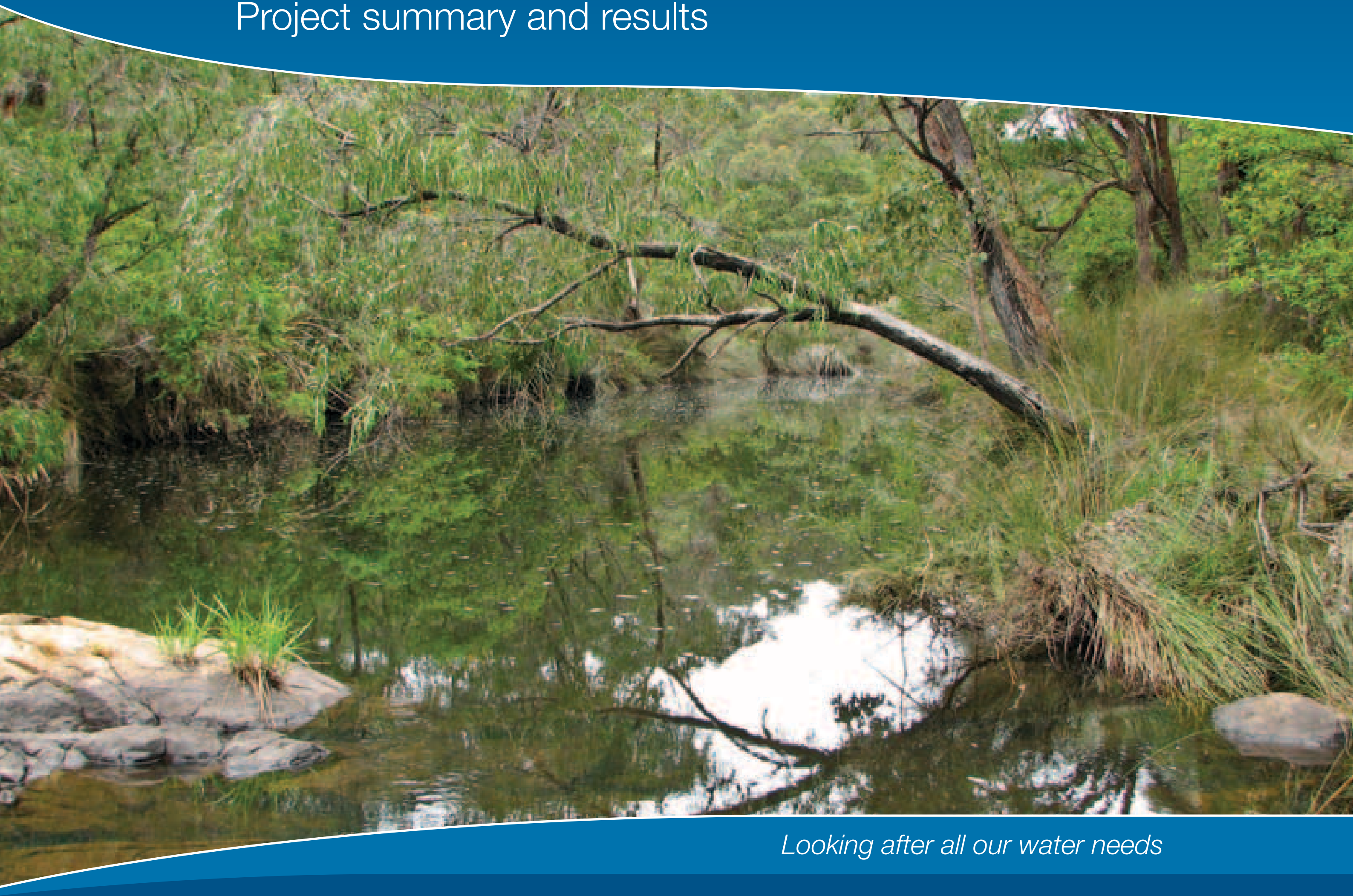
Government of **Western Australia**
Department of **Water**

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

Project summary and results



Looking after all our water needs

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Disclaimer

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Summary

The Framework for the Assessment of River and Wetland Health (FARWH) is a National Water Commission initiative designed to provide an Australia-wide baseline of river health to assess progress against the National Water Initiative's objectives. The south-west Western Australia (SWWA) FARWH project was funded through the Raising National Water Standards program.

The FARWH was developed to provide a standard approach for reporting the health of rivers and wetlands nationally, enabling locally relevant and comprehensive assessments yet being comparable across jurisdictions. To meet this objective, the FARWH was designed with sufficient flexibility to incorporate data from established state and territory river health programs, while providing guidance around methods and indicators where data did not exist.

The information provided in this (Storer et al. in press a) and the associated technical report (Storer et al. in press b) evaluates the relevance and applicability of the FARWH to flowing rivers in SWWA. Ephemeral rivers and wetlands were outside the scope and capabilities of this assessment.

Rivers in SWWA are under increasing pressure from a range of factors, including land use change, altered aquatic habitat, competition from exotic species, changes to flow regime, pollution and a changing climate. Appropriate river management requires that the direct and indirect impacts of these factors, both in the short and long term, are understood and quantified, with regional and system-specific conditions also being considered. The FARWH was evaluated for its ability to represent these broad impacts at a national scale.

The development of river health assessment methods for SWWA was particularly challenging because no statewide multi-parameter assessment programs existed, and thus data across the region was critically limited. This limitation was identified in an initial attempt to create a baseline assessment of river health in 2005 (the Australian Water Resources (AWR) 2005) and was the major driver for developing a national assessment framework.

This report discusses trials conducted between 2008 and 2010 to evaluate the FARWH for application to SWWA, and provides a baseline assessment of river health and the required integrated assessment protocol to achieve this. Two field trials and an extensive desktop analysis were conducted as part of this process, addressing the data limitations discussed above. The supplementary technical report (Storer et al. in press b) outlines the indicator development and validation process in more detail.

The SWWA-FARWH trials resulted in development of indicators representing critical elements within the six ecological themes of river health: Catchment Disturbance, Physical Form, Fringing Zone, Hydrological Change, Water Quality and Aquatic Biota. Indicators were shown to reflect health status and helped increase the resource knowledge and scientific understanding of the ecology of SWWA aquatic

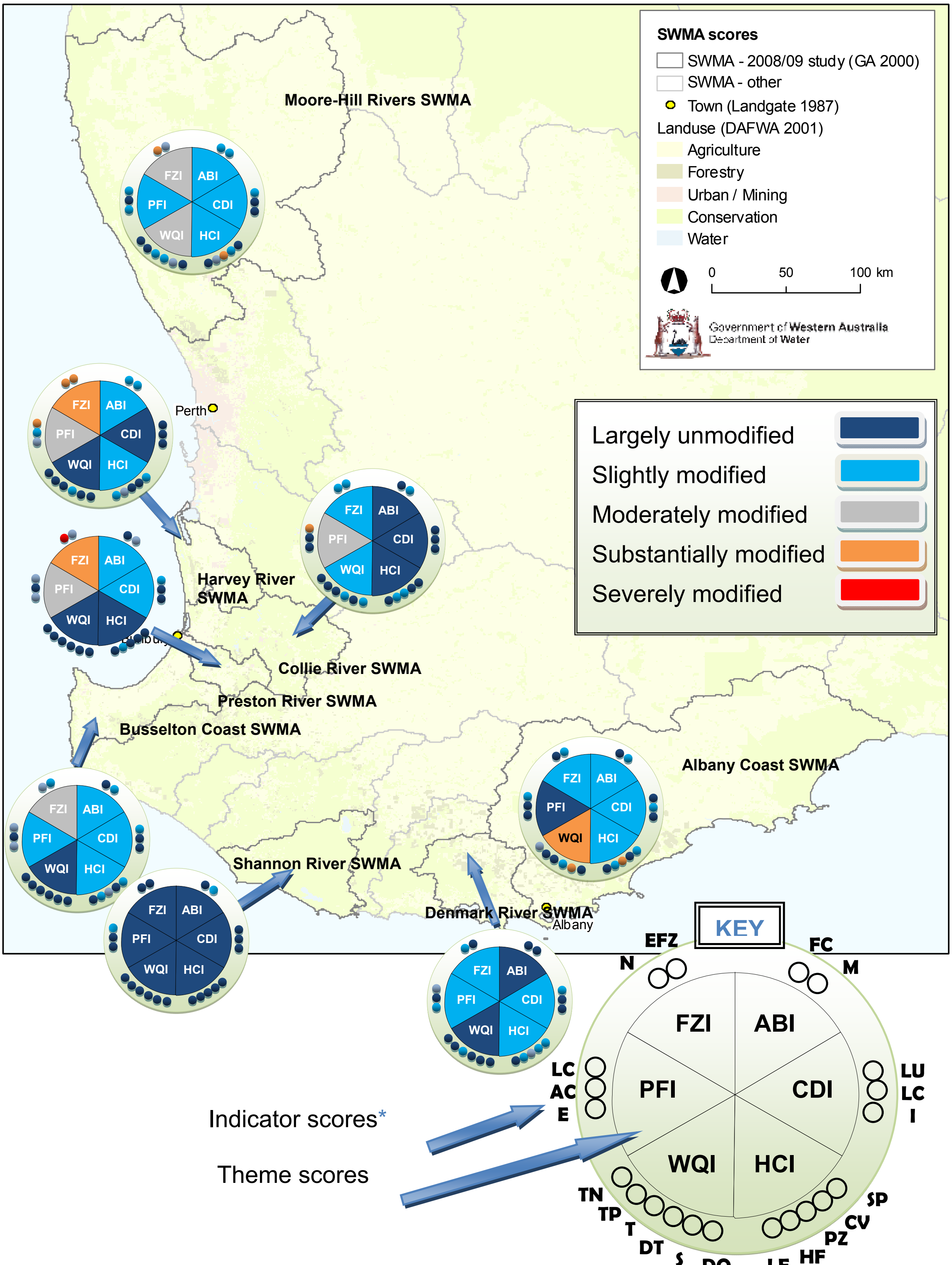
systems. Indices were selected to represent riverine health and condition while taking into account practicalities including the need for rapid broad-scale assessment, easily repeatable methods and non-prohibitive costs.

The fundamental aspects of the FARWH, in respect to maintaining comparability across regions, are endorsed through results of the SWWA-FARWH trials. These aspects include range standardisation, linearisation, integration and aggregation, reference condition, missing data, condition bands and sensitivity analysis.

For national reporting, the surface water management area (SWMA) scores calculated for SWWA through the FARWH trials are a reasonable representation of health where theme scores are reported. Reporting at theme level maintains the ability to readily interrogate data; for example, distinguish between pressures (e.g. status of catchment disturbance) and response (e.g. health of aquatic fauna). However, if a single health score for each SWMA is required in future, we recommend a precautionary approach for integration; that is, the lowest theme score for each SWMA is used as the overall SWMA score for river health. Note: this is intentionally conservative to maximise transparency while methods are being trialled.

The figure on the following page displays the SWMA-scale theme scores for river health generated by the SWWA-FARWH trials. From this, a number of general remarks on the state of SWWA's rivers can be made. For example, Water Quality is reduced in the Albany Coast SWMA (primarily due to salinisation in the SWMA's eastern half); Fringing Zone vegetation is modified in the south-west corner – substantially in the SWMAs of the Harvey and Preston rivers and to a lesser extent in those of the Collie River, Moore-Hill Rivers and Busselton Coast (correlating with high-intensity agriculture); and Physical Form is moderately modified in the Harvey, Preston and Collie SWMAs (due to modification of streams for drainage). The scores produced through the SWWA-FARWH trials align with our broad understanding of SWWA conditions. However, as should be apparent, combining these theme scores would result in a near total loss of variability. The table below shows river health scores by SWMA (integrated theme scores) in which little differentiation is shown; as such this approach is not recommended.

Harvey River SWMA	Preston River SWMA	Busselton Coast SWMA	Shannon River SWMA	Denmark River SWMA	Moore-Hill Rivers SWMA	Albany Coast SWMA	Collie River SWMA
0.6	0.6	0.7	0.9	0.7	0.6	0.6	0.7



* **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).

One of the key recommendations from the FARWH trials is that SWMA delineation be recalculated for SWWA to align more closely with environmental variability, and preferably method-standardised across Australia. SWMA delineation is based on river basins, with each state splitting their basins into SWMAs based on different factors including local government boundaries, prescribed groundwater abstraction areas, allocation and management plan areas, and regulation areas (Geoscience Australia 2004). Consequently SWMAs range from 3 km^2 to 495 000 km^2. This suggests potentially high variability in the accuracy of any scores designed to represent river health in an entire SWMA (given 'reasonable' sampling effort). Further, SWMAs in SWWA have been shown to cross significant boundaries of altitude (on a SWWA scale) and climate, and contain complete scales of impact; for example, completely vegetated through to completely cleared. As such, integration of scores will inherently desensitise any results. Appropriate modification to the SWMA boundaries and thus the reporting scale at which the FARWH operates may make generation of a single river health score (integration of scores) more relevant.

The SWWA-FARWH program and associated development of the South-West Index of River Condition (SWIRC) have greatly improved the capacity of resource managers in SWWA. They are now in a better position to provide:

- an understanding of the nature of SWWA river systems
- information about the condition of SWWA river systems
- a baseline or reference condition from which changes can be monitored
- an assessment tool for evaluating natural resource management activities
- monitoring of impacts of human activity
- prioritisation for investment based on the above
- strategic direction for future management.

However, building on the advances made through the SWWA-FARWH trials will require significant investment into the future to ensure the momentum is not lost and the capacity to conduct assessments is maintained.

The FARWH is endorsed as an effective method for undertaking a national-level assessment, and is only limited in SWWA by state deficiencies in underpinning data. Recommended specific refinements to the SWWA-FARWH protocol are detailed in Section 8.

1 Introduction

This report reviews trials to evaluate the national Framework for the Assessment of River and Wetland Health (FARWH, or the framework) in a selection of flowing rivers of south-west Western Australia (SWWA) [see Summary Box 1]. A more detailed description of indicator selection, development and assessment is available in Storer et al. (in press b).

The underlying purpose of this work 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 (see Section 3.1), a significant data-gathering phase (field and desktop) was required, including the development of river health 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 varied ecology and logistical constraints, see explanation in Section 4.2) were assessed for the 2005 baseline-year review (using available data and protocols developed through the trials).

Summary Box 1

Neither wetlands nor dry systems (at the time of assessment) were included in trials conducted in SWWA as these were outside the scope and capabilities of the SWWA-FARWH project. As such, the South-West Index of River Condition (SWIRC), which was developed to provide data to feed into the FARWH, only covers the river aspects of the framework.

1.1 Defining river health

Defining river health follows the same principles as those applied to human health, in that we are concerned with the elements of system functionality, physical injuries, diseases, and the ability to withstand change.

The term *river health* relates to the river's ecological condition, encompassing the individual components (e.g. water quality and quantity, diversity of habitats, and water-dependent plant and animal species) and the relationship between each of these components (e.g. maintenance of ecological processes, and the interaction between species and their biotic and abiotic environment). The terms *health* and *condition* also need differentiation, as in many cases these terms are used interchangeably. Health is a function of the condition of its elements; as such, a healthy river could be in poor condition. For example, impacts from cattle (erosion, vegetation loss, nutrients) result in a localised poor condition, yet the river can be otherwise healthy.

An appropriate definition for river health is important because historically definitions have been tailored to the specific needs of particular water users – rather than overall health. For instance, drinking water providers focus on quality for meeting regulatory guidelines, whereas irrigators and industrial users are primarily concerned with quantity. To protect all river uses and values, we require broader definitions of river health.

Misconceptions about river health definitions can lead to contradictory conclusions after the review of data (when assessed by various groups) and can be attributed to differences in the understanding of and response to results. This is common even among scientists or water resource managers. For instance, a nutrient modeller may rank systems based on nutrient levels alone, whereas observations of all other parameters may reveal that a highly nitrified system is otherwise pristine (resilient, vigorous and displaying a natural level of biological integrity). Similarly, early ideas on river health proposed measures of vigour (such as metabolism). If these data are not treated appropriately there is a risk of scoring highly productive systems as healthy and naturally oligotrophic systems as unhealthy (Costanza 1992).

1.2 Water resources: values and threats

Rivers and streams are critical components of the ecosystem: they are conduits for the passage of water and associated contaminants to their receiving waterbodies, support complex and diverse aquatic communities (in-turn supporting fundamental ecosystem processes such as nutrient cycling) and in many cases drive the structure and function of surrounding terrestrial ecosystems. The protection of ecosystem integrity, including protection of all components, is paramount.

The importance of rivers is highlighted by the fact that urban centres and the most productive agricultural lands are almost all linked to rivers. In terms of the economy, not only does the intrinsic appeal of rivers drive the recreation and tourism sectors, but their health promotes the high quality water that underpins almost all of Australia's industries. The 'value of water' is apparent in everything from commercial fishing to water for homes (including drinking water), and light industry to agriculture (irrigation and stock watering). The direct return from these industries (e.g. revenue from fishing licences and water rates) in Western Australia is in the order of hundreds of millions of dollars. The return from all the state's water-dependent industries has been valued in excess of $30 billion, based on figures from a review of water resources for the Department of Industry, Tourism and Resources (ACIL Tasman 2007). The value of water hinges on both quantity and quality, which is a direct function of ecological health.

For all of these reasons protecting SWWA rivers is vital to the state, and given the dramatic changes they have undergone and their generally declining health over the past century, the urgency has never been greater. Specific impacts on the health, function and value of water assets in SWWA are:

- reduced water availability

- eutrophication
- algal blooms
- contaminated drinking water sources
- loss of biodiversity and riparian vegetation
- sedimentation
- acidification
- salinisation
- proliferation of weeds
- increased water temperature.

1.3 River health assessment strategies

Concern about the degradation of rivers and streams has prompted the introduction of various systems of assessment. River health status is often difficult to define, but can be considered in terms of the degree of similarity between a particular impacted river and an unimpacted river of a similar type. Levels of impact on a river can therefore be determined by comparing the water quality, biological and physical characteristics.

Traditional methods for assessing riverine condition have largely relied on sampling and monitoring of physico-chemical parameters (such as pH), which do not necessarily provide an easily interpretable picture of a waterbody's ecological condition. Rivers are dynamic systems made up of many different elements all operating together: each one is important and must be monitored and managed in conjunction with the others. More recent efforts have involved an integrated approach to assessing river health, whereby characteristics of a waterbody and its catchment (e.g. depth, width, degree of erosion on banks), flow characteristics, available habitats and their condition, water quality and biological characteristics are measured and assessed. Impacts and stresses on a river system may arise from a number of different sources; for example, through riparian vegetation clearing, changes in water quality through pollution inflow, or stock access weakening bank stability.

