA species. Note: spring is currently the designated sampling period for the SWWA-FARWH to allow for corresponding macroinvertebrate analysis.

Limitations and recommendations

The current *fish/crayfish sub-index* has a number of limitations, which are discussed below:

Native fish distribution database

- Temporal and spatial gaps exist in the data, including the seasonal to ephemeral inland river systems such as the Avon (not applicable for the SWWA-FARWH study area).

Logistical requirements

- All required permits under Western Australian legislation must be obtained before sampling is conducted.
- Staff must be adequately trained in both trap placement and fish and crayfish identification.

Ecological understanding of SWWA species

- Biological information is required for most SWWA species, including those migrating between fresh water and the estuary (knowledge of aspects such as required habitat and water quality tolerances is currently limited).

Scoring protocols

- Catchability, or the probability of occurrence in traps, is not quantified for SWWA species. Expert knowledge has provided coarse groupings of rare and seasonal species to account for some variability. It is recommended that further work is conducted to examine assigning a percentage chance of capture for each species. This will improve the scoring protocol's robustness and reduce the effect of rare taxa. This work was outside the capacity of the current FARWH project.

- The quantifiable effects of exotic species on SWWA native fish populations are poorly understood. This knowledge would permit weightings to be applied to individual species based on ecological threat. This would need to include period-of-time established in systems, given a number of species have been in some systems for more than 100 years – such as *Perca fluviatilis* (redfin perch) and *Oncorhynchus mykiss* (rainbow trout) – compared with other species that may turn up in future and have a greater potential for acute impact (and thus a need for immediate management response). Weightings for exotic fish are being developed and current information about this can be obtained by contacting the Department of Water’s Water Science Branch.

Methodology

- Visiting sites over two consecutive days is the minimum field requirement to collect data for the *Aquatic Biota index* (due to the 24-hour trapping used for the *fish/crayfish sub-index*), based on methods required to conduct the SWWA-FARWH (as per this document). This can be reduced through rapid techniques such as electrofishing, however (for this example) it is at the cost of fewer data and reduced coverage potential.
- Current methods have focused on permanent and seasonal flowing rivers. New methods require development to assess streams with no flow at the time of sampling.
- *Gambusia holbrooki* (mosquitofish) were often sighted but not captured. As a short-term response, any sightings were added to the exotic species list so they could be accounted for in the ‘proportion native species’ metric. In the long term we will need to investigate other methods to help improve catchability of this particular species to allow accurate measurements of presence and abundance.

Indicator testing

- Multiple years of data are required to test and improve indicators (in terms of sensitivity to change).

Other indicators

- Scoring methods based on trophic dynamics were also investigated because it has been shown these are an effective way to reflect ecological health, providing additional information on which component of the system is breaking down. These were deemed unsuitable for SWWA due to the low number of native species and their generalist nature in terms of niche occupation.
- Some of the ‘diagnostic’ metrics used in the SRA fish index such as proportion of micro and mega carnivores, benthic species richness etc. could not be applied. These metrics have little applicability for rivers and streams in SWWA where there are few species, and where nearly all species do not have clearly differentiated habitats or feeding preferences (i.e. they are opportunistic and generalist).
- Population size: the study of populations has dominated much ecological research for decades. Some researchers assume that population size (expressed

as abundance or density) provides a reliable signal about water resource condition. But because abundances vary so much as a result of natural environmental variation, even in pristine areas, population size is rarely a reliable indicator of human influence. Large numbers of samples (> 25) were required, for example, to detect small (< 20%) differences in number of fish per 100 m^2 of stream surface area in small South Carolina streams (Paller 1995). This requires evaluation with more data.

- Population dynamics: indicators such as population dynamics can also be sensitive indicators of less obvious impacts. Minor changes in water quality may result in reduced growth or reproduction and these changes may not be detected in presence-absence data. In future the data may also be used to identify the presence of recruitment. Note: in Tasmania sampling is recommended in the summer/early autumn season to allow recruits and spawning adults of all species to be included in assessments. Sampling in winter and spring can miss detection of recruitment due to the absence of, or difficulty in catching, small, larval or young fish. The presence and condition of larval stages in a range of aquatic animals can provide important information, such as a system's ability to support reproduction and larval growth. In future, methods such as investigation of light and/or heat traps (to collect larvae) will be examined.
- Biomass: investigating the biomass of native species is recommended for inclusion in nativeness scoring (following SRA fish index guidelines).
- Migration: the use of other technology (e.g. audio tags and receiver gates) to determine fish movement is recommended to confirm connectivity of systems.
- Physical condition indicators, parasites, lesions, disease and other abnormalities: it is expected these elements would probably have most value for highlighting specific problems, but given the scale their inclusion in the SWWA-FARWH may not be applicable.
- Assessment of other biota such as macrophytes, aquatic weeds, algae, microinvertebrates, water-dependent animals (e.g. water rats and frogs) and even terrestrial animals is recommended. These were identified as important components of the aquatic ecosystem but not investigated in the current FARWH trials because appropriate sampling and analytical methods were not established or difficult and/or expensive, and reference data for SWWA was not readily available.

Sub-index: macroinvertebrates

Macroinvertebrates are commonly used as indicators for assessing river health because they are widely distributed, relatively immobile and easily identified and sampled (Rosenberg & Resh 1993). In particular, macroinvertebrates are targeted for assessment as they are sensitive to environmental disturbance, with even small changes to the physical or chemical environment altering community composition and structure through the loss, addition or replacement of taxa. Macroinvertebrate community dynamics have been shown to reflect a number of anthropogenic activities including changes in water chemistry (Metzeling 1993), sedimentation (Doeg & Milledge 1991), land use (Kay et al. 2001), flow regime (Wood & Petts 1994), salinity (Kay et al. 2001), heavy metal contamination (Grumiaux et al. 1998) and riparian vegetation loss (Quinn et al. 1992).

The macroinvertebrate fauna of rivers in SWWA is depauperate compared with south-eastern Australia and most other parts of the world, particularly with respect to the insect groups Trichoptera (caddisflies), Ephemeroptera (mayflies) and Plecoptera (stoneflies) (Bunn & Davies 1990). Therefore, indices need to be very much tailored to SWWA systems.

Data collection

Field collection was required for macroinvertebrate data as the available information was limited spatially and did not reflect current conditions; that is, was not collected in the past few years. (Aquatic biota can change rapidly due to acute impacts.) Further, collection of macroinvertebrates at the same time as other field data (e.g. water quality and fish/crayfish) greatly increases the ability to understand and explain any potential impacts.

Macroinvertebrates were sampled using the standard AUSRIVAS method, as described in Halse et al (2001), with channel habitat assessed at all sites to allow comparison between sites. A box-subsampler was used to facilitate the live pick, enabling the sampling to be carried out by people with only limited macroinvertebrate sampling experience. Samples were identified as per the AUSRIVAS protocols with the exception that Odonata (dragonflies and damselflies), Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddisflies) were identified to genus. This was done to increase the available pool of taxa with which to do an assessment.

Macroinvertebrate collection methods have a significant bearing on the type and number of species recovered. A detailed methodology is outlined in the *Inception report – volume 2: SWWA-FARWH* (van Looij & Storer 2009b).

Data verification

The macroinvertebrates collected from both field trials were identified by a laboratory with National Association of Testing Authorities (NATA) accreditation in the identification of macroinvertebrates. For quality assurance and control NATA requires recounting/cross-checking of a certain proportion of samples by another operator (5% for large projects, 10% for small projects) and these procedures were followed.

Scoring method and reference condition

A number of methods were assessed in terms of designating health status based on macroinvertebrate assemblages. Use of the existing AUSRIVAS model for Western Australia was selected and is described below. Other methods are discussed at the end of this section.

The WA Spring Channel AUSRIVAS model was developed during 1994 to 2000 under the Monitoring River Health Initiative and the First National Assessment of River Health (within the National River Health Program). The model is used to compare the macroinvertebrate family composition observed at a test site against the composition predicted at a site under unimpacted or reference conditions (expected). The reference condition or expected macroinvertebrate assemblage is determined from a set of minimally disturbed sites that have similar physical and geographical characteristics (predictor variables). The model uses the following predictor variables to determine the probability of a site belonging to a set of reference site groups: latitude, longitude, mean annual rainfall, flow velocity at time of sampling and mean annual discharge. The resultant observed/expected (O/E) score is used to describe departure from reference. AUSRIVAS O/E scores range from 0 to > 1.15, split into condition bands (see Table 55). The SWWA-FARWH scores are based on the resulting O/E score from the model (see below).

For the SWWA-FARWH, scores greater than one were modified by subtracting the amount by which they were greater than one from one, to give a final score of less than one. For example, if a site returned an O/E score of 1.08, then the final score is 0.92. This is done because scores greater than one are reported to reflect enriched systems and hence the more enriched, the more impact. In reality this had very little impact on overall site classification because the classification bands are in increments of 0.2 and it is unusual for a site to score greater than 1.2.

Note: work to update the WA Spring Channel model was done to include genus-level identifications for some macroinvertebrate taxa. The revised model is similar to the original model in terms of taxonomic resolution, with the exception of Odonata, Plecopterans and Trichopterans, which were identified to genus (previously family). However the model development was abandoned due to missing data for Odonata specimens at half of the sites within the family model. Instead it was decided the sensitivity of the existing model would be improved. This is discussed in detail later.

Table 55 AUSRIVAS band thresholds and condition categories for SWWA

Band	Band thresholds score	Condition
X	> 1.15	Enriched (slightly disturbed or biological hotspot)
A	0.85 – 1.15	Undisturbed
B	0.55 – 0.84	Significantly impaired
C	0.25 – 0.54	Severely impaired
D	0.00 – 0.24	Extremely impaired

Sensitivity analysis

Sensitivity analysis involved testing the WA Spring Channel model against a number of scenarios (pristine to severely impacted) to determine how the model functioned when taxa were removed. This was done using data from a site on the Denmark River.

Seventeen families were collected at the Denmark River SWMA site and working from this number, the model did appear to correlate well. That is, when taxa were removed the score gradually decreased, and anything less than three taxa resulted in scores within the worst condition band, which is ‘D’ (see Table 56).

The predicted number of families for the site (from the AUSRIVAS model) was 61, which is much higher than practically expected in SWWA (although this does allow for identification of biological hotspots or enriched systems, so the number will be somewhat higher than true expectations). Note: expected taxa richness for any one site is typically around 17 to 20.

Table 56 Scenarios for the WA Spring Channel model

Scenarios	OE50	Band	Taxa richness
Original site taxa plus taxa predicted by model	1.25	X	61
Original site data	1.02	A	17
16 taxa present	0.94	A	16
15 taxa present	0.86	A	15
14 taxa present	0.78	B	14
13 taxa present	0.78	B	13
12 taxa present	0.70	B	12
Seven taxa present	0.55	B	7
Five taxa present	0.39	C	5
Four taxa present	0.31	C	4
Three taxa present	0.23	D	3
Two taxa present	0.16	D	2
One taxa present	0.08	D	1
No taxa	0.00	D	0

As mentioned above, regardless of the apparent loss of sensitivity due to over-exaggerated species predictions, the WA Spring Channel model appears to reflect condition well (as determined by expert opinion).

Sub-index scores

Comparison of scores across SWWA showed reasonable correlation with land use and hydrological impacts, with ‘moderately modified’ condition present across most of the Swan Coastal Plain, eastern half of the Albany Coast SWMA and most of the Moore-Hill Rivers SWMA, which is dominated by cleared land for agriculture. The significant impacts observed in a few reaches (falling within the 0.2 – 0.39 band) related to systems that were dominated by, or contained only worms, midges and other dipteran families.

A couple of unexpected results occurred, such as some impact in the Shannon River SWMA which generally scored as 'pristine' in all other indices within the remaining ecological themes (including fish/crayfish). This may reflect a shortcoming of the AUSRIVAS model. The limitations and recommendations for the macroinvertebrate scoring protocol are discussed at the end of this section.

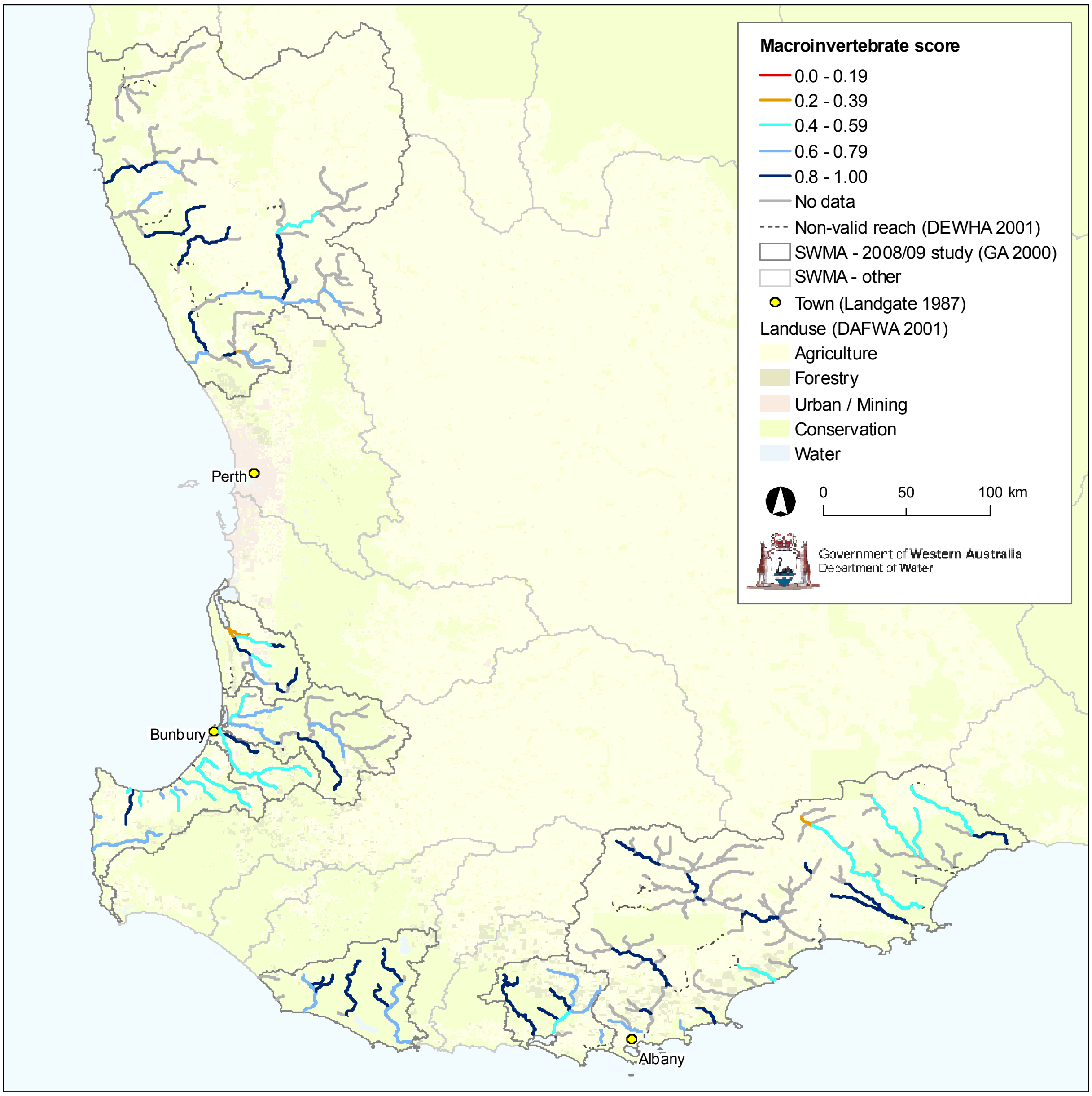


Figure 77 Macroinvertebrate sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Power analysis

Only Albany Coast and Moore-Hill Rivers SWMAs have more valid reaches than are required to achieve adequate power to represent a 20% change in mean. In all other SWMAs assessed, sampling of all reaches is required. In some instances, such as Albany Coast SWMA, it may not be practical to sample the required number of reaches. In a case such as this, sampling could either be conducted within resource capabilities and a higher level of error accepted, or macroinvertebrates not be included in assessments. However, improvement of scoring protocols may alleviate some ambiguity and thus reduce variability.

A table and graph depicting the results for the power analysis can be found in Appendix C.

Limitations

Sampling restrictions

The existing AUSRIVAS model is based on spring sampling, with assessment targeting baseflow conditions (typically between August and October), as well as avoidance of any rainfall events during this period. This significantly reduces the window of opportunity for sampling, especially considering that FARWH-style assessments are made over a wide climatic area. In many cases macroinvertebrate assessments were conducted in areas where the systems did not meet the above requirements, because time constraints meant revisiting the site later/earlier was not possible. This is a general limitation of any field work.

Validity of the current WA AUSRIVAS Spring Channel model

As was introduced within the review of ‘sensitivity’ above, the current AUSRIVAS model for Western Australian rivers and streams was examined for its ability to represent conditions and detect change.

A number of significant limitations to this model were found (discussed below), although this is not an indictment of the model – it was only ever designed as a beta version. It was always understood that ongoing validation and development was required to improve the model’s ability to represent SWWA systems. The model analysis was conducted by experts within the Department of Water, with guidance from model developers at eWater.

Limitations of the current WA AUSRIVAS Spring Channel model

Poor quality reference sites

- The physical parameters of reference sites show marked changes between sampling events; for example, at one site the substrate characteristics changed from a dominance of bedrock to sand. This highlights either the use of different sites between years sampled or sedimentation impacts.
- Duration of live-picks changed between sites included in the model. Sites assessed between 1994 and 1995 used a 30-minute live-pick. In subsequent assessments (1997–2000), live-picks were increased to 60 minutes to increase the number of taxa collected. Hence the sites assessed during the early stages of the model’s development may appear less healthy (lower species counts due to shorter picking duration).
- Notwithstanding the limitations above, available reference sites were still heavily biased by ‘best available sites’ (as opposed to ‘pristine’ sites). The original WA

AUSRIVAS Spring Channel model incorporated 23% pristine sites, 48% minimally disturbed and 29% best available sites.

- The model does not incorporate all river types. For example, many rivers on the south coast, particularly around Esperance Coast, are thought to be naturally saline. Reference condition for these systems would include pristine/minimally disturbed sites on rivers that are naturally saline. Naturally saline reference sites were not included in the Western Australian model because high salinity concentrations indicate catchment disturbance for most south-west rivers and streams. It is also not possible to use salinity levels to differentiate between naturally saline and secondary salinised sites because salinity concentrations can be similar in both (Halse et al. 2007). Given suitable reference sites are absent within the model, the condition of naturally saline sites will be under-estimated due to differences in macroinvertebrate family composition and richness. Naturally saline rivers and streams typically have a lower family richness and are dominated by specialised halophilic taxa compared with freshwater rivers.

Insufficient reference sites across SWWA

- Analysis of spatial coverage of the model's reference sites highlighted significant gaps in the data (see Figure 78) where entire SWMAs were represented by only one site (e.g. Moore-Hill Rivers SWMA) or sites were confined to a localised and unrepresentative area (e.g. Albany Coast SWMA). The inland portions of most SWMAs were also poorly represented, particularly the Avon River SWMA.
- A number of reaches were therefore outside the experience of the model. That is, because reference data were unrepresentative of the environmental variability, some sites could not be scored as they did not fall within the model's boundaries.
- Due to data limitations, the model appears to have simplified macroinvertebrate dynamics across SWWA – only designating five broad groups (e.g. almost all reaches within the Albany Coast SWMA fall within the 'southern saline wetlands' category).

As an example of the model's limitations (see data in Figure 78), all reaches within the Albany Coast SWMA are grouped together based on the reference sites shown on the eastern edge. Note: significant environmental scales exist across the Albany Coast SWMA area in rainfall, geology, altitude, hydrology and salinity.

Following the assessment, it was decided that all reference sites carrying the above limitations would be removed (e.g. all sites using 30-minute live-picks) and resubmitted to develop a new AUSRIVAS Spring Channel model. This was done using sites within SWWA only. The new model was completed but not received in time to conduct sufficient testing for it to replace scoring in the current SWWA-FARWH protocol. A summary of the new model outputs and a brief comparison with the previous model has been provided below [Summary Box 8].

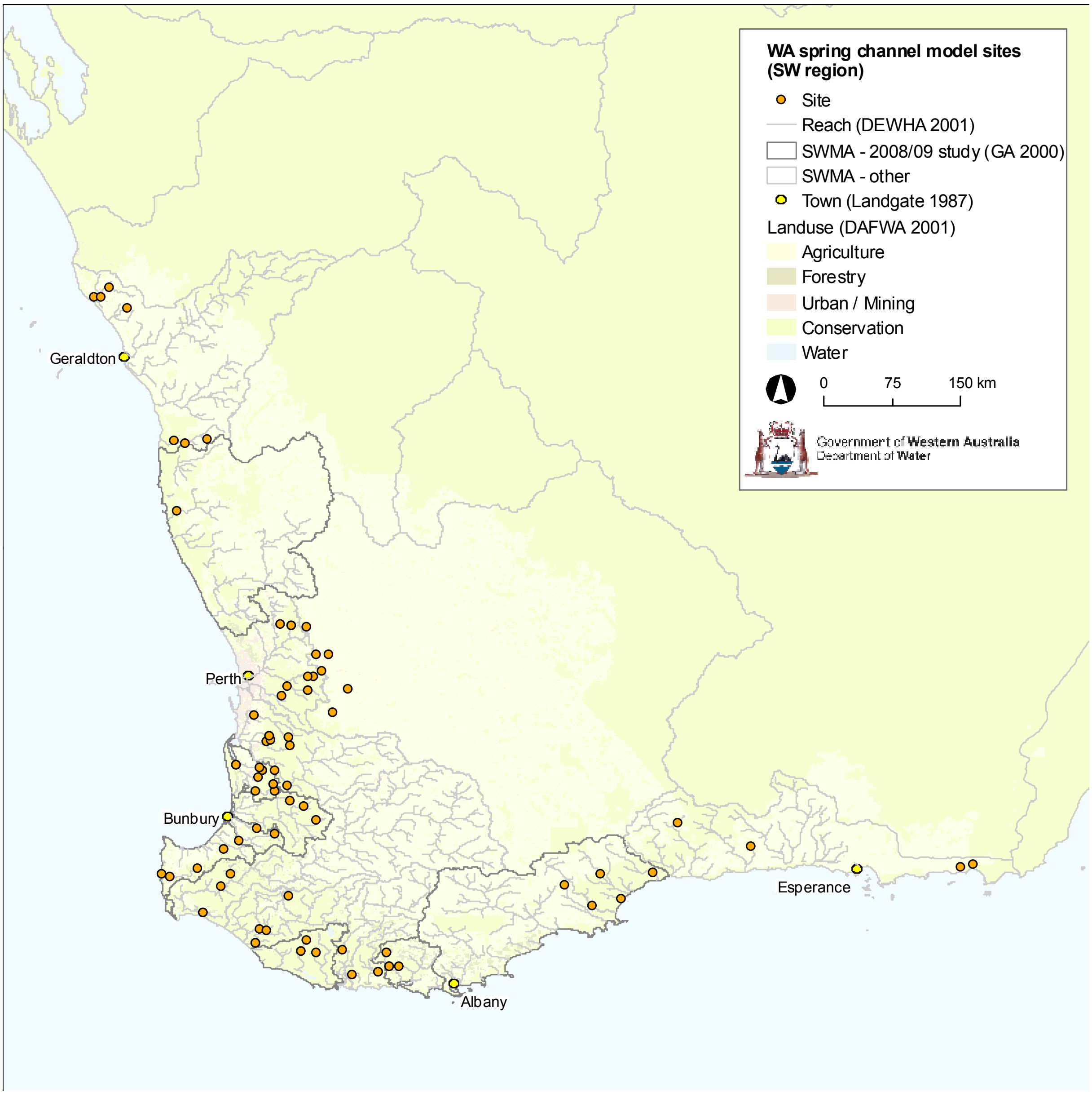


Figure 78 Reference sites used from SWWA to create the WA AUSRIVAS Spring Channel model

Summary Box 8: New model: South-West AUSRIVAS Spring Channel model

Development of the new Spring Channel model incorporated the following:

- spatial area reduced to only include SWWA: model area extends from the Hutt River in the north to the Thomas River in the south (near Esperance)
- removed data collected in the initial years (1994 and 1995) due to differences in live-pick methodologies
- removed sites with less than 10 families present from the reference list
- added more minimally disturbed sites to the dataset.

The new model is available for ongoing analysis from the AUSRIVAS website, but is not cleared for use for SWWA and will probably not be useful without additional sites.

The resulting model produced the following scores when run with SWWA-FARWH reach data (see next page).

Unfortunately the model was not prepared in time for adequate testing, however preliminary analysis highlighted a number of positive and negative attributes.

Advantages

- Quality of reference sites improved.
- All reaches returned scores (site within the model's ability).
- Highly saline areas were reported as substantially impacted. Given that salinity has increased and the general catchment is highly impacted (regardless of historical salinity), this appears more reasonable than the previous model.

Disadvantages

- Only resulted in three groups (as opposed to five in previous model), which may suggest reduced sensitivity. Sites in Collie, Albany and Moore-Hill SWMAs appeared to belong to the same group. The previous model also appeared to better reflect the condition of a few reaches – based on expert opinion (although as mentioned this was only a preliminary assessment).

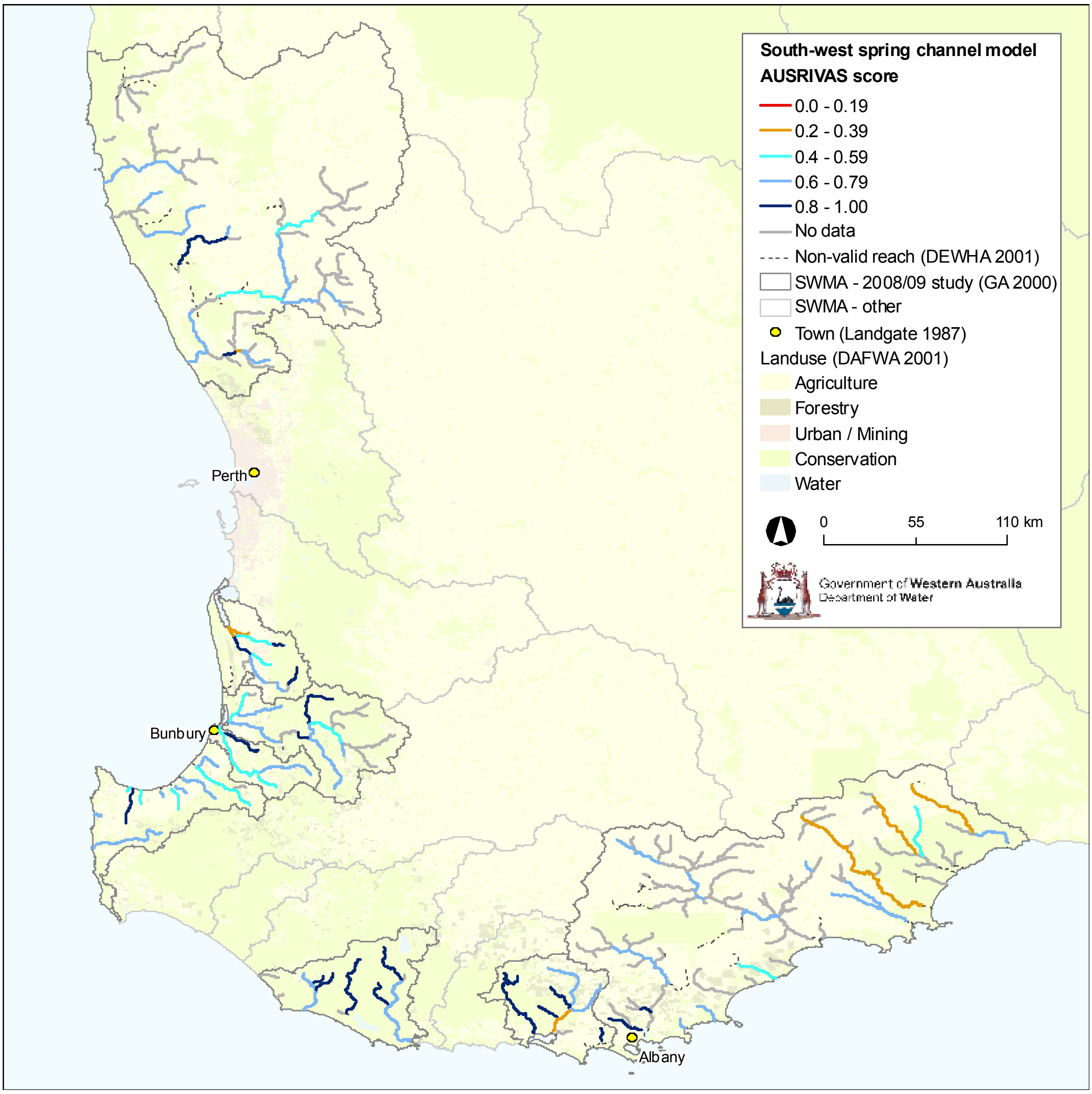


Figure 79 Macroinvertebrate sub-index scores using the new South-West AUSRIVAS Spring Channel model; for reaches in SWMAs assessed in spring 2008 and 2009 within the SWWA-FARWH trials

Ultimately the original AUSRIVAS model was used for scoring, accepting current limitations (Figure 77). This model has been used for approximately 10 years and, as such, its inclusion in the SWWA-FARWH allows comparison with results from previous studies.

Although it is suggested that both models adequately represent macroinvertebrate conditions at a SWMA scale, neither model appears to be particularly useful at a local management scale. It is agreed that macroinvertebrates are a sensitive indicator of health, based on the literature and the general observations of experts, yet the associated model requires significantly more data.

Inclusion of rare species

In AUSRIVAS and other O/E models such as RIVPACS, rare taxa – defined as those with < 50% chance of occurring at a site – are removed from the model. Rare species are typically removed from a model because generally they will not provide much information on a site – given the high possibility their absence is solely due to chance. This issue has been thoroughly tested by Hawkins & Norris (2000). Models that exclude rare taxa (< 50% chance of occurring) are typically more robust (Hawkins & Norris 2000). Inclusion of rare taxa, whose occurrence at a site is purely by chance, tends to add noise and obscure patterns in the data (Clarke & Warwick 1994).

This is problematic for SWWA due to the natural paucity of species: the exclusion of rare taxa further reduces the robustness of any associated models.