An impact on a river system may affect not only the physical characteristics and/or water quality, but also the habitats and environment of the fauna and flora associated with that river. Each of these biological groups will respond in different ways to stresses in their environment, and therefore can be good tools for diagnosis.

Integrated river health assessment approaches are being adopted and supported throughout the world: examples include the Water Framework Directive (WFD) employed in 25 countries across Europe (in operation for 17 years), the Ecosystem Monitoring and Assessment Program (EMAP) in the United States (30 years), the Australia China Environment Development Program (ACEDP) in China (two years), and the River Health Program (RHP) in South Africa (14 years). Each of these programs includes elements from a range of ecological themes, such as water quality and/or quantity, aquatic biota, fringing vegetation and aquatic habitat features. This approach to river health assessment has also been adopted elsewhere in Australia (the associated programs will be discussed later in this report).

2 Background

This section summarises the state of river health assessment in Australia, outlines the rationale behind a national-level system of reporting and assessment, and reviews development of the national FARWH.

2.1 Status of river health assessment in Australia

Across Australia river health assessment varies significantly in terms of spatial and temporal coverage, as well as the type and extent of the information processed to elucidate a measure of health. A number of states have long-term ecological monitoring programs applied at the state level. These include the Victorian Index of Stream Condition (ISC) and the Ecosystem Health Monitoring Program (EHMP) in Queensland (or previous versions of each). In addition, the Tasmanian River Condition Index (TRCI) is a multi-parameter assessment approach that has been developed but not yet implemented. River health assessments in other states are typically limited to routine water quality monitoring, plus often ad-hoc one-off sampling events in response to some immediate need.

The inconsistency in river health monitoring and assessment across Australia limits comparability between states. This prevents effective collaboration, and thus improvement of processes given that technical commonalities are limited. The process of prioritising river management at a national level is also hampered.

2.2 Need for a national framework for river health assessment

As discussed above, effective river health management in Australia requires a mechanism for national reporting, and associated assessment protocols, to ensure that data from the different jurisdictions are unbiased and comparable.

A national framework for the assessment of river health would function not only as a quality control device for the numerous state/regional-based programs, but permit a more informed prioritisation process at the national level – identifying high conservation properties, quantifying and qualifying impacts, and highlighting general trends (e.g. impacts from climate change).

2.3 Development of the FARWH (addressing NWI objectives)

Summary Box 2

The National Water Commission has funded development of the FARWH through the Raising National Water Standards program, as part of implementing the National Water Initiative's objectives. The FARWH was brought about in response to insufficient data across Australia to complete a national assessment of river and wetland health, identified in the AWR (2005) audit. The FARWH is being trialled in New South Wales, Queensland, the wet-dry tropics and SWWA, and has been previously tested in Victoria and Tasmania.

All states/territories in Australia are signatories to the National Water Initiative (NWI), which is implemented by the National Water Commission (NWC). The NWI's main aim is to achieve a nationally compatible market, with a regulatory and planning-based system of managing surface and groundwater resources for rural, social and environmental outcomes. To help achieve this aim, the NWC administers the Australian Government's Raising National Water Standards program. This $250 million program supports implementation of the NWI by funding projects that are improving Australia's national capacity to measure, monitor and manage our water resources.

In early 2006, the AWR 2005 Discovery Phase project investigated the availability of data with which to conduct a national river health assessment. This process determined that insufficient data existed in some parts of Australia. The national FARWH was then developed – which was closely linked to other major health assessment programs such as the Victorian ISC, Tasmanian Conservation of Freshwater Ecosystem Values Framework, and the Sustainable Rivers Audit (SRA).

The FARWH attempts to achieve national comparability by prescribing standard scoring protocols and reporting requirements, including 'themes' required to score within and suggestions for their required elements ('indicators'). The FARWH also incorporates appropriate data collection and analysis to promote unbiased and thus nationally comparable assessments of river health. Even though the FARWH provides guidance on suitable indicators to measure and monitor under the themes, it has been designed to allow locally relevant indices to be used, which can be compared within and across jurisdictions. Further, the FARWH is not intended to replace existing assessment programs – but rather to provide an overarching framework to allow any existing programs to report nationally. The approaches used in the FARWH that have particular relevance to SWWA are described in more detail in Section 4.

The FARWH has been successfully trialled in Victoria and Tasmania (review of this work is provided in NWC (2007a), NWC (2007b), NWC (2007c) and NWC (2007d), and is currently being trialled in New South Wales, Queensland, SWWA (this report and Storer et al. (in press b)), and the wet-dry tropics.

3 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 is 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, SWWA rivers are a particularly valuable resource for water supply. They 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 different complexities and data availability between states (see Section 2.3), 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.

3.1 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 (see Section 4.4).

The process of applying the FARWH is simplified with the application of existing indicators taken from established state-based ecological programs, or through development of new indicators with the aid of known historical (unimpacted) data (to score departure against current conditions).

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 22) and are discussed in more detail in Storer et al. (in press b).

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. The RHAS program is described in more detail later in this section, within *Applicability of existing river health programs,* and scores are provided in Section 5.3.

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 22) 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 (see Section 4.2, *Defining and validating reaches*).
- 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 22). 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.

3.2 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. This report includes river health scores for all SWMAs assessed in the 2008–09 trials (using the full suite of available indicators). The 2005 assessment is discussed below. For a detailed account of indicator development and testing see Storer et al. (in press b).

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.

Retrospective analysis of river health for 2005

An important component of this project was to conduct the 2005 data review to provide the baseline year for the NWI (see Section 2.3). To achieve this, a comprehensive data sourcing exercise was undertaken and assessments carried out for all SWMAs.

Due to deficits in data availability, the final scores within some themes were limited. These are discussed with the assessment results in Section 6.1.

Applicability of existing river health programs

As mentioned previously, the FARWH was designed to be used with existing state-based programs, so that data generated for state or regional management needs could be put through the framework to achieve an assessment comparable among states and applicable at a national review level. This aspect of the FARWH is primarily targeted at established programs in Victoria, Queensland and Tasmania.

One applicable program does exist in SWWA: the RHAS. This program is only in its infancy, having been developed and trialled between 2007–10 (ongoing), however data from the RHAS were tested against the framework to elucidate the relationship between scores generated for local objectives and those for national audiences. The RHAS is described below.

The River Health Assessment Scheme

Development of the RHAS was funded by the Australian and Western Australian governments' investment in the National Heritage Trust, administered by the then Swan Catchment Council in the Swan Coast Region. The project's aim was to develop a multi-parameter river health assessment scheme for the rivers and drains of the Swan-Canning catchment. As such, the scope was targeted in the selection of indicators and assessment methods. The RHAS collects data under five indicator types (the equivalent of the themes in FARWH), which are:

1. physical form
2. water quality
3. riparian vegetation
4. macroinvertebrates
5. fish and crayfish

The RHAS was based largely on the Victorian ISC and South East Queensland's EHMP, with modifications to suit local conditions. To date, four years of data (2007–10) have been collected, covering 20 sites from 12 of the 31 subcatchments in the Swan-Canning catchment. Report cards based on preliminary assessment of subcatchment health have been prepared but not yet published. If you wish to view/obtain a copy of the draft RHAS report cards, please contact the Department of Water's Water Science Branch.

Given the small amount of data and the associated limitations of spatial and temporal scale, it is not yet possible to determine how robust or sensitive the RHAS is. Spatially the assessments are limited because only two sampling sites were used to determine the score for each of the subcatchments monitored. It did, however, perform well in its first year of use, based on a close alignment between the scores from the RHAS model and expert opinion on the condition of selected systems. For more information on the RHAS, see Galvin et al. 2009a and Galvin et al. 2009b. A limitation of the RHAS is that it has been developed specifically for one river system (the Swan-Canning) – thus it cannot easily be applied to other areas without modification. However, the sampling techniques used – especially for water quality, macroinvertebrates and fish and crayfish – are reasonably standard and hence make the data broadly comparable. For example, macroinvertebrates were sampled using the national AUSRIVAS techniques.

The results from applying the RHAS to the SWWA-FARWH are discussed in Section 5.3.

3.3 Objectives

The overall objectives of the SWWA-FARWH project are to:

a. Assess the national FARWH for its relevance and applicability in meeting state-level requirements for monitoring and assessing aquatic ecosystems. Specific objectives embedded within this requirement are the:
    - development of robust indicators to represent ecological health, with associated data collection/generation
    - establishment of a ‘reference condition’ for SWWA rivers – through literature review, modelling, expert consultation and field validation – to provide the baseline for comparison of current health status
    - generation of data based on current health status to populate ecological indicators for selected SWMAs trialled in 2008–09 and for the 2005 baseline-year assessment.

b. Examine correlations or redundancies with existing regional assessment frameworks and state-level water quality monitoring programs.

c. Assess whether one river health approach can be used to provide both state and national needs.

d. Present a picture of water management and its relationship to river health for each trial region.

e. Develop an implementation plan for the FARWH’s roll out including monitoring scale and frequency.

f. Provide links to future reporting frameworks under the Australian Water Resources Information System (AWRIS).

Vision

Once developed, it is hoped the FARWH will aid in prioritising both broad and specific management needs; will help develop rules for integrated management of environmental, social and economic factors (e.g. characterising environmental water requirements to inform water licensing and allocation planning); and generally provide a standard approach for ongoing monitoring – including targeted works such as land use impact assessments or gauging the effectiveness of specific management actions (with associated ongoing modifications).

4 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.

4.1 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 3].

Summary Box 3: 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.

To meet the need for an accurate and consistent (temporally and spatially) assessment of river health, the FARWH provides guidance across a number of critical areas that underpin all assessment and reporting methods. These are:

- reporting and assessment scales
- reach and site selection strategies
- indicator selection principles
- reference condition
- dealing with missing data
- integration and aggregation protocols
- data analysis.

The FARWH includes a certain degree of flexibility within each of these elements to provide enough scope for the diverse range of conditions present across Australia. It should also be noted that the FARWH does not attempt to replace any existing programs, rather it aims to provide an overarching framework to report nationally.

The approach taken within each of these areas for the SWWA-FARWH trials is described in the following sections.

4.2 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 22 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 22), and subsequently modified following validation within the SWWA-FARWH trials. An overview of the ARC reaches and an explanation of how the reach dataset was improved are discussed later in this section: *Defining and validating reaches*.

SWMA selection: 2005 baseline-year assessment

As was introduced in Section 3, the SWWA study area is defined as all NRM regions with the exception of Rangelands. For the 2005 baseline-year assessment, all SWMAs with the majority of their reaches existing within the SWWA study area were assessed. This excludes five SWMAs that cross the boundary into the Rangelands NRM region (most of their recognised reaches being outside the SWWA study area): Wooramel River, Murchison River, Yarra Yarra Lakes, Ninghan and Salt Lake (Figure 4).

The Avon River SWMA was also excluded from the 2005 assessment. This was primarily due to ephemerality, making many data collection methods and scoring protocols inapplicable. Development of a separate protocol for assessing this system is recommended for the future.

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.

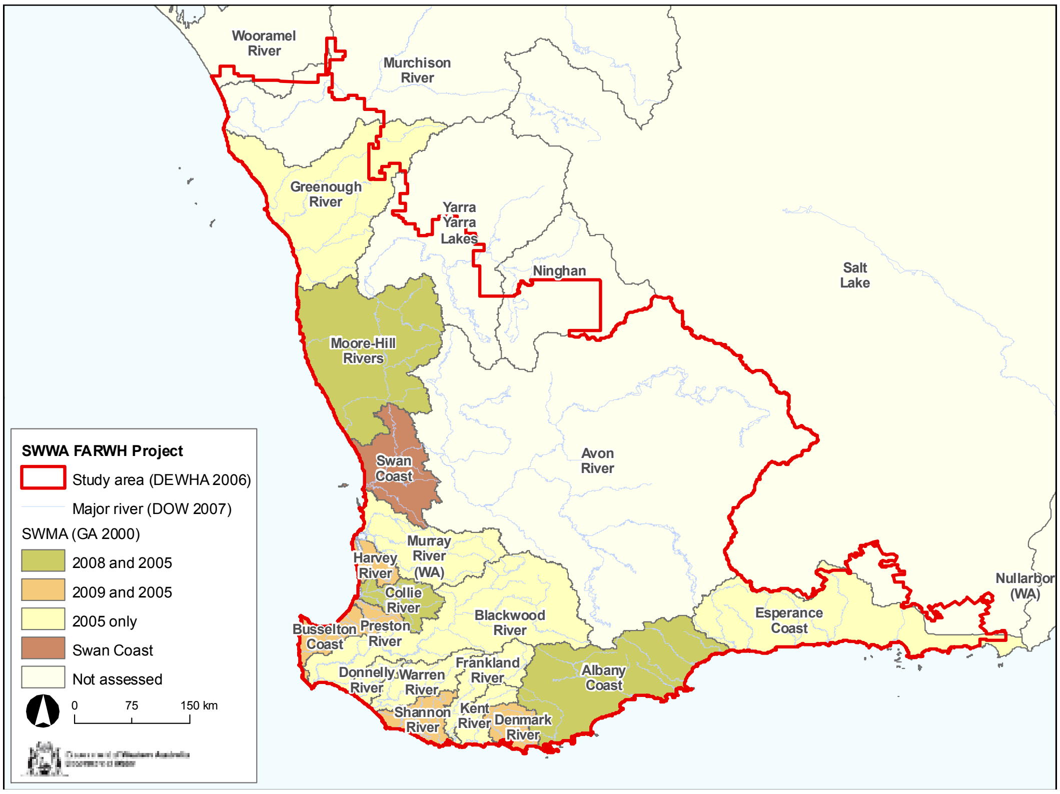


Figure 3   SWMAs chosen for assessment in the SWWA-FARWH trials

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 follows 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 22). 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).

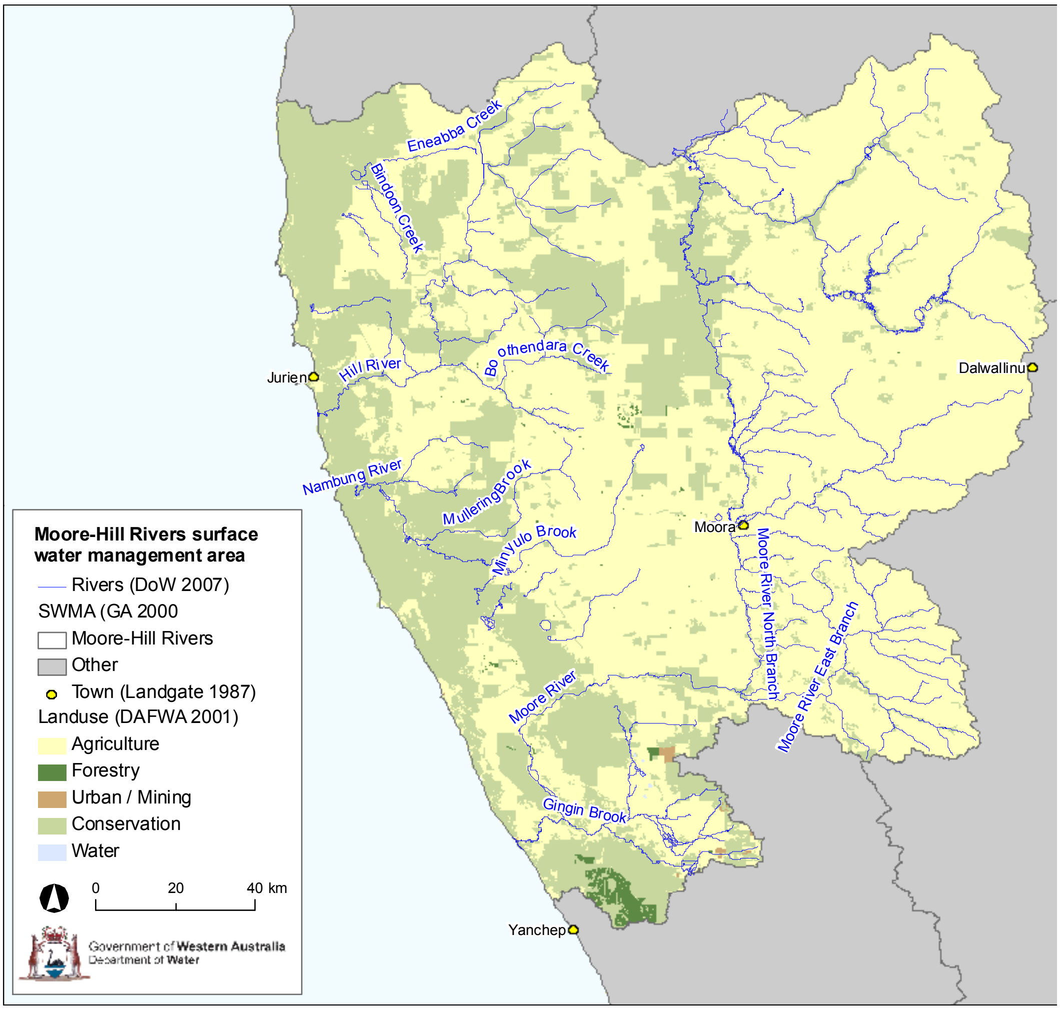


Figure 4 Moore-Hill Rivers surface water management area

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 22).

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.

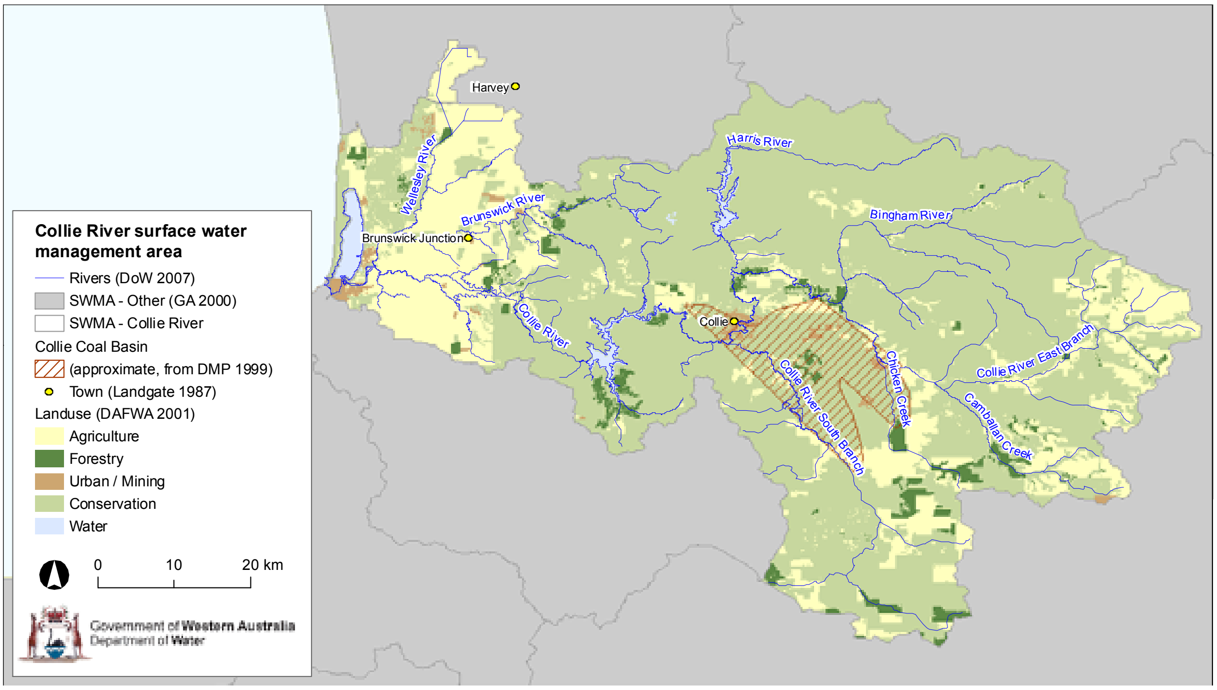


Figure 5 Collie River surface water management area

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 22). 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.

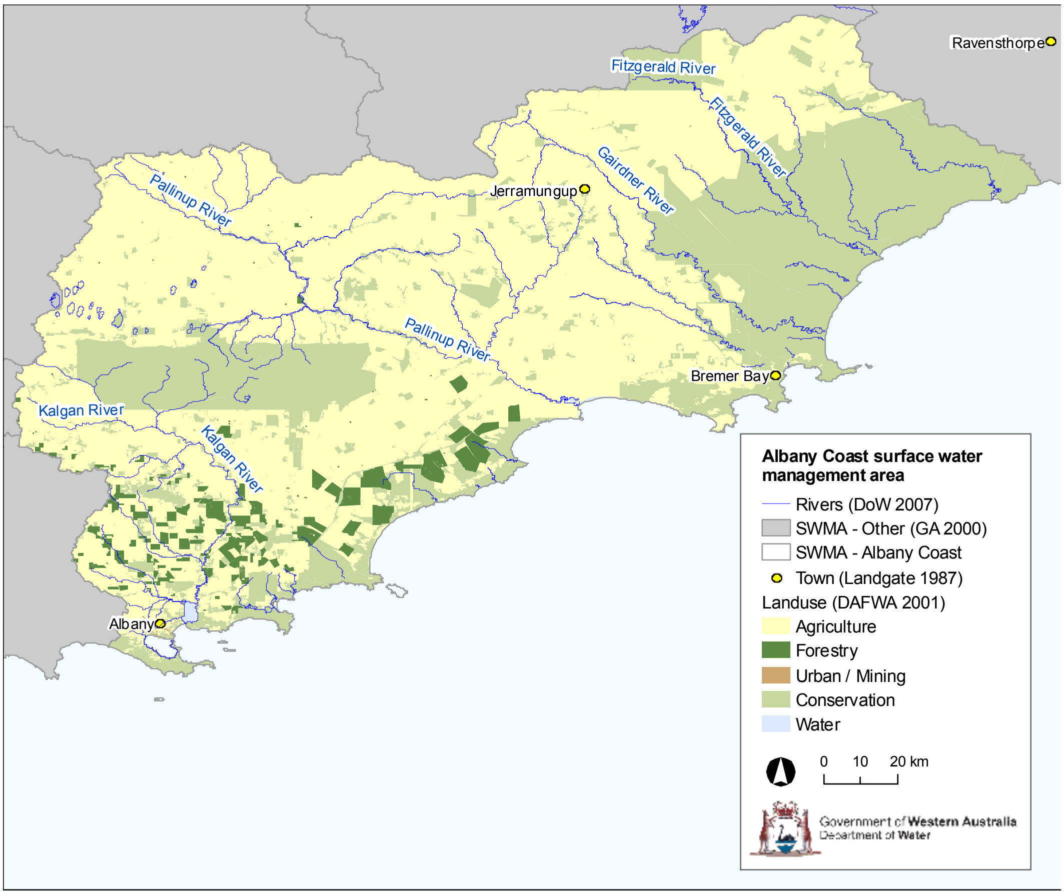


Figure 6 Albany Coast surface water management area

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 22).

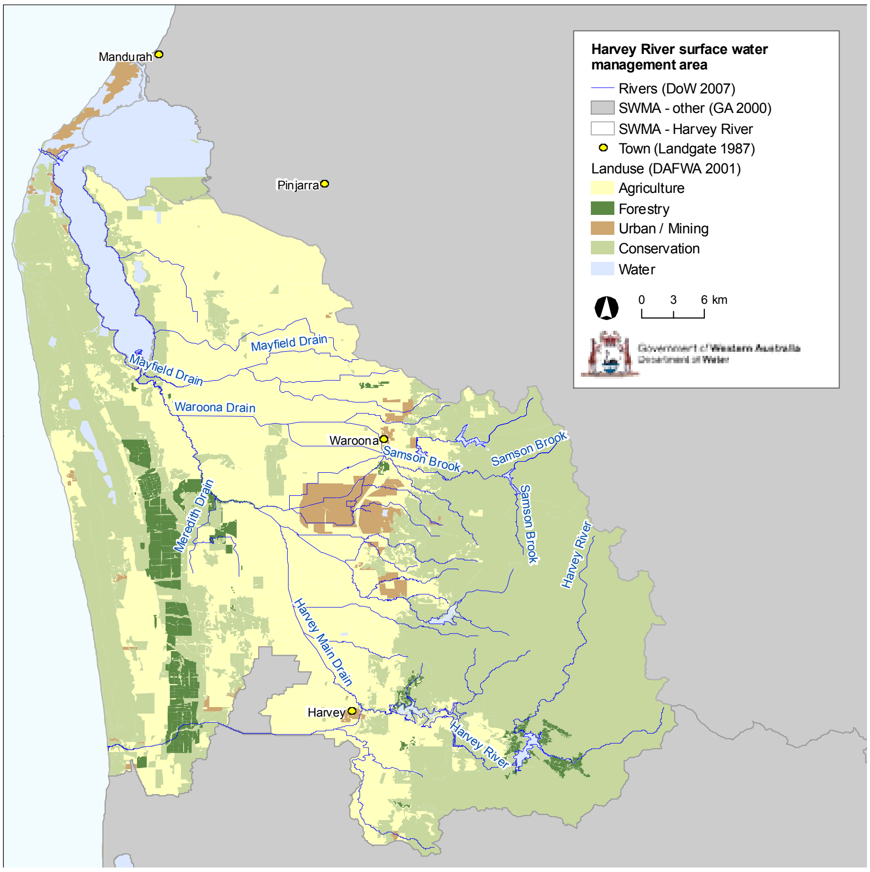


Figure 7 Harvey River surface water management area

Preston River SWMA (2009)

The Preston River SWMA is 1135 km^2. The Preston River's headwaters are situated 80 km inland on 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 22).

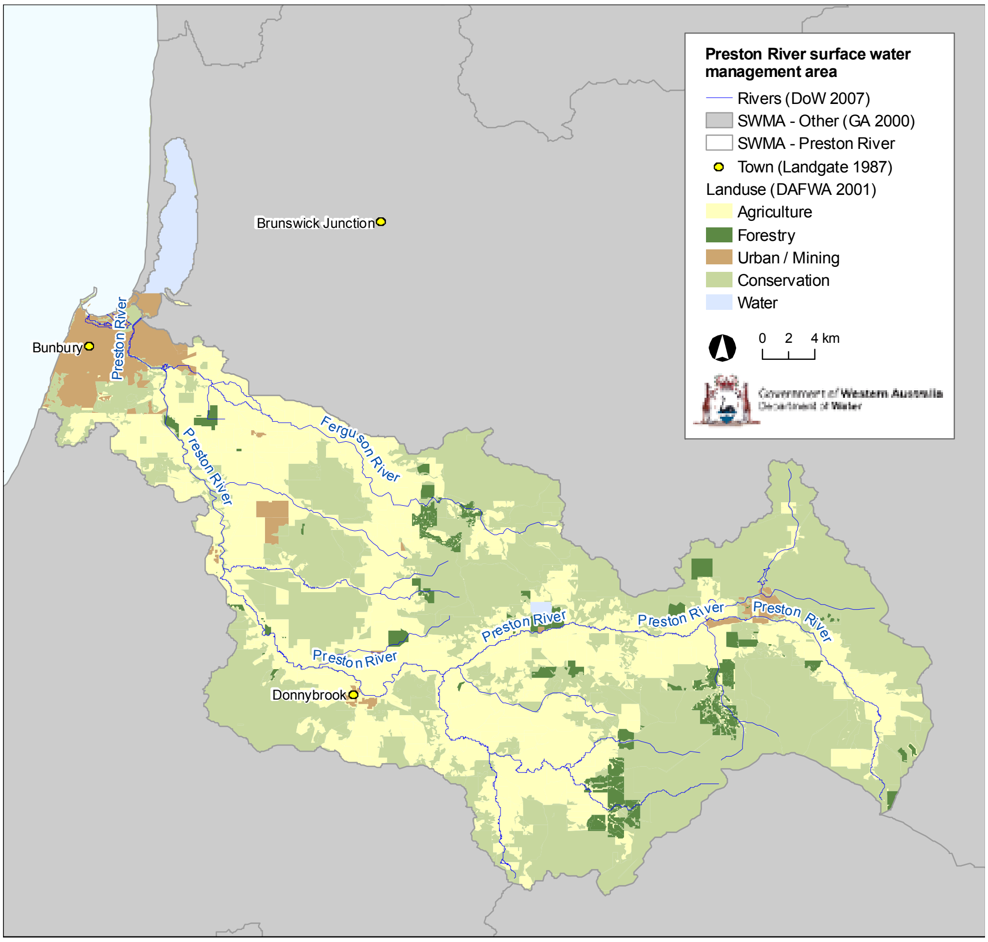


Figure 8 Preston River surface water management area

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 9). 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 22). 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.

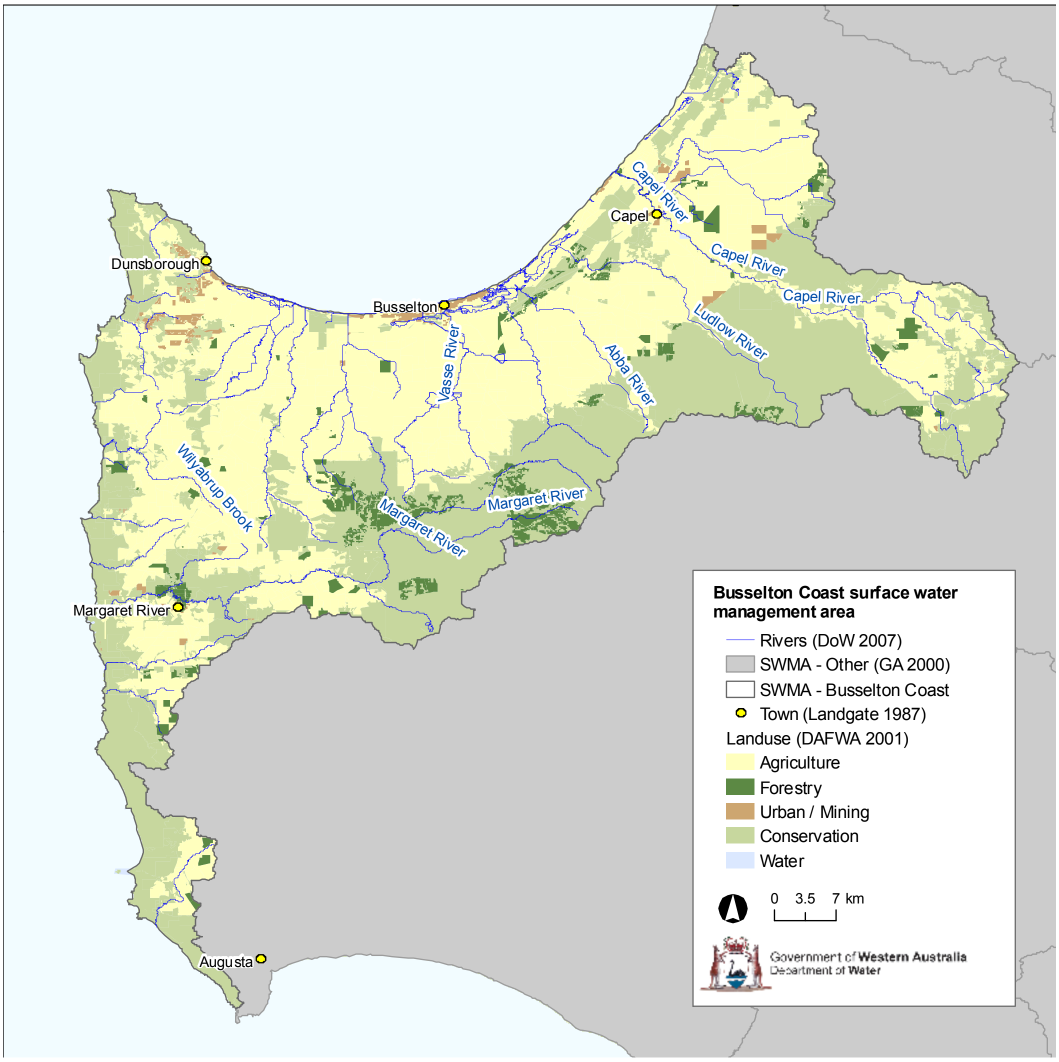


Figure 9 Busselton Coast surface water management area

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 22).

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.

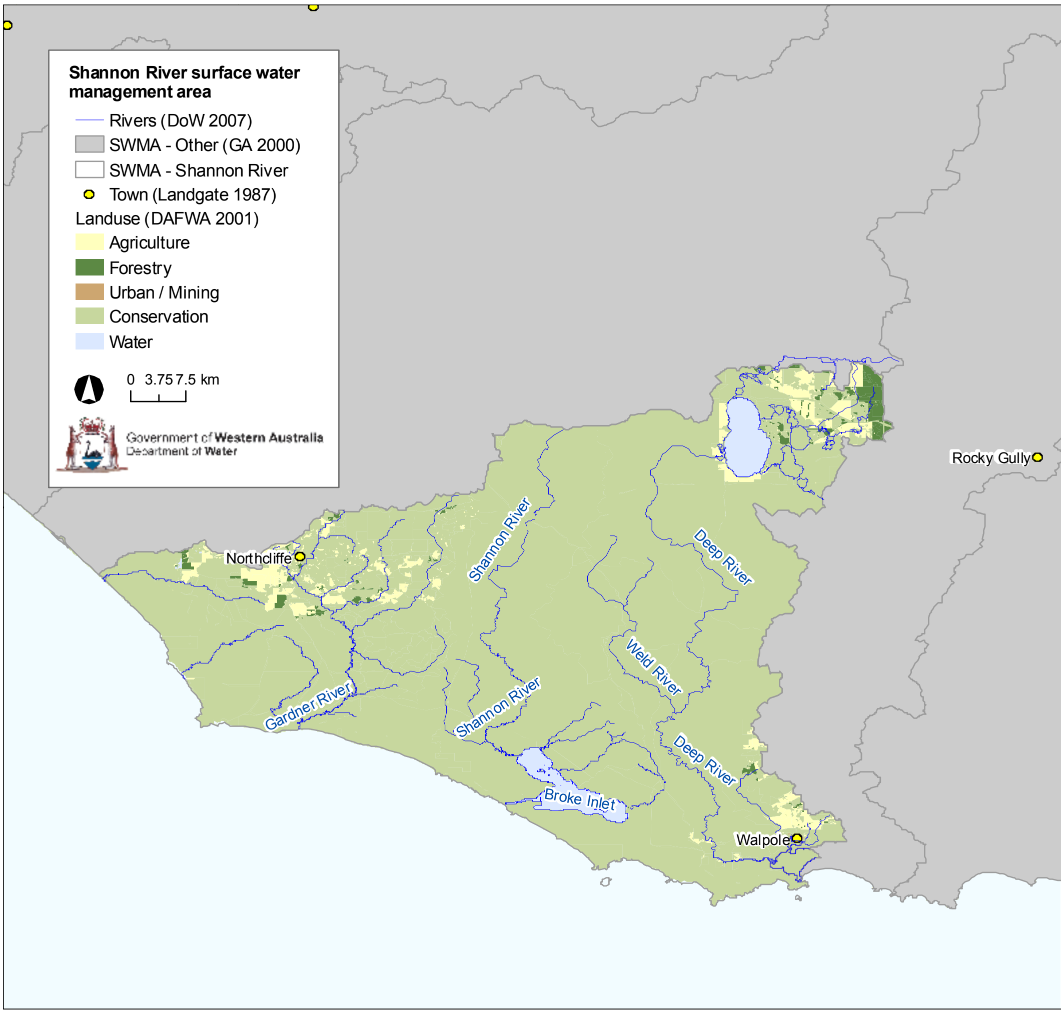


Figure 10 Shannon River surface water management area

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 22). 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.