With more data SWWA indicators can be tested further against these findings. Consistently, reliable metrics include a number of taxa-richness attributes (number of unique taxa in a sample, including rare ones) and percentages of individuals belonging to tolerant taxa. In study after study, the same major attributes give reliable signals of resource condition in different circumstances (e.g. see Chu & Karr 1999; Karr 1999).

Aquatic Biota index summary

Integration and aggregation

Integration follows the method suggested in the FARWH documentation (NWC 2007a). That is, the average is taken of the *fish/crayfish sub-index* and the *macroinvertebrate sub-index*.

Where there was more than one site on a reach, the *Aquatic Biota index* scores are generated for the individual sites and averaged to provide one score for the reach. Aggregation to the SWMA scale is done by calculating the length-weighted average of all the reach scores, as per NWC 2007a.

Theme scores

The final scores for the *Aquatic Biota index* based on the SWMAs assessed in the SWWA-FARWH trials are provided in Figure 80.

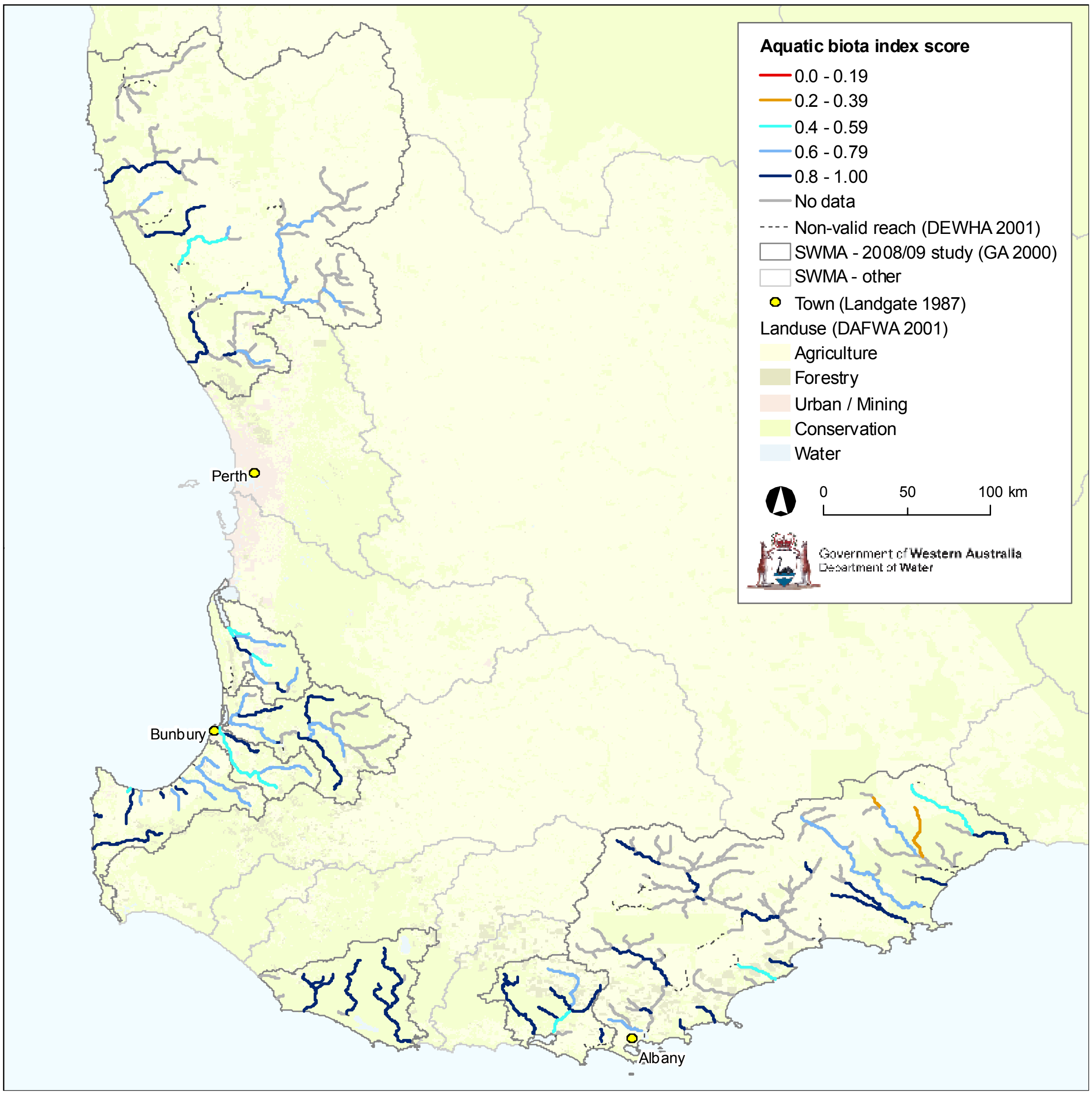


Figure 80 Aquatic Biota index scores for reaches in SWMAs assessed in spring 2008 and 2009 within the SWWA-FARWH trials

The scores above reflect the general understanding of reach health as determined by field officers and regional environmental managers, with much of SWWA slightly to moderately modified due to extensive clearing and associated agricultural land use impacts. There is a small degree of conjecture for a minority of reaches; for example, some reaches in the Shannon River SWMA are believed to be represented in a worse condition than is the case. This may be related to limitations of the *macroinvertebrate sub-index* or an indication of a yet-unknown impact (such as climate change). The most significant impacts are found in the eastern rivers of the Albany Coast SWMA, reflecting salinisation of the area.

The full range of impact was not apparent in the final scores, that is, no sites were reported in the 'severely impacted' category. This may reflect the relative robustness of the most tolerant fish and macroinvertebrate species, and also that most rivers have some ecological integrity remaining (e.g. remnant vegetation and limited intensive land uses). The SWWA-FARWH scores were assessed against data collected within the Perth metropolitan area, which would represent the highest degree of impact. Two systems – Woodlupine Brook and South Belmont Drain (significant permanent-flowing tributaries of the Swan-Canning system, although not FARWH reaches) – returned scores within the 'severely modified' category. Both systems retained only exotic fish and chironomid larvae. This example confirms the ability of the *Aquatic Biota index* to represent the complete impact scale.

Statistical analysis

The relationships between the indicators of the *Aquatic Biota index* were examined to determine whether any redundancies existed. A significant, low correlation existed between the *macroinvertebrate* and *fish/crayfish* sub-indices ($r = 0.2552$; $p = < 0.05$). The low relationship is expected as fish and macroinvertebrates exist at different scales within the aquatic environment and hence will respond differently to disturbances.

Within the *fish/crayfish sub-index*, the *expectedness component* was identified as having a significant, moderate correlation with the *nativeness component* ($r = 0.57$; $p = < 0.05$) and the nativeness metrics: native species ($r = 0.56$; $p = < 0.05$) and native abundance ($r = 0.54$; $p = < 0.05$).

The metrics of the *expectedness* and *nativeness* components were significant ($p = < 0.05$) and strongly correlated ($r \sim 0.9$), a direct result of these metrics being used to generate these scores.

Limitations

The overarching limitation for the *Aquatic Biota index* is lack of data. This is more an issue for biotic indices than in other themes, as the potential for use of other measurements, such as remote sensing, do not apply.

To improve the indices of this index, a better understanding of aquatic biota is required, including greater spatial and temporal awareness of distributions and a significant improvement in knowledge of general biology – specifically tolerances to environmental factors such as increases in salt concentration, life-stage requirements and swimming capabilities.

Other indicators

A number of important variables for future testing were identified through ongoing consultation with SWWA environmental management groups and through guidance nationally. These include the development of indicators for:

- aquatic weeds
- macrophytes

- algae (diatoms),
- terrestrial fauna (water dependent).

Note: indicators such as size and population dynamics can also be sensitive indicators of less obvious impacts (see review in fish/crayfish). For example, minor changes in water quality may result in reduced growth or reproduction of fish, with these changes not detected in presence-absence data.

A detailed report on the indicators investigated for macroinvertebrates is provided in van Looij et al. (2009).

4.7 Final indicator suite for the SWWA-FARWH

The indicators chosen within the six themes representing ecological health for the SWWA-FARWH are provided in Figure 81.

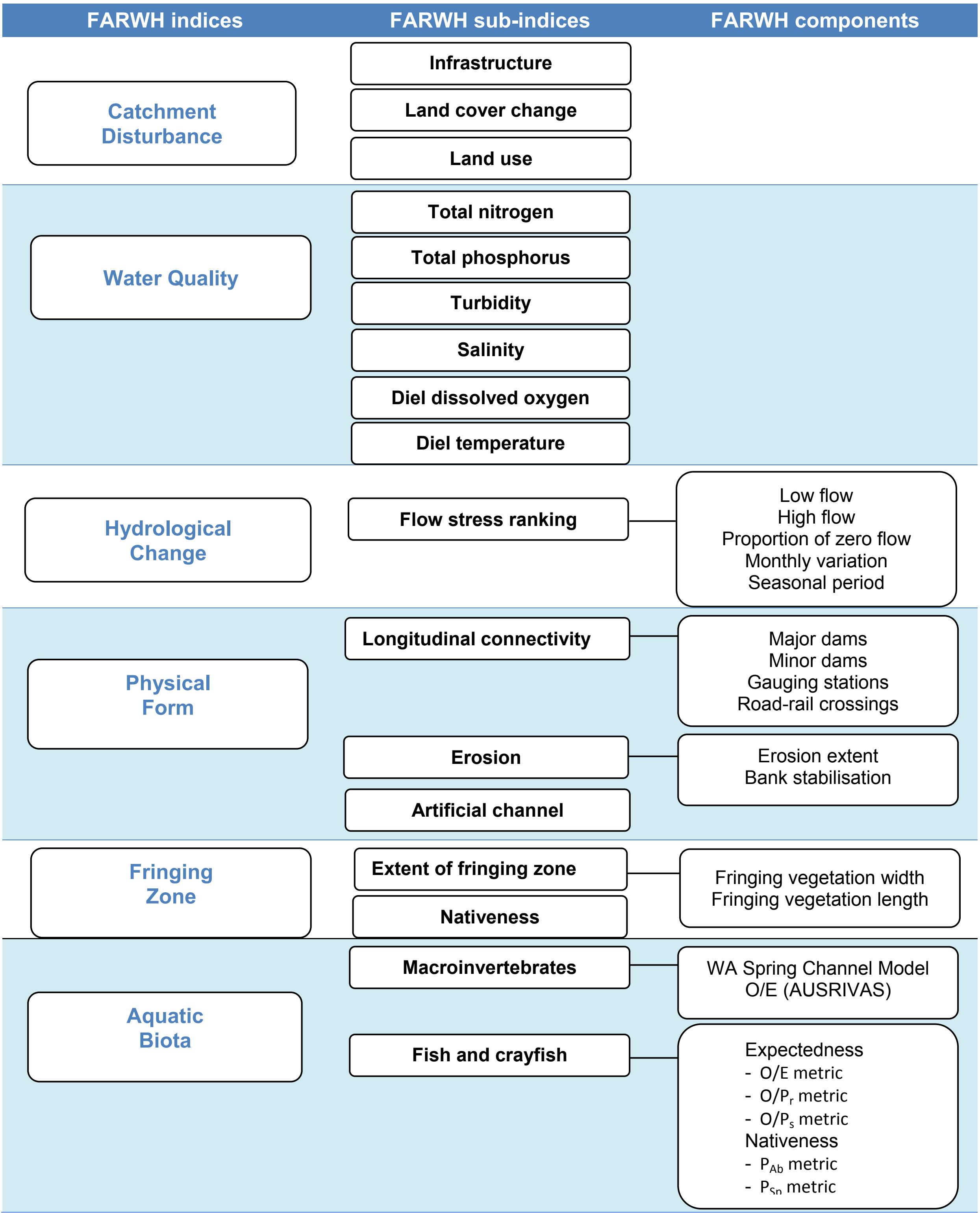


Figure 81 Indicators of the SWWA-FARWH

An extended summary of these indicators is provided in Table 57, including data sources (field or desktop), assessment scale (reach or site), data availability (generation frequency of data), recommended sampling frequency (based on rate of change) and how reference condition was defined (modelled, best professional judgement, literature based).

Table 57 Indicators chosen for assessment in the SWWA-FARWH, including data sources and availability, assessment scale, recommended sampling frequency, how reference condition was defined and minimum data requirements

Theme	Sub-indices *components*	Data source	Scale	Data availability	Recommended sampling frequency	Reference definition	Minimum data required
Catchment Disturbance (CDI)	Infrastructure	Desktop	Reach	Irregular	5 years	BPJ (no disturbance)	
	Land cover change	Desktop	Reach	Annual	5 years	BPJ (no disturbance)	
	Land use	Desktop	Reach	Irregular	5 years	BPJ (no disturbance)	Land use = minimum sub-index to calculate theme
Hydrological Change (HCI)	Flow stress ranking					Modelled (clearing and reservoirs)	All components required to calculate sub-index
	Low flow	Desktop	Reach	Annual	5 years		
	High flow	Desktop	Reach	Annual	5 years		
	Proportion zero flow	Desktop	Reach	Annual	5 years		
	Monthly variation	Desktop	Reach	Annual	5 years		
	Seasonal period	Desktop	Reach	Annual	5 years		
Water Quality (WQI)	Total nitrogen	Field	Site	Requires sampling	Annual	Literature (guidelines)	2 of the 4 secondary indicators to calculate secondary score. Plus at least one of the primary indicators (primary = salinity, DO. secondary = TN, TP, turbidity, temperature)
	Total phosphorus	Field	Site	Requires sampling	Annual	Literature (guidelines)	
	Turbidity	Field	Site	Requires sampling	Annual	Literature (guidelines)	
	Salinity	Desktop	Reach	Irregular	Annual	Literature (biotic tolerance)	
	Diel dissolved oxygen	Field	Site	Requires sampling	Annual	Literature (biotic tolerance)	
	Diel temperature	Field	Site	Requires sampling	Annual	Literature (biotic tolerance)	
Physical Form (PFI)	Longitudinal Connectivity (all components)	Desktop	Reach	Irregular	5 years	BPJ (no artificial barriers)	2 of 3 sub-indices required to calculate theme
	Artificial channel	Desktop	Reach	Irregular	5 years	BPJ (no artificial channels)	
	Erosion						Both components required to calculate sub-index
	Erosion extent	Field	Site	Requires sampling	Annual	BPJ (0-5% erosion)	
	Bank stabilisation	Field	Site	Requires sampling	Annual	BPJ (> 75% tree and shrub cover)	

Theme	Sub-indices *components*	Data source	Scale	Data availability	Recommended sampling frequency	Reference definition	Minimum data required
Fringing Zone (FZI)	Extent of fringing zone						
	Vegetation length	Desktop	Reach	Annual	5 years	BPJ (100% cover)	Both compo-nents required to calculate sub-index
	Vegetation width	Desktop	Reach	Annual	5 years		
	Nativeness	Field	Site	Requires sampling	Annual	BPJ (100% native)	Extent of FZ = minimum sub-index to calculate theme
Aquatic Biota (ABI)	Fish/crayfish						
	Expectedness	Field	Site	Requires sampling	Bi-annual	BPJ (literature, expert opinion)	Both compo-nents required to calculate sub-index
	Nativeness	Field	Site	Requires sampling	Bi-annual	BPJ (100% native)	
	Macroinvertebrates	Field	Site	Requires sampling	Annual in spring	Modelled (reference sites)	Required

Note: BPJ refers to best professional judgement

Provided in the table above are suggestions of how frequently each indicator should be re-assessed. This is determined based on likelihood of change in conditions or availability of newly generated data to conduct successive assessments. From this, only Aquatic Biota, Water Quality and one indicator in both Fringing Zone and Physical Form require an annual assessment, with the remaining FARWH indicators relevant at five-year cycles.

5 Discussion of results

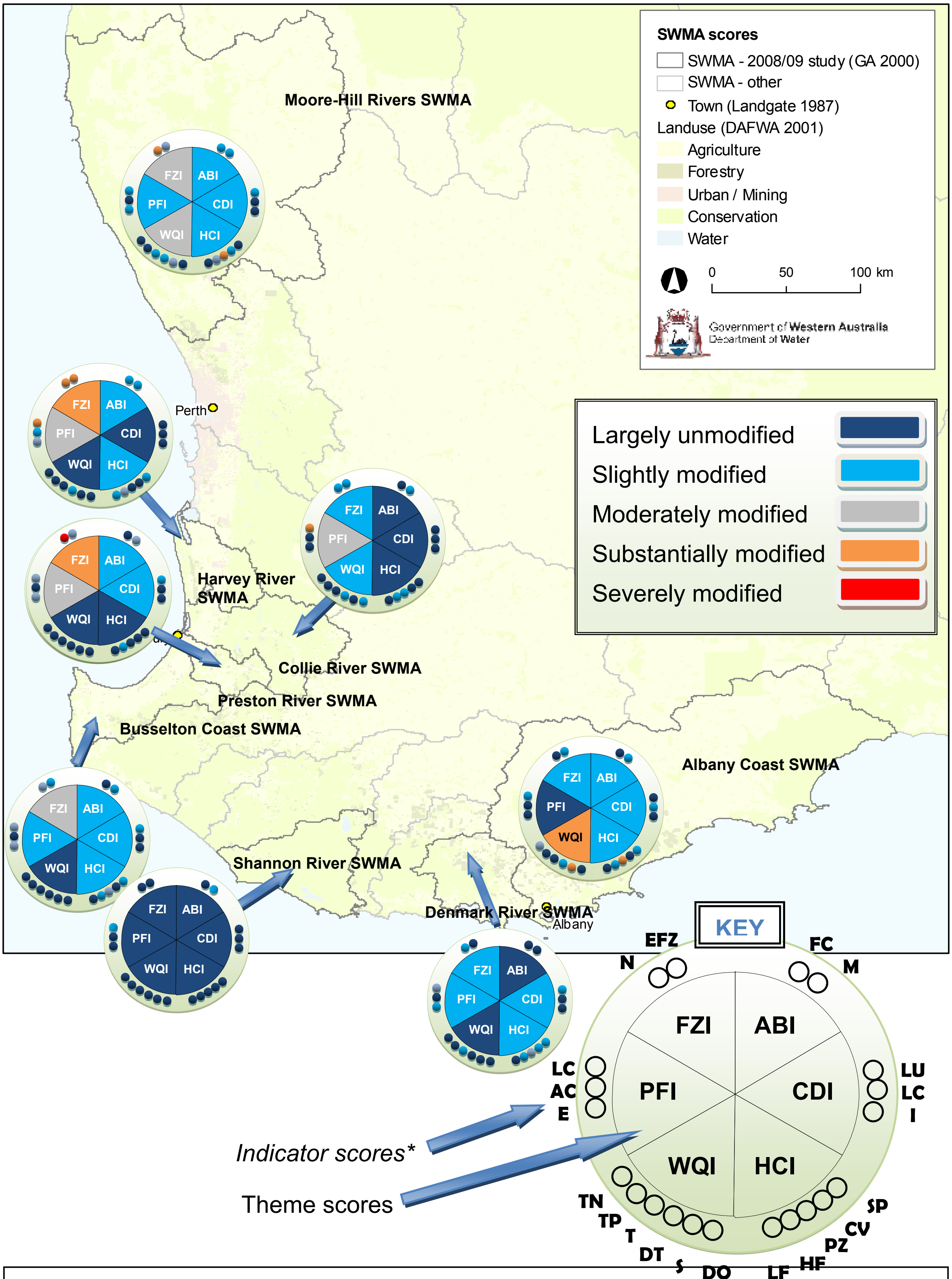
5.1 Performance of the FARWH (SWMA scores)

Individually, themes and indicators were shown to perform well in terms of capturing variability (known or inferred) and reflecting health status. This was demonstrated through sensitivity analysis, scenario testing and comparisons against expert opinion, as well as via efficiency assessments using power analysis and correlation-redundancy measures.

Themes and indicators were also shown to perform well (at the SWMA scale) when compared against indicators in other ecological themes (pressure-stressor responses) and against what is generally understood about the health of SWWA systems (see excerpt below and the SWMA reviews in Section 3.2: SWMA selection).

> Within SWWA the Shannon River SWMA is generally considered the most pristine of the SWMAs assessed, based on the low level of urban and agricultural development, minimal vegetation clearing, and absence of significant hydrological modification. Alternatively, most of the other SWMAs assessed have been extensively cleared for agriculture, especially in lowland/coastal areas and intensifying around the Harvey to Preston River SWMAs.

The final theme and indicator scores for each SWMA assessed within the SWWA-FARWH field trials are shown in Figure 82, which generally align with the understanding of river health in SWWA.



*** INDICATORS:** **PFI: LC** (longitudinal continuity), **AC** (artificial channel), **E** (erosion). **WQI: TN** (total nitrogen), **TP** (total phosphorus), **T** (turbidity), **DT** (diel temperature), **S** (salinity), **DO** (dissolved oxygen). **HCI**: **LF** (low flow), HF (high flow), **PZ** (period zero flow), **CV** (coefficient of variation), **SP** (seasonal period). **CDI: I** (infrastructure), **LC** (land-cover change), **LU** (land use). **ABI: FC** (fish-crayfish), **M** (macroinvertebrates). **FZI: N** (nativeness), **EFZ** (extent fringing zone).

Figure 82 SWMA scores, assessed during SWWA-FARWH trials (2008–2010)

As shown in Figure 82, scores for Shannon River SWMA reflected the low degree of disturbance, whereas a slight to moderate modification was apparent across all other SWMAs, with some elements of substantial modification in the Harvey River and Preston River SWMAs – as expected.) However, there are a number of exceptions, which do not appear to follow the general understanding of river health in SWWA. These exceptions are examined in the theme summaries below.

Fringing Zone theme

The overall Fringing Zone scores were as expected. Harvey River and Preston River SWMAs scored the lowest, being assigned the 'substantially modified' category. The majority of the associated subcatchments have been cleared to support agriculture and mining. In addition, many of the reaches were drains and only supported an exotic understorey consisting of grasses. Although much of the Albany Coast and Denmark River SWMAs have been cleared, they scored in the 'slightly modified' category as there appears to be corridors of native vegetation remaining along most river reaches. However, these areas have been invaded by exotics. The Shannon River SWMA is classified as 'largely unmodified'. This is the closest to 'pristine' of the SWMAs sampled with only a small percentage of the catchment cleared. The Collie River, Moore-Hill Rivers and Busselton Coast SWMAs were classified in the 'moderately modified' category. A more extensive invasion of exotics in these areas resulted in their lower overall score compared with Denmark River and Albany Coast SWMAs.

Hydrological Change theme

SWMA scores for hydrology show little differentiation at the SWMA level. A slight modification to hydrology was shown for all SWMAs, with the exception of Shannon River SWMA, which showed no hydrological alteration at even the component level. This is somewhat surprising given the degree of modification in the Harvey River, Preston River, Collie River and Busselton Coast SWMAs due to clearing, reservoirs and diversions. However, poor scores in these areas were balanced by higher scores in unmodified areas within the same SWMA – explaining the overall classification.

Water Quality theme

Generally most SWMAs scored in the 'slightly modified' to 'largely unmodified' category. The exception was the Albany Coast and Moore-Hill Rivers SWMAs which scored in the 'substantially' and 'moderately modified' categories respectively. This is primarily due to high salinity in the eastern parts of these SWMAs (high salinity occurred in over half the reaches in both SWMAs). Note: results for Albany Coast SWMA need to be considered in relation to varying confidence levels, as there is evidence to suggest that some degree of salinity is natural (see discussion in Section 5.3: Water quality). A potential issue is that reaches in the western parts of these SWMAs do not have high salinity, which is not reflected in the overall *Water Quality* *index* score. This issue relates to SWMA boundaries (see discussion in the Catchment Disturbance summary).

Scores for the remaining SWMAs are somewhat unexpected as the *Water Quality index* showed little relationship with the high degree of land use change and loss of fringing vegetation, especially in the Harvey River and Preston River SWMAs. Further, the Shannon River SWMA was in the same category (‘largely unmodified’) as the Preston River SWMA which is substantially more cleared and developed. This is most likely related to the inability of the *Water Quality index* to be effective using primarily point-source data. We recommend the use of logging equipment to capture longer-term data across multiple parameters.

Physical Form theme

The SWMA scores for the *Physical Form index* ranged from between 0.4 and 0.8. The differentiation between SWMAs was not necessarily as anticipated; for instance, SWMAs expected to be identified as ‘significantly modified’ showed only minor departure from reference. The lower scores derived for Harvey River, Preston River, Busselton Coast and Collie River SWMAs were expected because in these areas the quantity and quality of habitat is known to be impacted by drainage channels and dams for water supply. However, the scores for Moore-Hill Rivers and Albany Coast SWMAs were higher than expected and those for Shannon River and Denmark River SWMAs were lower than expected based on perceived levels of disturbance in these areas.

This finding may be a true indication of physical form or related to underpinning data. For instance, the barrier dataset used to calculate the *longitudinal connectivity sub-index* has not been validated for the SWMAs assessed – as such, the degree of impact of potential barriers in different areas may be very different. Understanding the impacts of physical form and the ability of the current protocols to reflect these conditions will be the focus of future assessments.

Aquatic Biota theme

SWMA scores for the *Aquatic Biota index* ranged between 0.6 and 0.8. The highest scores occurred in the Shannon River and Denmark River SWMAs, which was as anticipated based on perceived levels of disturbance to river systems in these areas. Similarly the lower scores derived for Harvey River and Preston River SWMAs aligned with knowledge of disturbance to the river systems caused by land use in these areas. The ranked health of SWMAs correlated with expectations, however at the SWMA scale there was little range in scores. This has been identified as a scale issue, with biota impacts observed at a site/reach level and thus any change is dampened at the SWMA scale (see discussion in the Catchment Disturbance summary below).

Catchment Disturbance theme

The SWMA scores for the *Catchment Disturbance index* and associated sub-indicator scores are all within the ‘slightly modified’ to ‘largely unmodified’ categories. The differentiation between SWMAs is generally as anticipated, with Preston River, Busselton Coast, Moore-Hill Rivers and Albany Coast SWMAs known to be more disturbed than the Shannon River SWMA. The exceptions are the Harvey River and Denmark River SWMAs. In SWWA the Harvey River SWMA is often perceived as one of the more impacted catchments in terms of having the highest proportion of clearing (of which a large component is used for dairy cattle). Denmark River SWMA is alternatively perceived as less modified than many of the SWMAs assessed, however this differentiation was not apparent at the SWMA scale.

These exceptions may be a function of multi-parameter effects on responses: where response is a result of a combination of factors that are acting differently under different natural environmental conditions (e.g. elevation and rainfall). However, a major overriding factor is the reporting scale, which effectively reduces the sensitivity of all scores. Impacts in SWWA are often confined to the lowland coastal areas, especially in the south-west corner (see Figure 83), whereas SWMA boundaries extend from lowland to upland zones.

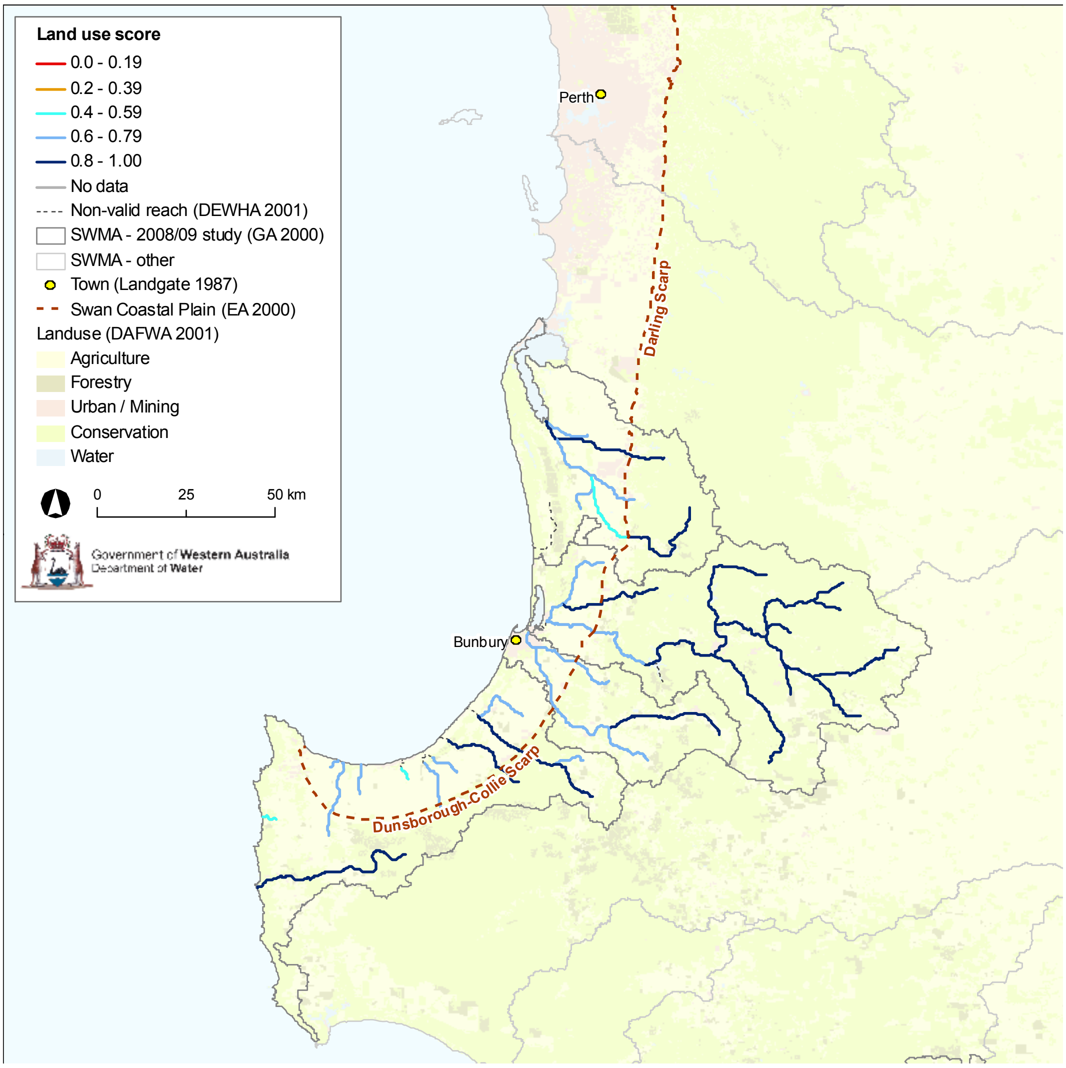


Figure 83 Land uses in SWWA, encompassing Harvey River, Collie River, Preston River and Busselton Coast SWMAs. The division between conservation-dominated upland areas and agriculture-dominated coastal lowland areas (west of Darling Scarp)

Although impacts in the lowland sections are identified and characterised through reach scores, both the severity and any variability between SWMAs is dampened by aggregation of scores in the more impacted lower catchments with the relatively unmodified upland regions. That is, scores towards the extreme end of the impact scale are lost and differences between areas are reduced (typically falling within the same category). Redefinition of SWMAs (e.g. splitting current areas by elevation) was not conducted due to time availability for the SWWA-FARWH trials, but this is a key recommendation for future work. Note: for local purposes, the reach scores provide an adequate assessment of the severity of more localised impacts.