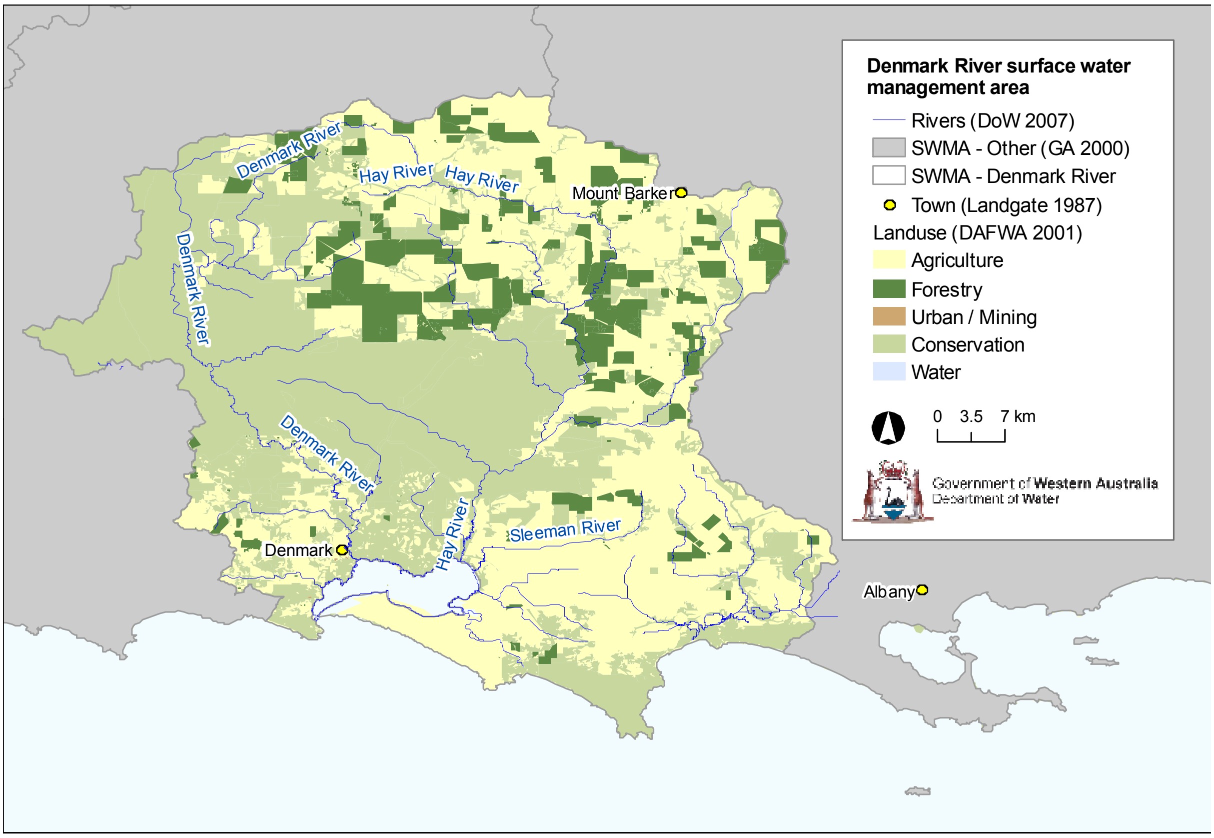


Figure 11 Denmark River surface water management area

Defining and validating reaches

The minimum grain size used for assessments to generate SWMA scores is the river reach, defined as an '…aggregation of river links that identifies a section of river with relatively uniform physical characteristics' (DEWHA 2009a).

The FARWH has the flexibility to enable each state to define its own reaches. The process of defining reaches was investigated for SWWA but was found to be beyond the timeframe and resources available for the current project.

As mentioned at the start of this section, the reaches used for the SWWA-FARWH trials were developed as part of the ARC (known as ARC reaches, see Table 22), which formed part of the NLWRA I. The ARC reaches were defined using the following process (for a full description see Norris et al. 2001):

- A stream network of river links was generated from the Geoscience Australia nine-second digital elevation model (DEM) (approximately 250 m pixels). The minimum catchment area for initiating a reach was 50 km^2, and the minimum catchment area for all links was 75 km^2.
- Links were split at the entry and exit to reservoirs and lakes as mapped in 1:2.5 million scale topographic data.
- Links were concatenated to reaches based on a series of rules relating to link slope and catchment area, which form a surrogate for stream power.
- Stream networks were checked against named streamlines in the Geoscience Australia 1:250 000 topographic map series. Links that did not match with named streamlines were excluded as they represented DEM-generated flow accumulations (these do not occur as watercourses on the ground): some examples are dispersion of flow, terminal lakes and lack of flow through dune systems.

Despite the checking process described above, a number of errors were found in the ARC reaches dataset, including:

- areas of low-lying land or wetlands defined as reaches
- reaches extending to the ocean where the system actually terminates in a lake or flows underground
- unconnected streamlines incorrectly connected together
- large reservoirs defined as reaches; for example, Harris Dam in the Collie River SWMA is not mapped at 1:2.5 million scale but is 14 km in length, covering just under half of the length of reach 6120836 which runs through it.

To overcome these errors all reaches in the SWWA project area were validated. The validation process also addressed two other issues, those of short reaches and estuaries (see below):

Short reaches: the ARC reaches dataset included a number of very short reaches: 33% of the reaches in the study area (including the Avon River SWMA) were < 5 km long, with the shortest being 0.07 km. Short reaches are artefacts of generating a stream network from a DEM and do not necessarily represent stretches of river with homogeneous characteristics. In addition, field sampling was conducted at a site defined as a 100 m length of river; therefore it was necessary to set a minimum reach length appropriate for the sampling method. Based on the best professional judgement of the authors, the minimum reach length was set at 2 km for SWWA. It is acknowledged that this value will need further validation in the future.

Estuaries: A number of ARC reaches were defined through estuaries. The scoring protocols developed under the SWWA-FARWH trials were appropriate for freshwater systems only and so could not be applied to estuaries; as such, estuarine portions needed to be addressed.

The following manual validation process was completed for the 990 reaches in the study area:

- Reaches were checked for length. If a reach was < 2 km in length it was merged with the reach upstream (or the reach downstream if there was no valid reach upstream), except for initiating reaches which were left intact. (Note: this process follows advice from Richard Norris, pers. comm. 2010.)
- Reaches were checked against streamlines in 1:250 000 scale topographic mapping data (Hydrography theme from GEODATA TOPO 250K Series 3 and a beta version of AusHydro v1.0, see Table 22) and were marked accordingly as hydrologically valid, partially valid or not valid. Note: the 1:250 000 topographic mapping data was used as the primary source for validation, however in cases where known streamlines were not mapped at this scale, the reach was checked against more detailed hydrography datasets (Hydrography Linear Hierarchy and Hydrography Linear, see Table 22).
- Reaches were checked for estuarine characteristics using the Hydrography Linear Hierarchy dataset. If < 2 km of the reach was estuarine it was considered to be valid; if > 2 km was estuarine it was marked as non-valid.
- The three factors above were used to determine the overall validity of each reach (valid, partially valid or not valid). Of the 990 original ARC reaches in the study area, 948 remained after validation (i.e. 42 were merged with other reaches in accordance with the minimum reach length). Of these, 642 were valid, 81 were partially valid and 225 were not valid (Figure 12).
- Reaches were checked for the presence of lakes and reservoirs mapped at 1:250 000 scale (Hydrography theme from GEODATA TOPO 250K Series 3 and a beta version of AusHydro v1.0), the presence of waterbodies were noted and sampling was amended accordingly (e.g. *extent of fringing zone* scores excluded waterbody portions of reaches because this would have resulted in an underestimate of vegetation along the banks of the river portion of the reach).

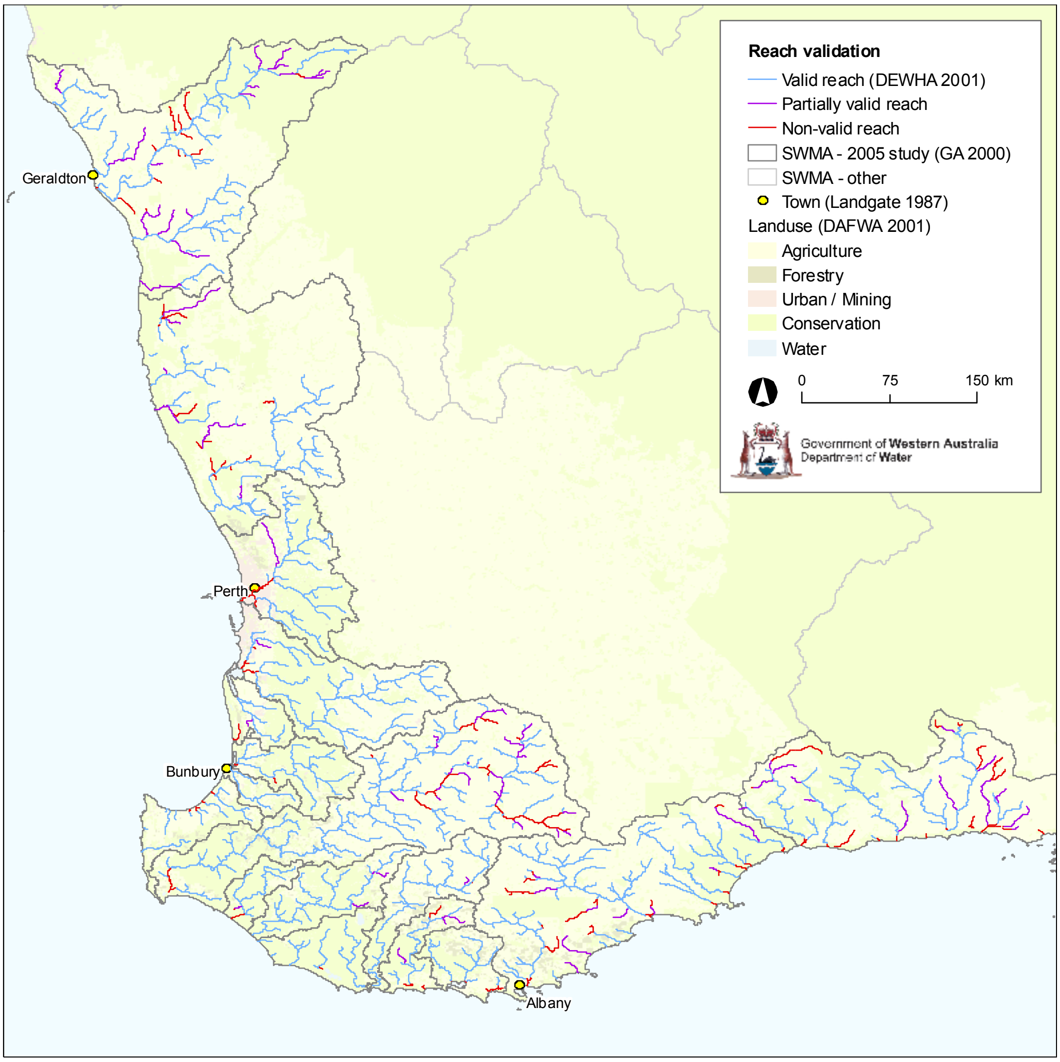


Figure 12 Reach validation for SWWA (coloured lines represent reaches as defined in the ARC reaches dataset, red and purple sections represent partially valid and invalid reaches respectively)

A further problem with the ARC reaches dataset was that some reaches were very long (up to 105 km, see Table 2) and did not appear to represent sections of river with homogenous characteristics. For example, reach 6110924 in the Preston River SWMA is 59.5 km long, extending from an elevation of 175 m on the Darling Scarp to sea level on the Swan Coastal Plain. While this difference in altitude is small relative to other parts of Australia (e.g. the highlands of Tasmania), it is of ecological significance for SWWA given that, for example, the structure of macroinvertebrate communities changes between upland and lowland rivers in the region (Davies 2005). Note: a trial was conducted where two long reaches in the Denmark River SWMA were split to analyse the effect of the reach definition process. The results of this trial are assessed outside this report.

Table 2 shows a summary of the reach statistics discussed above for each SWMA assessed within the SWWA-FARWH trials.

Table 2 Attributes of surface water management areas of Western Australia assessed within the SWWA-FARWH trials

SWMA	SWMA/ AWRC basin no.	SWMA area (km^2)	Total no. reaches	No. of valid reaches	No. of partially valid reaches	Valid reaches	
						Shortest reach (km)	Longest reach (km)
Esperance Coast	601	20 154	123	61	15	1.55	53.11
Albany Coast	602	19 604	154	86	9	2.14	105.74
Denmark River	603	2617	21	11	0	7.77	46.49
Kent River	604	2493	30	13	3	3.38	65.16
Frankland River	605	4651	29	26	1	3.08	44.40
Shannon River	606	3295	12	11	0	4.24	55.94
Warren River	607	4408	26	24	2	3.64	49.46
Donnelly River	608	1725	11	7	1	6.49	48.05
Blackwood River	609	22 590	201	119	21	0.31	59.38
Busselton Coast	610	3057	18	12	0	3.2	48.94
Preston River	611	1135	3	3	0	24.35	59.52
Collie River	612	3717	22	20	0	2.55	41.38
Harvey River	613	2001	18	13	1	1.09	21.95
Murray River (WA)	614	9941	62	53	1	0.7	53.46
Swan Coast	616	8237	52	42	1	2.27	38.62
Moore-Hill Rivers	617	24 533	94	59	9	2.57	47.75
Greenough River	701	25 029	114	82	17	1.66	56.17
Total			**990**	**642**	**81**		

**The total number of reaches pre- and post-validation is different as in some cases reaches were merged or were too small for assessment.*

The final issue identified in relation to the ARC reaches is their failure to align well with streamlines mapped at a finer resolution, being up to 2 km away in places. This is an artefact of generating a stream network from a coarse DEM. It has implications for indicators which are scored using geographical information systems (GIS) analysis. For example, using the ARC reaches to analyse the width and length of fringing vegetation will result in false results in locations where fringing vegetation only remains in narrow corridors alongside the streamline. In this instance the misaligned ARC reach is likely to fall on a cleared paddock adjacent to the river, resulting in poor vegetation width and length scores.

For the purpose of the SWWA-FARWH trials, these challenges have been addressed by reconstructing the reaches from 1:250 000 scale topographic mapping (Hydrography theme from GEODATA TOPO 250K Series 3 and a beta version of AusHydro v1.0, see Table 22) which align more closely with the actual location of waterways. Reaches were reconstructed for the valid ARC reaches and the valid portions of partially-valid ARC reaches. It includes portions of reaches running through lakes and reservoirs but excludes estuarine portions of reaches. The original reach identification numbers from the ARC reaches have been retained. Reference to the Reconstructed Reaches dataset is provided in Table 22.

Future direction

It is recommended the Reconstructed Reaches dataset be used for all future assessments (until reaches are redefined) to reduce the amount of error associated with scoring.

It is further recommended that reaches be defined specifically for SWWA. This would allow the reaches to be tailored to the region’s topographic conditions and enable finer-resolution DEMs and topographic mapping to define reaches that align more closely with actual watercourses. The possibility of defining reaches based on physical characteristics additional to stream power should be investigated. This could include geology, rainfall and vegetation zones; that is, any features that under unimpacted conditions may influence the form and function of an aquatic ecosystem.

Reach selection strategy

For most indicators of the SWWA-FARWH, all reaches within each SWMA were assessed in their entirety using desktop-based methods. For some indicators, such as Aquatic Biota, field assessments were needed. These assessments also provided supporting information or ground-truthing for many of the desktop-based indicators.

All indicators within the SWWA-FARWH are assessed at the reach scale and then results are aggregated to provide an assessment of the whole SWMA. As such, reach selection for field-assessed indicators is a critical element for assessing a SWMA. Note: the assessments described in this report are made for the purpose of national reporting and the results must be used accordingly [see Summary Box 4]. With this in mind, the selected reaches must achieve the following objectives:

- return an assessment that is representative of the SWMA’s condition

- be sufficient in number for statistical analysis to help the development of indices and scoring protocols
- meet field sampling practicalities (e.g. accessibility).

> *Summary Box 4*
>
> Reach assessments can be derived both from desktop analysis and field assessment of representative sites within the reach. Reporting outside of NWC's FARWH requirements can be made at any scale, but for local management, scores and associated data must be considered at the level it was created for. For example, indicators within the FARWH Fringing Zone theme target broad dynamics (e.g. vegetation length/width) and are not designed to highlight many of the specific conditions that resource managers need for local assessments.

The recommended strategy for representative and unbiased selection of reaches for field assessment is either a completely randomised design (CRD), where reaches are chosen via some form of random number generation, or a randomised block design (RBD). A RBD involves a randomised selection of reaches (following the same method as for the CRD) within any number of strata. The use of strata is designed to represent major zones across a landscape (e.g. upland and lowland divisions) to ensure that each zone is reflected fairly in final scoring. These zones should be limited to natural conditions rather than types of impact, as the theory behind RBD is to separate assessment of components displaying different natural ecological dynamics (form and function). Note: different indicators or scoring protocols are recommended when assessing areas that behave differently – highlighting the different strata makes this process more transparent.

Finally, it should be noted that selecting too many strata has the potential to confound interpretation. (For more discussion, see outcomes from the FARWH workshops. While these workshop reports were not publicly released, the NWC can be contacted for the information gained in these sessions.)

However, for the 2008 SWWA-FARWH field trials, reaches were selected with the primary goal of developing robust indicators. This required testing indicators against the complete scale of impacts existing in the study area, and therefore ensuring that all potential stressors were assessed within the range of natural ecological zones. This involved the use of multiple impact-type and ecological strata (e.g. land use types, geology, topography, rainfall) – effectively a complex RBD. Reaches were also selected based on availability of existing data, as temporal data comparison was desired to determine and test indicators against natural variability.

Given these considerations, the method used for reach selection needed to be a robust and scientifically defensible process. To demonstrate the method adopted for the 2008 trials, the Albany Coast SWMA has been provided as an example. The following environmental variables/attributes and datasets were assessed to select sites across the Albany Coast SWMA:

Natural ecological aspects:

- watercourse hierarchy (main channel, major and minor tributaries)
- topography/altitude
- rainfall
- geology
- fish distributions (consideration of potential areas of rare and endangered fauna).

Impact types:

- land use
- specific potential impacts (dams/extraction areas).

Existing data:

- includes data such as aquatic biota and gauged water quality records.

Each of these variables/attributes for the Albany Coast SWMA is described below.

Variables/attributes for the Albany Coast SWMA

The SWMA's watercourse hierarchy is shown in Figure 13, identifying the estuarine portion, main channel and major and minor tributaries of each river system from a hydrological perspective. This watercourse hierarchy was defined by examining aerial photographs, modelled flow volumes and expert local knowledge.

Figure 13 Watercourse hierarchy in the Albany Coast SWMA

Reaches were selected for sampling at the top, middle and bottom of each of the main streams (above the estuary) where possible. Reaches were also selected below any major tributaries to the main stream as well as in each of the major tributaries – in an attempt to capture inputs. Figure 14 highlights the outcome of the above principles of reach selection.