Note: while there is some differentiation between the scores of the SWMAs assessed in 2008 and 2009, the effectiveness of the *Catchment Disturbance index* for SWWA cannot be properly evaluated until the remaining SWMAs, including the metropolitan areas of SWWA, are assessed (it is anticipated there will be greater differentiation between rural and urban SWMAs).

5.2 Statistical analysis

Correlation/redundancy measures

Correlations between all SWWA-FARWH scores – comparing themes (index), sub-indices, components and metrics between themes – were assessed using PRIMERs Relate function. Numerous weak correlations existed, showing there was some interplay between ecological features, but no strong correlations (r > 0.6) existed. Figure 84 displays results at the index level.

Index	CDI					
FZI	0.21 (0.1%)	**FZI**				
PFI	0.032 (15.6%)	0.26 (0.1%)	**PFI**			
WQI	0.173 (0.1%)	0.055 (4%)	0.089 (7.1%)	**WQI**		
HCI	0.188 (0.1%)	0.065 (1.8%)	0.083 (6.4%)	0.121 (0.8%)	**HCI**	
ABI	0.027 (22%)	0.114 (0.1%)	0.175 (0.7%)	0.156 (0.5%)	0.024 (32.4%)	**ABI**

Figure 84 Sample statistics (Rho) generated from the Relate procedure using the Spearman coefficient to match resemblance matrices of the FARWH indexes. Significance level (expressed as a percentage) is indicated in brackets.

To determine whether any redundancies existed, the relationships between theme indices were also examined discretely with Statistica (v9) using linear regression and scatter plots. No strong correlations existed, confirming no redundant indices. Limited correlation relationships existed between *Catchment Disturbance* and *Fringing Zone* (r = 0.48), *Hydrological Change* (r = 0.40) and *Water Quality* (r = 0.39) and between *Fringing Zone* and *Physical Form* (r = 0.48).

Multivariate statistical analysis (local management scale)

A preliminary statistical analysis of the drivers of ecological health based on SWWA-FARWH data has been initiated for local management purposes. Although this is somewhat outside the national FARWH program's scope – given it is designed at a different scale (sites are grouped based on features driving ecology rather than working at an SWMA scale) – it was considered important to support the SWWA-FARWH indicators' ability to represent health (i.e. identifying correlations between pressure and response). The process and preliminary results are summarised below.

The objective was/is to determine what variables are driving river health in terms of biotic responses. Multivariate analyses performed in PRIMER (Clarke & Gorley 2006) were used to classify the SWWA-FARWH biological datasets into groups, based on similarity in the species abundance of fish and macroinvertebrates. Macroinvertebrates and fish were dealt with separately because they operate on different scales and hence are likely to respond differently to environmental variables (disturbance factors and natural environmental conditions). Examples illustrated within the following overview are from the analyses undertaken with the macroinvertebrate dataset.

Hierarchical classification and ordination by Non-Metric Multi-Dimensional Scaling (NMDS) were performed on the biological data to examine groupings based on species abundance. Ordinations were based on the Bray–Curtis similarity matrix. Figure 85 shows the NMDS ordination of the macroinvertebrate community composition recorded at sites within the eight SWMAs sampled in 2008 and 2009.

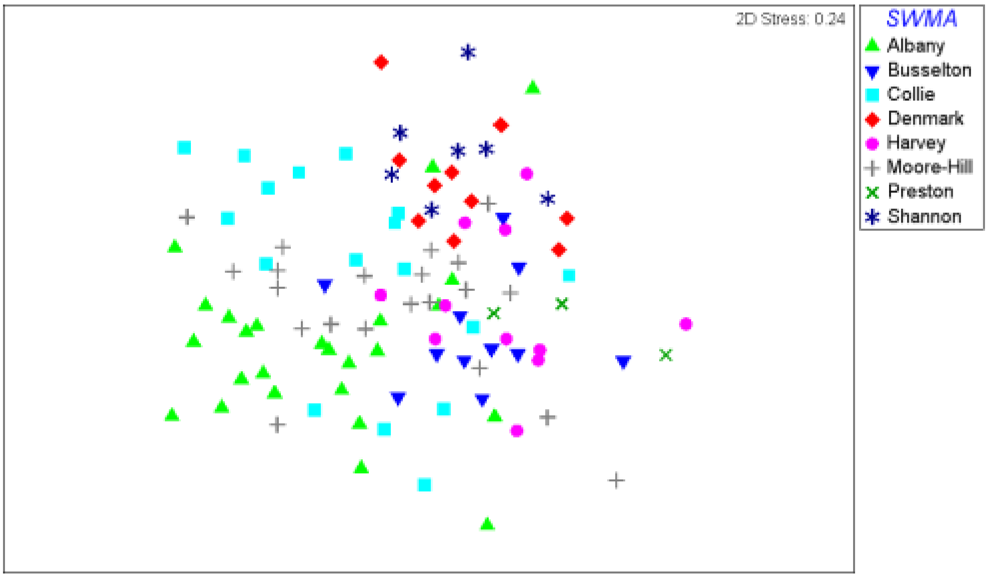


Figure 85 NMDS ordination of the macroinvertebrate community composition recorded at sites within the eight SWMAs in SWWA

The DISTLM procedure in PRIMER was used to examine the relationship between the environmental and disturbance variables and the biological data cloud. This was to determine which variables best explain the variation seen in the biological datasets. Within the DISTLM the BEST selection procedure (using 'An Information Criteria') was chosen to generate the best overall possible combinations of variables.

Analyses revealed that no single environmental or disturbance variable (or combination thereof) significantly influenced the groupings of the macroinvertebrate and fish datasets. Marginal tests within the DISTLM procedure indicated a number of variables that individually explained approximately 10% of the variability in the macroinvertebrate composition data cloud: these included conductivity, mean annual rainfall, elevation, evapotranspiration, the *salinity sub-index* and the *Water Quality index* score (due to effect of salinity). This variability was also seen through Principle Component Analysis (PCA – environmental data) (PCA results shown in Figure 86).

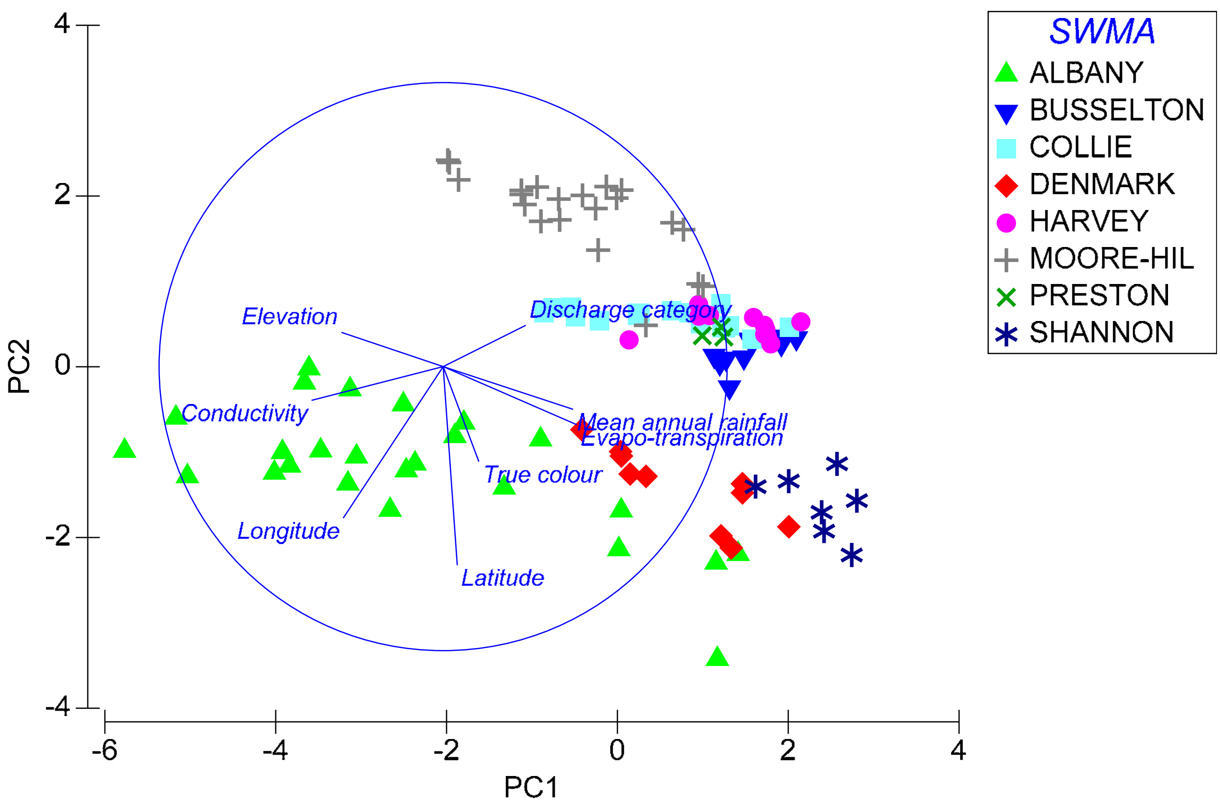


Figure 86 Principle Component Analysis of non-impact environmental variables, conductivity and colour. Data were normalised prior to analysis.

Principle Components (PC) 1 and 2 accounted for 46.4% and 20.7% of the variation respectively (Table 58). PC 1 indicates that conductivity, mean annual rainfall, elevation, evapotranspiration and longitude accounts for most of the variation (r ~ 0.46) in the sites sampled, while PC 2 indicates that colour was also important (r = 0.36).

Table 58 Eigenvalues for PCA shown in Figure C. Data shown only for the first three vectors.

Principle Component	Eigenvalues	%variation	Cum.% variation
1	3.71	46.4	46.4
2	1.66	20.7	67.1
3	1.06	13.3	80.4

Coefficients in the linear combinations of variables making up Principle Components

Variable	PC1	PC2	PC3
Longitude	-0.351	-0.534	0.027
Latitude	0.05	-0.699	0.373
Discharge category	0.291	0.145	0.37
Conductivity (mS/cm)	-0.463	-0.119	0.118
Colour (TCU)	0.126	-0.335	-0.743
Evapotranspiration	0.47	-0.204	0.067
Elevation (m)	-0.358	0.12	0.307
Mean annual rainfall	0.458	-0.151	0.241

The PCA plot shows that sites within a SWMA tended to group together with the exception of Albany SWMA (Figure 86). Albany sites are being influenced by salinity (conductivity), colour and geographic position (elevation, latitude and longitude). It is clear from the PCA plot that the dataset should be divided into smaller subsets before further analysis.

Sites located on the left of the NMDS (Figure 85) were characterised by high salinities, high elevation, low evapotranspiration, low mean annual rainfall and non-coloured systems. However the correlation of these variables (indicated by the marginal tests) individually and combined with other variables were low; typically less than 40%. Marginal tests performed on the fish dataset showed similar results. The lack of significant correlations at this level is expected given the variability between sites due to differences in the natural physical environmental variables (latitude, longitude, elevation, rainfall, stream size etc.) and varying levels of disturbance.

Values of natural and disturbance variables were overlaid onto the NMDS using bubble plots to allow a visual assessment of the relationship between the biological data and environmental and biotic variables (Clarke & Gorley 2006). An example of bubble plots of variables identified as having the most influence on biota groups at the SWWA scale (as highlighted by DISTLM and PCA) are shown in Figure 87. Note: bubble plots of all variables were examined to ensure no relationships were missed by PCA/DISTLM; this is discussed later.

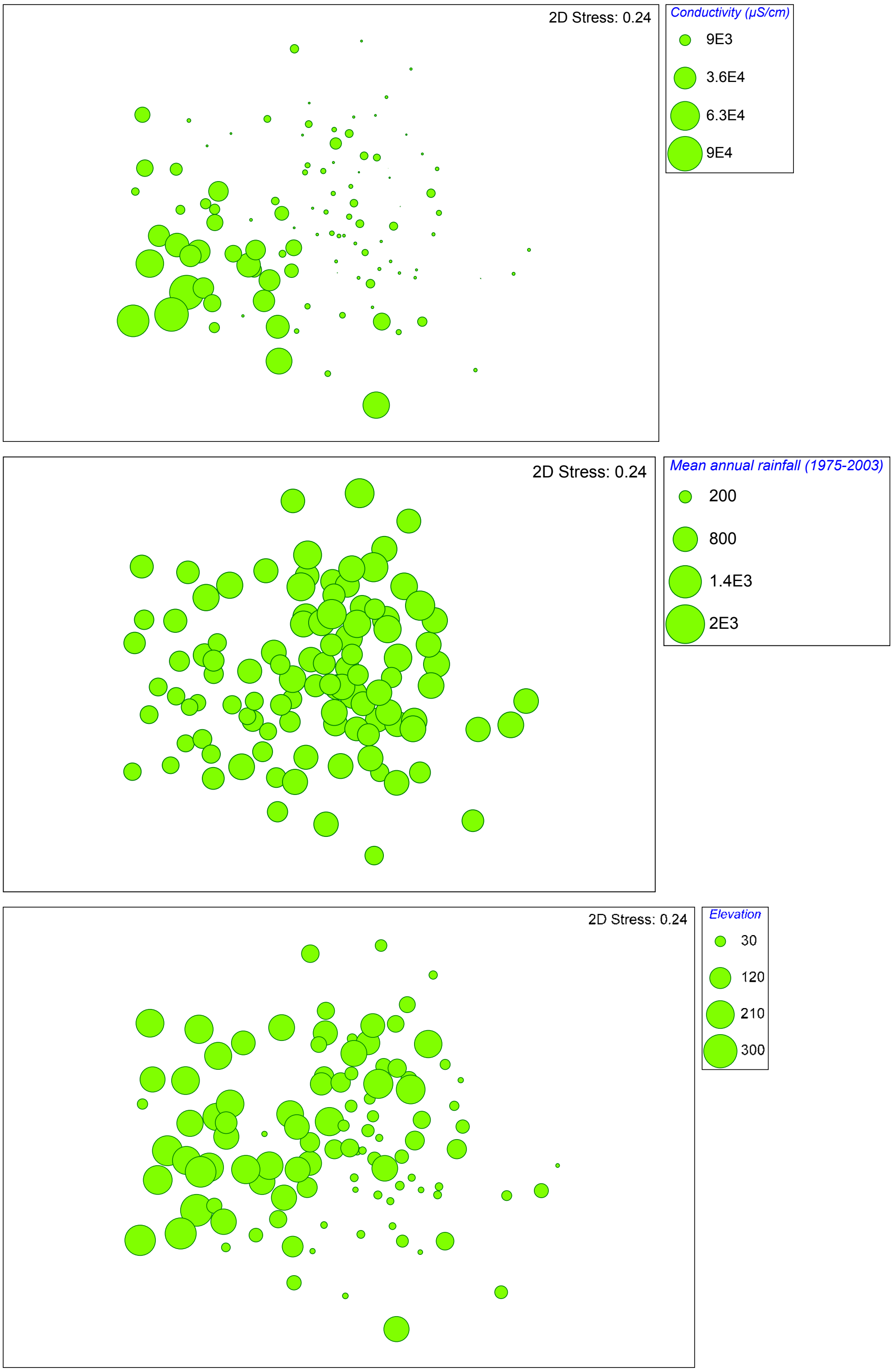


Figure 87 Association of environmental variables with macroinvertebrate data. Plots are: conductivity, mean annual rainfall, and elevation.

Examination of identified variables shows that natural features (not disturbance factors) appeared to be the major drivers of biotic community composition. This suggests that ecology remains a function of natural conditions rather than being driven by disturbance (at the SWWA scale – all sites).

Based on the findings above, sites were grouped using the identified variables. Normal Euclidean Distance was used to create a similarity matrix for the chosen variables: this included latitude, longitude, evapotranspiration, mean annual rainfall and elevation. In addition, conductivity and colour were included as these were considered to be important drivers of biotic assemblage and without this division would have added noise to subsequent analyses. (Note: although conductivity is a known impact variable (salinisation) it is also reported as a natural ecological driver in a number of systems across SWWA.) NMDS was then performed on the similarity matrix.

Hierarchical clustering of the sites based on these environmental variables generated four groups and these groups were superimposed onto an ordination of the same data (Figure 88). Group 1 was dominated by low rainfall and high salinities. Groups 2 and 3 comprised freshwater tannin-stained sites. Group 4 consisted of freshwater systems that were predominantly non-coloured.

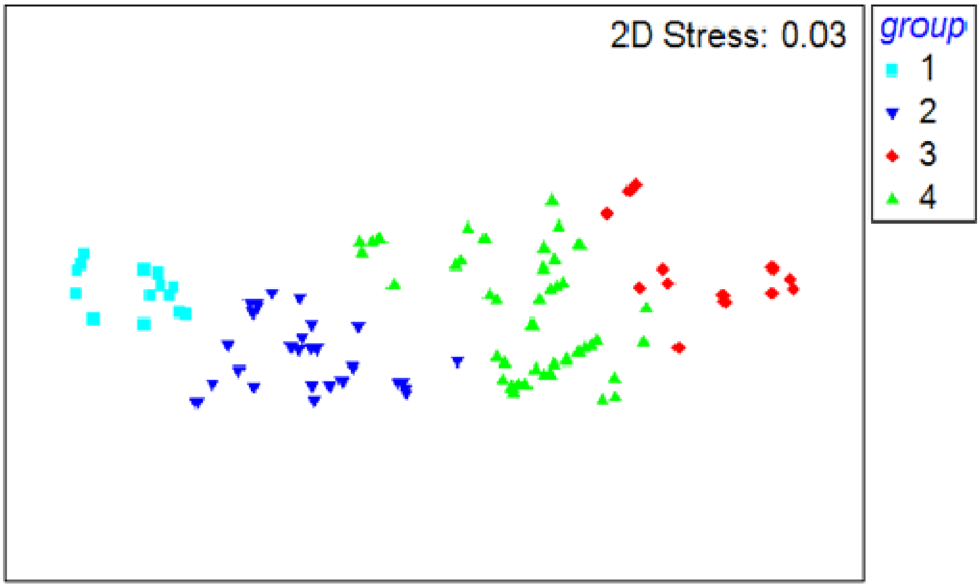


Figure 88 Two-dimensional non-metric multidimensional scaling (NMDS) ordination plot (inlay: stress 0.03) based on the non-impact environmental dataset

Using one group as an example (Group 4) macroinvertebrate assemblage data was assessed against impact variables. Group 4 was chosen because it contained sites that were mainly fresh and contained the greatest range of disturbance. Hierarchical classification and ordination by NMDS were performed on the macroinvertebrate data within Group 4 to examine groupings based on species abundance. Ordinations were based on Bray–Curtis similarity matrix. Hierarchical clustering of the sites generated six groups sharing at least 37% similarity (Figure 89). Subsequent analyses were undertaken using the DISTLM procedure to identify variables that best explained the data cloud. Marginal tests within the DISTLM procedure indicated a number of variables that individually explained approximately 10% of the variability in the macroinvertebrate composition data cloud: these included elevation, *Fringing Zone index* score and *extent of fringing zone sub-index* score. Sequential tests (where a combination of environmental variables is examined) also produced low correlations.

Examination of the bubble plots indicate that compared with the other groups, groups 3 and 6 were characterised by poor riparian vegetation in terms of extent and width and were generally located at lower elevations (Figure 90). Based on data and the method for generating fringing zone scores, there is no obvious ‘natural’ explanation for the correlation between elevation and vegetation (i.e. the same extent of fringing zone is expected in all areas); as such it is likely this result is a direct function of the impact of clearing.

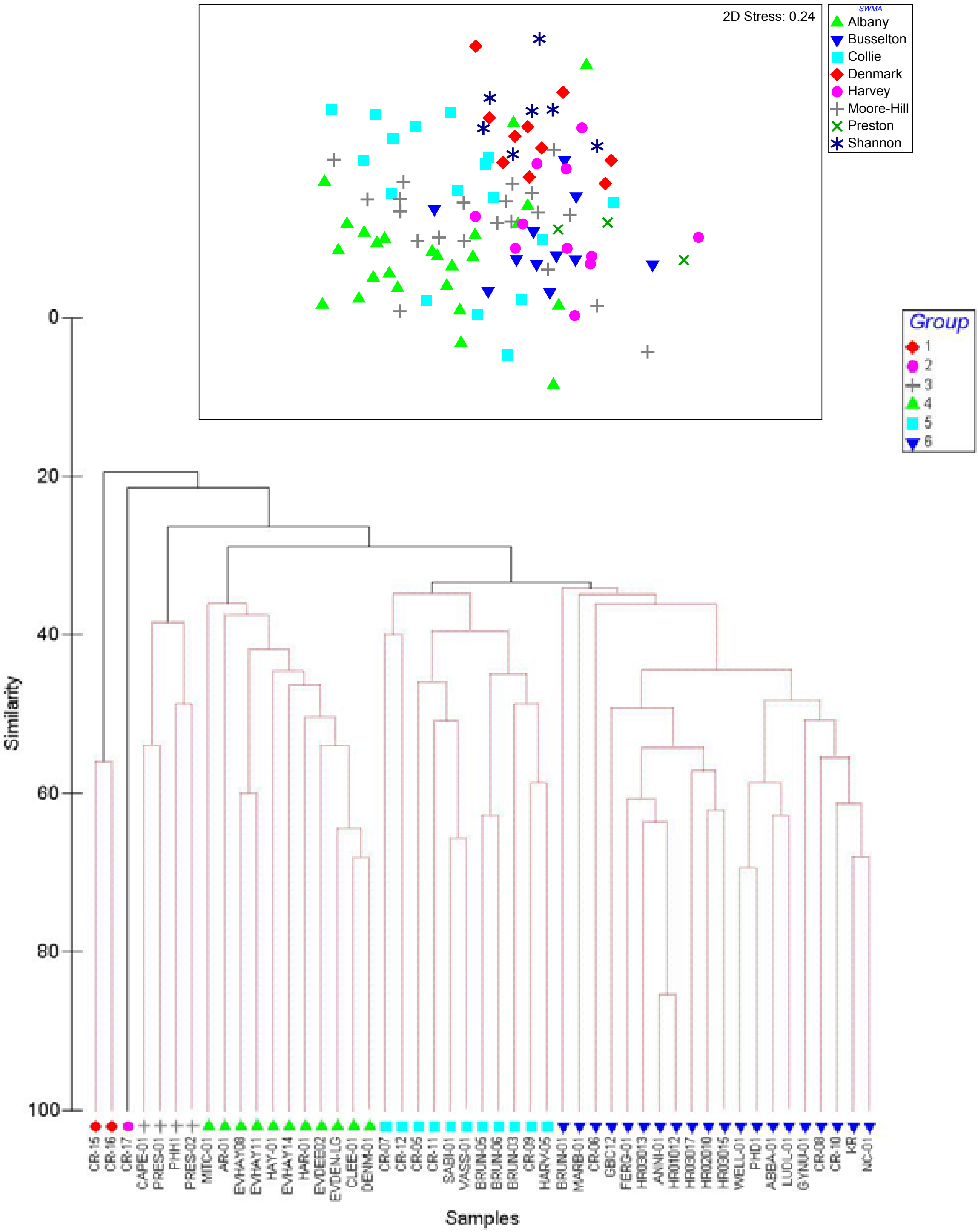


Figure 89 Two-dimensional NMDS ordination plots (top) and hierarchical cluster diagram (bottom) based on the macroinvertebrate community Group 4.

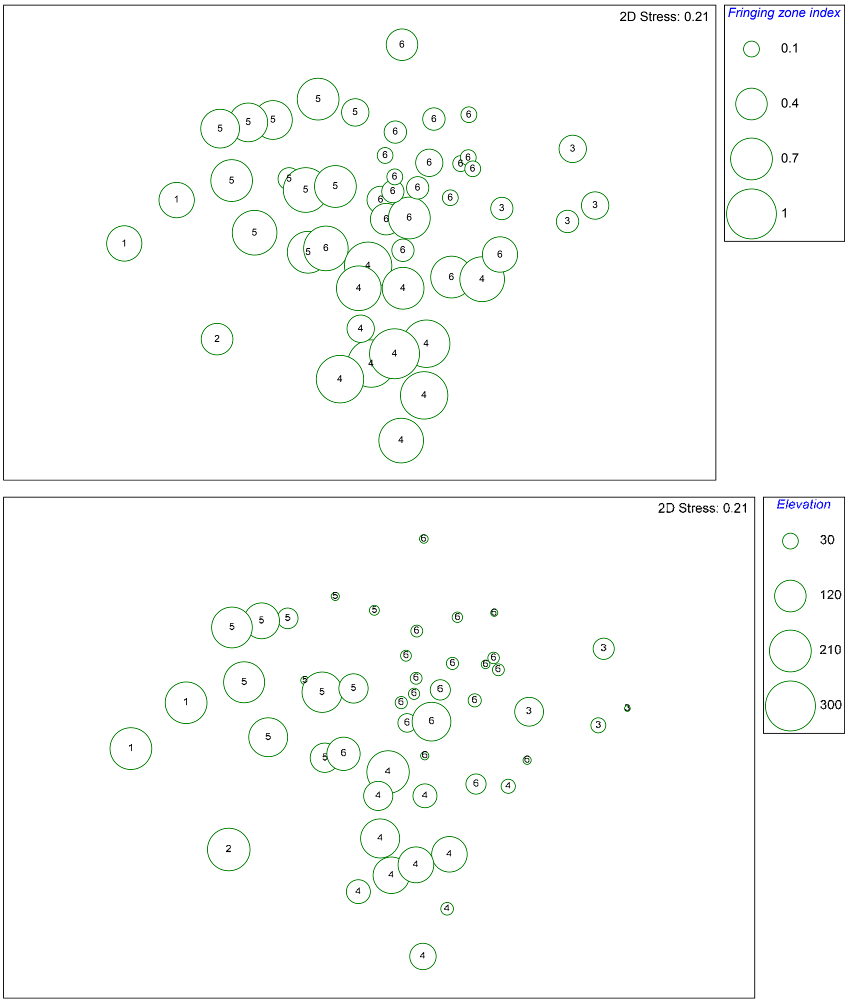


Figure 90 Bubble plots showing the association of environmental variables with the macroinvertebrate sub-set dataset. Larger bubbles indicate higher values of each variable. Plots depict: (top) fringing zone index score and (bottom) elevation.

Note: factors which may have been expected to correlate with biotic stress (e.g. catchment disturbance) showed no overriding relationship, however this can generally be explained. For instance (using catchment disturbance as an example), because groups are defined on elevation, and land use in SWWA is correlated with elevation, it is likely this wouldn't be a defining feature within groups. Note: land use is still an important indicator of river health at the SWMA scale; and an important indicator of pressure for local management.

The analyses described above are only preliminary given time restrictions between availability of data and reporting deadlines (e.g. more factors require collation and assessment). This will be extended to evaluate potential models for a range of impact variables – for both fish and macroinvertebrates (e.g. extending AUSRIVAS). Subsequent analyses will explore relationships further and include an examination of typologies based on the Australian National Aquatic Ecosystem (ANAE) framework for riverine systems. However, any finer-scale assessment that will likely result in increasing the number of 'river types' is hampered due to low power, as sites are reduced into smaller groups through this process. A critical requirement is the collection of more data across SWWA before re-running these analyses, both within currently assessed SWMAs and throughout remaining areas yet to be sampled.

5.3 Summary

1 Themes and indicators performed well at the reach and SWMA scale and given the current availability of river health data.

2 The multi-parameter approach is supported given that no one indicator or theme was found to represent health. This was further supported by field observations (e.g. sites with the same catchment land use displayed large differences in the extent of both understorey and large trees in the river corridor, thus neither vegetation nor catchment disturbance indicators are sufficient individually).

3 The overriding issue for national reporting is the reporting scale. Aggregation to the SWMA scale was identified as having a dampening effect on scores (reducing sensitivity) and had different effects in different areas (bias). SWMA boundaries require redefinition to resolve this issue, including accounting for land use changes with elevation. Note: this is primarily a state issue due to the requirement for local relevance, however national comparability must be considered.

Appendices

Appendix A Complete final scores for SWWA-FARWH: indicators/themes for reaches/SWMAs

Note:

- Some indicators have scores for all reaches, whereas others only have scores for reaches that were sampled in the field. Where a score has not been calculated, due to missing data and/or it being a field assessed indicator, the cell has been left blank.
- For indicators that are assessed at each site, where more than one site has been sampled on each reach, all site scores have been shown (i.e. Water Quality theme and Aquatic Biota theme).
- For themes that use a combination of reach and site-assessed scores, only the reach score is shown (i.e. Fringing Zone theme and Physical Form theme).
- Reaches 6031138 and 6031540 were split into 60311381, 60311382 and 60315401 and 60315402. However, for the *Hydrological Change index* only the full reach (i.e. 6031138 and 6031540) was scored.
- See shortened forms for abbreviations.

Catchment Disturbance theme

Catchment Disturbance theme

Reach	CDI	ISI	LUSI	LCCSI
Albany Coast SWMA				
6020938	0.9	1	0.9	1
6020965	0.5	1	0.5	1
6020973	0.5	1	0.5	1
6020981	0.5	1	0.5	1
6020991	1	1	1	1
6020995	0.5	1	0.5	1
6021000	0.5	1	0.5	1
6021001	0.6	1	0.6	1
6021003	0.5	1	0.5	1
6021004	0.5	1	0.5	1
6021008	0.5	1	0.5	1
6021009	0.5	1	0.5	1

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
6021010	0.5	1	0.5	1
6021012	0.8	1	0.8	1
6021013	0.7	1	0.7	1
6021021	0.5	1	0.5	1
6021024	1	1	1	1
6021025	1	1	1	1
6021026	0.5	1	0.5	1
6021027	0.5	1	0.5	1
6021028	1	1	1	1
6021034	0.6	1	0.6	1
6021035	0.5	1	0.5	1
6021036	1	1	1	1
6021037	1	1	1	1
6021038	0.5	1	0.5	1
6021042	0.5	1	0.5	1
6021043	0.5	1	0.5	1
6021048	0.5	1	0.5	1
6021052	0.5	1	0.5	1
6021053	0.6	1	0.6	1
6021058	0.6	1	0.6	1
6021062	0.7	1	0.7	1
6021063	0.5	1	0.5	1
6021065	0.5	1	0.5	1
6021066	0.5	1	0.5	1
6021069	0.7	1	0.7	1
6021073	0.5	1	0.5	1
6021076	0.8	1	0.8	1
6021097	0.5	1	0.5	1
6021098	0.9	1	0.9	1

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
6021099	1	1	1	1
6021100	0.7	1	0.7	1
6021108	0.5	1	0.5	1
6021110	0.8	1	0.8	1
6021111	0.5	1	0.5	1
6021115	0.8	1	0.8	1
6021117	0.6	1	0.6	1
6021123	0.8	1	0.8	1
6021128	0.4	1	0.6	0.8
6021136	0.5	1	0.6	0.9
6021137	0.5	1	0.6	0.9
6021143	0.8	1	0.8	1
6021146	0.5	1	0.6	0.9
6021147	0.5	1	0.5	1
6021149	0.8	1	0.8	1
6021497	0.7	1	0.7	1
6021501	0.5	1	0.5	1
6021515	0.5	1	0.5	1
6021518	0.6	1	0.6	1
6021526	0.4	1	0.5	0.9
6021531	0.5	1	0.5	1
6021534	0.6	1	0.7	0.9
6021536	0.5	1	0.6	0.9
6021715	1	1	1	1
6021717	0.5	1	0.5	1
6021727	0.5	1	0.5	1
6021842	0.6	1	0.6	1
6021928	0.5	1	0.5	1
6021929	1	1	1	1

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
6021933	0.5	1	0.5	1
6022002	0.5	1	0.5	1
6022004	0.5	1	0.5	1
6022005	0.6	1	0.6	1
6022110	0.5	1	0.5	1
6022158	0.5	1	0.5	1
6022199	0.7	1	0.7	1
6022280	0.5	1	0.5	1
6022282	0.7	1	0.7	1
6022301	0.5	1	0.5	1
6022319	0.5	1	0.5	1
6022322	0.6	1	0.6	1
6022340	0.7	1	0.7	1
6022350	0.7	1	0.7	1
6022352	0.7	1	0.7	1
6022450	0.6	1	0.6	1
6022560	0.5	1	0.5	1
6022566	0.5	1	0.5	1
6022594	0.6	1	0.6	1
6022603	0.7	1	0.7	1
6022611	1	1	1	1
6022615	1	1	1	1
6022623	1	1	1	1
6022697	0.5	1	0.5	1
6022702	0.5	1	0.5	1
Denmark River SWMA				
6031121	0.9	1	0.9	1
6031122	0.8	1	0.8	1
6031131	0.6	1	0.6	1

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
6031132	0.8	1	0.8	1
6031138				
6031142	0.9	1	0.9	1
6031150	0.6	1	0.6	1
6031152	0.6	1	0.6	1
6031540				
60311381	0.6	1	0.6	1
60311382	0.8	1	0.8	1
60315401	0.9	1	0.9	1
60315402	0.8	1	0.8	1
Shannon River SWMA				
6061118	0.9	1	0.9	1
6061119	0.9	1	0.9	1
6061120	0.9	1	0.9	1
6061124	0.9	1	0.9	1
6061125	0.9	1	0.9	1
6061126	0.9	1	0.9	1
6061129	1	1	1	1
6061133	0.9	1	0.9	1
6061139	1	1	1	1
6061140	1	1	1	1
6061535	0.9	1	0.9	1
Busselton Coast SWMA				
6100902	0.6	1	0.6	1
6100929	0.7	1	0.7	1
6100931	0.6	1	0.6	1
6100933	0.7	1	0.7	1
6100936	0.5	1	0.5	1
6100939	0.8	1	0.8	1

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
6100946	0.6	1	0.6	1
6100948	0.8	1	0.8	1
6100956	0.7	1	0.7	1
6100967	0.5	1	0.5	1
6100978	0.6	1	0.6	1
6101002	0.8	1	0.8	1
Preston River SWMA				
6110873	0.7	1	0.7	1
6110909	0.8	1	0.8	1
6110924	0.7	1	0.7	1
Collie River SWMA				
6120802	0.7	1	0.7	1
6120819	0.9	1	0.9	1
6120825	0.8	1	0.8	1
6120826	0.9	1	0.9	1
6120836	0.9	1	0.9	1
6120842	0.9	1	0.9	1
6120869	0.8	1	0.8	1
6120880	0.8	1	0.8	1
6120903	0.8	1	0.9	0.9
6120928	0.9	1	0.9	1
6121461	0.9	1	0.9	1
6121686	0.7	1	0.7	1
6121687	0.9	1	0.9	1
6121690	0.8	1	0.8	1
6122055	0.8	1	0.8	1
6122103	0.9	1	0.9	1
6122151	0.9	1	0.9	1
6122191	0.9	1	0.9	1

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
6122227	0.7	1	0.7	1
6130802	0.6	1	0.6	1
Harvey River SWMA				
6130739	0.6	1	0.6	1
6130747	0.9	1	0.9	1
6130762	0.7	1	0.7	1
6130769	0.6	1	0.6	1
6130787	0.9	1	0.9	1
6131420	0.9	1	0.9	1
6131437	0.9	1	0.9	1
6131679	0.9	1	0.9	1
6131810	0.8	1	0.8	1
6131816	0.9	1	0.9	1
6131912	0.5	1	0.5	1
6131990	0.5	1	0.5	1
6132049	0.7	1	0.7	1
6132220	0.8	1	0.8	1
Moore-Hill Rivers SWMA				
6170192	0.6	1	0.6	1
6170204	0.8	1	0.8	1
6170219	0.6	1	0.6	1
6170222	0.6	1	0.6	1
6170248	1	1	1	1
6170259	0.6	1	0.6	1
6170264	0.6	1	0.7	0.9
6170266	0.6	1	0.6	1
6170271	0.7	1	0.7	1
6170281	0.6	1	0.6	1
6170304	0.5	1	0.5	1

Catchment Disturbance theme

Reach	CDI	ISI	LUSI	LCCSI
6170306	0.6	1	0.7	0.9
6170309	0.5	1	0.5	1
6170311	0.6	1	0.7	0.9
6170324	0.5	1	0.5	1
6170338	0.6	1	0.7	0.9
6170339	0.5	1	0.5	1
6170342	0.5	1	0.5	1
6170377	0.5	1	0.5	1
6170381	0.5	1	0.5	1
6170384	0.5	1	0.5	1
6170386	0.5	1	0.5	1
6170388	0.5	1	0.5	1
6170399	0.5	1	0.5	1
6170409	0.6	1	0.6	1
6170414	0.5	1	0.5	1
6170415	0.5	1	0.5	1
6170424	0.7	1	0.7	1
6170443	0.8	1	0.8	1
6170454	0.7	1	0.7	1
6170465	0.6	1	0.6	1
6170472	0.9	1	0.9	1
6170475	0.7	1	0.7	1
6171267	0.6	1	0.6	1
6171274	0.8	1	0.9	0.9
6171311	0.6	1	0.6	1
6171572	0.6	1	0.6	1
6171585	0.6	1	0.6	1
6171595	0.6	1	0.8	0.8
6171604	0.5	1	0.5	1

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
6171614	0.7	1	0.7	1
6171615	0.5	1	0.5	1
6171772	0.5	1	0.5	1
6171780	0.6	1	0.6	1
6171961	0.8	1	0.8	1
6171963	0.5	1	0.5	1
6171964	0.9	1	1	0.9
6171966	1	1	1	1
6172023	0.9	1	0.9	1
6172028	0.5	1	0.5	1
6172033	0.5	1	0.5	1
6172036	0.7	1	0.7	1
6172077	0.5	1	0.5	1
6172079	0.8	1	0.8	1
6172083	0.6	1	0.6	1
6172085	0.7	1	0.7	1
6172121	1	1	1	1
6172128	0.5	1	0.5	1
6172172	0.7	1	0.7	1
6172969	0.5	1	0.5	1
6172970	0.5	1	0.5	1
6172975	0.5	1	0.5	1
6172976	0.6	1	0.6	1
6172977	0.9	1	0.9	1
6172978	0.9	1	0.9	1
6172983	0.5	1	0.5	1
6172987	0.6	1	0.6	1
6172994	0.8	1	0.8	1

Hydrological Change theme

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
Albany Coast SWMA						
6020938	0.8	1	0.8	0.4	0.9	0.8
6020965	0.6	1	0.7	0	0.7	0.6
6020973	0.6	1	0.6	0	0.7	0.7
6020981	0.6	1	0.7	0	0.7	0.7
6020991	0.9	1	0.9	0.6	1	0.9
6020995	0.6	1	0.7	0	0.7	0.7
6021000	0.6	1	0.6	0.1	0.7	0.7
6021001	0.7	1	0.4	0.6	0.9	0.8
6021003	0.7	1	0.7	0.1	0.7	0.7
6021004	0.6	1	0.7	0	0.7	0.7
6021008	0.7	1	0.7	0.1	0.7	0.7
6021009	0.6	1	0.5	0.2	0.7	0.7
6021010	0.6	1	0.7	0.1	0.7	0.7
6021012	0.8	1	0.8	0.5	0.9	0.8
6021013	0.8	1	0.8	0.5	0.9	0.8
6021021	0.6	1	0.7	0	0.7	0.7
6021024	0.9	1	1	0.8	1	0.7
6021025	0.9	1	1	0.8	1	0.7
6021026	0.6	1	0.5	0.1	0.7	0.7
6021027	0.6	1	0.7	0	0.6	0.6
6021028	0.9	1	1	0.7	1	0.9
6021034	0.7	1	0.7	0.1	0.7	0.7
6021035	0.7	1	0.7	0.3	0.8	0.7
6021036	0.9	1	1	0.7	1	0.9
6021037	0.7	1	0.8	0.4	0.8	0.8
6021038	0.6	1	0.7	0	0.7	0.7
6021042	0.6	1	0.7	0	0.7	0.6

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6021043	0.6	1	0.4	0	0.7	0.7
6021048	0.6	1	0.6	0.2	0.8	0.7
6021052	0.7	1	0.7	0.3	0.8	0.7
6021053	0.6	1	0.2	0.3	0.7	0.8
6021058	0.6	1	0.7	0.1	0.7	0.7
6021062	0.7	1	0.4	0.4	0.8	0.8
6021063	0.6	1	0.7	0.1	0.7	0.7
6021065	0.6	1	0.2	0.2	0.7	0.7
6021066	0.7	1	0.6	0.2	0.7	0.7
6021069	0.6	1	0.7	0	0.6	0.6
6021073	0.6	1	0.6	0.2	0.7	0.7
6021076	0.8	1	0.8	0.5	0.9	0.8
6021097	0.6	1	0.7	0	0.7	0.7
6021098	0.8	0.9	1	0.5	0.9	0.8
6021099	0.8	0.8	1	0.5	1	0.9
6021100	0.7	1	0.4	0.5	0.9	0.7
6021108	0.7	1	1	0.1	0.7	0.7
6021110	0.6	0	0.3	1	0.9	1
6021111	0.9	1	1	0.9	0.8	0.7
6021115	0.6	0	0.3	1	1	0.8
6021117	0.9	0.9	1	1	0.8	0.7
6021123	0.6	0	0.4	1	1	0.8
6021128	0.6	0	0.3	1	0.9	0.8
6021136	0.6	0	0.5	0.9	0.9	0.9
6021137	0.6	0	0.4	0.8	0.8	0.8
6021143	0.6	0	0.3	1	0.9	0.9
6021146	0.6	0	0.5	0.7	0.8	0.7
6021147	0.5	0	0.5	0.7	0.8	0.7
6021149	0.7	0	0.4	1	0.9	1

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6021497	0.7	1	0.7	0.3	0.8	0.8
6021501	0.6	1	0.7	0	0.7	0.7
6021515	0.6	1	0.7	0	0.7	0.7
6021518	0.7	1	0.7	0.2	0.8	0.7
6021526						
6021531	0.8	0.9	1	0.5	0.9	0.8
6021534	0.6	0	0.3	1	1	0.8
6021536	0.6	0	0.5	0.8	0.8	0.8
6021715	0.8	1	0.9	0.4	0.9	0.8
6021717						
6021727	0.8	1	0.8	0.9	0.8	0.7
6021842	0.7	1	0.7	0.2	0.8	0.7
6021928	0.6	1	0.7	0	0.7	0.7
6021929	0.9	1	1	0.6	1	0.9
6021933	0.7	1	0.7	0.2	0.8	0.7
6022002	0.7	1	0.7	0.1	0.8	0.7
6022004	0.9	1	1	0.7	0.9	0.8
6022005	0.8	1	0.8	0.4	0.9	0.8
6022110	0.6	1	0.7	0.1	0.8	0.7
6022158	0.6	1	0.7	0.1	0.8	0.7
6022199						
6022280	0.6	1	0.7	0	0.7	0.7
6022282	0.7	1	0.6	0.1	0.8	0.7
6022301	0.6	1	0.7	0	0.7	0.7
6022319	0.6	1	0.7	0	0.7	0.7
6022322	0.6	1	0.6	0.1	0.8	0.7
6022340	0.7	1	0.7	0.3	0.8	0.8
6022350	0.7	1	0.8	0.3	0.8	0.8
6022352	0.7	1	0.7	0.4	0.9	0.8

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6022450	0.6	1	0.7	0	0.7	0.7
6022560	0.7	1	0.7	0.2	0.8	0.7
6022566	0.7	1	0.7	0.2	0.8	0.7
6022594	0.8	1	0.8	0.4	0.9	0.8
6022603	0.7	1	0.7	0.3	0.9	0.8
6022611	0.7	1	0.7	0.4	0.9	0.8
6022615	0.8	1	0.8	0.4	0.9	0.8
6022623	0.7	1	0.8	0.3	0.8	0.8
6022697	0.6	1	0.7	0	0.7	0.7
6022702	0.6	1	0.7	0	0.7	0.7
Denmark River SWMA						
6031121	0.8	1	0.8	0.5	1	0.7
6031122	0.7	1	0.6	0.3	0.9	0.7
6031131	0.5	1	0.2	0	0.6	0.5
6031132	0.7	0.6	0.6	0.6	0.9	0.8
6031138	0.7	0.8	0.8	0.4	0.9	0.6
6031142	1	1	0.9	1	1	1
6031150						
6031152	0.6	0	0.2	1	0.9	1
6031540	0.8	1	1	0.8	0.4	1
60311381						
60311382						
60315401						
60315402						
Shannon River SWMA						
6061118						
6061119						
6061120	0.9	1	1	0.9	1	0.9
6061124	0.9	1	0.8	0.8	1	0.7

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6061125	0.9	1	0.8	0.8	1	0.8
6061126	0.9	1	0.9	0.8	1	0.8
6061129	1	0.9	0.8	1	1	1
6061133	0.9	1	1	0.8	1	0.8
6061139	0.9	1	1	0.9	1	0.9
6061140	1	1	1	0.9	1	0.9
6061535	0.9	1	1	0.9	1	0.9
Busselton Coast SWMA						
6100902	0.6	0	0.2	0.9	0.8	0.9
6100929						
6100931	0.7	1	0.5	0.3	0.9	0.6
6100933	0.6	1	0.5	0.1	0.9	0.6
6100936	0.7	1	1	0.1	0.8	0.7
6100939	0.7	1	0.6	0.2	0.9	0.6
6100946	0.6	1	0.4	0.3	0.8	0.5
6100948						
6100956	0.7	1	0.6	0.6	0.9	0.2
6100967	0.7	1	0.6	0.3	0.9	0.6
6100978	0.6	1	0.5	0.2	0.9	0.6
6101002	0.8	1	0.7	0.7	1	0.8
Preston River SWMA						
6110873	0.6	0	0.6	0.9	0.8	0.8
6110909	0.9	1	0.7	0.9	1	0.9
6110924	0.9	1	0.7	0.9	0.9	0.9
Collie River SWMA						
6120802	0.7	0.1	0.6	0.9	0.9	0.8
6120819						
6120825	0.7	0.2	0.6	0.9	0.8	0.8
6120826	1	1	1	0.9	1	1

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6120836	0.5	1	0	0.4	0.5	0.6
6120842	1	1	1	0.9	1	1
6120869	0.6	0.9	0.5	0.3	0.9	0.6
6120880	0.8	1	0.6	0.7	0.8	1
6120903	0.9	1	0.7	0.8	0.9	1
6120928	0.9	1	0.8	0.9	0.9	1
6121461	0.6	0.9	0.5	0.3	0.9	0.6
6121686	0.6	0.5	0.5	0.4	0.7	0.7
6121687	0.8	1	0.9	0.3	1	0.7
6121690	0.8	0.9	0.6	0.4	1	0.7
6122055	0.8	1	0.8	0.4	1	0.7
6122103	0.9	1	0.8	0.9	0.9	0.9
6122151						
6122191	0.4	0.6	0	0.5	0.8	0.3
6122227	0.7	1	0	0.7	0.9	0.9
6130802						
Harvey River SWMA						
6130739	0.7	0.1	0.3	1	1	0.9
6130747	0.6	0.3	0.5	1	0.9	0.3
6130762	0.9	1	0.9	0.7	0.9	0.7
6130769						
6130787	1	0.8	1	1	1	1
6131420	0.6	0.1	0	1	1	1
6131437	0.6	0.6	0.3	0.8	0.9	0.2
6131679	0.4	0.1	0.2	0.8	0.7	0.4
6131810	0.6	0.5	0.4	0.7	0.8	0.7
6131816	0.6	0.3	0	0.8	0.9	0.9
6131912	0.6	0.6	0.9	0.4	0.8	0.6
6131990						

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6132049	0.8	1	0.6	0.8	0.9	0.7
6132220	0.8	0.9	0.2	1	1	0.9
Moore-Hill Rivers SWMA						
6170192	0.6	1	0.5	0.1	0.6	1
6170204	0.7	1	0.7	0.3	0.7	0.8
6170219	0.6	1	0.5	0.2	0.6	0.8
6170222	0.6	1	0.5	0.1	0.6	0.8
6170248						
6170259	0.7	1	0.6	0.3	0.7	0.8
6170264	0.8	1	0.8	0.5	0.8	0.9
6170266	0.7	1	0.6	0.3	0.7	0.8
6170271	0.8	1	0.7	0.4	0.8	0.9
6170281	0.6	1	0.5	0.3	0.6	0.8
6170304	0.6	1	0.6	0.1	0.8	0.6
6170306	0.7	1	0.7	0.3	0.7	0.8
6170309	0.6	1	0.5	0	0.7	0.6
6170311	0.7	1	0.8	0.3	0.7	0.8
6170324	0.6	0.9	0.5	0.1	0.8	0.6
6170338	0.6	1	0.5	0.2	0.6	0.8
6170339	0.5	1	0.3	0	0.7	0.6
6170342	0.6	0.9	0.4	0.1	0.8	0.6
6170377	0.6	0.9	0.4	0.2	0.8	0.6
6170381	0.6	0.9	0.5	0.2	0.8	0.6
6170384						
6170386	0.7	1	0.2	0.4	0.7	0.9
6170388	0.6	0.9	0.6	0.2	0.8	0.6
6170399	0.7	1	0.2	0.4	0.7	0.9
6170409	0.8	1	0.2	0.7	0.9	0.9
6170414	0.7	1	0.2	0.5	0.7	0.9

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6170415	0.7	1	0.2	0.4	0.7	0.9
6170424	0.8	1	0.3	0.8	0.9	0.9
6170443	0.8	1	0.4	0.9	0.9	1
6170454	0.8	1	0.4	0.9	0.9	1
6170465						
6170472	0.8	1	0.4	0.9	0.9	1
6170475	0.8	1	0.3	0.7	0.8	0.9
6171267	0.7	1	0.5	0.3	0.7	0.8
6171274	0.7	1	0.6	0.3	0.7	0.8
6171311	0.7	1	0.3	0.5	0.8	0.9
6171572	0.5	1	0.9	0	0.4	0.4
6171585	0.6	1	0.4	0.2	0.6	0.8
6171595	0.7	1	0.8	0.3	0.7	0.8
6171604	0.7	1	0.3	0.5	0.7	0.9
6171614	0.8	1	0.3	0.8	0.9	0.9
6171615	0.8	1	0.2	0.7	0.8	0.9
6171772	0.7	1	0.3	0.5	0.7	0.9
6171780	0.8	1	0.3	0.8	0.9	0.9
6171961	0.7	1	0.5	0.3	0.7	0.8
6171963	0.6	0.9	0.6	0	0.7	0.7
6171964	0.8	1	0.7	0.4	0.8	0.9
6171966	0.6	1	0.5	0.1	0.5	0.7
6172023	0.7	1	0.5	0.3	0.7	0.8
6172028	0.6	1	0.5	0.1	0.6	0.7
6172033	0.7	1	0.3	0.5	0.8	0.9
6172036	0.8	1	0.3	0.8	0.9	0.9
6172077	0.6	0.9	0.6	0.1	0.7	0.6
6172079						
6172083	0.7	1	0.2	0.4	0.7	0.9

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6172085	0.8	1	0.3	0.8	0.9	0.9
6172121						
6172128	0.6	0.9	0.6	0.2	0.8	0.6
6172172	0.7	1	0.6	0.3	0.7	0.8
6172969	0.6	0.9	0.6	0.3	0.8	0.6
6172970	0.7	0.8	0.6	0.3	0.9	0.6
6172975	0.7	0.9	0.6	0.3	0.8	0.6
6172976	0.6	0.9	0.6	0.2	0.8	0.6
6172977	0.6	0.9	0.6	0.2	0.8	0.6
6172978	0.6	0.9	0.6	0.2	0.8	0.6
6172983	0.6	0.9	0.6	0.2	0.8	0.6
6172987	0.6	0.9	0.6	0.3	0.8	0.6
6172994	0.7	0.9	0.6	0.3	0.8	0.6

Water Quality theme

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
Albany Coast SWMA									
AR-01	6021149	0.8	0.6	0.8	0.8	0.8	0.8	1.0	1.0
BR-02	6021069	0.2	0.4	0.6	0.8	0.8	0.7	0.2	1.0
BR-03	6021515	0.2	0.6	0.8	0.8	0.8	0.8	0.2	1.0
ER-01	6021115	0.2	0.8	0.8	1.0	0.4	0.8	0.2	0.6
EVBRE01	6021069	0.2	0.6	0.8	1.0	0.8	0.8	0.2	1.0
EVGAI01	6022350	0.0	0.4	0.8	0.8	0.8	0.7	0.0	1.0
EVGAI02	6022350	0.0	0.6	0.8	1.0	0.4	0.7	0.0	1.0
EVKAL01	6022005	0.8	0.6	0.8	0.8	0.8	0.8	0.8	0.9

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
EVKAL03	6021727	0.8	0.6	0.8	0.8	0.8	0.8	0.8	1.0
EVSUS02	6021013	0.0	0.4	0.6	1.0	0.4	0.6	0.0	1.0
FR-02	6022603	0.0	0.4	0.6	0.8	0.4	0.6	0.0	1.0
FR-03	6022594	0.0	0.6	0.8	0.8	0.4	0.7	0.0	0.9
GAR-03	6022301	0.7	0.6	0.8	1.0	0.4	0.7	0.0	1.0
HAMR-01	6021715	0.2	0.6	1.0	0.8	0.8	0.8	0.2	0.6
HAMR-02	6021497	0.0	0.6	0.8	1.0	0.4	0.7	0.0	1.0
HAMR-03	6021497	0.0	0.4	0.8	1.0	0.4	0.7	0.0	1.0
KR	6021147	0.6	0.6	0.4	0.6	0.8	0.6	0.9	1.0
NC-01	6021536	0.6	0.4	0.6	0.6	0.8	0.6	0.8	0.9
PR-01	6022280	0.0	0.6	0.8	1.0	0.8	0.8	0.0	1.0
PR-02	6021034	0.5	0.4	0.6	0.4	0.4	0.5	0.0	1.0
PR-03	6022560	0.0	0.6	0.8	1.0	0.8	0.8	0.0	0.9
PR-04	6022319	0.0	0.6	0.8	1.0	0.4	0.7	0.0	1.0
PR-05	6021008	0.0	0.6	0.8	1.0	0.4	0.7	0.0	0.9
PR-06	6021003	0.0	0.6	0.8	0.8	0.4	0.7	0.0	0.9
SMR-01	6021929	0.7	0.6	0.8	0.4	0.8	0.7	1.0	1.0
WIC-01	6021534	0.5	0.6	0.8	0.4		0.6	0.5	
WR-01	6021143	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0
Denmark River SWMA									
CLEE-01	6031121	0.8	1.0	1.0	0.8	0.4	0.8	0.8	0.9
DENM-01	6031122	0.5	1.0	1.0	1.0	0.8	1.0	0.8	0.5
DENM-03	60315402	0.9	0.8	1.0	0.8	0.8	0.9	1.0	1.0

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
EVDEN-LG	60315401	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0
EVHAY08	60311382	0.8	1.0	1.0	0.8	0.8	0.9	0.8	1.0
EVHAY11	6031132	0.8	1.0	1.0	0.8	0.8	0.9	0.8	1.0
EVHAY14	60311381	0.7	0.6	1.0	0.4	0.8	0.7	0.8	0.7
HAY-01	6031131	0.7	0.8	0.8	0.4	0.8	0.7	0.8	1.0
MARB-01	6031152	0.8	0.8	0.6	0.8	0.8	0.8	1.0	1.0
MITC-01	6031142	0.9	1.0	1.0	0.8	0.8	0.9	1.0	1.0
Shannon River SWMA									
BOOR-01	6061124	0.9	1.0	0.8	0.8	0.8	0.9	1.0	1.0
EVDEE02	6061120	0.9	0.8	1.0	0.8	0.8	0.9	1.0	1.0
EVDEE05	6061535	0.9	1.0	1.0	0.8	0.8	0.9	1.0	1.0
EVGAR02	6061126	0.8	1.0	1.0	0.8	0.8	0.9	1.0	0.8
EVGAR05	6061125	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0
EVSHA04	6061139	0.9	0.8	1.0	0.8	0.8	0.9	1.0	1.0
WELD-01	6061133	0.9	1.0	1.0	0.8	0.8	0.9	1.0	1.0
Busselton Coast SWMA									
ABBA-01	6100933	0.9	1.0	0.8	0.8	0.8	0.9	1.0	1.0
ANNI-01	6100931	0.8	0.8	0.8	0.8	0.8	0.8	1.0	1.0
CAPE-01	6100948	0.9	1.0	1.0	0.8	0.8	0.9	1.0	1.0
CARB-01	6100978	0.9	1.0	1.0	0.8	0.8	0.9	1.0	1.0
GBC12	6100946	0.9	0.8	0.8	1.0	0.8	0.9	1.0	1.0
GYNU-01	6100902	0.4	0.8	0.6	0.6	0.8	0.7	1.0	0.4

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
LUDL-01	6100939	0.9	1.0	0.8	0.8	0.8	0.9	1.0	1.0
MARG-02	6101002	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0
SABI-01	6100956	0.0	0.6	0.4	0.6	0.8	0.6	1.0	0.0
VASS-01	6100936	0.7	0.8	0.6	0.8	0.4	0.7	1.0	1.0
WILY-01	6100967	0.9	1.0	0.8	1.0	0.8	0.9	1.0	1.0
Preston River SWMA									
FERG-01	6110873	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0
PRES-01	6110909	0.9	1.0	1.0	0.8	0.8	0.9	1.0	1.0
PRES-02	6110924	0.9	1.0	1.0	0.8	0.8	0.9	1.0	1.0
Collie River SWMA									
BRUN-01	6121686	0.7	0.6	0.6	0.8	0.8	0.7	1.0	0.7
BRUN-03	6120825	0.7	1.0	1.0	1.0	0.8	1.0	1.0	0.7
BRUN-05	6120825	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0
BRUN-06	6120825	0.8	1.0	1.0	1.0	0.8	1.0	1.0	0.8
CR-05	6122227	0.8	1.0	1.0	1.0	0.8	1.0	1.0	0.8
CR-06	6122227	0.9	1.0	1.0	1.0	0.4	0.9	1.0	1.0
CR-07	6122227	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0
CR-08	6122191	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0
CR-09	6122103	0.7	1.0	1.0	1.0	0.8	1.0	0.9	0.7
CR-10	6120928	0.6	1.0	1.0	1.0	0.8	1.0	0.8	0.6
CR-11	6120928	0.4	0.8	1.0	1.0	0.8	0.9	0.8	0.4
CR-12	6122055	0.8	1.0	1.0	0.8	0.8	0.9	0.8	1.0

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
CR-15	6121690	0.4	1.0	1.0	1.0	0.4	0.9	0.8	0.4
CR-16	6121690	0.6	0.8	0.8	0.4	0.8	0.7	0.8	0.6
CR-17	6120880	0.8	1.0	1.0	1.0	0.4	0.9	0.8	0.9
HAR-01	6120836	0.9	1.0	1.0	1.0	0.8	1.0	1.0	0.9
WELL-01	6120802	0.5	0.8	0.6	1.0	0.8	0.8	1.0	0.5
Harvey River SWMA									
HARV-05	6131679	1.0	1.0	1.0	1.0		1.0	1.0	
HARV-06	6130787	1.0	1.0	1.0	1.0	0.8	1.0	1.0	1.0
HR01012	6131810	0.9	1.0	0.8	0.8	0.8	0.9	1.0	1.0
HR02010	6132049	0.7	1.0	0.8	0.6	0.4	0.7	1.0	0.9
HR03013	6130762	0.9	1.0	0.8	0.8	0.8	0.9	1.0	0.9
HR03015	6131912	0.4	1.0	0.8	0.6	0.4	0.7	1.0	0.4
HR03017	6131990	0.7	1.0	0.8	0.6	0.4	0.7	1.0	1.0
PHD1	6130739	0.8	1.0	0.8	1.0	0.4	0.8	1.0	0.9
PHH1	6132220	0.9	1.0	0.8	0.8	0.8	0.9	1.0	1.0
SAM-01	6131420	0.9	1.0	1.0	1.0	0.8	1.0	1.0	0.9
SAM-02	6130747	1.0	1.0	1.0	1.0		1.0	1.0	
Moore-Hill Rivers SWMA									
HR-01	6172172	0.9	0.8	0.8	1.0	0.8	0.9	0.9	1.0
HR-02	6172172	0.7	0.6	0.6	0.8	0.8	0.7	0.9	1.0
HR-03	6172172	0.8	0.8	0.8	0.6	0.8	0.8	0.9	0.9
HR-04	6171585	0.8	0.8	0.8	0.6	0.8	0.8	0.9	1.0
MB-01	6172028	0.6	0.6	0.6	0.6	0.4	0.6	0.8	1.0