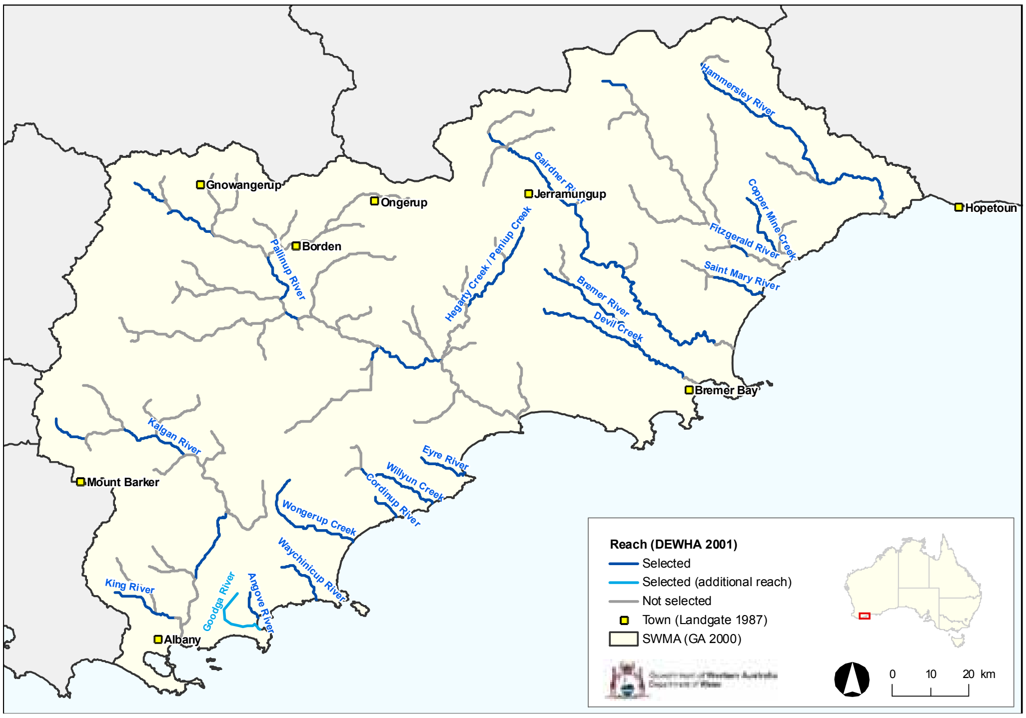


Figure 14 Output from reach selection process

This step identified all of the reaches to be sampled. They were then verified against a number of other attributes to ensure the reaches selected would adequately represent the SWMA from an indicator development perspective. On a few occasions extra reaches were selected based on the attributes examined to ensure the full range of conditions were sampled in each SWMA (to allow for robust indicator development). Additional information used in the reach selection process – including topography, mean annual rainfall and land use – is described below.

The topography of the Albany Coast SWMA is shown in Figure 15. This highlights the relatively flat nature of this area, with the maximum elevation of most of the SWMA being approximately 300 m. The elevations of the selected reaches were checked to ensure they were representative of the elevation across the whole SWMA (i.e. as most of the SWMA lies at 200 to 300 m, most of the reaches needed to be in areas with this altitude).

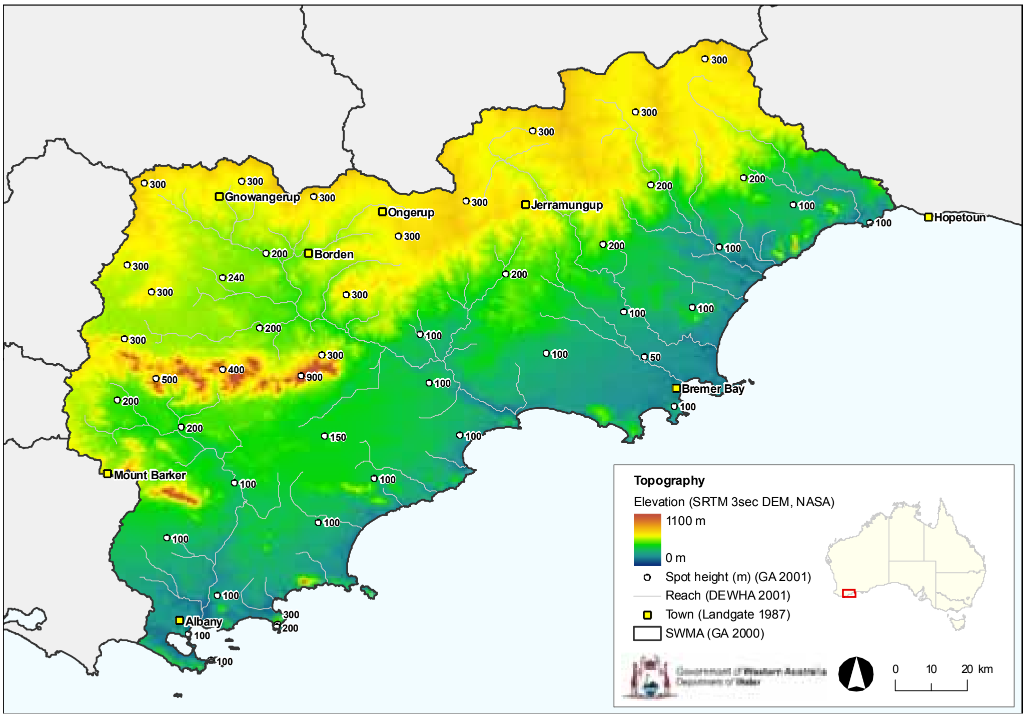


Figure 15 Topography of the Albany Coast SWMA

The rainfall gradient in the Albany Coast SWMA is shown in Figure 16. This indicates a general trend of higher rainfall near the coast and towards the west. Reaches selected were checked to ensure they adequately covered the range of rainfall experienced in the SWMA and that they were distributed according to the rainfall zones (thus more reaches needed to be selected in the 500 mm rather than the 900 mm rainfall zone as a much larger portion of the SWMA experiences 500 mm rainfall/yr).

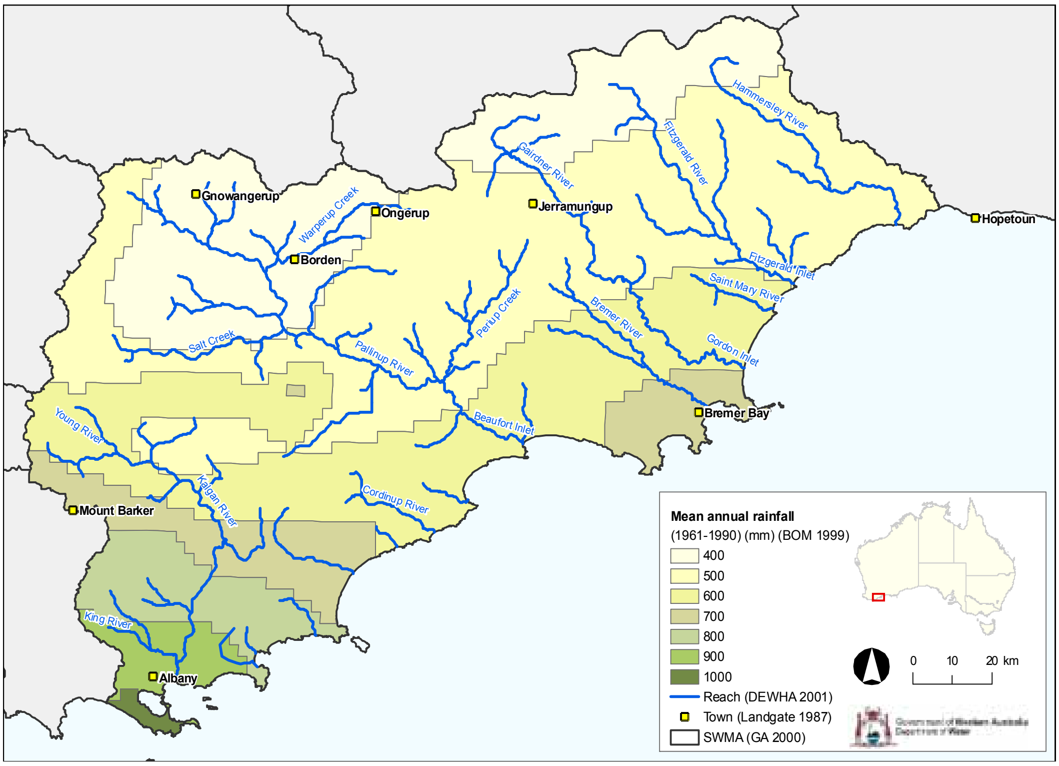


Figure 16 Mean annual rainfall in the Albany Coast SWMA

As can be seen in Figure 17, the dominant land use in the Albany Coast SWMA is cropping, with a few large areas of nature conservation present and scattered plantation forestry (predominantly blue gums) in its south-west. The distribution of the selected reaches was checked to ensure they adequately covered the range of land use types present, and that their distribution was proportionate to the area of each land use type (e.g. approximately 75% of the selected reaches needed to capture cropping land use and 20% nature conservation).

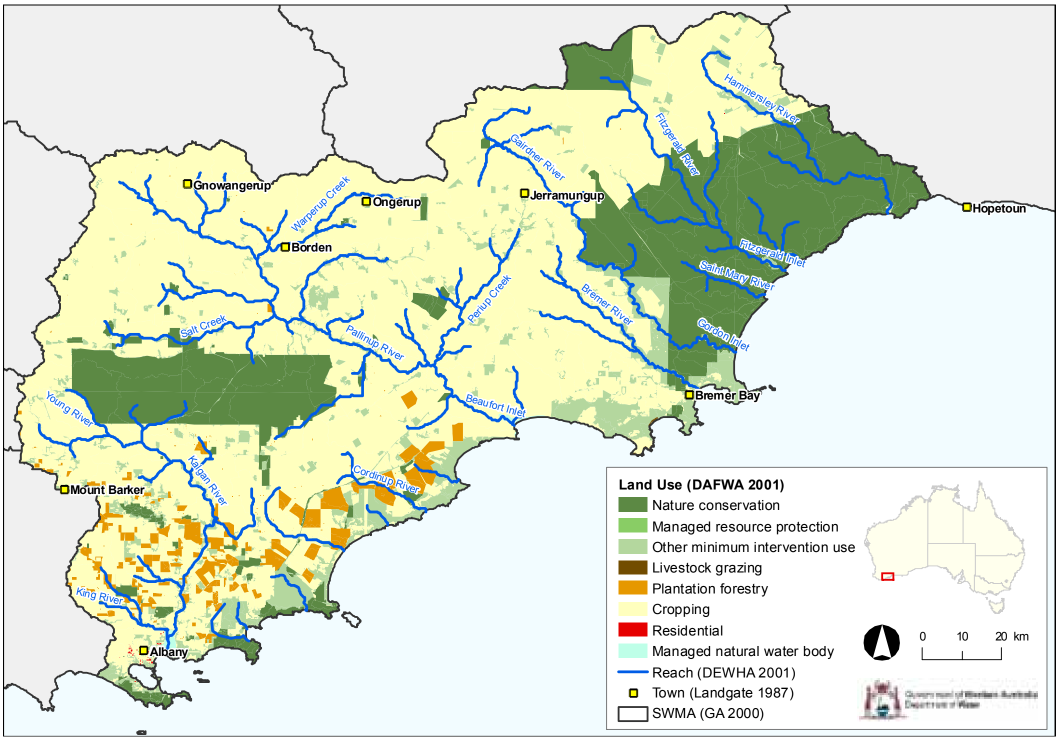


Figure 17 Land use in the Albany Coast SWMA

The Albany Coast SWMA's two dominant geological features are the granite and gneiss along the northern portion; and the marine limestone, sandstone and valley-filled deposits along the southern portion (Figure 18).

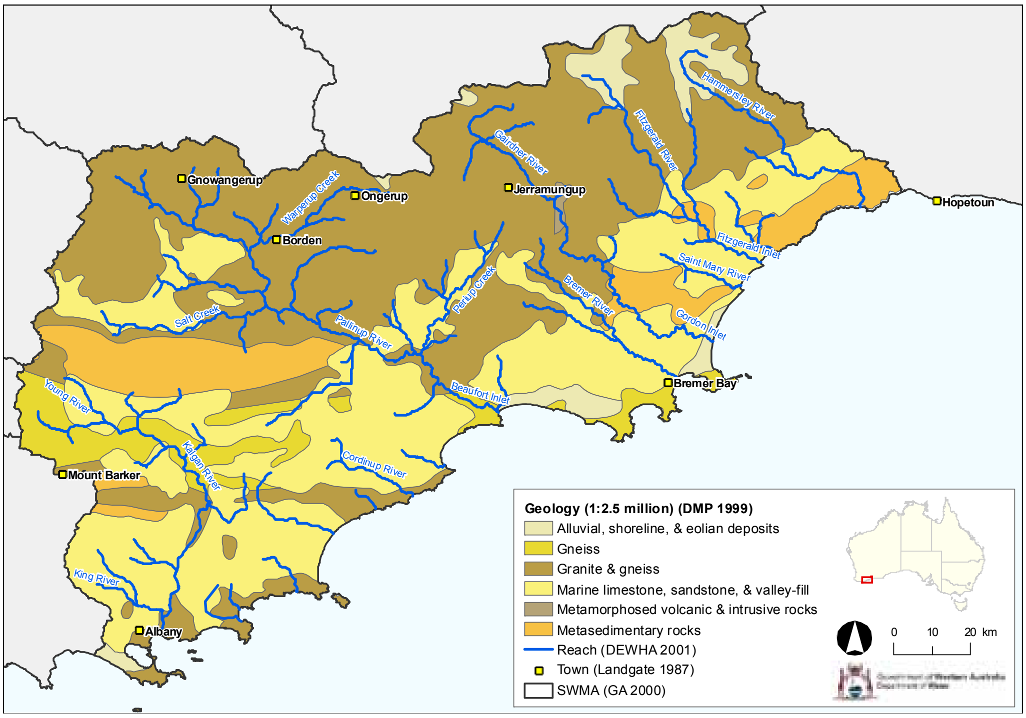


Figure 18 Geology in the Albany Coast SWMA

The locations of the selected reaches were checked to ensure they adequately represented the geology present and were proportionate to the geology.

Existing sampling locations in the Albany Coast SWMA are shown in Figure 19. This information was used to help select reaches (and also sites, see next section) for sampling, given the added advantage of historical data being present (typically either water quality or macroinvertebrates) and the increased likelihood of being able to access the sites. Gauging station locations are also shown for sites with a long data record, minimal missing data and which are still in operation.

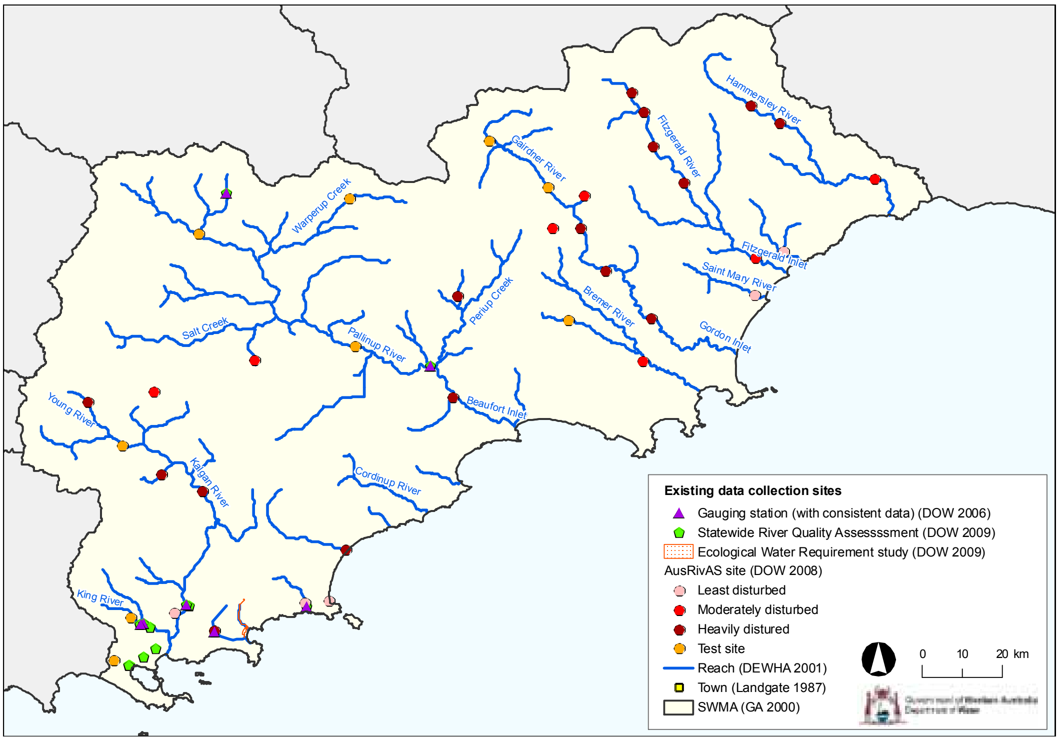


Figure 19 Existing data collection points in the Albany Coast SWMA

The various levels of information described in this section were used to assign sites to ensure each major zone was represented and accordingly, that indicators of health could be tested against the capacity to represent the full suite of possible conditions.

Note: an extended review of reach selection methods is provided in van Looij and Storer (2009a). This includes use of additional datasets; for example, the use of potential impacts or presence of biodiversity hotspots or rare species.

In terms of recommended future methods for reach selection, this process highlights the disadvantages in using too many strata; that is, reach selection no longer appears random and will effectively weight each strata evenly unless extreme care is taken to aggregate scores based on the percentage of the SWMA that each strata represents. As there were no underlying spatial patterns observed during the SWWA-FARWH trials, the CRD is recommended for future work – although the RBD is still worth noting because important strata may be identified in future.

Note: a reach selection strategy was not employed for the 2009 field trials as the selected SWMAs were relatively small with few reaches. All assessable reaches (given access and flow conditions) were surveyed.

Site selection strategy

Assessment within the majority of indicators described in this report can be conducted remotely at a reach level (e.g. desktop analysis of gauge data or through GIS). However, a number of indicators (e.g. Aquatic Biota and certain indicators of Water Quality) require field assessment. As such, sites need to be selected on reaches.

Ideally, sites should be selected randomly; that is, by splitting a reach into multiple sections, assigning each section a number, randomly selecting from these using their numbers, and then placing a site on the selected sections. However, given the lack of confidence in the reach definitions (resulting in reaches that did not represent homogenous sections of river), effort was made to place sites in a perceived representative location. This was achieved through analysis of broad environmental conditions, using the same strata considered for reach selection (see example given in the previous section) and consultation with regional staff. In many cases, site selection was a direct result of accessibility, with access to many reaches only possible at a few places.

In addition, sites were selected in areas outside the immediate influence of roads or other potential point-sources of contamination. Sampling upstream of these impacts was conducted where possible (this was difficult in some areas, especially urban centres).

Further, sampling was not conducted at sites that were dry or had become disconnected: Water Quality and Aquatic Biota data could not be collected in dry systems. Because the ecology and processes occurring in pools differ from flowing waters, the scoring methods developed would not have been relevant [see Summary Box 5]. Given the time available for this project, development of a tailored program for non-flowing systems was not possible.