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
MB-02	6171966	0.6	0.6	0.8	0.6	0.4	0.6	0.8	1.0
MR-04	6172036	0.4	0.6	0.4	0.6	0.8	0.6	1.0	0.4
MR-05	6172036	0.7	0.6	0.4	0.8	0.8	0.7	1.0	0.8
MR-06	6171615	0.6	0.6	0.4	0.6	0.8	0.6	1.0	0.9
MR-07	6170465	0.4	0.8	0.6	0.6	0.8	0.7	1.0	0.4
MR-09	6172976	0.2	1.0	0.8	0.8	0.8	0.9	0.2	0.6
MR-10	6172083	0.2	0.8	1.0	1.0	0.8	0.9	0.2	0.9
MR-12	6172975	0.5	0.8	1.0	0.8	0.4	0.8	0.5	0.9
MR-13	6172128	0.6	0.6	0.8	0.6	0.4	0.6	0.8	1.0
MR-16	6171311	0.5	0.8	0.8	0.8	0.4	0.7	0.5	1.0
MR-17	6172128	0.7	0.6	0.8	1.0	0.4	0.7	0.8	1.0
MR-18	6172976	0.2	1.0	0.8	0.6	0.8	0.8	0.2	0.9
MRC01	6172994	0.5	0.8	0.8	0.8	0.8	0.8	0.5	0.9
MRC02	6172987	0.5	1.0	0.8	0.8	0.4	0.8	0.5	0.9
NR-04	6170338	0.6	0.6	0.8	0.4	0.4	0.6	0.9	0.6
NR-06	6170306	0.9	1.0	1.0	0.8	0.8	0.9	0.0	1.0

Physical Form theme

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
Albany Coast SWMA										
6020938	0.9	1	0.9	1	1	0.8	1			
6020965	0.9	1	0.9	1	1	0.8	0.8			
6020973	0.8	1	0.7	1	0	1	0.8			

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6020981	0.8	1	0.7	1	0	1	0.8			
6020991	0.9	1	0.9	1	1	0.5	0.8			
6020995	0.8	1	0.7	1	0.3	1	0.8			
6021000	0.9	1	0.8	1	0.5	1	0.8			
6021001	0.8	1	0.7	1	0.3	1	0.8			
6021003	0.6	1	0.6	1	0	0.8	0.5	0.5		
6021004	0.7	1	0.6	1	0	0.8	0.8			
6021008	0.5	1	0.6	1	0	0.5	0.8	0.3		
6021009	0.6	1	0.4	1	0	0	0.5			
6021010	0.7	1	0.6	1	0	0.5	0.8			
6021012	0.7	1	0.6	1	0	0.5	0.8			
6021013	0.9	1	0.9	1	1	0.8	0.8	1		
6021021	0.8	1	0.7	1	0	1	0.8			
6021024	1	1	1	1	1	1	0.8			
6021025	1	1	1	1	1	1	0.8			
6021026	0.9	1	0.9	1	1	1	0.5			
6021027	0.7	1	0.6	1	0	0.8	0.5			
6021028	0.9	1	0.8	1	0.8	0.5	0.8			
6021034	0.6	1	0.7	1	0	1	0.8	0.3		
6021035	0.8	1	0.7	1	0.3	1	0.8			
6021036	1	1	1	1	1	1	1			
6021037	0.9	1	0.9	1	0.8	1	0.8			
6021038	0.9	1	0.9	1	0.8	1	0.8			
6021042	0.6	1	0.5	1	0	0	0.8			
6021043	0.7	1	0.6	1	0.3	0.3	0.8			
6021048	0.8	1	0.7	1	0	1	1			
6021052	0.8	1	0.7	1	0.3	1	0.8			
6021053	0.8	1	0.7	1	0	1	0.8			
6021058	0.8	1	0.7	1	0	1	0.8			

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6021062	0.8	1	0.7	1	0.3	1	0.5			
6021063	0.7	1	0.6	1	0	0.8	0.8			
6021065	0.7	1	0.6	1	0	0.5	0.8			
6021066	0.7	1	0.6	1	0	0.5	0.8			
6021069	0.7	1	0.5	1	0	0	0.8	0.8		
6021073	0.6	1	0.5	1	0	0.3	0.8			
6021076	0.8	1	0.7	1	0	1	0.8			
6021097	0.7	1	0.6	1	0.3	0.3	0.8			
6021098	0.8	1	0.7	1	0	1	0.8			
6021099	0.8	1	0.7	1	0.3	1	0.5			
6021100	0.8	1	0.7	1	0	1	0.8			
6021108	0.8	1	0.7	1	0	1	0.8			
6021110	0.8	1	0.7	1	0	1	0.8			
6021111	0.7	1	0.6	1	0	1	0.5			
6021115	0.8	1	0.7	1	0	1	0.8	1		
6021117	0.8	1	0.7	1	0	1	0.8			
6021123	0.7	1	0.6	1	0	1	0.5			
6021128	0.8	1	0.7	1	0	1	0.8			
6021136	0.6	1	0.5	1	0	0.3	0.8			
6021137	0.7	1	0.6	1	0	0.5	0.8			
6021143	0.6	1	0.5	1	0	0	0.8	0.5		
6021146	0.6	1	0.4	1	0	0	0.3			
6021147	0.6	1	0.5	1	0	0	0.8	0.5		
6021149	0.7	1	0.5	1	0	0	0.8	1		
6021497	0.7	1	0.8	1	1	0	0.8	0.7		
6021501	0.8	1	0.7	1	0	1	0.8			
6021515	0.6	1	0.5	1	0	0	0.8	0.5		
6021518	0.6	1	0.5	1	0.3	0	0.8			
6021526	0.9	1	0.8	1	0.8	0.8	0.8			

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6021531	0.8	1	0.7	1	0.3	1	0.5			
6021534	0.8	1	0.7	1	0	1	0.8	1		
6021536	0.7	1	0.6	1	0	0.5	0.8	0.8		
6021715	0.9	1	0.8	1	1	0	0.8	1		
6021717	0.9	1	0.8	1	0.5	1	1			
6021727	0.7	1	0.6	1	0	1	0.5	0.8		
6021842	0.7	1	0.6	1	0.3	0.3	0.8			
6021928	0.8	1	0.7	1	0	1	0.8			
6021929	1	1	1	1	1	1	0.8	1		
6021933	0.7	1	0.6	1	0.3	0.3	0.8			
6022002	0.9	1	0.8	1	0.5	1	0.8			
6022004	0.7	1	0.6	1	0	0.8	0.5			
6022005	0.7	1	0.6	1	0	0.8	0.8	0.8		
6022110	0.7	1	0.6	1	0	0.8	0.8			
6022158	0.8	1	0.7	1	0.3	1	0.8			
6022199	0.7	1	0.6	1	0	0.8	0.8			
6022280	0.7	1	0.5	1	0	0.3	0.8	0.8		
6022282	0.6	1	0.5	1	0	0.3	0.8			
6022301	0.7	1	0.7	1	0.3	1	0.8	0.5		
6022319	0.6	1	0.6	1	0	0.8	0.8	0.5		
6022322	0.6	1	0.5	1	0	0	1			
6022340	0.8	1	0.7	1	0	1	0.8			
6022350	0.8	1	0.7	1	0	1	0.8	0.8		
6022352	0.8	1	0.7	1	0.3	1	0.8			
6022450	0.8	1	0.7	1	0	1	0.8			
6022560	0.8	1	0.7	1	0	1	1	0.8		
6022566	0.8	1	0.7	1	0	1	0.8			
6022594	0.6	1	0.9	1	1	0.8	0.8	0.3		
6022603	0.8	1	0.7	1	0.8	0	0.8	1		

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6022611	0.9	1	0.8	1	0.8	0.5	1			
6022615	0.9	1	0.8	1	0.8	0.8	0.8			
6022623	0.9	1	0.9	1	0.8	0.8	1			
6022697	0.6	1	0.5	1	0	0.3	0.8			
6022702	0.7	1	0.6	1	0.3	0.5	0.8			
Denmark River SWMA										
6031121	0.7	1	0.4	0.8	0.3	0	0.8	1	1	0.9
6031122	0.6	1	0.4	0.8	0	0.3	0.8	0.8	1	0.7
6031131	0.6	1	0.6	1	0	0.5	0.8	0.4	0.3	0.4
6031132	0.5	1	0.6	1	0	0.5	0.8	0.3	0	0.7
6031138										
6031142	0.5	1	0.6	1	0.5	0	0.8	0.3	0	0.5
6031150	0.6	0.6	0.7	1	0	1	0.8			
6031152	0.5	1	0.4	1	0	0	0.3	0.5	0.7	0.3
6031540										
60311381	0.7	1	0.6	1	0	0.5	0.8	0.8	1	0.7
60311382	0.5	1	0.5	1	0	0	0.8	0.3	0	0.7
60315401	0.7	1	0.5	1	0	0	0.8	0.7	1	0.3
60315402	0.5	1	0.1	0	0	0	0.8	0.8	1	0.5
Shannon River SWMA										
6061118	1	1	1	1	1	1	1			
6061119	0.9	1	0.9	1	1	0.5	0.8			
6061120	0.8	1	0.8	1	1	0.5	0.5	0.8	1	0.7
6061124	0.7	1	0.7	1	0.5	0.5	0.5	0.6	0.7	0.6
6061125	0.7	1	0.6	1	0.5	0	0.5	0.8	1	0.5
6061126	0.7	1	0.5	1	0	0.3	0.5	0.8	1	0.7
6061129	1	1	1	1	1	1	1			
6061133	0.8	1	0.8	1	1	0	0.8	0.8	1	0.6
6061139	0.7	1	0.5	1	0	0	0.8	1	1	1

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6061140	0.9	1	0.9	1	1	0.5	0.8			
6061535	0.7	1	0.8	1	1	0	0.8	0.6	0.3	0.9
Busselton Coast SWMA										
6100902	0.7	1	0.6	1	0.5	0	0.5			0.3
6100929	0.7	1	0.6	1	0	0.5	0.8			
6100931	0.5	0.3	0.6	1	0	1	0.5	0.6	1	0.2
6100933	0.6	1	0.7	1	1	0	0.5	0.3	0	0.5
6100936	0.7	1	0.7	1	1	0	0.5	0.6	1	0.3
6100939	0.5	1	0.5	1	0	0	0.8	0.4	0.7	0.1
6100946	0.5	0.7	0.6	1	0	1	0.5	0.3	0.7	0
6100948	0.5	1	0.5	1	0	0	0.8	0.3	0	0.5
6100956	0.6	1	0.9	1	1	1	0.5	0.4	0.5	0.3
6100967	0.7	1	0.5	1	0	0	0.8	0.8	1	0.7
6100978	0.7	1	0.5	1	0	0	0.8	0.8	1	0.5
6101002	0.6	1	0.4	1	0	0	0.5	0.8	1	0.5
Preston River SWMA										
6110873	0.4	0.9	0.4	1	0	0	0.5	0.2	0	0.3
6110909	0.5	1	0.4	1	0	0	0.5	0.3	0.2	0.5
6110924	0.6	1	0.5	1	0	0	0.8	0.5	0.7	0.3
Collie River SWMA										
6120802	0.5	0.9	0.3	0.5	0	0	0.8	0.5		
6120819	0.6	1	0.5	1	0	0	0.8			
6120825	0.4	1	0	0	0	0	0.5	0.7		
6120826	0.5	1	0.3	0.8	0	0	0.5			
6120836	0.5	1	0.2	0	0.5	0	0.8	1		
6120842	0.6	1	0.4	0.8	0	0.3	0.8			
6120869	0.6	1	0.4	0.8	0	0	0.8			
6120880	0.7	1	0.4	0.8	0	0.3	0.5	1		
6120903	0.5	1	0.3	0.8	0	0	0.5			

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6120928	0.5	1	0.2	0.5	0	0	0.5	0.9		
6121461	0.5	1	0.3	0.8	0	0	0.5			
6121686	0.6	1	0.3	0.5	0.3	0	0.3	0.8		
6121687	0.6	1	0.4	0.5	0.3	0.3	1			
6121690	0.5	1	0.2	0.3	0.3	0	0.8	0.5		
6122055	0.5	1	0.1	0.3	0	0	0.5	0.8		
6122103	0.5	1	0.2	0.5	0	0	0.3	0.5		
6122151	0.5	1	0.3	0.3	0.3	0.3	0.8			
6122191	0.5	1	0.1	0	0	0.3	0.8	1		
6122227	0.4	1	0	0	0	0	0.5	0.8		
6130802	0.2	0	0.6	0.8	0.5	0.5	0.8			
Harvey River SWMA										
6130739	0.2	0	0.5	1	0	0	0.8	0.3	0.5	0.2
6130747	0.5	1	0.2	0	0.5	0	0.5	1	1	0.9
6130762	0.2	0.1	0.5	1	0	0.3	0.5	0	0	0.1
6130769	0.8	1	0.7	1	0	1	0.8			
6130787	0.6	1	0.4	0.5	0.5	0.3	0.3	0.8	1	0.7
6131420	0.5	1	0.2	0	0.3	0.3	0.8	0.8	1	0.7
6131437	0.3	1	0	0	0	0	0.3			
6131679	0.5	1	0.2	0.3	0	0.3	0.3	0.7	0.7	0.8
6131810	0.2	0.1	0.2	0.3	0	0.5	0.5	0.4	0.3	0.4
6131816	0.4	1	0.1	0	0	0	0.8			
6131912	0.2	0.4	0.1	0.3	0	0	0.5	0.2	0.3	0
6131990	0.1	0	0.5	0.5	0.5	0.3	0.8	0	0	0
6132049	0.6	0.8	0.5	0.8	0.5	0	0.8	0.5	1	0
6132220	0.4	1	0.4	0.8	0.3	0	0.5	0.2	0.3	0.1
Moore-Hill Rivers SWMA										
6170192	0.8	1	0.7	1	0	1	0.8			
6170204	0.6	1	0.5	1	0.3	0	0.8			

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6170219	0.8	1	0.7	1	0	1	1			
6170222	0.8	1	0.7	1	0	1	0.8			
6170248	1	1	1	1	1	1	1			
6170259	0.7	1	0.6	1	0.3	0.5	0.8			
6170264	0.7	1	0.6	1	0	0.5	1			
6170266	0.7	1	0.6	1	0	0.5	0.8			
6170271	0.9	1	0.8	1	0.5	0.8	0.8			
6170281	0.8	1	0.7	1	0.3	0.8	0.8			
6170304	0.8	1	0.7	1	0.5	0.3	0.8			
6170306	0.7	1	0.7	1	0	1	0.8	0.5		
6170309	0.8	1	0.7	1	0.5	0.3	0.8			
6170311	0.9	1	0.8	1	0.5	1	1			
6170324	0.7	1	0.6	1	0.5	0	0.8			
6170338	0.8	1	0.7	1	0	1	0.8	0.8		
6170339	0.6	1	0.5	1	0	0.3	0.8			
6170342	0.8	1	0.7	1	0.3	1	0.8			
6170377	0.8	1	0.7	1	0.3	0.8	0.8			
6170381	0.7	1	0.6	1	0	0.8	0.8			
6170384	0.8	1	0.7	1	0.3	0.8	0.5			
6170386	0.7	1	0.6	1	0	0.8	0.8			
6170388	0.7	1	0.6	1	0	0.5	0.8			
6170399	0.8	1	0.7	1	0.3	0.8	0.5			
6170409	0.7	1	0.6	1	0	0.5	0.8			
6170414	0.7	1	0.6	1	0	0.8	0.8			
6170415	0.9	1	0.8	1	0.5	0.8	0.8			
6170424	0.9	1	0.8	1	0.8	0.8	0.8			
6170443	0.7	1	0.6	1	0.3	0.3	0.8			
6170454	0.7	1	0.6	1	0	0.5	0.8			
6170465	0.7	1	0.5	1	0	0	0.8	1		

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6170472	0.7	1	0.6	1	0.3	0.3	0.8			
6170475	0.6	0.9	0.5	1	0	0	0.8			
6171267	0.9	1	0.8	1	0.3	1	1			
6171274	0.9	1	0.8	1	0.5	1	0.8			
6171311	0.5	1	0.6	1	0	0.5	0.8	0.3		
6171572	0.9	1	0.8	1	0.3	1	1			
6171585	0.7	1	0.5	1	0.3	0	0.8	0.8		
6171595	0.9	1	0.8	1	0.5	1	0.5			
6171604	0.8	1	0.7	1	0.3	0.8	0.8			
6171614	0.7	1	0.6	1	0.3	0.3	0.8			
6171615	0.5	1	0.4	1	0	0	0.5	0.3		
6171772	0.7	1	0.6	1	0	0.5	0.8			
6171780	0.7	1	0.6	1	0.3	0.3	1			
6171961	0.7	1	0.6	1	0	0.5	0.8			
6171963	0.8	1	0.7	1	0.5	0.3	0.8			
6171964	0.9	1	0.8	1	0.5	1	0.8			
6171966	0.7	1	0.7	1	0	1	0.8	0.5		
6172023	0.6	1	0.5	1	0	0.3	0.8			
6172028	0.4	1	0.7	1	0	1	0.8	0		
6172033	0.7	1	0.6	1	0	0.5	0.8			
6172036	0.8	1	0.6	1	0.3	0.3	0.5	1		
6172077	0.6	1	0.5	1	0.3	0	0.8			
6172079	0.9	1	0.8	1	0.5	1	1			
6172083	0.7	1	0.5	1	0	0	0.8	0.8		
6172085	0.6	1	0.5	1	0	0	0.8			
6172121	0.8	1	0.7	1	0	1	0.8			
6172128	0.5	1	0.5	1	0	0	0.8	0.2		
6172172	0.7	1	0.5	1	0	0	0.8	0.9		
6172969	0.9	1	0.8	1	0.8	0.5	1			

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
6172970	0.8	1	0.7	1	0.8	0	0.8			
6172975	0.7	1	0.5	1	0	0.3	0.8	0.8		
6172976	0.6	1	0.5	1	0.3	0	0.8	0.8		
6172977	0.9	1	0.9	1	1	0.5	1			
6172978	0.9	1	0.8	1	0.8	0.8	0.8			
6172983	0.9	1	0.8	1	0.8	0.5	1			
6172987	0.6	1	0.6	1	0.5	0	0.8	0.5		
6172994	0.7	1	0.6	1	0.5	0.3	0.5	0.8		

Fringing Zone theme

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
Albany Coast SWMA				
6020938	0.5	0.6	0.6	0.5
6020965	0.4	0.5	0.5	0.4
6020973	0.3	0.3	0.3	0.2
6020981	0.3	0.3	0.3	0.3
6020991	1	1	1	1
6020995	0.1	0.1	0.1	0.1
6021000	0.1	0.1	0.1	0.1
6021001	0.9	1	1	0.9
6021003	0.2	0.4	0.4	0.3
6021004	0.4	0.4	0.4	0.3
6021008	0.4	0.7	0.7	0.6
6021009	0.2	0.3	0.3	0.2
6021010	0.3	0.3	0.3	0.2
6021012	0.6	0.7	0.7	0.6
6021013	0.8	0.7	0.7	0.7
6021021	0.6	0.6	0.6	0.5

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
6021024	0.9	1	1	0.9
6021025	1	1	1	1
6021026	0.5	0.5	0.5	0.4
6021027	0.2	0.3	0.3	0.2
6021028	0.3	0.4	0.4	0.3
6021034	0.4	0.3	0.3	0.2
6021035	0.9	0.9	0.9	0.9
6021036	0.9	0.9	0.9	0.9
6021037	1	1	1	1
6021038	0.2	0.2	0.2	0.2
6021042	0.8	0.8	0.8	0.7
6021043	0.9	0.9	0.9	0.9
6021048	0	0.1	0.1	0
6021052	1	1	1	1
6021053	0.9	0.9	0.9	0.9
6021058	0.8	0.8	0.8	0.7
6021062	0.8	0.8	0.8	0.7
6021063	0.6	0.6	0.6	0.5
6021065	0.6	0.7	0.7	0.6
6021066	0.6	0.6	0.7	0.5
6021069	0.9	0.9	0.9	0.8
6021073	0.7	0.7	0.7	0.6
6021076	0.6	0.7	0.7	0.6
6021097	1.0	1.0	1.0	1.0
6021098	0.8	0.8	0.8	0.8
6021099	0.9	0.9	0.9	0.9
6021100	0.6	0.6	0.6	0.6
6021108	0.2	0.3	0.3	0.2
6021110	0.1	0.1	0.1	0.1

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
6021111	0.3	0.3	0.3	0.3
6021115	0.9	0.8	0.8	0.8
6021117	0.2	0.2	0.2	0.2
6021123	0.9	0.9	0.9	0.9
6021128	1.0	0.9	0.9	0.9
6021136	0.8	0.8	0.8	0.7
6021137	0.5	0.6	0.6	0.5
6021143	1.0	1.0	1.0	1.0
6021146	0.6	0.6	0.6	0.5
6021147	0.3	0.5	0.5	0.4
6021149	0.9	1	1	1
6021497	0.9	0.8	0.8	0.8
6021501	0.2	0.2	0.2	0.1
6021515	1	0.9	0.9	0.9
6021518	0.8	0.8	0.8	0.7
6021526	0.9	0.9	0.9	0.9
6021531	0.3	0.3	0.3	0.3
6021534	1.0	0.9	0.9	0.9
6021536	0.4	0.6	0.6	0.6
6021715	1	0.9	0.9	0.9
6021717	0	0	0	0
6021727	0.5	0.3	0.3	0.3
6021842	0.8	0.8	0.8	0.8
6021928	0.6	0.6	0.6	0.5
6021929	1.0	1.0	1.0	0.9
6021933	0.8	0.9	0.9	0.8
6022002	0	0	0	0
6022004	0.3	0.3	0.3	0.2
6022005	0.3	0.5	0.5	0.4

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
6022110	0.3	0.4	0.4	0.3
6022158	0.1	0.2	0.2	0.1
6022199	0.2	0.2	0.2	0.1
6022280	0.6	0.5	0.5	0.4
6022282	0.6	0.6	0.6	0.6
6022301	0.6	0.2	0.2	0.2
6022319	0.4	0.7	0.7	0.6
6022322	0.6	0.7	0.7	0.6
6022340	0.2	0.2	0.2	0.1
6022350	0.8	0.7	0.7	0.6
6022352	0.6	0.7	0.7	0.6
6022450	0.7	0.8	0.8	0.7
6022560	0.5	0.9	0.9	0.8
6022566	0.8	0.8	0.8	0.7
6022594	0.6	0.2	0.2	0.2
6022603	0.6	0.5	0.5	0.4
6022611	0.8	0.8	0.8	0.7
6022615	0.7	0.7	0.7	0.6
6022623	0.4	0.5	0.5	0.4
6022697	0.5	0.5	0.5	0.4
6022702	0.6	0.7	0.7	0.6
Denmark River SWMA				
6031121	0.9	1.0	1.0	1.0
6031122	0.9	1.0	1.0	1.0
6031131	0.3	0.6	0.6	0.5
6031132	0.7	0.8	0.8	0.8
6031138	0.8	0.8	0.8	0.7
6031142	0.9	1.0	1.0	1.0
6031150	0.3	0.4	0.4	0.3

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
6031152	0.5	0.8	0.8	0.7
6031540	0.7	0.9	0.9	0.8
60311381	0.8	0.7	0.7	0.6
60311382	0.8	0.9	0.9	0.8
60315401	0.8	1.0	1.0	1.0
60315402	0.7	0.7	0.8	0.6
Shannon River SWMA				
6061118	1.0	1.0	1.0	1.0
6061119	1.0	1.0	1.0	1.0
6061120	1.0	1.0	1.0	1.0
6061124	0.8	1.0	1.0	1.0
6061125	0.9	1.0	1.0	1.0
6061126	0.9	1.0	1.0	1.0
6061129	0.9	0.9	0.9	0.9
6061133	1.0	1.0	1.0	1.0
6061139	0.9	1.0	1.0	1.0
6061140	1.0	1.0	1.0	1.0
6061535	0.9	1.0	1.0	1.0
Busselton Coast SWMA				
6100902	0.2	0.4	0.4	0.3
6100929	0.4	0.4	0.4	0.3
6100931	0.1	0.2	0.2	0.1
6100933	0.1	0.2	0.2	0.2
6100936	0.2	0.3	0.3	0.2
6100939	0.3	0.5	0.5	0.4
6100946	0.2	0.3	0.3	0.2
6100948	0.2	0.4	0.4	0.3
6100956	0.3	0.4	0.5	0.3
6100967	0.8	1	1	0.9
6100978	0.9	0.7	0.8	0.6

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
6101002	0.8	0.9	0.9	0.9
Preston River SWMA				
6110873	0.2	0.3	0.3	0.2
6110909	0.2	0.3	0.3	0.2
6110924	0.3	0.5	0.5	0.4
Collie River SWMA				
6120802	0.2	0.4	0.4	0.3
6120819	0.6	0.7	0.7	0.6
6120825	0.6	0.6	0.6	0.5
6120826	0.7	0.8	0.8	0.7
6120836	0.9	0.8	0.6	0.9
6120842	0.4	0.4	0.4	0.4
6120869	0.2	0.2	0.2	0.1
6120880	0.4	0.7	0.7	0.7
6120903	0.5	0.6	0.6	0.5
6120928	0.7	0.7	0.7	0.6
6121461	0.1	0.1	0.1	0.1
6121686	0.4	0.7	0.8	0.6
6121687	0.9	0.9	0.9	0.8
6121690	0.5	0.9	0.9	0.8
6122055	0.8	0.8	0.8	0.7
6122103	0.8	0.9	0.9	0.8
6122151	0.1	0.2	0.1	0.2
6122191	0.8	0.6	0.3	0.8
6122227	0.7	0.7	0.7	0.6
Harvey River SWMA				
6130802	0	0	0	0
6130739	0.1	0	0	0
6130747	0.9	0.8	0.8	0.8
6130762	0.1	0.1	0.1	0.1

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
6130769	0.3	0.3	0.3	0.3
6130787	0.9	1	1	1
6131420	0.9	0.9	0.9	0.8
6131437	0.8	0.8	0.6	1
6131679	0.7	0.6	0.6	0.6
6131810	0.1	0.1	0.1	0.1
6131816	0	0	0	0
6131912	0.1	0.2	0.2	0.1
6131990	0.1	0	0	0
6132049	0.2	0.3	0.3	0.2
6132220	0.3	0.6	0.6	0.5
Moore-Hill Rivers SWMA				
6170192	0.3	0.3	0.3	0.3
6170204	0.3	0.3	0.3	0.2
6170219	0.3	0.3	0.3	0.2
6170222	0.1	0.1	0.1	0
6170248	0.4	0.4	0.4	0.3
6170259	0.8	0.9	0.9	0.8
6170264	0.2	0.2	0.2	0.1
6170266	0.5	0.5	0.5	0.4
6170271	0.4	0.4	0.4	0.4
6170281	0.3	0.6	0.6	0.5
6170304	0	0	0	0
6170306	0.5	0.4	0.4	0.3
6170309	0.1	0.1	0.1	0
6170311	0.3	0.4	0.4	0.3
6170324	0.3	0.3	0.3	0.2
6170338	0.5	0.5	0.5	0.4
6170339	0.2	0.3	0.3	0.2

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
6170342	0	0.1	0.1	0
6170377	0.3	0.4	0.4	0.3
6170381	0.5	0.5	0.5	0.4
6170384	0.2	0.2	0.2	0.1
6170386	0.3	0.3	0.3	0.3
6170388	0.5	0.5	0.5	0.4
6170399	0	0.1	0.1	0
6170409	0.7	0.8	0.8	0.7
6170414	0.3	0.3	0.3	0.2
6170415	0.4	0.4	0.5	0.3
6170424	0.4	0.4	0.4	0.3
6170443	0.1	0.1	0.1	0.1
6170454	0.3	0.3	0.3	0.3
6170465	0.2	0.3	0.3	0.2
6170472	0.8	0.9	0.9	0.8
6170475	0.4	0.5	0.5	0.4
6171267	0.3	0.3	0.3	0.3
6171274	0.4	0.4	0.4	0.3
6171311	0.7	0.7	0.7	0.7
6171572	0	0	0	0
6171585	0.6	0.6	0.6	0.5
6171595	1	1	1	1
6171604	0.6	0.7	0.7	0.6
6171614	0.2	0.2	0.2	0.2
6171615	0.2	0.4	0.4	0.3
6171772	0.3	0.4	0.4	0.3
6171780	0.9	0.9	0.9	0.8
6171961	0.6	0.6	0.6	0.5
6171963	0	0	0	0

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
6171964	1	1	1	1
6171966	0.2	0.3	0.3	0.2
6172023	0.8	0.9	0.9	0.8
6172028	0.3	0.6	0.6	0.5
6172033	0.4	0.5	0.5	0.4
6172036	0.6	0.9	0.9	0.8
6172077	0.2	0.2	0.2	0.1
6172079	0.1	0.1	0.1	0
6172083	0.8	0.7	0.8	0.6
6172085	0.8	0.8	0.8	0.7
6172121	0.5	0.5	0.5	0.5
6172128	0.3	0.5	0.5	0.4
6172172	0.6	0.9	0.9	0.8
6172969	0	0	0	0
6172970	0.3	0.4	0.4	0.3
6172975	0.3	0.5	0.5	0.4
6172976	0.7	0.9	0.9	0.9
6172977	0.8	0.8	0.8	0.8
6172978	0.4	0.4	0.4	0.3
6172983	0.5	0.6	0.6	0.5
6172987	0.3	0.5	0.5	0.4
6172994	0.4	0.7	0.7	0.6

Aquatic Biota theme

Aquatic Biota theme										
Site	Reach	ABI	FCSI	EXP	O/E	O/P	NAT_{FC}	P_{Ab}	P_{Sp}	MSI
Albany Coast SWMA										
AR-01	6021149	0.8	0.9	0.7	0.7	0.8	1.0	1.0	1.0	0.7
BR-02	6021069	0.8	0.8	0.6	0.6	0.7	1.0	1.0	1.0	0.8

BR-03	6021515	0.8	0.8	0.6	0.6	0.7	1.0	1.0	1.0	0.8
ER-01	6021115	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
EVBRE01	6021069	0.8	0.8	0.7	0.7	0.7	1.0	1.0	1.0	0.8
EVGAI01	6022350	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5
EVGAI02	6022350	0.7	1.0	0.9	0.9	1.0	1.0	1.0	1.0	0.4
EVKAL01	6022005	0.8	0.7	0.3	0.3	0.3	1.0	1.0	1.0	0.9
EVKAL03	6021727	0.8	0.7	0.6	0.6	0.6	0.9	0.9	0.8	0.8
EVSUS02	6021013	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
FR-02	6022603	0.6	0.8	0.5	0.5	0.5	1.0	1.0	1.0	0.4
FR-03	6022594	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
GAR-03	6022301	0.6	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.3
HAMR-01	6021715	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9
HAMR-02	6021497	0.6	0.8	0.5	0.5	0.5	1.0	1.0	1.0	0.5
HAMR-03	6021497	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
KR	6021147	0.7	0.7	0.5	0.4	0.5	1.0	1.0	1.0	0.7
NC-01	6021536	0.9	0.9	0.8	0.8	0.8	1.0	1.0	1.0	1.0
PR-01	6022280	0.8	0.8	0.7	0.7	0.7	0.8	1.0	0.7	0.8
PR-02	6021034	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8
PR-03	6022560	0.9	0.9	1.0	1.0	1.0	0.8	1.0	0.7	0.9
PR-04	6022319	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8
PR-05	6021008	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8
PR-06	6021003	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8
SMR-01	6021929	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
WIC-01	6021534	0.5	0.5	0.1	0.2	0.0	1.0	1.0	1.0	0.5
WR-01	6021143	0.8	0.8	0.7	0.7	0.7	1.0	1.0	1.0	0.8
Denmark River SWMA										
CLEE-01	6031121	0.9	0.8	0.6	0.6	0.70	1.0	1.0	1.0	0.9
DENM-01	6031122	0.9	1.0	1.0	1.0	1.00	1.0	1.0	1.0	0.8
DENM-03	60315402	0.9	0.9	0.8	0.8	0.80	1.0	1.0	1.0	1.0
EVDEN-LG	60315401	1.0	1.0	1.0	0.9	1.00	1.0	1.0	1.0	0.9
EVHAY08	60311382	0.8	1.0	1.0	1.00	1.00	1.0	1.0	1.0	0.7

EVHAY11	6031132	1.0	1.0	1.0	1.00	1.00	1.0	1.0	1.0	1.0
EVHAY14	60311381	0.5	0.7	0.3	0.3	0.30	1.0	1.0	1.0	0.4
HAY-01	6031131	0.7	0.7	0.4	0.4	0.3	1.0	1.0	1.0	0.7
MARB-01	6031152	0.8	1.0	0.9	0.8	1.0	1.0	1.0	1.0	0.7
MITC-01	6031142	1.0	1.0	0.9	0.8	1.0	1.0	1.0	1.0	1.0
Shannon River SWMA										
BOOR-01	6061124	0.9	1.0	0.9	0.8	1.00	1.0	1.0	1.0	0.9
EVDEE02	6061120	0.8	0.8	0.6	0.7	0.50	1.0	1.0	1.0	0.8
EVDEE05	6061535	0.8	1.0	1.0	0.9	1.00	1.0	1.0	1.0	0.6
EVGAR02	6061126	0.9	1.0	0.9	0.8	1.00	1.0	1.0	1.0	0.9
EVGAR05	6061125	0.8	1.0	0.9	0.8	1.00	1.0	1.0	1.0	0.6
EVSHA04	6061139	0.9	1.0	1.0	1.	1.00	1.0	1.0	1.0	0.8
WELD-01	6061133	0.8	0.9	0.9	0.8	1.00	1.0	1.0	1.0	0.8
Busselton Coast SWMA										
ABBA-01	6100933	0.8	0.9	0.8	0.8	0.8	0.9	1.0	0.8	0.7
ANNI-01	6100931	0.5	0.7	0.4	0.4	0.4	1.0	1.0	1.0	0.4
CAPE-01	6100948	0.6	0.8	0.8	0.8	0.8	0.9	1.0	0.8	0.5
CARB-01	6100978	0.9	1.0	1.0	0.90	1.0	1.0	1.0	1.0	0.9
GBC12	6100946	0.6	0.9	0.8	0.8	0.8	0.9	0.9	0.8	0.4
GYNU-01	6100902	0.6	0.7	0.8	0.80	0.8	0.6	0.6	0.6	0.5
LUDL-01	6100939	0.7	0.9	0.8	0.8	0.8	0.9	1.0	0.8	0.5
MARG-02	6101002	0.8	1.0	1.0	1.00	1.00	1.0	1.0	1.0	0.7
SABI-01	6100956	0.6	0.8	0.7	0.7	0.7	0.9	0.9	0.8	0.4
VASS-01	6100936	0.8	0.9	0.8	0.8	0.8	1.0	1.0	1.0	0.7
WILY-01	6100967	0.8	0.9	0.8	0.8	0.8	1.0	1.0	1.0	0.7
Preston River SWMA										
FERG-01	6110873	0.8	0.9	0.8	0.8	0.8	1.0	1.0	1.0	0.8
PRES-01	6110909	0.7	0.8	0.7	0.7	0.7	0.9	1.0	0.8	0.5
PRES-02	6110924	0.5	0.7	0.3	0.3	0.3	1.0	1.0	1.0	0.4
Collie River SWMA										
BRUN-01	6121686	0.6	0.8	0.7	0.7	0.7	0.9	1.0	0.8	0.5

BRUN-03	6120825	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7
BRUN-05	6120825	0.8	1.0	1.0	1.0	1.0	0.9	1.0	0.9	0.7
BRUN-06	6120825	0.7	0.7	0.6	0.6	0.6	0.9	1.0	0.8	
CR-05	6122227	0.6	0.7	0.4	0.4	0.4	1.0	1.0	1.0	0.4
CR-06	6122227	0.8	0.8	0.5	0.5	0.5	1.0	1.0	1.0	0.8
CR-07	6122227	0.8	0.8	0.7	0.7	0.7	1.0	1.0	1.0	0.7
CR-08	6122191	0.9	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.8
CR-09	6122103	0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.8	0.9
CR-10	6120928	0.7	0.8	0.8	0.8	0.8	0.8	0.9	0.7	0.7
CR-11	6120928	0.9	0.9	1.0	0.9	1.0	0.8	0.8	0.7	1.0
CR-12	6122055	0.6	0.6	0.6	0.6	0.6	0.7	0.5	0.8	
CR-15	6121690	0.7	0.8	0.8	0.8	0.8	0.8	0.9	0.7	0.7
CR-16	6121690	0.7	0.7	1.0	1.0	1.0	0.5	0.1	0.9	0.7
CR-17	6120880	0.7	0.8	0.7	0.7	0.8	0.8	0.8	0.8	0.7
HAR-01	6120836	0.9	0.9	1.0	0.9	1.0	0.8	0.9	0.7	
WELL-01	6120802	0.6	0.9	0.8	0.8	0.8	0.9	1.0	0.8	0.4
Harvey River SWMA										
HARV-05	6131679	0.9	1.0	1.0	1.00	1.0	1.0	1.0	1.0	0.9
HARV-06	6130787	0.6	0.3	0.2	0.2	0.2	0.4	0.3	0.5	0.9
HR01012	6131810	0.6	0.7	0.5	0.5	0.5	0.9	1.0	0.8	0.5
HR02010	6132049	0.8	0.7	0.7	0.6	0.67	0.8	0.9	0.7	0.9
HR03013	6130762	0.4	0.4	0.5	0.5	0.5	0.4	0.2	0.5	0.4
HR03015	6131912	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.6	0.7
HR03017	6131990	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7
PHD1	6130739	0.5	0.7	0.7	0.6	0.7	0.8	0.9	0.7	0.3
PHH1	6132220	0.4	0.5	0.4	0.4	0.4	0.6	0.6	0.5	0.3
SAM-01	6131420	0.7	0.4	0.2	0.4	0.2	0.6	0.9	0.3	1.0
SAM-02	6130747	0.7	0.6	0.4	0.4	0.4	0.8	1.0	0.7	0.7
Moore-Hill Rivers SWMA										
HR-01	6172172	0.7	0.8	0.8	0.8	0.8	0.8	0.9	0.8	0.6
HR-02	6172172	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.9

HR-03	6172172	0.8	0.9	1.0	1.0	1.0	0.8	0.7	0.8	0.8
HR-04	6171585	0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.6
MB-01	6172028	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.9
MB-02	6171966	0.7	0.7	1.0	1.0	1.0	0.4	0.5	0.3	0.8
MR-04	6172036	1.0	1.0	0.9	0.9	1.0	1.0	1.0	1.0	1.0
MR-05	6172036	0.9	0.9	1.0	0.9	1.0	0.9	1.0	0.9	0.8
MR-06	6171615	0.6	1.0	0.9	0.9	1.0	1.0	1.0	1.0	0.2
MR-07	6170465	0.7	0.8	0.6	0.6	0.7	1.0	1.0	1.0	0.6
MR-09	6172976	0.7	0.8	0.7	0.6	0.7	0.9	1.0	0.8	0.7
MR-10	6172083	0.7	0.7	0.5	0.5	0.5	1.0	1.0	1.0	0.6
MR-12	6172975	0.7	0.7	0.5	0.5	0.5	0.8	0.9	0.8	0.8
MR-13	6172128	0.6	0.7	0.6	0.6	0.6	0.8	0.8	0.8	0.5
MR-16	6171311	0.6	0.7	0.6	0.6	0.6	0.7	0.7	0.8	0.6
MR-17	6172128	0.5	0.5	0.4	0.4	0.4	0.7	0.7	0.7	0.6
MR-18	6172976	0.7	0.9	0.8	0.8	0.8	1.0	1.0	1.0	0.4
MRC01	6172994	0.8	0.8	0.7	0.7	0.7	1.0	1.0	1.0	0.7
MRC02	6172987	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.8	0.8
NR-04	6170338	0.8	0.9	1.0	1.0	1.0	0.7	0.7	0.7	0.8
NR-06	6170306	0.7	0.8	0.5	0.5	0.5	1.0	1.0	1.0	0.6

Appendix B SWWA river health assessment field sheets

Date ______________ Site code ______________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
COVER SHEET

SITE CODE ______________

SWMA ______________

RIVER SYSTEM ______________

RIVER/STREAM NAME ______________

SITE NAME ______________

DATE ______________ COC ______________ SAMPLE NUMBER ______________

NAME OF SAMPLERS ______________

NOT ASSESSED IN FIELD

ALTITUDE ______ (m) SLOPE ______ (m/km) DFS ______ (km) STREAM ORDER ______ (km)

NEAREST RAINFALL STATION ______ (name) DISTANCE AWAY ______ km AVERAGE ANNUAL RAINFALL ______ (mm)

FLOW PATTERN CATEGORY ______________ DISCHARGE CATEGORY ______ (mm)

ORDER OF SAMPLING – DAY 1

1. Take water quality samples: grab followed by in-situ
2. Collect macroinvertebrates
3. Deploy water quality loggers. *Note: after loggers have been deployed only enter river downstream.*
4. Process macroinvertebrate sample
5. Deploy fish/crayfish traps and fyke nets
6. Site photos (important to capture conditions on first day as factors such as water level and flow can change rapidly)
7. Field sheets (if time permits)

ORDER OF SAMPLING – DAY 2

1. Collect fish/crayfish traps and fyke nets
2. Collect water quality loggers: after 25 hours (144 logged measurements)
3. Complete field sheets
4. Complete site photos: fill-in checklist below.

Photo checklist

[ ] Upstream and downstream photos; taken at the top, middle and bottom of the 100m sampling site (6 photos total)
[ ] Representative site photos
[ ] Macroinvertebrate sampling area
[ ] Representative video taken
[ ] Canopy shots (taken from edge of stream of both sides – representative of density of canopy throughout site)

Acronyms
LB: Left Bank, **RB:** Right Bank

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS

GPS DATUM ______________

LONGITUDE (°E) or EASTING ______________

LATITUDE (°S) or NORTHING ______________

MAP NAME and YEAR OF PUBLICATION ______________ SCALE ______________

PAGE REFERENCE OR MAP NUMBER ______________

ACCESS DETAILS ______________

PROPERTY OWNER ______________

PHONE NUMBER ______________

ADDRESS ______________

NOTIFY BEFORE EACH VISIT [ ] Yes [ ] No PERMISSION REQUIRED [ ] Yes [ ] No

KEY REQUIRED [ ] Yes [ ] No KEY NUMBER / AVAILABLE FROM ______________

ACCESS MAP – SKETCH ROUTE BELOW OR ATTACH MAP TO BACK OF FIELD SHEET

Include flow direction, site location, roads, crossings, north arrow, distances and landmarks.

MAP ATTACHED ☐

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
GENERAL SITE ASSESSMENT – 100m sampling site

Artists name ______________________

LONGITUDINAL DIAGRAM (AERIAL VIEW)

Essential features	Legend
Flow direction	→ → →
Loggers	L
Macroinvertebrate sample	M
Water quality sample	W
Fyke nets	▶ or ◀
North arrow	↑ N

Possible features	DIY legend	*Possible features*	DIY legend
Macrophyte habitat		Vegetation type A: ________	
Large trees		Vegetation type B: ________	
Woody debris		Vegetation type C: ________	
Riffles			
Sandbars/sediment deposits			
Significant erosion			
Natural or artificial barriers			

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
GENERAL SITE ASSESSMENT – 100m sampling site

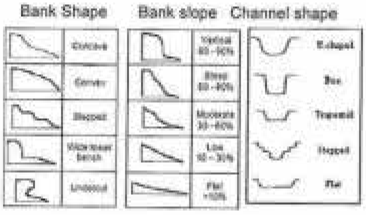
CROSS SECTION DIAGRAM

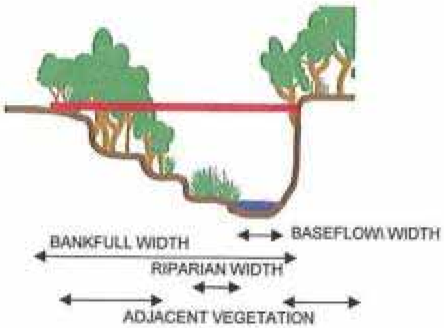
Representative of sampling region (where high variability exists draw two cross-sections).

Suggested information to include on cross section diagram above
- Bank shape (see below)
- Bank slope (see below)
- Channel shape (see below)
- Base-flow and bank-full width (m)
- Streamside and adjacent vegetation width and structure
- Presence of bars, benches, toes

Circle diagrams below

Bank Shape Bank slope Channel shape





STREAM WIDTH MEASURMENTS

	Top	Middle	Bottom
Bankfull width (m)	______	______	______
Current water width (m)	______	______	______

Water width compared to base-flow (circle)				
No flow dry isolated	Low < low water mark	Moderate Equal to base-flow	High > high water mark	Flood

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
AQUATIC HABITAT ASSESSMENT – 100m sampling site

STREAM HABITAT DIVERSITY

Habitat area	%
Channel (includes woody debris)	
Macrophytes	
Riffle	
Pool	
Total	100

Macrophyte types	%
Emergent	
Submerged	
Floating	
Total	100

Large woody debris ☐ **present** ☐ **absent** *(Size relative to 'un-impacted' conditions for specific area)*	
Diversity (circle)	**Abundance** (circle) *
Wood of similar size	Sparse (few pieces)
2-3 different sizes	Moderate *
Variety of sizes	Dense (throughout most of site)

* A few sections of moderate density or low density across most of site

Bank vegetation draped in water ** (percentage of bank length)	

*Note: section relates to habitat (not shading). ** Dead vegetation not included*

Roots overhanging and draped in water			
None	Limited	Moderate	Extensive
Overhanging banks			
None	Limited	Moderate	Extensive

Limited = 1-10% of bank length, Moderate = 11-50%, Extensive >50% of bank.

Flow *(circle)*
Uniform flow (e.g. drain)
Moderately varied flow
Varied flow (eg eddies, backwaters, fast, slow)

Depth *(circle)*
Uniform depth (eg drain)
Moderately varied depth
Varied depths

Stream shading	Percentage of bank length		Average distance from bank (m) **Average stream width** _______ m	
	LB	RB	LB	RB
Tree cover #				
Shrub overhang				
Grass overhang (rushes/sedges)				

Note: density of canopy will be determined from canopy photographs; therefore only total area should be assessed

Physical substrate DIVERSITY	Increasing complexity (circle one number)
Mainly bedrock or artificial substrate	1 2 3 4 5
Silt or sand or a mixture of silt and sand	6 7 8 9 10
Mainly sand with some pebbles &/or boulders	11 12 13 14 15
Mix of boulders, pebbles & sand etc	16 17 18 19 20

Note: increasing complexity or density are not a direct indication of health (i.e. boulders are not expected at all sites)

Biological substrate DENSITY *Tip: try breaking site into sub-sections (i.e. 10 x 10m sections for a 100m sampling site), to estimate cover*	Increasing density (circle one number)
<10% of substrate cover	0 1 2 3 4 5
11-30%	6 7 8 9 10
31-60%	11 12 13 4 15
>60%	16 17 18 19 20

Biological substrate DIVERSITY (circle)

leaves	twigs	branches	detritus *	Epiphytes

** Detritus relates to undifferentiated organic material*

Sediment deposition	None or minor	Not obvious	Obvious

Type (sand/silt): _______________________

WATER AND SEDIMENT

Circle the appropriate description under each category.

Water odours	***Water Oils***	***Turbidity***	***Tannin staining ****		***Algae in water column***	***Algae on substrate***	***Plume*****	***Sediment oils***	***Sediment odours***
Normal/None	None	Clear	Clear		0%	0%	Small	Absent	Normal/None
Anaerobic	Slick	Slight	Slight		1 to 10%	1 to 10%	Moderate	Light	Sewage
Sewage	Sheen	Turbid	Light tea		11 to 50%	11 to 50%	Large	Moderate	Petroleum
Petroleum	Globs	Opaque	Dark tea		51 to 75%	51 to 75%		Profuse	Chemical
Chemical	Flecks		Black		> 75%	> 75%			Anaerobic

* tannin staining can be confused when combined with systems containing fine suspended sediment (if problematic assess from filtered water sample)
** relates to amount of fine sediment generated and time take to settle (i.e. a large plume may extend for a meter diameter and remain suspended for 5 seconds or more)

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SW-WA RIVER HEALTH ASSESSMENT – FIELD SHEETS
PHYSICAL FORM/CATCHMENT IMPACT ASSESSMENT – 100m sampling site

BANKS AND PHYSICAL FORM

AMOUNT of erosion Length of bank affected (%)		
0 to 5%	LB	RB
>5 to 20%	LB	RB
21 to 50%	LB	RB
> 50%	LB	RB

SEVERITY of erosion, and bank stability	Circle	
Severe: LITTLE TO NO STRUCTURAL INTEGRITY Banks are predominantly bare. Significant sections of erosion (undercutting/slumping) on both outside bends and straight stretches (sediment deposits in river). Exposed roots obvious (where applicable), with significant loss of vegetation in eroding areas. Channel shape, bank shape and depth likely to change in near future.	LB	RB
High: POOR STRUCTURAL INTEGRITY Evidence of bank instability (undercutting/slumping); with signs of soil loss from banks, and possibly areas of sedimentation (i.e. sandbars or toes) and scouring. Some exposed roots (where applicable), with loss of vegetation in eroding areas. Erosion typically around outside bends.	LB	RB
Low-Moderate: GOOD STRUCTURAL INTEGRITY Banks relatively stable – exposed and superficially eroding bank (erosion doesn't penetrate deeply into bank wall) or stabilised by only exotic grasses. Little likelihood of significant change to channel/bank shape, depth or loss of bank material in near future.	LB	RB
Minor: EXCELLENT STRUCTURAL INTEGRITY Banks stable and mostly intact (minor slumping, undercutting or bare banks expected naturally): stabilised by vegetation or bedrock.	LB	RB

Factors affecting bank stability	Circle	
Feral animals	LB	RB
Livestock access (if yes, compete table below)	LB	RB
Human access	LB	RB
Cleared vegetation	LB	RB
Runoff		
Irrigation draw-down		
Flow and waves		
Culvert, bridge, dam		
Drain pipes	LB	RB
Other (specify)		

Stabilisation works Yes ☐ No ☐		
Choose one or more	Circle	
Rock wall protection	LB	RB
Bank matting	LB	RB
Logs/planks strapped to bank	LB	RB
Concrete lining	LB	RB
Revegetation plantings	LB	RB
Fenced human access (deterrent)	LB	RB
Fenced livestock access	LB	RB
Fenced stock watering points	LB	RB
Other (specify)	LB	RB

Indicate livestock types ______________________________ & indicate their impact (major or minor) for each category below.

CATEGORY	MINOR	Tick box	MAJOR	Tick box
Vegetation damage	Only small patches of vegetation grazed		Most groundcover vegetation grazed.	
Bank damage	Isolated areas (1 or 2) of livestock damage		Near continuous livestock damage to stream	
Pugging	Isolated (1or 2) areas of pugging		Extensive pugging along the stream length	
Manure	≤2 significant manure deposits per site		>2 significant manure deposits per site	
Tracks	≤1 track per site		>1 track per site	

POLLUTION SOURCES

Local point source pollution		*None evident* ☐
Potential	Obvious	Indicate type/s:
Within site	Within site	
Upstream	Upstream	
Downstream	Downstream	

Local non-point source pollution		*None evident* ☐
Potential	Obvious	Indicate type/s:
Within site	Within site	
Upstream	Upstream	
Downstream	Downstream	

LANDUSE AT SITE - WITHIN 50m FROM EDGE OF STREAM

Circle all applicable for each bank

LB	Conservation	Remnant vegetation	Water Catchment	State Forest	Aboriginal Reserve	Vacant Crown Land	Agriculture	Pastoralism	Tourism	Mining	Industrial	Urban
RB	Conservation	Remnant vegetation	Water Catchment	State Forest	Aboriginal Reserve	Vacant Crown Land	Agriculture	Pastoralism	Tourism	Mining	Industrial	Urban

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
VEGETATION ASSESSMENT - 100m sampling site

RIPARIAN VEGETATION

Riparian zone = a clear distinction in vegetation type between water dependant and non-water-dependent vegetation

Riparian zone ABSENT ☐ >>>> Due to: **human impact** ☐ **natural feature (eg bedrock)** ☐ **fire/flood...** ☐ **unknown** ☐

Riparian zone PRESENT ☐ [complete rest of box]

Indicate riparian layers PRESENT*?	circle		
Ground layer (i.e. sedges, rushes)	yes	no	reduced
Shrub layer (woody)	yes	no	reduced
Tree layer	yes	no	reduced

Width of riparian zone Left bank ______m Right bank ______m

Dominant riparian species (if unknown write: refer to photographs):

* this refers to the presence of riparian species (intactness is incorporated below). Note: if only 1 or 2 shrubs remain (for example) circle 'no'.

STREAMSIDE ZONE VEGETATION (FIRST 10m) - NATIVE AND EXOTIC VEGETATION

Percentage cover	0%		1 - 10%		10 to 50%		50 - 75%		> 75%	
	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB
Bare ground (not bedrock)										
Ground cover/grasses/sedges/rushes										
Shrubs (woody, multi-stem)*										
Trees < 10m										
Trees > 10m										

*Shrubs include Blackberry, Tea trees

STREAMSIDE ZONE VEGETATION (FIRST 10m) - EXOTIC VEGETATION

Proportion (%) of exotic vegetation in each vegetation layer	0%		1 - 10%		10 to 50%		50 - 75%		> 75%	
	LB	RB	LB	RB	LB	RB	LB	RB	LB	RB
Ground cover/grasses/sedges/rushes										
Shrubs (woody, multi-stem)*										
Trees < 10m										
Trees > 10m										

STREAMSIDE ZONE VEGETATION (FIRST 10m) - NATIVE WOODY VEGETATION

Recruitment evidence	*Recruitment type*	*Extent of recruitment*	*Recruitment health*
None	Trees	Limited	Poor
Natural	Shrubs	Moderate	Moderate
Planted	Both	Abundant	Healthy

ADJACENT ZONE VEGETATION (10 to 100m)

Tick box for the DOMINANT feature in each zone	10 to 50m		50 to 100m		100m +	
	LB	RB	LB	RB	LB	RB
Minimal vegetation Typical of areas of urban development / industry / mining						
Weeds/Grasses May have a few scattered trees (typical of agriculture)						
Remnant vegetation Mostly native trees and/or shrubs (may have exotic understorey).						
Forest Native trees, shrubs and understorey. Few or no exotics.						
Plantations **Type:** ______________________						
Other (describe)						

COMMENTS (VEGETATION IN ADJACENT ZONE): ______________________________

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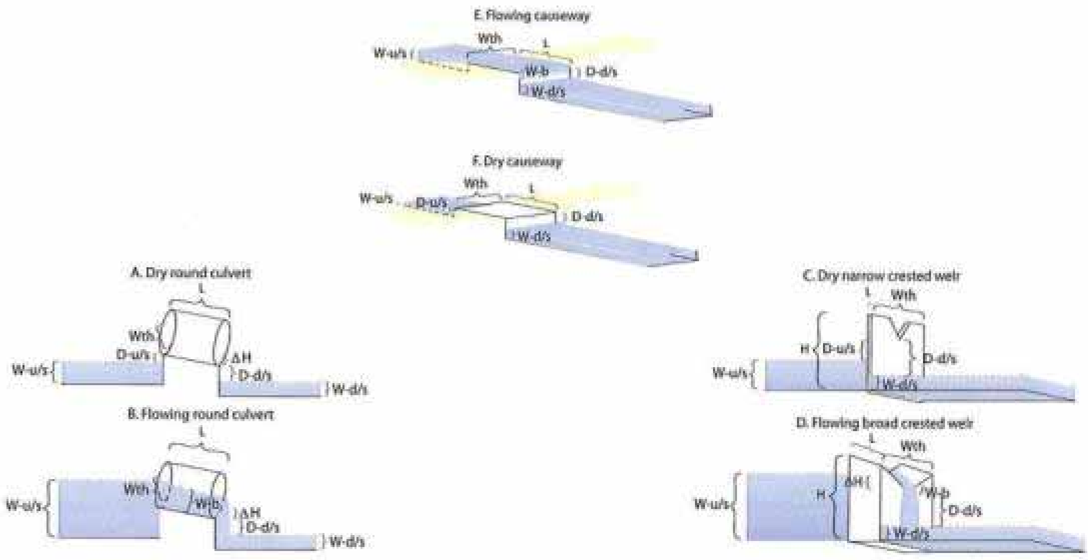
SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
BARRIER ASSESSMENT - 100m sampling site

NATURAL AND ARTIFICIAL BARRIERS IN 100m SITE

No barriers ☐

Description		Barrier 1	Barrier 2	Barrier 3
	Type of Barrier – artificial (see bottom of page for types) or natural			
	Longitude or Northing			
	Latitude or Easting			
	Tick when photo taken			
L	Length (longitudinal) (m)			
ΔH	Height difference across barrier (m)			
Wth	Width or diameter (cross-section) (m)			
H	Height (m)			
W – b	Water depth across barrier (m)			
D – d/s	Downstream drop (bottom of barrier to water) (m)			
W – d/s	Water depth – downstream (m)			
D – u/s	Upstream drop (bottom of barrier to water) (m)			
W – u/s	Water depth – upstream (m)			
	Blockage – overgrowth or sedimentation % cross-sectional area			
	Flow over barrier (either measure or describe)			
	Structure material (e.g. concrete, timber, steel, plastic, loose rock)			
	If culvert, number or pipes or boxes			
	Barrier floods at flow condition (extremely high, high, medium, low flows)			

Note: Not all of the above measurements will apply to natural barriers.



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SW-WA RIVER HEALTH ASSESSMENT – FIELD SHEETS
100m sampling site

NATURAL OR ARTIFICIAL BARRIERS OUTSIDE 100m SITE

Artificial barriers outside 100m site (upstream or downstream)		Circle
Unknown	None	Yes (see below)
Description and distance from site (if time, assess as per previous page).		

Natural barriers outside 100m site (upstream or downstream)		Circle
Unknown	None	Yes (see below)
Description and distance from site (if time, assess as per previous page).		

CHANNELISATION

Signs of channelisation	No ☐	Yes ☐ (describe below)

Note whether channelisation is due:

1. **Direct causes:** deepening and straightening by humans to increase water flow (e.g. to reduce flooding), or
2. **Indirect causes:** deepened systems with more vertical banks due to bank erosion and bed scouring; a result of increased flows from changes such as catchment clearing or hydrological modifications.

WATER VELOCITY (FLOW) ACROSS 100m SAMPLE SITE

Flow information is recorded on the Macroinvertebrate Sampling Sheet and WQ 2 Sheet, if neither is being used for this assessment use space provided below.

Meter or Method used ________________________ units ________ Velocity ___________

WEATHER CONDITIONS

Rain in past week	Tick box
Yes	
No	
If known, mm	

Cloud cover	%
Day 1	
Day 2	

Rain	Tick box
Day 1	Yes ☐ No ☐
Day 2	Yes ☐ No ☐

Weather comments ________________________________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
WATER QUALITY 1: GRAB AND IN-SITU SAMPLES

Recorders name ______________________

PRE - INSTRUMENT CALIBRATION

Instrument Type ______________________ Instrument Number ______________________

Pre – field calibration	Electrical Conductivity (mS/cm)	pH 7	pH 10	Dissolved Oxygen (% sat)	Salinity	Temperature
Pre reading						
Post reading						

NOTE: In most cases salinity and temperature are not calibrated prior to use.