Summary Box 5: Field assessments target baseflow conditions

As many of the streams in SWWA are ephemeral, the timing of sampling is crucial to ensure that winter flows have receded to their baseflow level and that the smaller headwater streams have not yet dried out. Because it is not always possible to achieve both of these aims (and some of the smaller streams only flow for short periods of time after heavy winter rains) there will always be a compromise between sampling the maximum number of higher-order reaches in a SWMA and having sensible sampling conditions in the lower reaches. Allowances were made for some systems where water was flowing faster than required (based on AUSRIVAS protocols). In future, health assessments will incorporate sampling in flow conditions outside of those targeted for the current trials. This will most likely see the loss of certain indicators, particularly biotic ones. A discussion on the number and type of indices required for a robust ecological assessment is provided in Section 4.5.

Note: site selection was discussed at the FARWH workshops conducted across all jurisdictions trialling the framework. While the workshop reports were not publicly released, the NWC can be contacted for the information gained in these sessions.

4.3 Indicator selection

The FARWH organises ecological data within six themes representing ecological integrity (as introduced in Section 4.1). 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.

General principles of indicator selection

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

[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. The AUSRIVAS is described further in Storer et al. (in press b).

- 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 (discussed in the next section).

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 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
- Wild Rivers data
- ad hoc biological data.

For a complete list of the datasets reviewed for indicator development, see the list of data sources in Table 22. 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

Note: indicators that were identified and trialled for the SWWA-FARWH (both accepted and rejected) are reviewed in Storer et al. (in press b).

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.

The methods used to assess the effectiveness of indicators tested within the SWWA-FARWH are provided in Storer et al. (in press b).

4.4 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 3 and discussed in more depth in Storer et al. (in press b).

4.5 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 Section 6.2, 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 in Storer et al. (in press b).

4.6 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, and is described in Storer et al. (in press b) [see Summary Box 6 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 20).

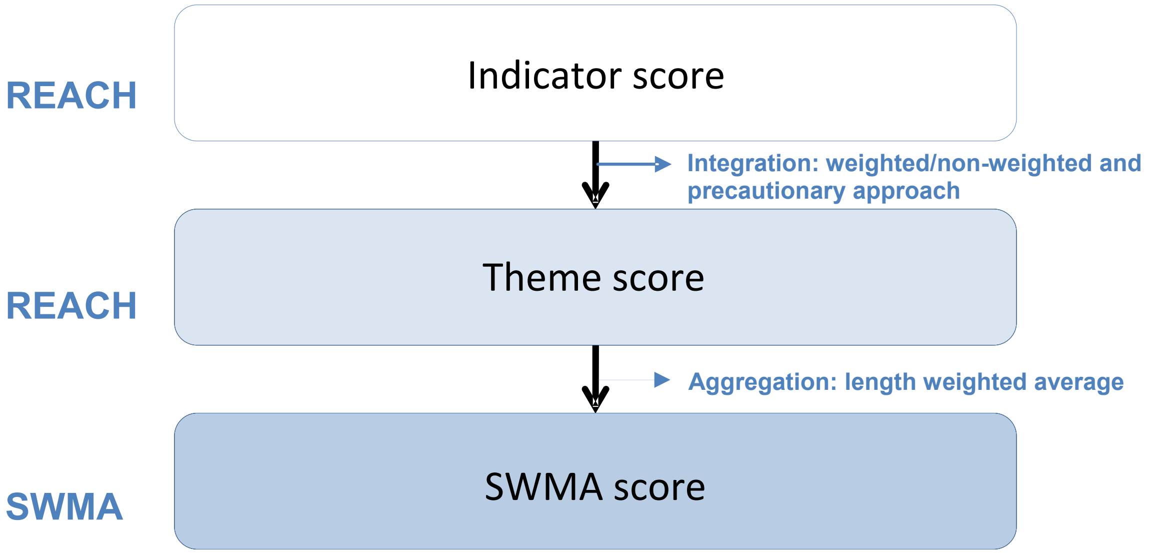


Figure 20 Integration-aggregation pathway for developing FARWH scores

Summary Box 6

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.

The original requirement for national reporting was to integrate theme scores at a SWMA level into an overall health score, however it was determined that this would produce an overall score that was meaningless (all SWMAs tested received similar mid-range scores) and would not be relevant at either a state or national level. This was endorsed by the national technical steering committee for the national FARWH program. This is especially important because combining pressure, stressor and response indicators – which are by nature designed for interpretation rather than combination – would in most cases only highlight very impacted or near-pristine systems.

4.7 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).

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 provided in the indicator reviews in Storer et al. (in press b). 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 Storer et al. (in press b).

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 Storer et al. (in press b).

4.8 Alignment with jurisdictional programs

This project ties in closely with other FARWH assessments being undertaken in Queensland (by the Queensland Government, Department of Environment and Resource Management) and for northern Australia's wet/dry tropics (by TRaCK). Links have been established with the teams for both these projects and regular dialogue is maintained to ensure the projects complement each other. Links with the NSW FARWH wetlands project have also been established, yet because this project's focus is on wetlands and not rivers, the nature of the questions being asked differ in a number of ways. This project also links to the NWC's FARWH national technical steering committee through participation in workshops and meetings, providing data and other project deliverables, and review of final report documentation. The committee was established to evaluate all the FARWH trials being undertaken and develop a synthesis report to be nationally and internationally peer reviewed.

Alignment with other jurisdictions in terms of general principles/guidelines has been promoted through the establishment of a significant technical review process. Members of the major river health programs across Australia (e.g. ISC, TRCI, SRA, EHMP) along with representatives from relevant organisations (e.g. DEWHA, NWC, CENRM) have all been involved in a number of workshops to discuss the general progress of both specific programs and the national approach.

4.9 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 21.

An extended summary of these indicators is provided in Table 3, 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 or literature based).

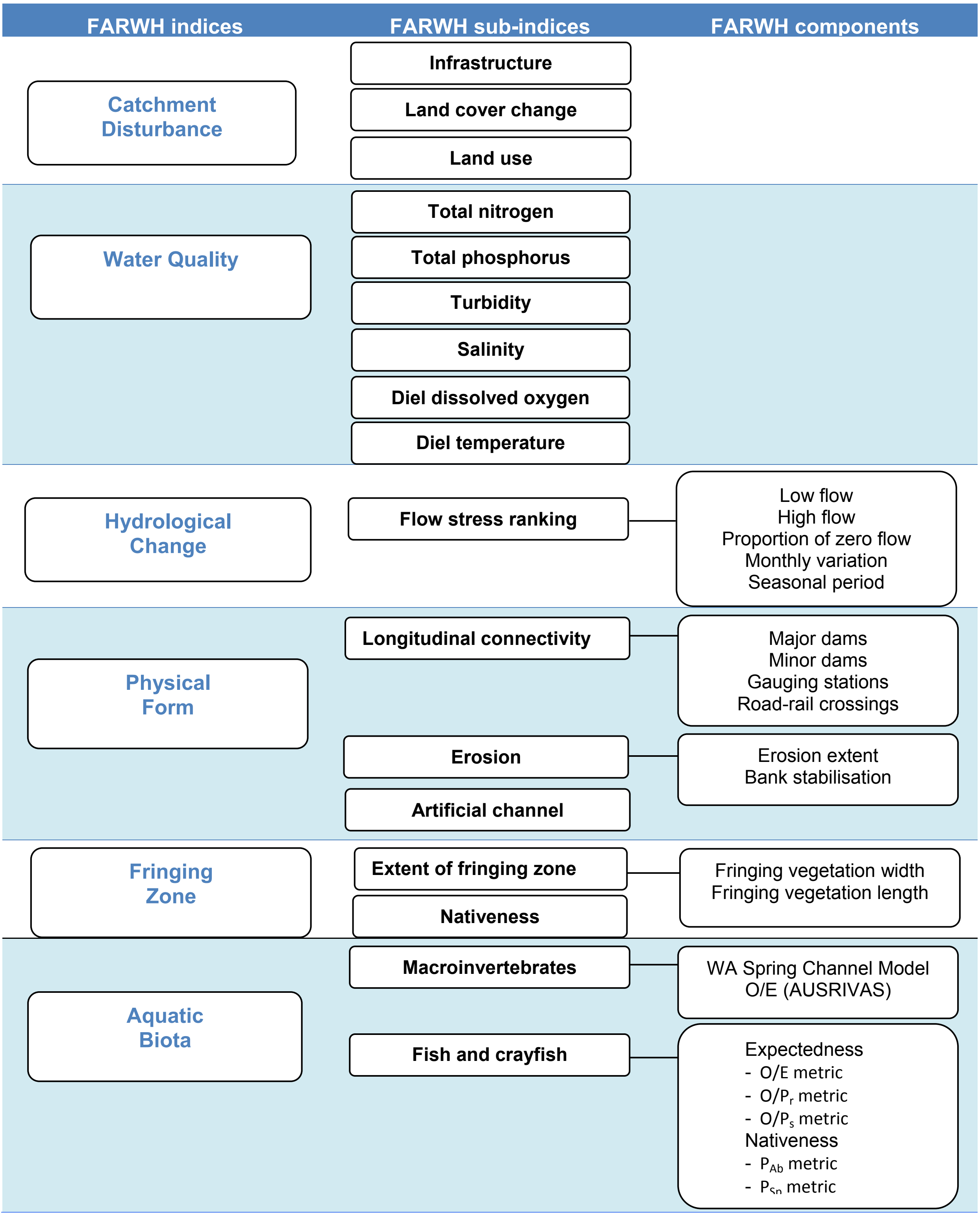


Figure 21 Indicators of the SWWA-FARWH

Table 3 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

The table above recommends the frequency for re-assessment of each indicator. This is determined based on the likelihood for change in conditions or availability of newly generated data to conduct successive assessments. 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 Results of the FARWH assessments

The results of the 2008–09 FARWH field trials as well as the 2005 AWR baseline assessment are provided below. The alignment between FARWH and RHAS is also discussed. Detailed information on indicator development and validation are given in Storer et al. (in press b). Individual reach scores are given in Appendix A.

5.1 2008–09 field trials assessment

A total of eight SWMAs were sampled during the 2008–09 field trials, three in 2008 (Moore-Hill, Collie and Albany-Coast SWMAs) and five in 2009 (Harvey River, Preston River, Busselton Coast, Shannon River and Denmark River SWMAs). The results are discussed below:

> *Note: in November 2008 (the sampling period for the SWWA-FARWH trials) 226 mm of rain was recorded in the Albany townsite, which was the highest since records began in 1877 (November average is 44 mm) <www.bom.gov.au>. This would have a bearing on the results obtained, although it is difficult to determine the extent of the effect. Sampling could not be postponed due to time constraints for field work.*

Catchment Disturbance

The *Catchment Disturbance index* scores for reaches assessed in the 2008–09 trials are shown in Figure 22. Note: scores are available for all reaches as this index was calculated remotely, rather than relying on field data. Scores ranged from 0.4 to 1.0. The scores generally followed the same spatial pattern as the *land use sub-index* scores (see Figure 23), given low variability in the other sub-indices: *infrastructure* and *land cover change* (see Figure 24 and Figure 25 respectively). This is discussed further in Storer et al. (in press b).

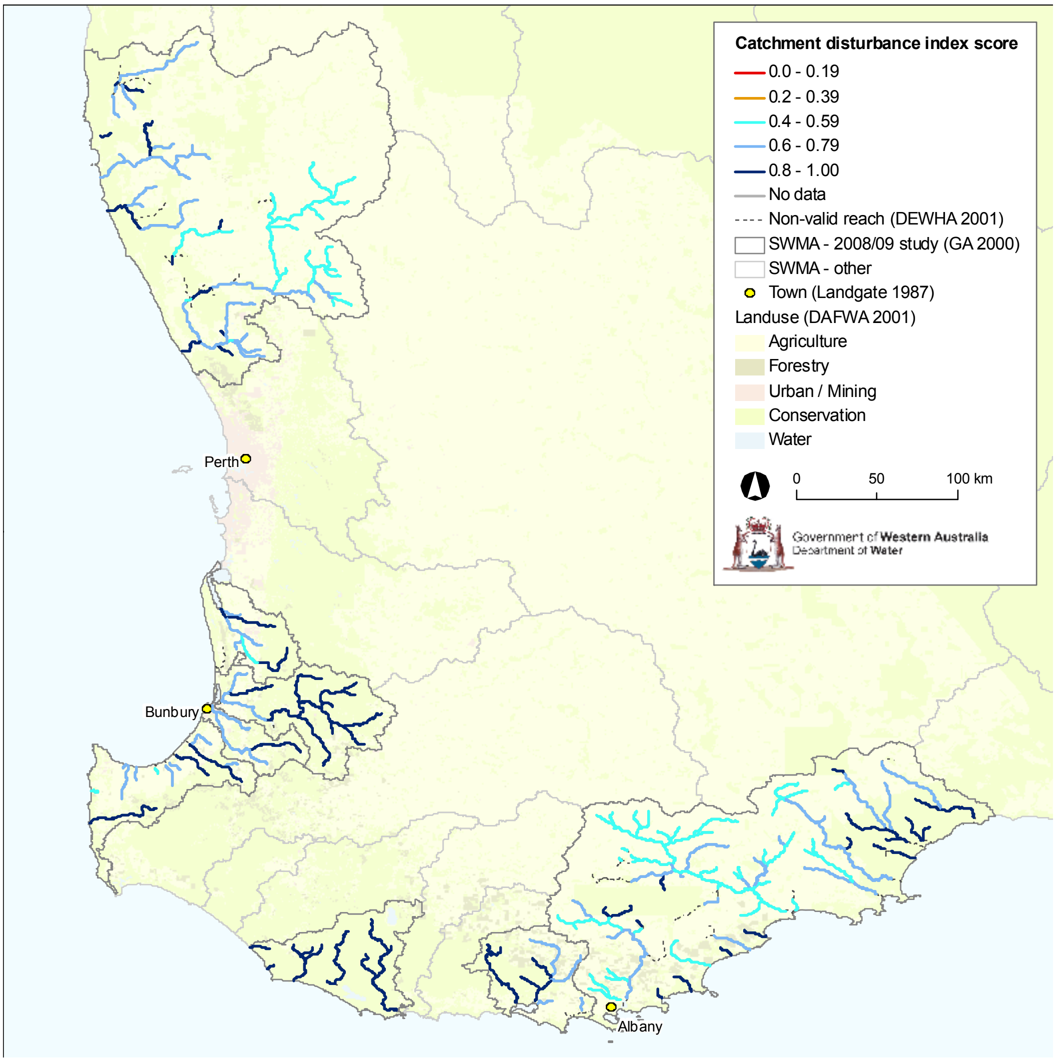


Figure 22 Catchment Disturbance index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Scores for the three sub-indices that make up the overall *Catchment Disturbance index* are outlined below and given in detail in Appendix A.

Land use sub-index

The *land use sub-index* scores for reaches assessed in the 2008 and 2009 field trials are shown in Figure 23 and can be found in Appendix A. Scores ranged between 0.5

and 1.0 (out of a possible 0.3 to 1.0; no land use scenario was deemed to represent a completely modified catchment with no ecological health value – see rationale in Storer et al. (in press b)). The lowest-scoring reaches occurred in Minyulo Brook and the upper reaches of the Moore River in the Moore-Hill River 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.

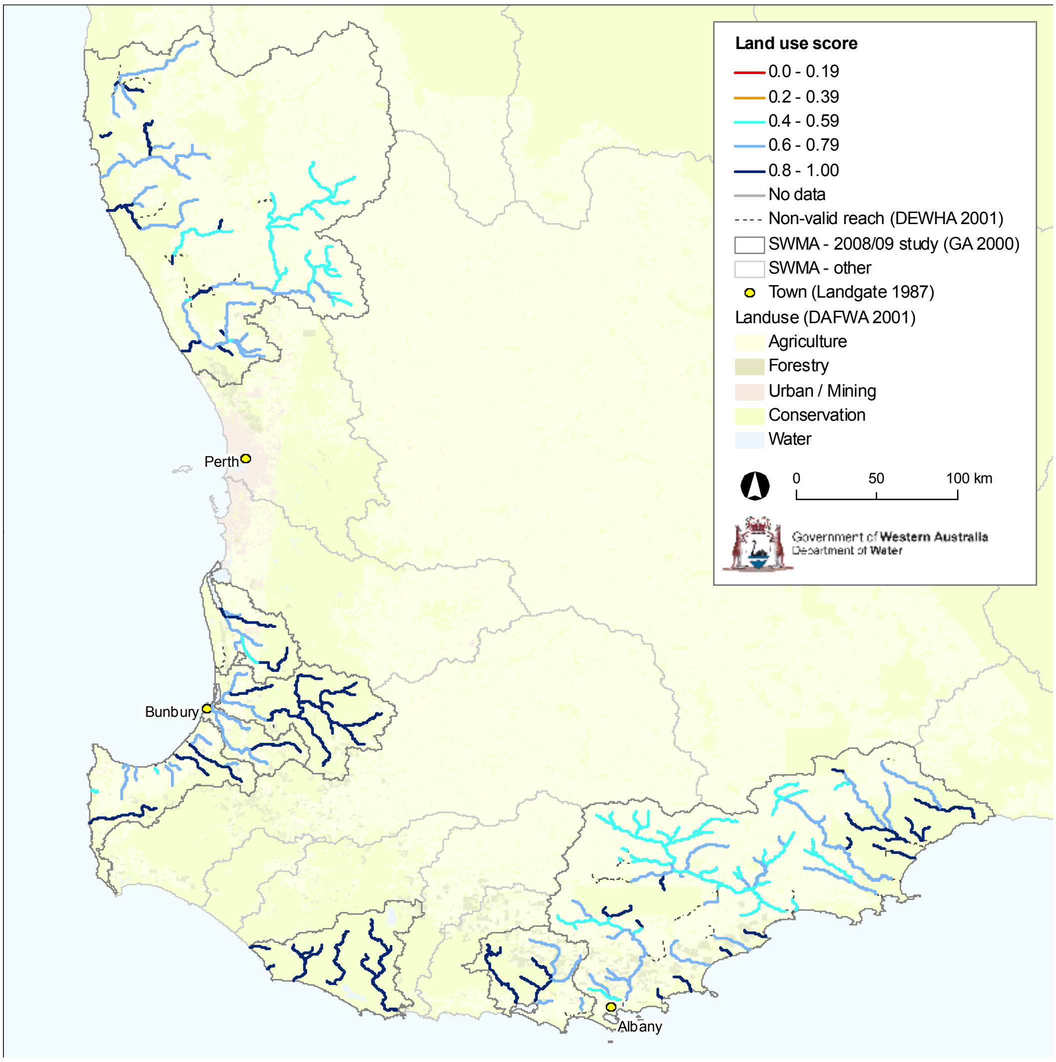


Figure 23 Land use sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Infrastructure sub-index

The *infrastructure sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 24 and can be found in Appendix A. 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. A finer resolution for this indicator (e.g. infrastructure in a narrow river corridor) has been suggested for future assessment – see rationale in Storer et al. (in press b).