Circle:

Conductivity units	uncomp	comp (25°C)	
Conductivity setting	fresh	salt	none
Salinity setting	2311	Other (indicate):	
Electrical conductivity calibration solution used	1.413 mS/cm	Other (indicate):	
Dissolves oxygen calibrated to	100% sat. in air	Other (indicate):	

Barometric pressure from BOM (if required) for DO calibration

Full state: 1900 955 366
Coastal: 1900 969 902

________ hPa ______ mmHg
(mmHg = hPa x 0.7502)

GRAB WATER QUALITY

Water quality samples taken

Date ______________ Time ______________

Sample number ______________ COC ______________

IN-SUTU WATER QUALITY

	Date	Time (24 hrs)	Salinity (ppt)	pH	Dissolved oxygen (mg/L)	Dissolved Oxygen (% sat)	Electrical Conductivity (mS/cm)	Temperature (°C)	Add any others here	
Surface										
Bottom										

Note: Usually only surface water samples are taken.

POST - INSTRUMENT CALIBRATION

Post – field calibration	Electrical Conductivity (mS/cm)	pH 7	pH 10	Dissolved Oxygen (% sat)	Salinity	Temperature (°C)
Pre reading						
Post reading						

NOTE: In most cases pH 10 does not require post calibration. Dissolved oxygen is only checked, not post calibrated

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Date ________________ Site code ________________

Government of Western Australia
Department of Water

SW-WA FARWH – FIELD SHEETS
WATER QUALITY 2: DIEL DISSOLVED OXYGEN AND TEMPERATURE

Recorders name ______________________________

PRE-DEPLOYMENT MEASUREMENTS

Deployment date ________________ Deployment time ________________

Probe Letter	Pump Number	Field air calibration			Water readings (mg/L)	Pump running (yes or no)	Water depth to first inlet hole (cm)	Actual water depth (m)
		Pre-cal (mg/L)	Span (%)	Post-cal (mg/L)				

LOCATION OF LOGGERS

Circle one each category (except for in-stream vegetation)

Location in stream	In main flow	Off main flow	Other (describe)	
Angle loggers deployed	90° (vertical)	45 to 90°	< 45°	
Canopy cover over loggers	0%	10 to 50%	50% to 80%	100%
In-stream vegetation* (tick all applicable)	None	Emergent	Submerged	Floating
Density of in-stream, vegetation*	N/A	Sparse	Medium	Dense
Density of algae in water column*	None	Sparse	Medium	Dense
Riffles/cascades (upstream of loggers)**	None		If yes ____________ m upstream	

* within 1m from loggers. ** within 50m from loggers

Notes ____

WATER VELOCITY (FLOW) AT LOGGER SITE

Meter or Method used ______________________ units ________ Velocity___________

POST DEPLOYMENT MEASUREMENTS

Retrieval date ____________ Retrieval time ____________

Probe Letter	Pump running	Condition of HOUSING	Condition of MEMBRANE		Water reading (mg/L)	Air reading (mg/L)
	No Slow Fast	Clean Slightly dirty Very dirty	Clean Slightly dirty Very dirty	Bubbles No bubbles		
	No Slow Fast	Clean Slightly dirty Very dirty	Clean Slightly dirty Very dirty	Bubbles No bubbles		

Weather observations in past 24 hours and/or any noticeable changes to site or loggers ______________________________
____
____

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Date ______________ Site code ______________

Government of Western Australia
Department of Water

SW-WA FARWH – FIELD SHEETS
WATER QUALITY 3: MULTI PARAMETER LOGGING

Recorders name ______________________

PRE-DEPLOYMENT INSTRUMENT CALIBRATION

Instrument Type ________________ Logger Number ____________ Handpiece Number ____________

Pre – field Calibration	Salinity	pH 7	pH 10	Dissolved Oxygen (% sat)	Electrical Conductivity (mS/cm)	Temperature (°C)
Reading						
Calibrated to						

NOTE: In most cases salinity and temperature are not calibrated prior to use.

Barometric pressure from BOM (if required) for DO calibration

Full state: 1900 955 366
Coastal: 1900 969 902

________ hPa ______ mmHg
(mmHg = hPa x 0.7502)

LOGGING INFORMATION

Deployment date ____________ Deployment time ____________

Parameters set to log (tick)

[ ] Dissolved Oxygen [ ] Temperature [ ] Electrical conductivity
[ ] pH [ ] Turbidity [ ] Other ____________

Loggers set to record every ______________ mins for ______________ days / hours (circle)

LOCATION OF LOGGERS

Circle one option for each category (except for in-stream vegetation)

Location in stream	In main flow	Off main flow	Other (describe)	
Angle loggers deployed	90° (vertical)	45 to 90°	< 45°	
Canopy cover over loggers	0%	10 to 50%	50% to 80%	100%
In-stream vegetation* (tick all applicable)	None	Emergent	Submerged	Floating
Density of in-stream, vegetation*	N/A	Sparse	Medium	Dense
Density of algae in water column*	None	Sparse	Medium	Dense
Riffles/cascades (upstream of loggers)**	None		If yes ____________	m upstream

* within 1m from loggers. ** within 50m from loggers

Notes ____

WATER VELOCITY (FLOW) AT LOGGER SITE

Meter or Method used ________________ units ______ Velocity __________

LOGGER REMOVAL

Logger removal date __________ Logger removal time __________

Weather observations in past 24 hours and/or any noticeable changes to site or loggers ________________________

Post – field Calibration	Salinity	pH 7	pH 10	DO%	Electrical Conductivity (mS/cm)	Temperature (°C)
Reading						
Calibrated to						

NOTE: In most cases pH 10 does not require post calibration. Dissolved oxygen is only checked, not post calibrated

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Date ________________ Site code ________________

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SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
FISH AND CRAYFISH

Recorders name ____________________ Date traps deployed ____________________

☐ (tick) Local Fisheries WA officer called (1800 815 507) up to one day prior (need permit number, car registration and samplers names)

TRAP SETTING – BOX TRAPS

Trap #	Small trap (S) or Large trap (L)	Left bank (LB) Right bank (RB) or Centre (C)	Water Depth (cm)	Describe location of trap e.g. in woody debris, under log, amongst emergent macrophytes, in full sun, % shaded, under overhanging vegetation, amongst tree roots.

TRAP SETTING – FYKE NETS

TYPE		Water Depth (cm)	% stream width *	Comments e.g. fyke in eddy, gaps between wings and bank or river bottom
Dome (D) or Rectangle (R)	Upstream (US) or Downstream DS)			

*If both wings are fully extended to edge of bank this would be 100%. If spaces exist between wings and bank or between wings and surface of water (due to depth), estimate coverage and provide explanation of set-up.

LIST FISH/CRAYFISH SPECIES OBSERVED BUT NOT CAUGHT

____

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Date ________________ Site code ________________

Government of Western Australia
Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
FISH AND CRAYFISH

Recorders name ________________________ Date traps collected ________________________

TRAP COLLECTION

Trap #		Size class (mm)					Evidence of Reproduction*	Comments (for example)
	Fish	0-20	20 - 50	50 - 100	100 +	Other	none	• staining, parasites, disease, injury
	Crayfish	0-20	20 - 50	50 - 76	76 - 100	100+	✓ (few)	• smallest size gravid individual • size of largest individual
	Large fish	0-100	100-200	200-400	400+	Other	✓✓ (many)	***Note size of marron over 76mm***

**Evidence of reproductive condition includes gravid females &/or characteristic colours*

Legend
WM = Western Minnow, **TM** = Trout Minnow, **BSM** = Black-stripe Minnow, **NF** = Nightfish, **WPP** = Western Pygmy Perch, **BPP** = Balstons Pygmy Perch, **SWG** = South West Goby, **SRG** = Swan River Goby, **COB** = Cobbler, **JOL** = Jollytail, **GAM** = Gambusia, **1SPOT** = One spot live bearer, **WH** = Western Hardy Head, **ELONG** = Elongata, **BB** = Black Bream, **RP** = Redfin Perch, **RT** = Rainbow Trout, **BT** = Brown Trout, **MM** = Mud Minnow, **GIL** = Gilgie, **GH** = Hybrid Gilgie, **MAR** = Marron, **HMAR** = Hairy Marron, **K** = Koonac, **KX** = Koonac sp X, **Y** = Yabbie, **FS** = Freshwater Shrimp.

Large fish include: cobbler, trout, redfin, lamprey.

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[additional sheets provided in field kit; explaining disparity in page numbers]

Date ______________ Site code ______________

Government of Western Australia
Department of Water

SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
MACROINVERTEBRATES: AUSRIVAS FIELD SHEET

Recorders name ______________________

DATE SAMPLE TAKEN ______________________ TIME SAMPLE TAKEN ______________________

COLLECTED BY ______________________ PICKED BY ______________ AND ______________

HABITAT ______________________ % OF 100 m reach ______________________

SAMPLE NUMBER ______________________ COC NUMBER ______________________

SAMPLING CONDITIONS [ ] good [ ] average [ ] poor

PICKING CONDITIONS [ ] good [ ] average [ ] poor

BREAKDOWN OF 10m SAMPLING AREA

Mineral Substrate	%	Habitat surface area	%	*Density (circle) (1= sparse, 5 = dense)*
Bedrock		Mineral substrate		
Boulders (>256mm or scorer ball)		Emergent macrophyte		1 2 3 4 5
Cobble (64 to 256mm or cricket to soccer ball		Submerged macrophyte		1 2 3 4 5
Pebble (16 to 64mm or 5c piece to cricket ball)		Floating macrophyte		1 2 3 4 5
Gravel (4 to 16mm or raw sugar to 5c piece)		Detritus		1 2 3 4 5
Sand (1 to 4mm)		Algal Cover		1 2 3 4 5
Silt (<1mm)		Riparian veg draped in water		
Clay		Other (e.g. woody debris)		
Total	100%	Total (may be > 100%)		

DEPTH

Depth macroinvertebrate sample taken (circle) <25cm <50cm <100cm < 200cm > 200cm

WATER VELOCITY (FLOW) AT MACROINVERTEBRATE SITE

Meter or Method used ______________ units ________ Max velocity ____________ Min velocity____________

BOX SUB-SAMPLER TALLY

Number of cells picked ____________

Number of cells in box ____________

Total number of macroinvertebrates picked ____________

Comments (if any)

____

____

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Appendix C Power analysis results

Power analysis is used to determine the sampling effort required to adequately represent the data population being assessed. Power has been assessed for all indicators examined in the SWWA-FARWH trials (except those where a score for each reach was determined) using a two-tailed t-test to predict the number of samples required to detect a given percentage change in the mean. Alpha has been set at 0.05 and Beta at 0.8 (to minimise the potential type I and type II error rates respectively). As the analysis was conducted using one year's worth of data for each SWMA (because this was all that was available) there is no knowledge of how variable repeat visits to the same site are. Therefore the results of the power analysis are indicative only at this stage and will need to be repeated once more data becomes available.

For SWWA-FARWH trials the number of samples required to represent an effect size of both 10% and 20% has been reported, along with the power based on the sampling effort employed in the trials. Power analysis was done post-hoc.

Catchment Disturbance index

Land use sub-index

As this sub-index was calculated for all reaches a power analysis was not conducted.

Infrastructure sub-index

As this sub-index was calculated for all reaches a power analysis was not conducted.

Land cover change sub-index

As this sub-index was calculated for all reaches a power analysis was not conducted.

Hydrological Change index

Flow stress ranking sub-index

As this sub-index was calculated for all reaches a power analysis was not conducted.

Water Quality index

Total nitrogen sub-index

Following power analysis it would appear the current sampling effort is reasonable, accounting for a 20% change in the mean or better. For some SWMAs sampling could be reduced, such as in the Harvey River and Preston River (which showed little variability throughout the SWMA) and to a lesser extent in Albany Coast, Collie River and Moore-Hill Rivers. As time is not a limiting factor in terms of collection of data – given that existing programs are in place to do this (piggybacking) – the decision to reduce sampling effort is primarily a function of associated laboratory costs.

Table 59 Power analysis results for the total nitrogen sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River*	14	1	1	11	1
Busselton Coast	12	40	11	11	20
Preston River*	3	1	1	3	1
Denmark River	11	39	11	10	21
Shannon River	11	24	7	7	20
Collie River	20	32	9	11	20
Albany Coast	95	80	21	24	19
Moore-Hill Rivers	68	53	14	16	19

** indicates no variance in reach scores*

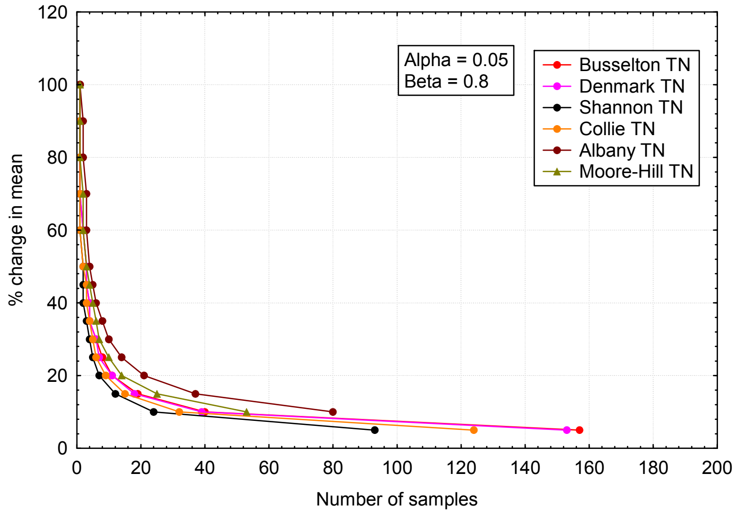

Figure 91 Power analysis results for the total nitrogen sub-index (2008 and 2009 SWMAs) (SWMAs with no variance in the scores are not shown on the graph)

Total phosphorus sub-index

Adequate power in current sampling effort is supported, with around 20% of variation explained with the number of samples collected. If increased efficiency was required the effort can be reduced in some SWMAs; for example, almost 50% less sites could be sampled in Albany Coast. Note: in some SWMAs, such as Busselton Coast, the required number of reaches to describe even 20% change is not possible given the number of existing reaches; therefore all reaches would be sampled.

Table 60 Power analysis results for the total phosphorus sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River	14	22	7	11	16
Busselton Coast	12	95	25	11	31
Preston River*	3	1	1	3	1
Denmark River	11	39	11	10	21
Shannon River	11	19	6	7	16
Collie River	20	49	13	11	32
Albany Coast	95	47	13	24	15
Moore-Hill Rivers	68	119	31	16	29

** indicates no variance in reach scores*

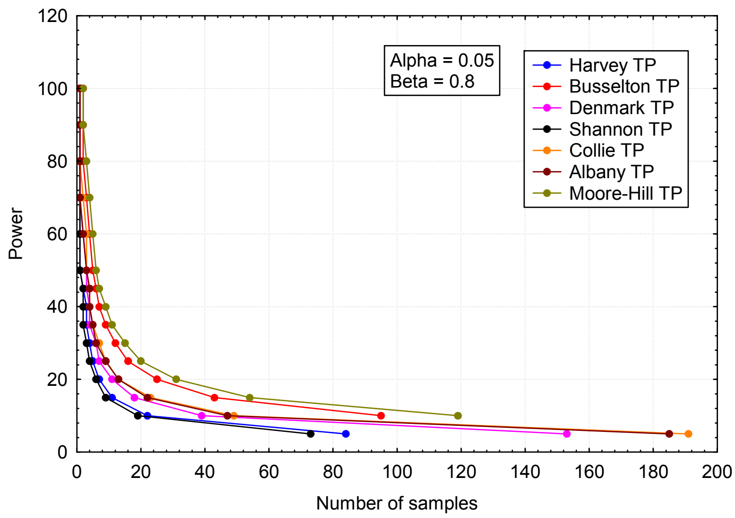

Figure 92 Power analysis results for the total phosphorus sub-index (2008 and 2009 SWMAs) (SWMAs with no variance in the scores are not shown on the graph)

Turbidity sub-index

High variability, especially for the SWMAs assessed in 2009 (as seen from associated power), suggests that all reaches should be assessed. Note: the use of logged data in future – to reduce variability due to natural diurnal patterns – may reduce the required sampling effort.

Table 61 Power analysis results for the turbidity sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River	14	66	18	11	27
Busselton Coast	12	48	13	11	23
Preston River	3	31	9	3	38
Denmark River	11	121	31	10	36
Shannon River*	11	1	1	7	1
Collie River	20	23	7	11	15
Albany Coast	95	95	25	24	20
Moore-Hill Rivers	68	63	17	16	20

** indicates no variance in reach scores*

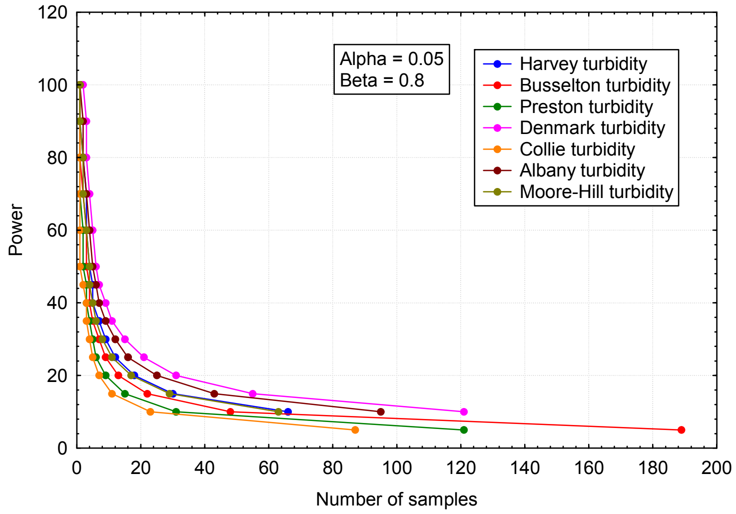

Figure 93 Power analysis results for the turbidity sub-index (2008 and 2009 SWMAs) (SWMAs with no variance in the scores are not shown on the graph)

Salinity sub-index

As this sub-index was calculated for almost all reaches a power analysis was not conducted.

Diel dissolved oxygen

Power varied depending on SWMA, therefore the general rule would be to sample all reaches. However, sites can be reduced for Harvey River, Preston River, Shannon River and Albany Coast SWMAs if required. If assessments are being conducted in conjunction with aquatic biota, then dissolved oxygen is recommended regardless of power analysis results to inform responses.

Table 62 Power analysis results for the diel dissolved oxygen sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River	14	1	1	9	1
Busselton Coast	12	253	64	11	52
Preston River	3	1	1	3	1
Denmark River	11	56	15	10	22
Shannon River	11	12	4	7	12
Collie River	20	110	29	11	32
Albany Coast	95	27	8	23	11
Moore-Hill Rivers	68	70	19	16	23

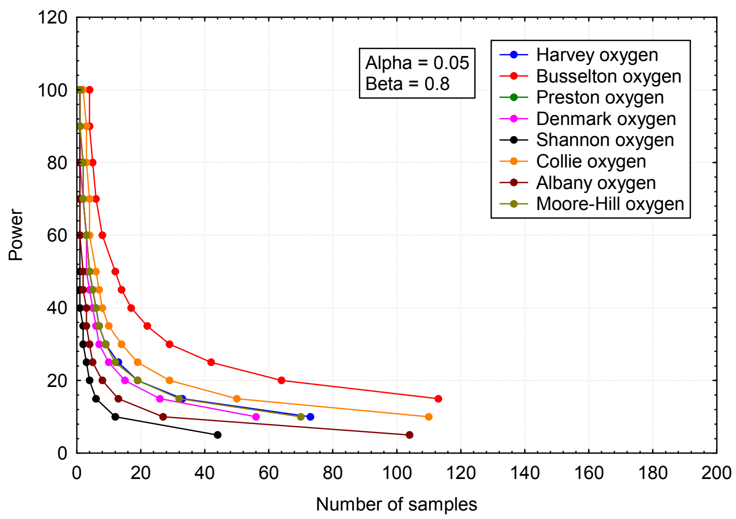

Figure 94 Power analysis results for the diel dissolved oxygen sub-index (2008 and 2009 SWMAs)

Diel temperature sub-index

With the exception of Preston River and Shannon River SWMAs, all reaches need to be assessed to return appropriate power.

Table 63 Power analysis results for the diel temperature sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River	14	182	47	9	47
Busselton Coast	12	41	11	11	20
Preston River*	3	1	1	3	1
Denmark River	11	47	13	10	23
Shannon River*	11	1	1	7	1
Collie River	20	53	14	11	22
Albany Coast	95	165	42	23	29
Moore-Hill Rivers	68	160	41	16	33

** indicates no variance in reach scores*

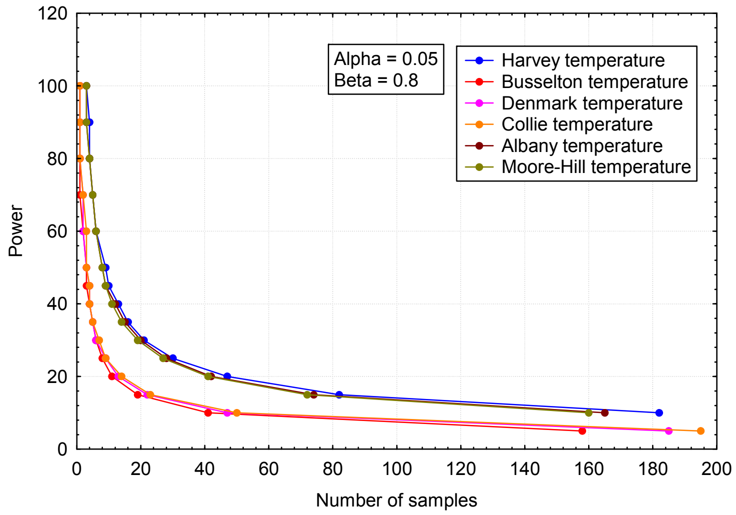

Figure 95 Power analysis results for the diel temperature sub-index (2008 and 2009 SWMAs) (SWMAs with no variance in the scores are not shown on the graph)

Physical Form index

Longitudinal continuity sub-index

As this sub-index was calculated for all reaches a power analysis was not conducted.

Artificial channel sub-index

As this sub-index was calculated for all reaches a power analysis was not conducted.

Erosion sub-index

The number of samples required to detect a 10 or 20% change in the mean *erosion sub-index* score exceeded the number of reaches within every SWMA assessed in 2008 and 2009.

Table 64 Power analysis results for the erosion sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River	14	898	226	11	96
Busselton Coast	12	78	21	11	28
Preston River	3	32	9	3	42
Denmark River	11	169	43	10	46
Shannon River	11	87	23	7	37
Collie River	20	107	28	11	33
Albany Coast	95	196	50	24	29
Moore-Hill Rivers	68	356	90	16	28

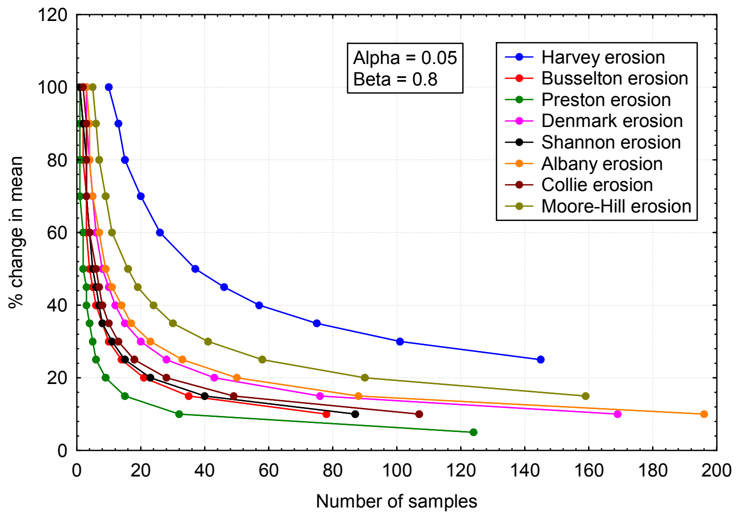

Figure 96 Power analysis results for the erosion sub-index (2008 and 2009 SWMAs)

Fringing Zone index

Extent of fringing zone sub-index

As this sub-index was calculated for all reaches a power analysis was not conducted.

Nativeness sub-index

Power analysis requires that all reaches be assessed to represent the population.

Table 65 Power analysis results for the nativeness sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River	14	1736	435	11	> 100
Busselton Coast	12	2159	541	11	> 100
Preston River	3	100	26	3	76
Denmark River	11	290	74	10	55
Shannon River	11	46	13	7	27
Collie River	20	767	793	12	79
Albany Coast	95	1832	429	25	85
Moore-Hill Rivers	68	428	108	18	50

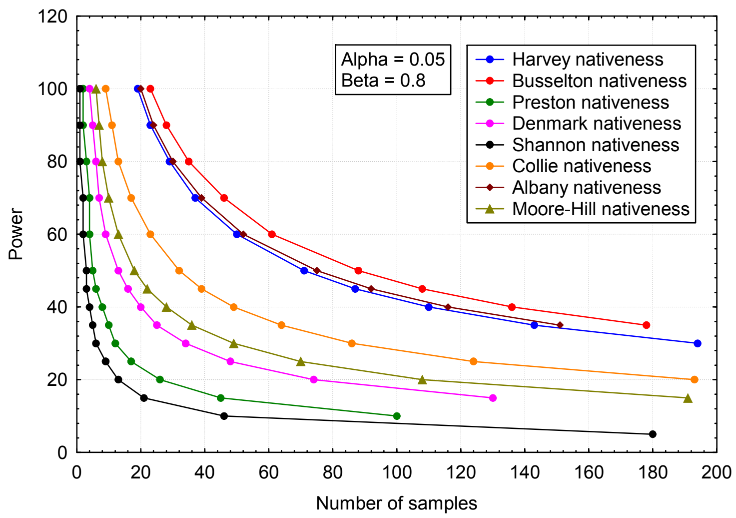

Figure 97 Power analysis results for the nativeness sub-index (2008 and 2009 SWMAs)

Aquatic Biota index

Fish and crayfish sub-index

Power analysis suggests that anywhere between 3 and 56 sites are required depending on the SWMA being assessed. This is not always possible because some SWMAs have only a few reaches and available resources can be limited. Therefore it is recommended that all reaches be assessed where possible (as this will ensure appropriate power is met and relevance to local management scales), but if time/funding is limited, sampling effort can be reduced in the less variable SWMAs (Collie River, Shannon River and Busselton Coast).

Table 66 Power analysis results for the fish and crayfish sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River	14	170	44	11	41
Busselton Coast	12	23	7	11	15
Preston River	3	38	11	3	43
Denmark River	11	34	10	10	19
Shannon River	11	10	3	7	12
Collie River	20	24	7	11	14
Albany Coast	95	218	56	24	32
Moore-Hill Rivers	68	33	9	16	16

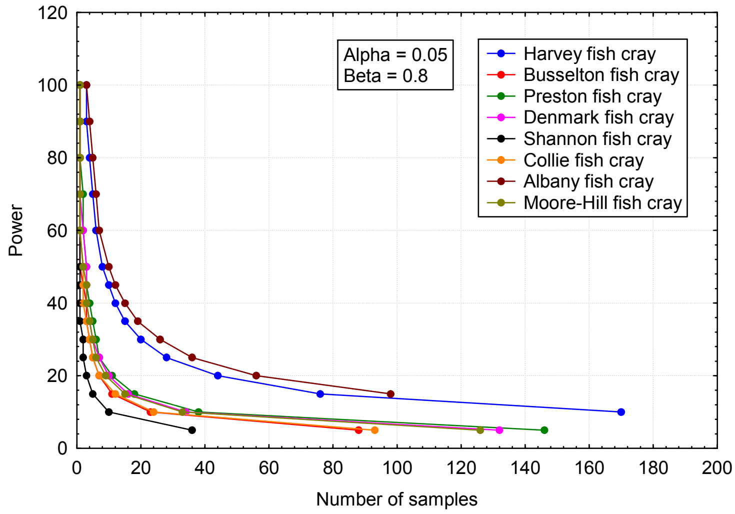

Figure 98 Power analysis results for fish and crayfish sub-index (2008 and 2009 SWMAs)

Macroinvertebrate sub-index

Only Albany Coast and Moore-Hill Rivers SWMAs have more valid reaches than are required to achieve adequate power to represent a 20% change in mean. In all other SWMAs assessed, sampling of all reaches is required. In some instances, such as Albany Coast SWMA, it may not be practical to sample the required number of reaches. However, improvement of scoring protocols may alleviate some ambiguity and thus reduce variability.

Table 67 Power analysis results for the macroinvertebrate (AUSRIVAS) sub-index (2008 and 2009 SWMAs)

SWMA	Number of valid reaches in SWMA	Number of samples to detect 10% Δ in mean	Number of samples to detect 20% Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Harvey River	14	227	58	11	51
Busselton Coast	12	146	38	11	38
Preston River	3	164	42	3	92
Denmark River	11	97	25	10	33
Shannon River	11	46	13	7	28
Collie River	20	88	23	9	38
Albany Coast	95	130	34	22	25
Moore-Hill Rivers	68	130	34	16	30

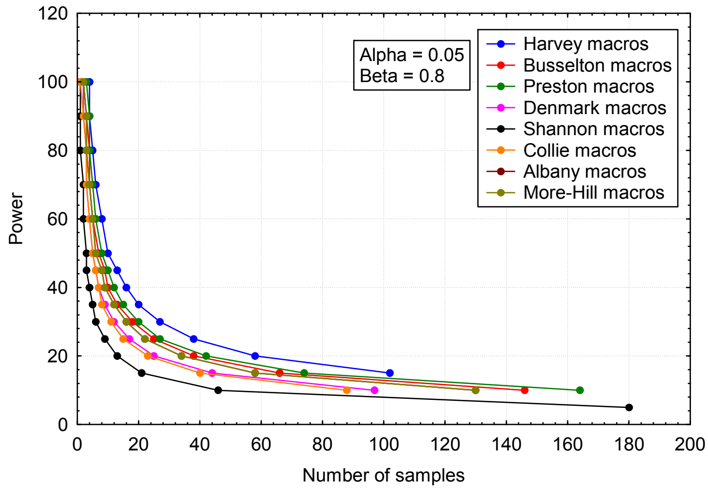

Figure 99 Power analysis results for the macroinvertebrate (AUSRIVAS) sub-index (2008 and 2009 SWMAs)

Appendix D Methodology for further work on farm dams for the *Hydrological Change index*

The following information details preliminary work on development of an additional indicator within the *Hydrological Change index* to account for the effect of farm dams. Three alternatives are suggested.