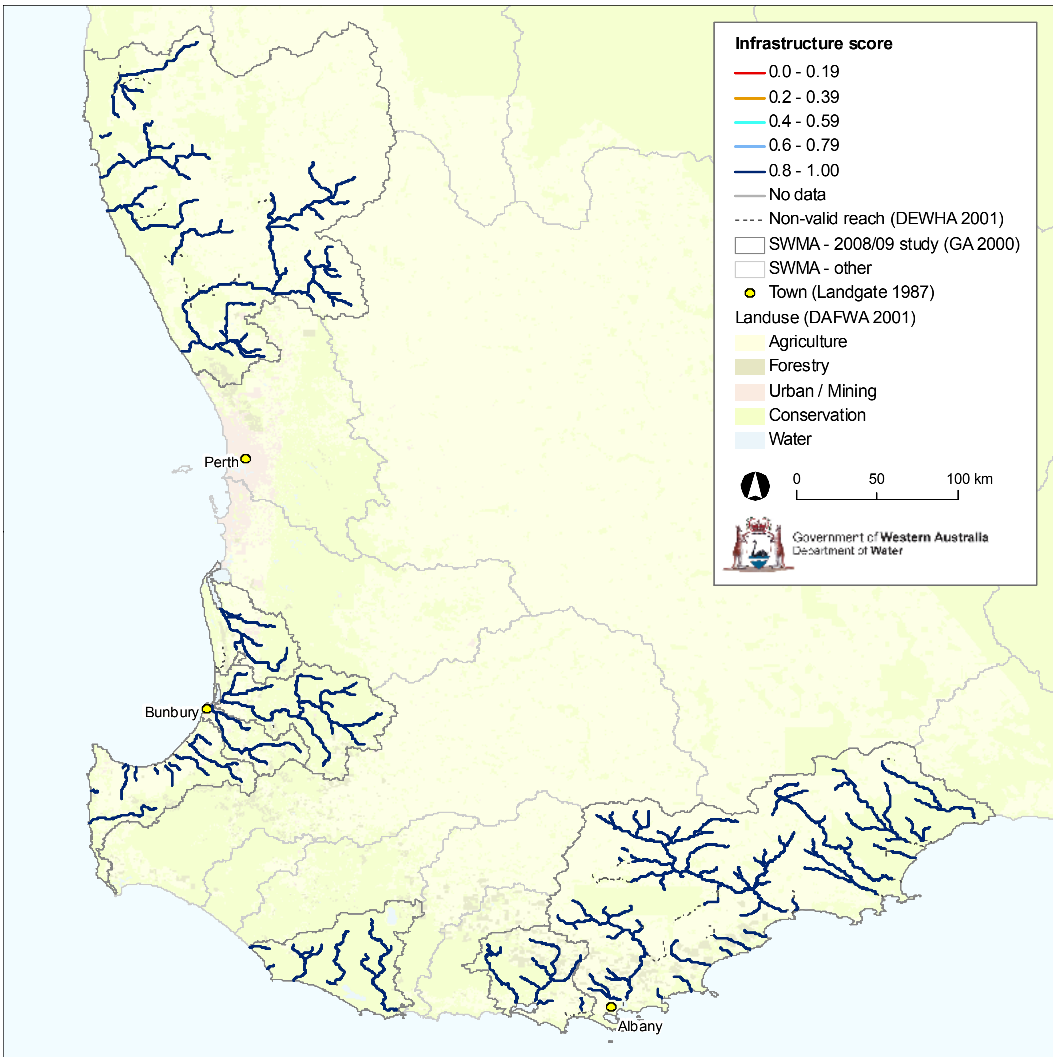


Figure 24 Infrastructure sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Land cover change sub-index

The *land cover change sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 25 and can be found in Appendix A. The majority of reaches (94%) scored 1.0 and all reaches scored in the largely unmodified category. 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 (see comments relating to future work in the *infrastructure sub-index* summary above).

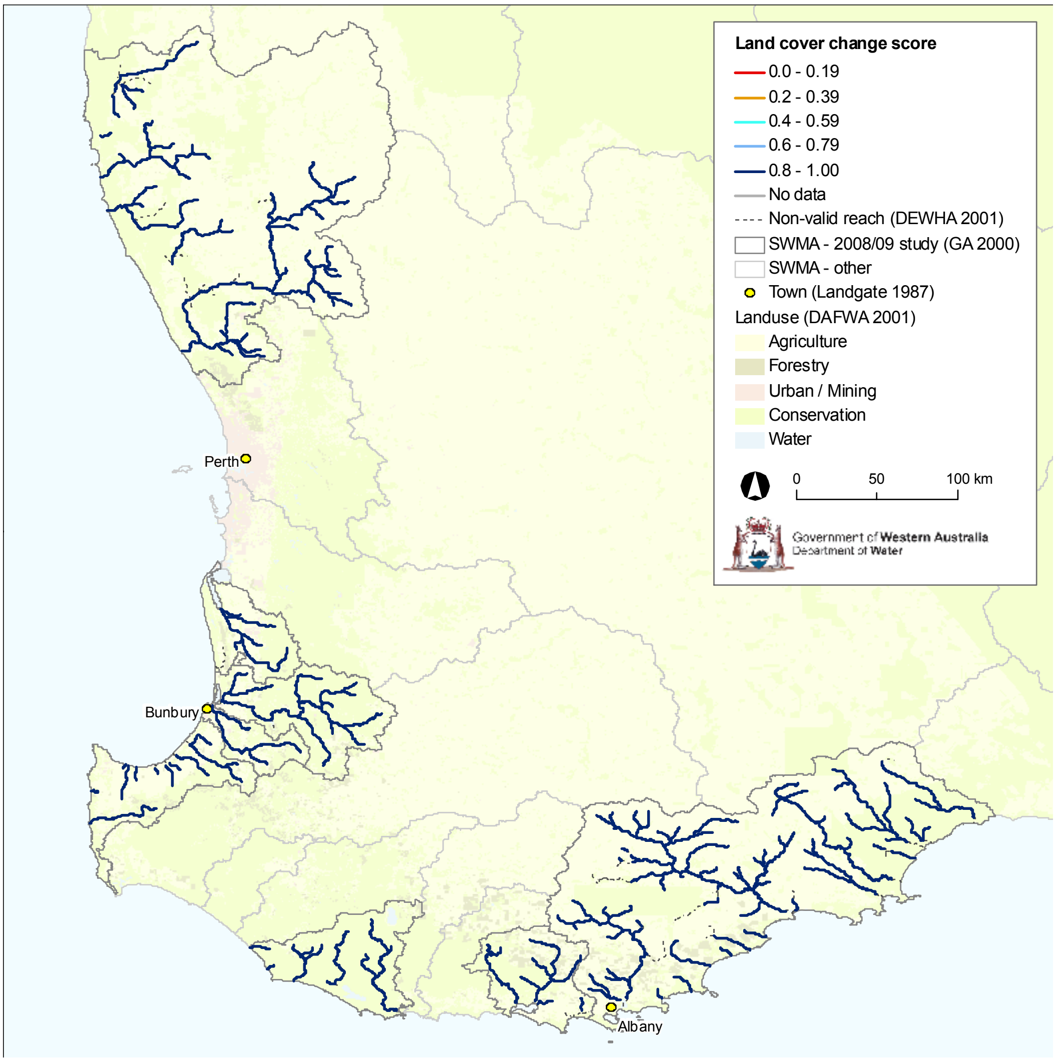


Figure 25 Land cover change sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Hydrological Change

Reach scores for the *Hydrological Change index* are provided in Figure 26. Note: scores are available for all reaches as this index was calculated remotely, rather than relying on field data (see Appendix A). *Hydrological Change index* scores show there is differentiation across SWWA, with lower scores generally correlating with areas that have a high proportion of agricultural land use.

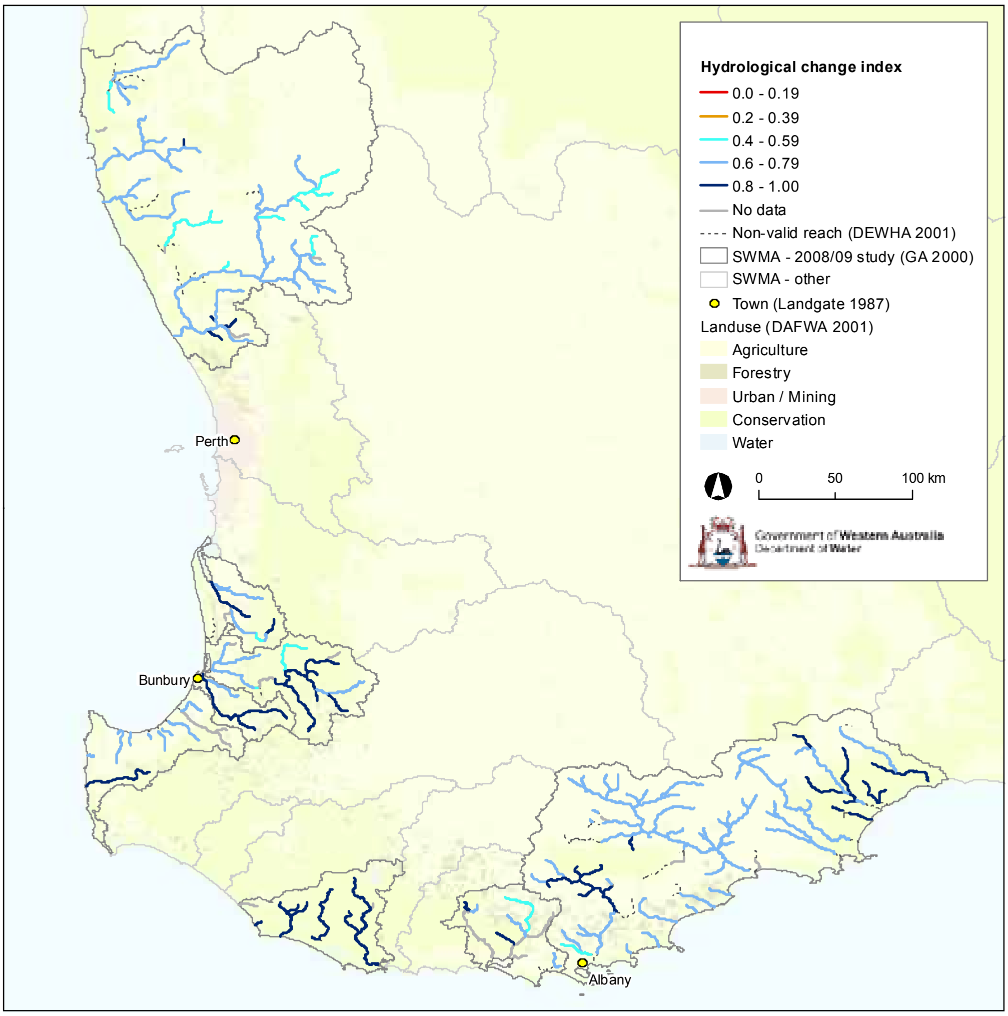


Figure 26 Hydrological Change scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Flow stress ranking sub-index

The scores for the five components (*low flow*, *high flow*, *proportion of zero flow*, *monthly variation* and *seasonal period*) that make up the *flow stress ranking sub-index* for reaches assessed in the 2008 and 2009 trials are shown in Figure 27 and can be found in Appendix A.

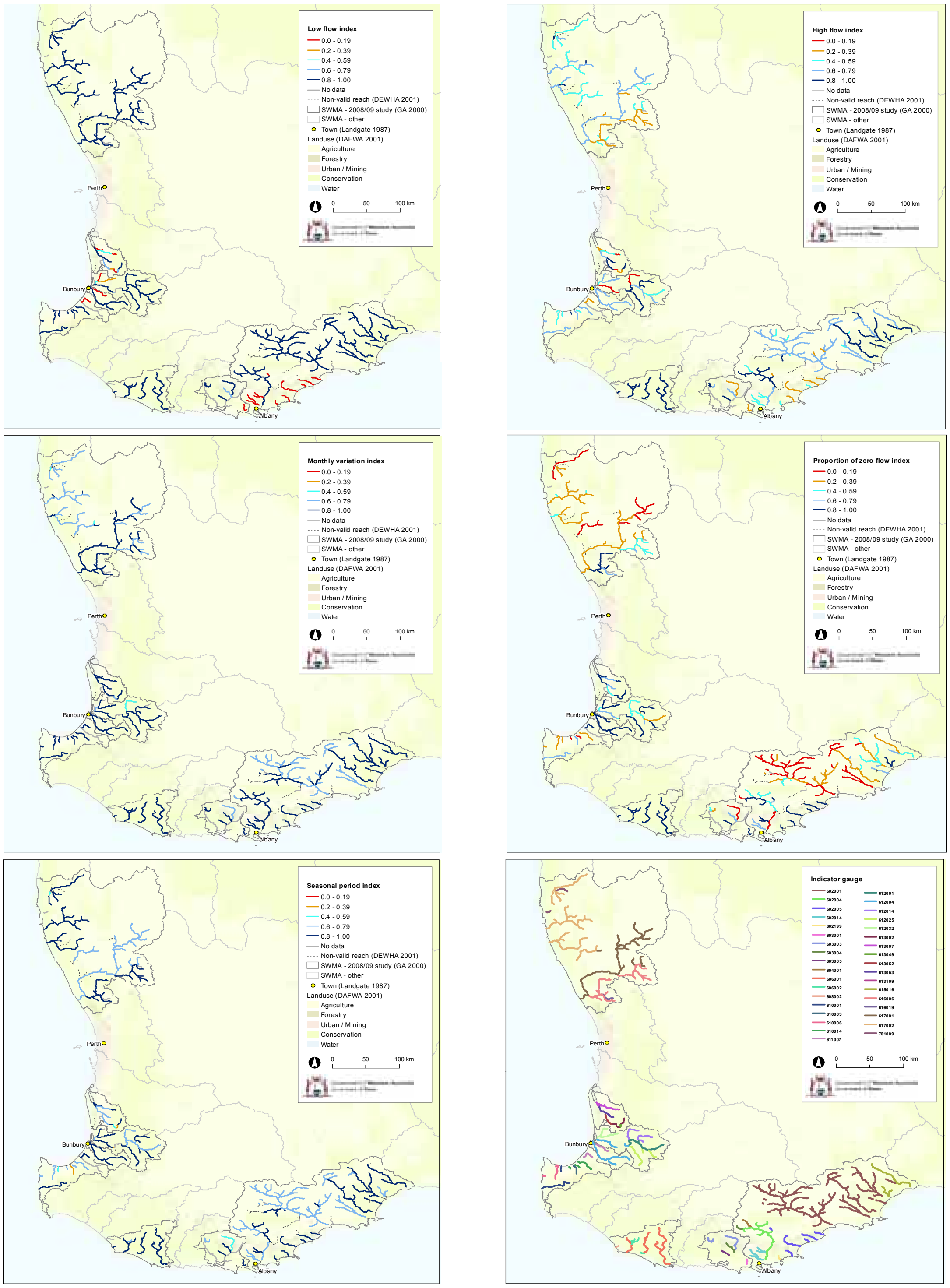


Figure 27 Component reach scores of the flow stress ranking: low flow (top left), high flow (top right), monthly variation (middle left), proportion of zero flow (middle right), seasonal period (bottom left). Indicator gauges used for determining flow for all reaches are also shown (bottom right)

The *low flow component* scores tended to the extremes with most reaches scoring as either largely unmodified or severely modified. Those reaches that scored as severely modified in the Harvey River, Collie River, Preston River and Busselton

Coast SWMAs tended to be either located in catchments where the presence of dams had reduced the catchment size of the reach or where extensive clearing of native vegetation had occurred, resulting in increased flows. This was not the case in the Albany River SWMA where reaches that scored as severely modified did not have dams in their catchments and were not necessarily highly cleared (with some catchments still retaining more than 50% of their vegetation). It is hypothesised that these reaches are showing stress due to being permanent reaches located in a high-rainfall area with a small rainfall:runoff ratio. These reaches therefore have more potential to be modified (with clearing increasing the magnitude of low flow) than those that are located further east in the SWMA, in the lower rainfall zone.

The *high flow component* scores were also influenced by the presence of dams. The severely modified reaches in both the Collie and Harvey SWMAs are located below water supply reservoirs (and therefore now have smaller catchment areas and smaller high flows than under pre-impact conditions). The substantially modified reaches in the Moore-Hill SWMA all occur in the south-east corner. It is unclear whether these scores are a remnant of the indicator gauge used to calculate the *high flow component* scores of these reaches (the scores for most of these reaches were calculated using the same indicator gauge, see bottom right map in Figure 27) or due to the different land use in this portion of the SWMA.

Most reaches that scored poorly in the *proportion of zero flow component* now experience much shorter periods of zero flow than under pre-impact conditions. This can generally be attributed to extensive clearing increasing the duration of river flows by raising groundwater levels.

Water Quality

The final scores for the *Water Quality index* for reaches assessed during the 2008 and 2009 field trials are provided in Figure 28.