Farm dam density (FDD)

An additional indicator for the *Hydrological Change index* is being developed to include measurement of the impact of farm dams on hydrology. This indicator is based on storage volume within farm dams and the associated catchment area. Catchments with a high density of farm dams will therefore be more altered and the score will reflect this.

Required data

- Catchment area (km^2)
- Farm dam volume (ML)

Methodology

- Catchment area is calculated from GIS database Hydrographic catchments, and has already been calculated to compute the Flow Stress Ranking (FSR).
- Farm dam volumes are created using an equation based on the surface area of the farm dams (SKM 2008)

$$V = 0.0007 \times A^{1.0709}$$

Where V = storage capacity of a farm dam in ML and A = surface area of the farm dam in m^2

- The *farm dam density* value is the farm dam volume divided by the catchment area

Scoring

Values for *farm dam density* have been placed into the FARWH condition bands as per Table A below.

Table A Farm dam density values and corresponding condition bands

FARWH condition band	Farm dam density (ML/km^2)
Severely modified condition	> 25.0
Substantially modified condition	10.1–25.0
Moderately modified condition	10.0
Slightly modified condition	5.0
Largely unmodified condition	0.0

These condition bands were based on calculated values of *farm dam density* for eight catchments (SKM 2007a; SKM 2008) as well as their results when the FSR was applied to their corresponding pre-dam and post-dam timeseries (see Table B below). Rational for their inclusion follows:

- Severely modified: > 25 ML/km^2: Channybearup catchment has a *farm dam density* of 45.7 ML/km^2, which is the highest calculated thus far. In the farm dam investigation (Table B) this site scored in the 'substantially modified' condition for the *low flow component*, indicating the presence of farm dams is impacting on the magnitude of the low flow events.
- Substantially modified: 10.1–25 ML/km^2: Lefroy and Wilyabrup brooks have *farm dam density* values of 24.8 and 25.0 ML/km^2 respectively. These are the highest values calculated (with only Channybearup returning a higher value). In reference to the calculated *low flow component,* these sites scored as 'substantially modified' and 'moderately modified' respectively.
- Moderately modified: 5.1–10 ML/km^2: includes catchments of Cowaramup, Capel River and Chapman Brook.
- Slightly modified condition: 0–5 ML/km^2: Margaret River and Lower Collie scored within this band.
- Largely unmodified condition: 0 ML/km^2: only areas without farm dams will score within this category.

Table B Flow Stress Ranking (FSR) values for eight catchments (using pre-dam and post-dam time series)

Reach	LF	HF	PZ	CV	SP	FSR
Lower Collie	0.77	1.0	1.0	1.0	0.9	0.9
Capel River	0.54	0.9	1.0	0.9	0.9	0.9
Chapman Brook	1.00	1.0	1.0	1.0	1.0	1.0
Cowaramup Brook	0.92	1.0	0.7	0.9	0.7	0.8
Lefroy Brook	0.23	0.9	1.0	0.8	0.9	0.8
Margaret River	1.00	1.0	1.0	1.0	1.0	1.0
Wilyabrup Brook	0.46	0.9	1.0	0.9	1.0	0.9
Channybearup	0.38	0.9	1.0	0.8	0.8	0.8

LF = low flow component, HF = high flow component, PZ = proportion of zero flow component, CV = monthly variation component, SP = seasonal period component

<u>*Farm dam development (FDDev)*</u>

This potential indicator for the *Hydrological Change index* is an alternative for measuring the impact of farm dams on hydrology. It is based on the volume of mean annual flow compared with the storage volume within the dams.

Required data

- Historical mean annual flow (ML)
- Farm dam volume (ML)

Methodology

- Mean annual flow is created from the monthly flow timeseries which was required to create the FSR.
- Farm dam volumes are created using an equation based on the surface area of the farm dams (SKM 2008)

$$V = 0.0007 \times A^{1.0709}$$

Where V = storage capacity of a farm dam in ML and A = surface area of a the dam in m²

- The *farm dam development* value is the farm dam volume divided by the mean annual flow.

Scoring

Values for *farm dam development* have been placed into FARWH condition bands as per Table C.

Table C Farm dam development values and corresponding condition bands

FARWH condition band	Farm dam development (%)
Severely modified condition	> 20
Substantially modified condition	10–20
Moderately modified condition	5–10
Slightly modified condition	0–5
Largely unmodified condition	0

These condition bands were based on calculated values of *farm dam development* for eight catchments (SKM 2007a; SKM 2008) as well as their results when applied to the FSR (see Table B). Rational for their inclusion follows:

- Severely modified: > 20%: Channybearup catchment has a *farm dam development* value of 30.3%, which is the highest calculated thus far. In the farm dam investigation (Table D) this site scored within the 'substantially modified' band for the *low flow component,* indicating the presence of farm dams is impacting on the magnitude of the low flow events.

- Substantially modified: 10–20%: Lefroy Brook catchment has a *farm dam development* value of 16.5%. In the farm dam investigation (Table B) this site scored within the 'substantially modified' band for the *low flow component,* indicating the presence of farm dams is impacting on the magnitude of the low flow events.
- Moderately modified: 5–10%: the catchments of Cowaramup, Capel and Wilyabrup score within this category. In the farm dam investigation, Capel and Wilyabrup scored within the 'moderately modified' band for the *low flow component* while Cowaramup scored within the 'slightly modified' band for the *proportion of zero flow component* and the *seasonal period component*, indicating that farm dams are having an influence on seasonality.
- Slightly modified condition: 0–5%: Margaret River, Lower Collie and Chapman Brook all scored within this category. In the farm dam investigation they all scored within the 'largely unmodified' band for each of the categories, however the fact that dams are present have put them in this category.
- Largely unmodified condition: 0%: the presence of a farm dam will have some impact on hydrology, and therefore only if the *farm dam development* value is calculated to be 0 can it fall into this category. Areas without farm dams will fall into this category.

Table D Flow Stress Ranking (FSR) values for eight catchments (using pre-dam and post-dam timeseries)

Reach	LF	HF	PZ	CV	SP	FSR
Lower Collie	0.77	1.0	1.0	1.0	0.9	0.9
Capel River	0.54	0.9	1.0	0.9	0.9	0.9
Chapman Brook	1.00	1.0	1.0	1.0	1.0	1.0
Cowaramup Brook	0.92	1.0	0.7	0.9	0.7	0.8
Lefroy Brook	0.23	0.9	1.0	0.8	0.9	0.8
Margaret River	1.00	1.0	1.0	1.0	1.0	1.0
Wilyabrup Brook	0.46	0.9	1.0	0.9	1.0	0.9
Channybearup	0.38	0.9	1.0	0.8	0.8	0.8

LF = low flow component, HF = high flow component, PZ = proportion of zero flow component, CV = monthly variation component, SP = seasonal period component

Farm dam flow change

This indicator is designed to account for the seasonal variations caused by farm dams.

Required data

- Current flow timeseries
- Farm dam density (ML/km^2)
    - farm dam volume
    - catchment area (km^2)

Methodology

Option A

- Using the following curve (SKM 2007a; SKM 2008), scale monthly flow from the 'current dataset' used in FARWH FSR calculations.

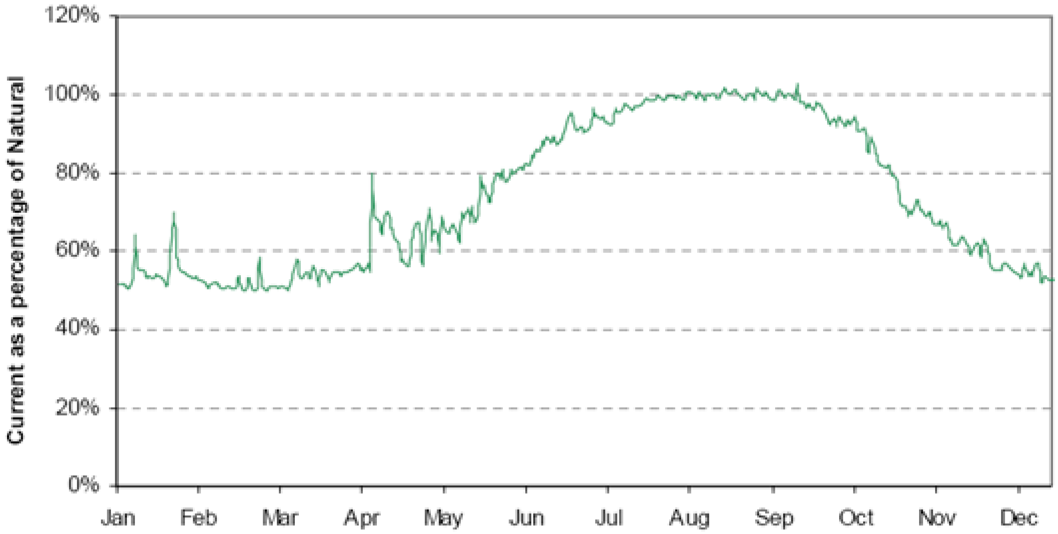

Figure A Difference in average daily flow due to farm dams (expressed as a percentage of natural flow) for the Capel River (SKM 2007a)

- Run the timeseries through Forest Cover Flow Change (FCFC), then re-calculate the FSR.

Option B

1 Start with 'unimpacted' dataset and scale this dataset with the percent change

2 Re-calculate the FSR using data created in step above and 'current dataset'

Glossary of terms

FARWH-specific terms:

Theme (FARWH)	The FARWH identified six **themes** that represent the ecological integrity of the river system. They are Catchment Disturbance, Hydrological Change, Water Quality, Physical Form, Fringing Zone and Aquatic Biota.
Index (FARWH)	The suite of indicators and associated integration scoring protocol, within each FARWH theme; for example, the *Aquatic Biota index* incorporates indicators for fish health and macroinvertebrate health, and the method for integrating scores.
Sub-index (FARWH)	Referring to the indicators within each FARWH index, e.g. the *Fringing Zone index* has two sub-indices: *extent of fringing vegetation* and *nativeness*.
Component (FARWH)	Indicators contributing to a sub-index (see above).
Indicator or measure	Something used to gauge another thing; for example, sedimentation is an indicator of erosion. Used interchangeably within scoring hierarchy above.

General terms

Ephemeral	Only filled [flows] after unpredictable rainfall and runoff. Surface water dries within days of filling [flowing] and seldom supports macroscopic aquatic life (adapted from Boulton & Brock 1999 by AETG).
Episodic	Annual inflow [flow] is less than the minimum annual loss of 90% of years. Dry most of the time with rare and very irregular wet phases and may persist for months (adapted from Boulton & Brock 1999 by AETG).
Intermittent	Alternately wet and dry every year but less frequently and regularly than seasonal wetlands [systems]. Surface water persists for months to years (adapted from Boulton & Brock 1999 by AETG).
Seasonal	Alternately wet and dry every year, according to season. Usually fills [flows] during the wet part of the year and dries predictably and annually. Surface water persists for months, long enough for some macroscopic plants and animals to complete the aquatic stages of their lifecycles (adapted from Boulton & Brock 1999 by AETG).
Permanent or	Predictably filled [flows] although water levels may vary. Annual inflow

near-permanent (perennial)	> minimum annual loss in 90% of years. During extreme droughts, these wetlands [systems] may dry. Much of their aquatic biota cannot tolerate desiccation (adapted from Boulton & Brock 1999 by AETG).
Diadromous	Describes the horizontal migration of fish between fresh and salt water.
Catadromous	Describes a sub-set of diadromous fish which specifically live mostly in fresh waters but breed in oceanic waters.
Anadromous	Describes a sub-set of diadromous fish which predominantly live in the ocean, but breed in fresh waters.
Potadromous	Describes the migration of fish entirely within freshwater systems.
Euclidean Distance	The distance as measured in Euclidean space; that is, as one would with a ruler. In the FARWH it is used to measure how different a reach is from the reference condition using information from the measures comprising of an index or sub-index (NWC 2007a).

Shortened forms

ABI	Aquatic Biota index
ACSI	Artificial channel sub-index
AETG	Aquatic Ecosystem Task Group
ALCC	Agricultural Land Cover Change
ALUM	Australian Land Use Management classification
ANAE	Australian National Aquatic Ecosystem
ANZECC	Australian and New Zealand Environment and Conservation Council
ARL	Aquatic Research Laboratory (University of Western Australia)
ARC	Australian Assessment of River Condition
ASWMA	Australian Surface Water Management Areas
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AUSRIVAS	Australian River Assessment System
AWR	Australian Water Resources
AWRIS	Australian Water Resources Information System
BPJ	Best professional judgement
BRS	Bureau of Rural Sciences
BS	Bank stabilisation
CRCCH	Cooperative Research Centre for Catchment Hydrology
CDI	Catchment Disturbance index
CENRM	Centre of Excellence for Natural Resource Management
CFEV	Conservation of Freshwater Ecosystem Values program
CHEAT	Complete Hydrological Evaluation of the Assumptions in TEDI (Tool for Estimating Farm Dam Impacts)
CRD	Completely randomised design
CV	Monthly variation (coefficient of variation of monthly flows between current and unimpacted conditions)
DAFWA	Department of Agriculture and Food Western Australia
DEC	Department of Environment and Conservation, Western Australia
DEM	Digital Elevation Model
DEWHA	Department of the Environment, Water, Heritage and the Arts
DO	Dissolved oxygen

DoW	Department of Water
DPIPWE	Department of Primary Industries, Parks, Water and Environment
EE	Erosion extent
EFZ	Extent of fringing zone sub-index
EHMP	South East Queensland's Environmental Health Monitoring Program
EMAP	Environmental Monitoring Assessment Program (US EPA)
EPA	Environmental Protection Authority
EPT	Macroinvertebrate orders Ephemeroptera, Plecoptera and Trichoptera
ESI	Erosion sub-index
EVC	Ecological Vegetation Class
EXP	Expectedness (component of fish/crayfish sub-index)
FARWH	Framework for the Assessment of River and Wetland Health
FCFC	Forest Cover Flow Change
FCSI	Fish/crayfish sub-index
FIFA	Fertiliser Industry Federation of Australia
FSR	Flow stress ranking
FVL	Fringing vegetation length
FVW	Fringing vegetation width
FZI	Fringing Zone index
GA	Geoscience Australia
GIS	Geographical information system
GPP	Gross primary production
GS	Gauging station
HCI	Hydrological Change index
HF	High flow
HYDSYS	A PC-based hydrologic data package, widely used throughout the water industry in Australia
ISC	Victorian Index of Stream Condition
ISI	Infrastructure sub-index
LCCSI	Land cover change sub-index
LUSI	Land use sub-index
LCSI	Longitudinal connectivity sub-index
LF	Low flow

LIDAR	Light Detection and Ranging data
MSI	Macroinvertebrate sub-index
MjD	Major dam
MnD	Minor dam
NAT_{FC}	Nativeness (component of fish-crayfish sub-index)
NAT_{FZ}	Nativeness (component of fringing zone sub-index)
NATA	National Association of Testing Authorities
NATMAP	National topographic map series 1:250 000 scale
NDVI	Normalised Difference Vegetation Index
NLWRA	National Land and Water Resources Audit
NLWRA I	National Land and Water Resource Audit mark I
NNRMM&EF	Natural Resource Management Ministerial Council, Natural Resource Management Monitoring and Evaluation Framework
NMI	National Measurement Institute
NOAA	National Oceanic and Atmospheric Administration
NRM	Natural resource management
NSW	New South Wales, Australia
NVIS	National Vegetation Information System
NWC	National Water Commission
NWI	National Water Initiative
O/E	Observed/expected ratio
O/P	Observed/predicted ratio
P_{Ab}	Proportion native abundance
P_{Sp}	Proportion native species
PFI	Physical Form index
P/R	Photosynthesis/respiration ratio
PZ	Proportion of zero flow
QA/QC	Quality assurance/quality control
RBD	Randomised block design
RHP	River Health Program (South Africa)
RHAS	River Health Assessment Scheme
RHCG	River Health Contact Group
RIVPACS	River Invertebrate Prediction and Classification System

RNWS	Raising National Water Standards program
RPH	River Health Program (South Africa)
RRC	Roads/rail crossings
SCDB	Spatial cadastral database
SCNRM	South Coast Natural Resource Management
SEAP	Stream and Estuarine Assessment Program
SedNet	Sediment Network modelling software
SILO	A Bureau of Meteorology web service aimed specifically at agricultural areas
SKM	Sinclair Knight Mertz consultants
SP	Seasonal period
SRA	Sustainable Rivers Audit
SWIRC	South-West Index of River Condition
SWMA	Surface water management area
SWWA	South-west Western Australia
TASVEG	Tasmanian Vegetation Mapping program
TRaCK	Tropical Rivers and Coastal Knowledge
TN	Total nitrogen
TP	Total phosphorous
TPS	Manufacturer (brand) of dissolved oxygen and temperature meters used for SWWA-FARWH trials
TRCI	Tasmanian River Condition Index
WA	Western Australia
WFD	Water Framework Directive (European Union)
WIN	Department of Water's Water Information Network
WRC	(former) Water and Rivers Commission
WQI	Water Quality index

Data sources

The Department of Water has produced the maps in this publication with the intent that they be used in this report only. While the department has made all reasonable efforts to ensure the accuracy of these data, it accepts no responsibilities for any inaccuracies, and persons relying on them do so at their own risk.

The department acknowledges the following datasets and their custodians in the analysis of data and the production of the maps. Please contact the relevant custodian for further details about the data. For data produced during the SWWA-FARWH project, including scores and spatial datasets, please contact Tim Storer, Water Science Branch, Department of Water.

Table 68 Data reviewed within the south-west FARWH trials

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
SWMA and study area				
Australian Surface Water Management Areas (ASWMA) 2000	Geoscience Australia (GA)	2000	1999–2000	Vector dataset, boundaries of SWMA across Australia. Used as unit for reporting scores and for illustration (maps).
Natural Resource Management (NRM) Region Boundaries	Department of Water Heritage and Arts (DEWHA)	2006	2005	Vector dataset, NRM regions for Natural Heritage Trust (NHT2) / National Action Plan for Salinity and Water Quality (NAP) programs for WA. Used to define project boundary and for illustration (maps).
Reaches				
Australia – Assessment of River Condition (Reach) 2001 (known as ARC reaches)	DEWHA	2008	2001	Vector dataset, created for the NLWRA. Reaches were defined using a 9-second DEM. Used as unit for reporting scores, and for illustration (maps).
Reconstructed Reaches	Department of Water (DoW) Water Science Branch	Unpublished, contact Water Science Branch	2009	Vector dataset, created during the SWWA-FARWH project. Produced by selecting features from 1:250 000 topographic mapping datasets which corresponded to ARC reaches. Used for GIS analysis to calculate *extent of fringing zone sub-indicator* for FZI and *artificial channel sub-indicator* for PFI in place of ARC reaches.

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
Watercourses and catchments				
Hydrography Linear	DoW	2006	Unknown – 2004	Vector data derived from topographic mapping at between 1:25 000 and 1:100 000 scale. Investigated as a source of data for farm dams, however coarse-scale topographic mapping does not represent these features accurately enough for analysis purposes. Investigated as a source of data for *artificial channel sub-indicator* for PFI, however inconsistencies were noted in the distribution of these features. Used to identify locations of dams and diversions for the HCI.
Hydrography Linear Hierarchy (also known as 'Rivers')	DoW	2007	1995–2007	Vector data derived from topographic mapping at between 1:25 000 and 1:100 000 scale. Mapped streamlines with attributes for hierarchy (main stream, tributary etc.) Used to identify estuarine portions of reaches for reach validation, and used as a secondary data source for hydrological validation of reaches.
Hydrography theme (watercourse lines, canal lines, lakes, reservoirs) from GEODATA TOPO 250K Series 3	GA	2006	2001–2006	Vector dataset, national topographic mapping at 1:250 000 scale. Used to calculate *artificial channel sub-indicator* scores for PFI. Used to note presence of waterbodies during reach validation process.

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
AusHydro v1.0	GA / Bureau of Meteorology (BoM)	Draft metadata 2009, final metadata due May 2010	Unknown	Vector datasets, seamless surface hydrography data for Australia. Broadly based on data from GEODATA TOPO 250K Series 3 with additional data added. Beta version investigated for use to generate Reconstructed Reaches, however data was embargoed until final version was released.
Hydrographic Subcatchments	DoW	2007	1993–2007	Vector dataset, catchment boundaries defined based on topography. Used to calculate catchment areas for HCI.
Sustainable Diversion Limits (SDL) catchments	DoW / Sinclair Knight Merz (SKM)	2008	n/a	Spatial dataset created for SDL study (SKM). Used to determine which indicator gauges to use in ungauged areas.
Subcatch reach geog	University of Canberra	No metadata	Unknown	Vector dataset, catchments generated for reaches from a 9-second DEM (see ARC reaches). Used for GIS analysis of disturbance datasets to calculate CDI scores.
Farm Dams	DoW	2008	2006–2008	Vector dataset, detailed mapping of farm dams from aerial photos and satellite interpretation. Investigated for use in HCI and PFI but coverage was limited to small portion of study area.
Hydrology and climate				
SILO patched point data (rainfall and evaporation)	BoM/ Queensland Government	Not applicable (non-spatial data)	1991–2008	Rainfall and evaporation daily time series. Input for FCFC which was used to create reference condition for HCI.

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
Flow data	DoW / Water Corporation (WC)	Not applicable (non-spatial data)	1991–2008	Daily time series data extracted from Department of Water's internal database or sourced from Water Corporation. Used for current condition and for input to FCFC to create reference condition for HCI.
Mean Annual Rainfall Surface (1975–2003) – Southwest WA	DoW	2005	1975–2003	Vector dataset, rainfall surface based on the mean annual rainfall for the standard 28 year period 1975-2003. Used to calculate mean annual rainfall and mean annual discharge for sites for macroinvertebrate model.
Mean Annual Rainfall Data (Base Climatological Data Sets)	BOM	1999	1961 - 1990	Vector dataset, mean annual rainfall grid based on the standard 30-year period 1961-1990. Used for site selection and illustration (maps).
Geology and topography				
Atlas of Mineral Deposits and Petroleum Fields 1999 (1:2 500 000)	Department of Mines and Petroleum (DMP)	1999	1999	Vector dataset, geology and tectonic boundaries mapped at 1:2 500 000 scale. Used for site selection and illustration (maps).
Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) (3 arc-second)	National Aeronautics and Space Administration (NASA)	No date	2000	Raster dataset, digital elevation model constructed at 3 arc-second (approx. 90 m) resolution from shuttle-based radar. Used for site selection and illustration (maps).
Land use				
Land Use of Australia Version 3 2001/02	Bureau of Rural Sciences (BRS)	2006	2001–2002	Raster dataset, 0.01 degree pixels (approx. 1 km), map of land use across Australia, based on satellite interpretation (for agricultural areas) and existing digital maps (non-agricultural areas). Investigated as an indicator for *land use sub-indicator* for CDI, however the resolution was too coarse to accurately reflect land use in the SWMAs.

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
NLWRA Land Use	Department of Agriculture WA (DAFWA)	2001	1996–2001	Vector dataset, land use of cadastral parcels, based on field officer knowledge and aerial photograph interpretation. Used to calculate *land use sub-indicator* for CDI, and for illustration (maps).
Infrastructure				
CALM Operational Graphic Trails	Department of Environment and Conservation (DEC)	2005	1990–2005	Vector dataset, delineates location of tracks, based on mapping from 1:25 000 scale aerial photographs. Used to calculate *infrastructure sub-indicator* scores for CDI.
Railways – WA State	Landgate	2000	2000	Vector dataset, delineates location of railway lines, based on topographic mapping at 1:25 000 scale. Used to calculate *infrastructure sub-indicator* scores for CDI.
Road Centrelines DLI	Landgate	2008	1968–2008	Vector dataset, delineates roads between 1:25 000 and 1:100 000 scale. Used to calculate *infrastructure sub-indicator* scores for CDI.
WA Petroleum Pipelines	DMP	2005	1989–2008	Vector dataset, delineates petroleum pipelines. Used to calculate *infrastructure sub-indicator* scores for CDI.
Spatial Cadastral Database	Landgate	2001	1982–2009	Database of cadastral boundaries for WA. Investigated as a source of data for infrastructure, however the database does not represent all infrastructure types.

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
Fish Barriers Database	DoW, Water Science Branch	Unpublished, contact Water Science Branch	2009	Vector dataset, geodatabase of structures in WA which have potential to prevent movement of fish/crayfish, compiled from a number of different spatial datasets. To date limited ground-truthing of structures has been completed, however this is the only available source of data on barriers. Used to calculate *longitudinal connectivity sub-indicator* scores for PFI.
Wild Rivers Impoundments layer	Australian National University (ANU)	Unable to locate data or metadata	Unknown	Raster image showing presence/absence of dams and locks at 250 m resolution. Unable to locate data, evaluation based on description in NWC 2007b.
Wild Rivers Levees layer	ANU	Unable to locate data or metadata	Unknown	Raster image showing presence/absence of levees at 250 m resolution. Unable to locate data, evaluation based on description in NWC 2007b.
Water Information Network (WIN) sites	DOW	2006	1901 – present	Vector dataset, points where surface water and groundwater data has been collected. Used for site selection, illustration (maps) and to verify data for the WQI.
Vegetation				
Land Monitor Vegetation Change Products: Vegetation extent files for relevant years: Lm50_south_VegMask_200x_mga, and Lm50_nwest_VegMask_200x_mga	Landgate on behalf of the Land Monitor II project	2009	Annual snapshot datasets	Raster dataset, 25 m pixels, maps of extent of perennial vegetation produced from interpretation of satellite data. Used to calculate *extent of fringing zone* scores for FZI, and *land cover change* scores for CDI.

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
Vegetation – Pre-European Settlement (1788)	GA	2003	1780s	Vector dataset, vegetation complexes reconstructed for the 1780s, including growth form of the tallest and lower stratum, foliage cover of tallest stratum and dominant floristic type. Investigated for deriving reference condition for vegetation structure for the FZI, however the dataset did not provide sufficient information regarding percentage cover of each layer to define reference.
Australia – Estimated Pre-1750 Major Vegetation Groups – NVIS Stage 1, Version 3.0	DEWHA	2007	Pre-1750	Vector dataset, map of major vegetation groups reconstructed for pre-1750s. Investigated for deriving reference condition for vegetation structure for the FZI, however the dataset does not provide relevant data.
Pre-European Vegetation	DAFWA	2002		Vector dataset, map of vegetation complexes reconstructed for pre-1750s. Investigated for deriving reference condition for vegetation structure for the FZI, however the dataset does not provide relevant data.
Native vegetation current extent – WA	DAFWA	2009	1996–2009	Vector dataset,1:10 000 to 1:20 000 scale, map of remnant vegetation in WA. Used for calculation of area of catchment cleared for HCI.
Agricultural land cover change 1990 –1995	BRS	2000	1990–1995	Raster dataset, 250 m pixels, increase/decreased in woody vegetation. Investigated for calculation of *land cover change indicator* for CDI, however the dataset is less current and more coarse than data available from the Land Monitor II project.

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
National Oceanographic and Atmospheric Administration (NOAA) Fire Affected Areas 2003, 2004, 2005, 2006 and 2007	Landgate (original data from NOAA satellite)	2007	Annual datasets	Raster datasets, 1 km pixels, maps of fire-affected areas created from satellite interpretation. Investigated for use within the *land cover change indicator* for CDI.
Water quality				
Stream salinity status	DoW	No metadata available	1985–2002	Vector dataset, modelled salinity status of rivers in south-west WA. Used to calculate *salinity sub-indicator* scores for WQI.
Water Information Network (WIN)	DoW	Not applicable (non-spatial data)	Approx. 1960 to present	Database of water quality data collected by Department of Water and other agencies. Used to calculate *total nitrogen, total phosphorus* and *turbidity* scores for WQI.
Biota				
Freshwater fish database	Department of Fisheries (DoF)	Not applicable (non-spatial data).	1677 to present	Database of locations of known occurrence of freshwater fish and crayfish species based on literature. Used to define reference condition for *fish/crayfish indicator* for ABI.
Ecological Values of Waterways in the South Coast Region, WA	Centre for Excellence in National Resource Management (CENRM) (for DoW)	Not applicable (non-spatial data).	2006–2007	Spreadsheet of results from ecological values study (see Cook et al. 2008). Used to define reference condition for *fish/crayfish indicator* for ABI.
Threatened Fauna Database	DEC	No metadata supplied	Unknown	Vector dataset of indicative locations of threatened fauna, drawn from the Threatened Fauna Database. Used to define reference condition for *fish/crayfish indicator* for ABI.

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
Expected distribution of freshwater fish and crayfish in SWWA.	DoW, Water Science Branch	Unpublished, contact Water Science Branch	1988–present	Spreadsheet of location of known occurrence of freshwater fish species based on Department of Water sampling (RHAS and SWWA-FARWH projects) and a literature review, created as part of this project. Used to define reference condition for *fish/crayfish indicator* for ABI.
Australia, Interim Biogeographic Regionalisation for Australia (IBRA), Version 5.1	Environment Australia (EA)	2000	1995 – 2000	Vector dataset, delineates regions based on major environmental influences which shape the occurrence of flora and fauna and their interaction with the physical environment. Used for illustration (maps).
Contextual data				
Australian Coastline, WRC	DoW	2006	Unknown	Vector dataset, coastline of Australia derived from topographic mapping. Used for illustration (maps).
Western Australia Towns	Landgate	No date	1987–2001	Vector dataset, location of towns extracted from the GONOMA database. Used for illustration (maps).
Wild Rivers	DoW	2006	1995–2002	Vector dataset, delineates catchments which were assessed as being undisturbed and therefore of very high environmental value. Used to identify catchments for scenario testing for HCI.
Bunbury 2031 Mar 2006 Mosaic	Landgate	2009	2006	Raster dataset, aerial photograph of Bunbury area at 50 cm resolution. Used for illustration (maps).

The maps have been provided using the following data and projection information:

- Vertical Datum: AHD (Australian Height Datum)
- Horizontal Datum: GDA 94 (Geocentric Datum of Australia 1994)
- Projection System: Map Grid of Australia (MGA) 1994 Zone 50

Original ArcMap documents (*.mxd):

- J:\gisprojects\Project\B_Series\B5047\007b_Final_Report\mxds\

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