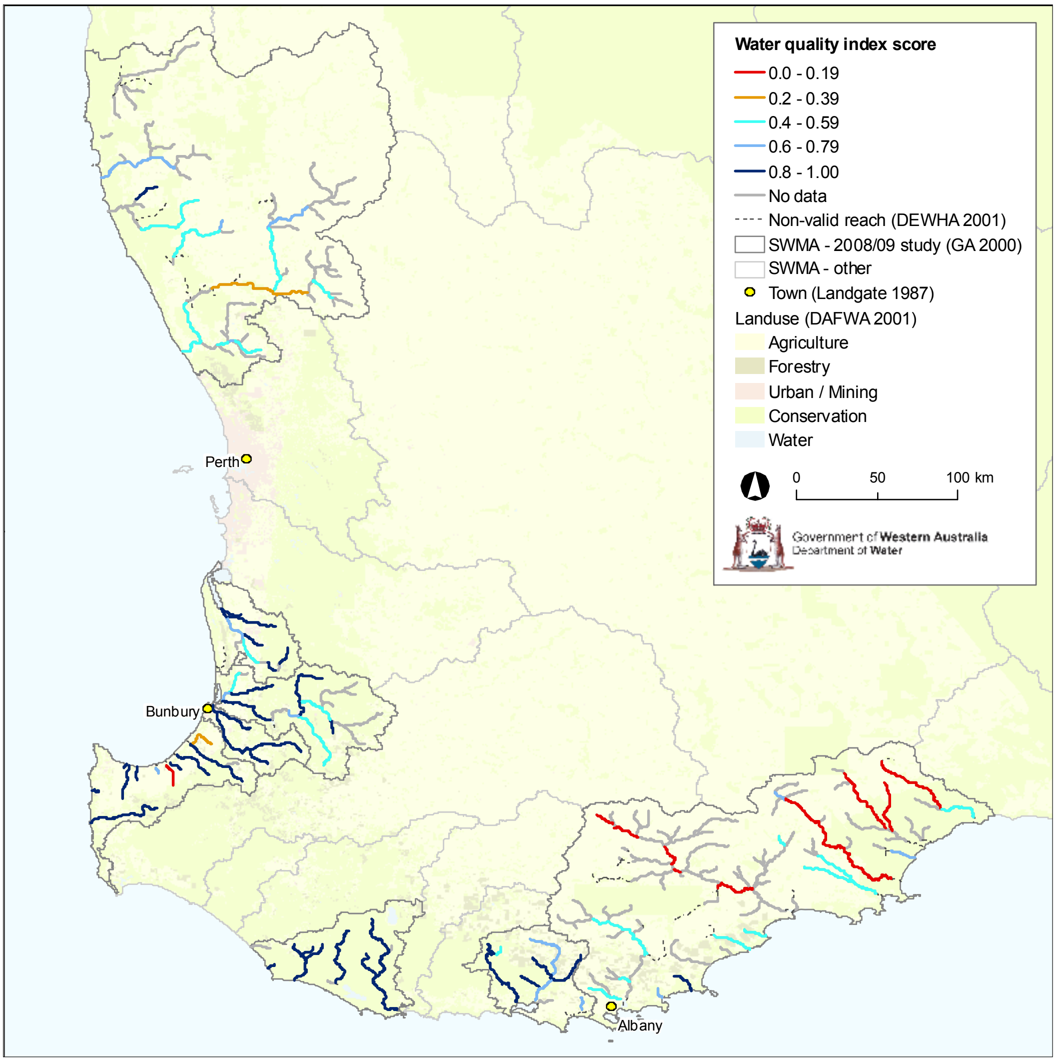


Figure 28 Water Quality index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

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 middle 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 – 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 (only salinity would be targeted because of the data used to generate the index and because the precautionary approach was applied). The *Water Quality index* should be viewed as an interpretive index, where management priorities are set on other values (e.g. protecting biodiversity) and to highlight specific impacts to be addressed.

Total nitrogen sub-index

The final scores for the *total nitrogen sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are provided in Figure 29.

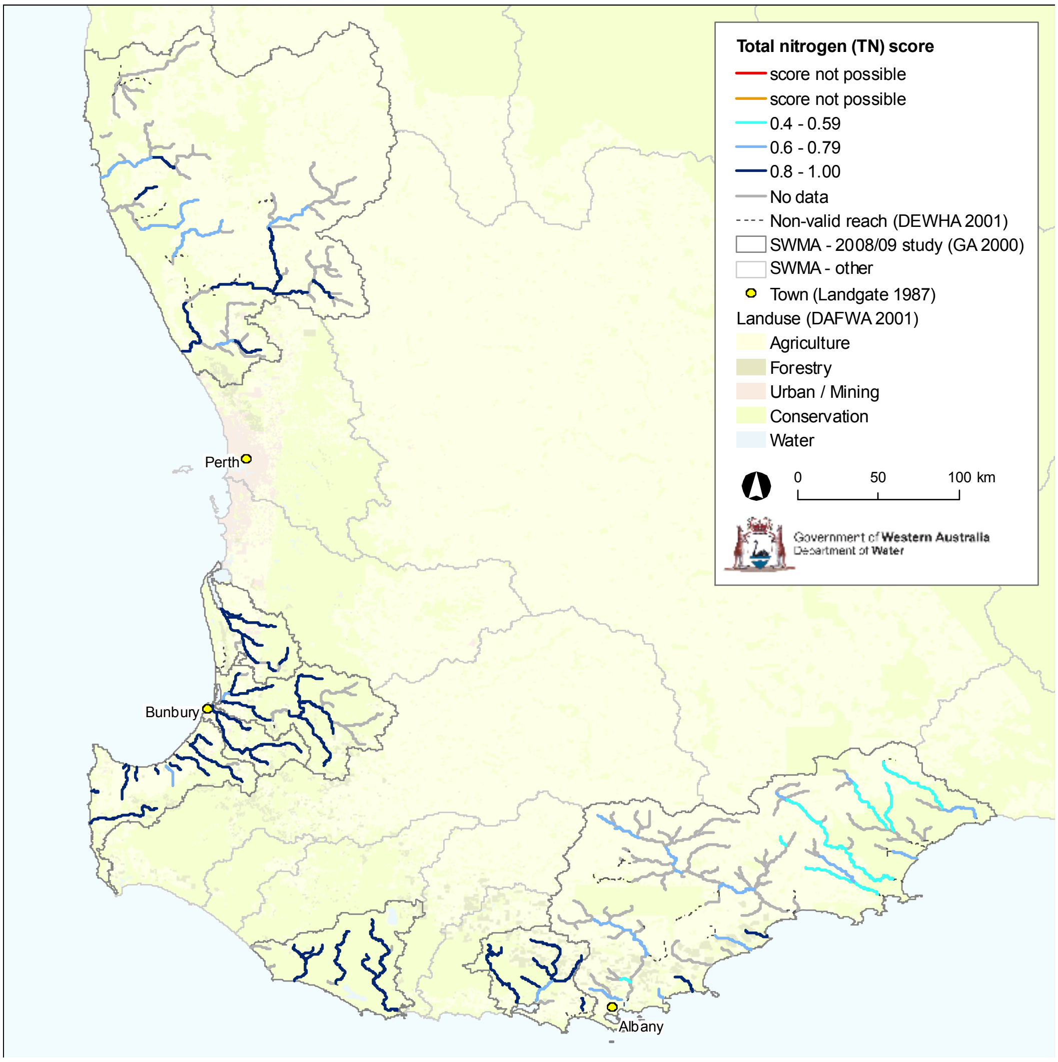


Figure 29 Total nitrogen sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

All possible SWWA-FARWH scores across the impact scale for total nitrogen (TN) were present within SWWA (note: scores less than 0.4 are not possible with the current scoring protocols, see review in Storer et al. (in press b)). A general trend is apparent across SWWA, with nitrogen 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, livestock having unimpeded access. Agricultural areas in the south-west corner of SWWA (which have lower nitrogen concentrations) have higher rainfall and typically more intact streamside vegetation.

Total phosphorus sub-index

The final scores for the *total phosphorus sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are provided in Figure 30.

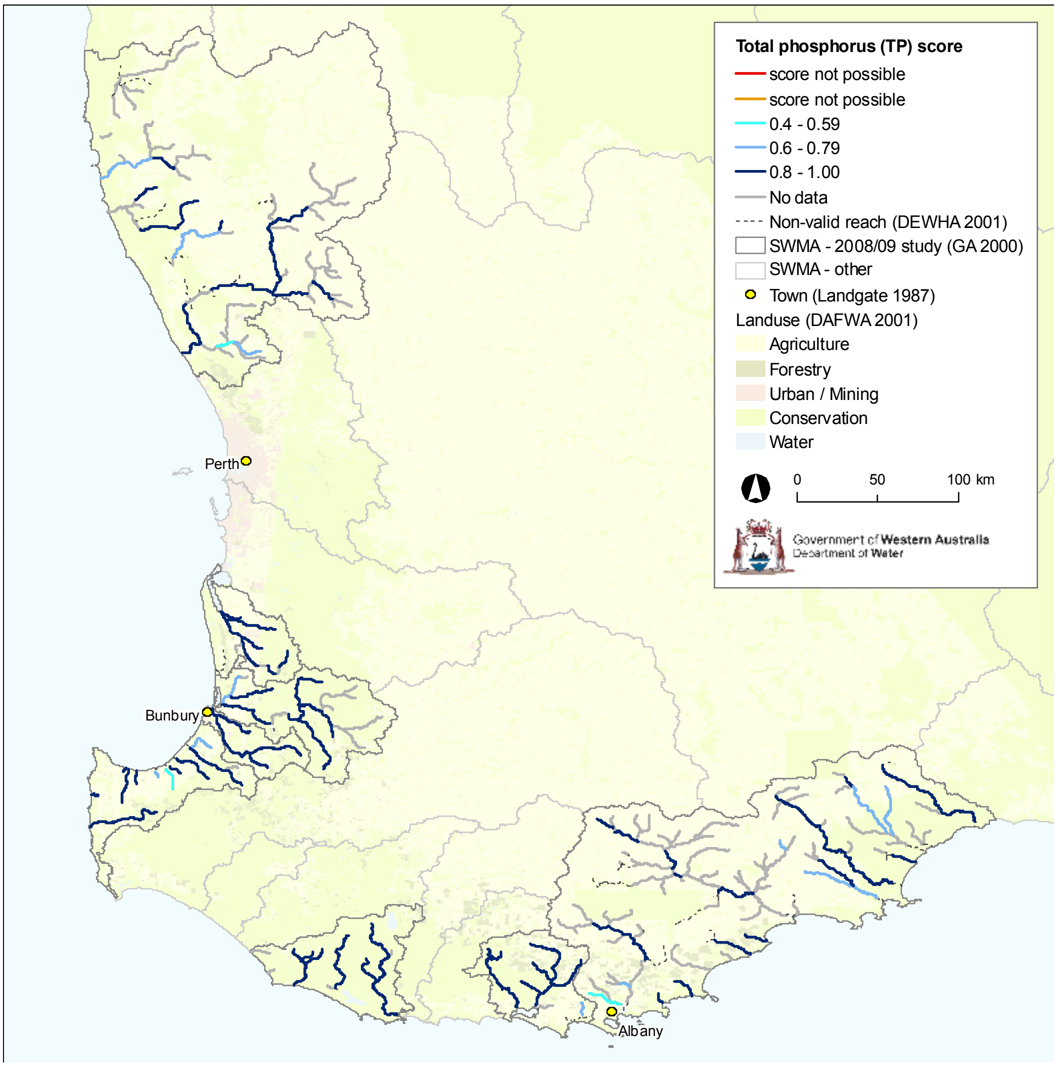


Figure 30 Total phosphorus sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Total phosphorus (TP) concentrations were relatively low across SWWA (largely unmodified), based on the categories assigned by the SWWA-FARWH. There were some localised systems with elevated phosphorus concentrations that fell into the moderately modified band. Note: reaches that scored 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 categories do not exist for this sub-index.

Turbidity sub-index

The final scores for the *turbidity sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are provided in Figure 31.

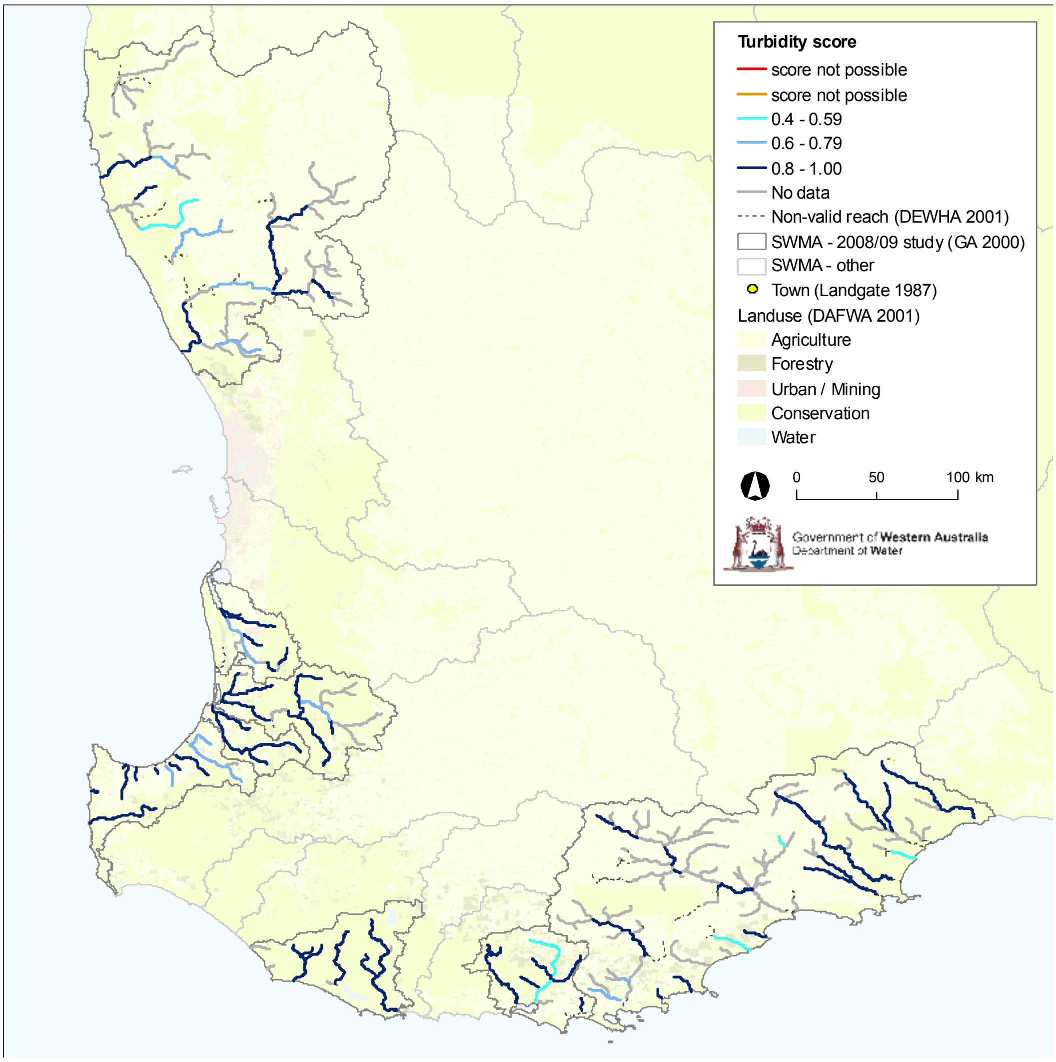


Figure 31 Turbidity sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Turbidity was elevated in a number of areas but a regional pattern was not apparent; that is, turbidity did not appear to be related to natural features. Even though turbidity did not present as a serious issue for SWWA (most reaches scoring as slightly modified or largely unmodified), the scores did show sensitivity to something other than natural features: hence the inclusion of turbidity in the future is supported.

Salinity sub-index

The final scores for the *salinity sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are provided in Figure 32. Note: salinity scores are available for most reaches as these were calculated using an existing dataset that comprised both measured and modelled data.

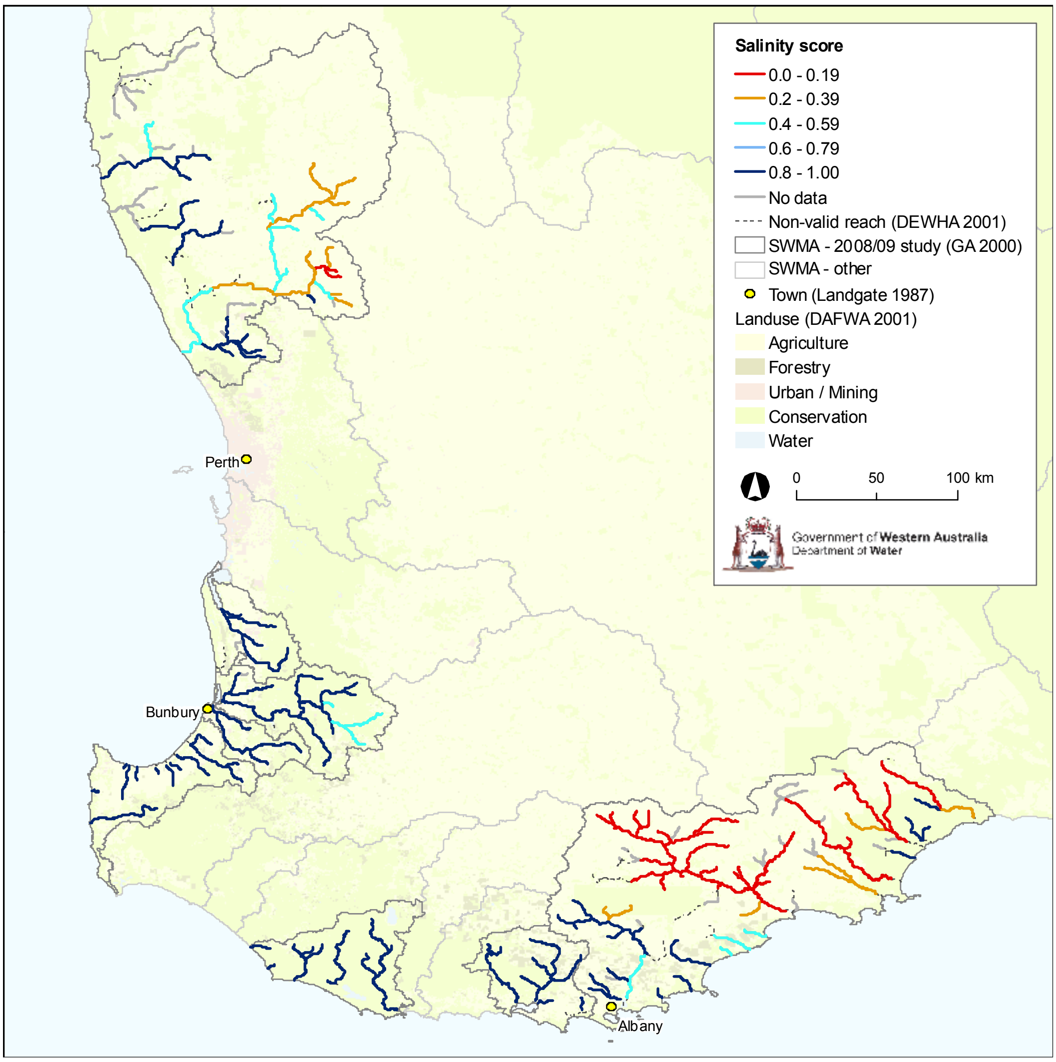


Figure 32 Salinity sub-index scores for reaches in SWMAs assessed in spring 2008 and 2009 within the SWWA-FARWH trials

Salinity sub-index scores were generally the worst of the sub-indices of the *Water Quality index*, with numerous reaches presenting as severely modified (primarily in the Albany Coast SWMA) and some 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 those 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.

Diel dissolved oxygen sub-index

The final scores for the *diel dissolved oxygen sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are provided in Figure 33.

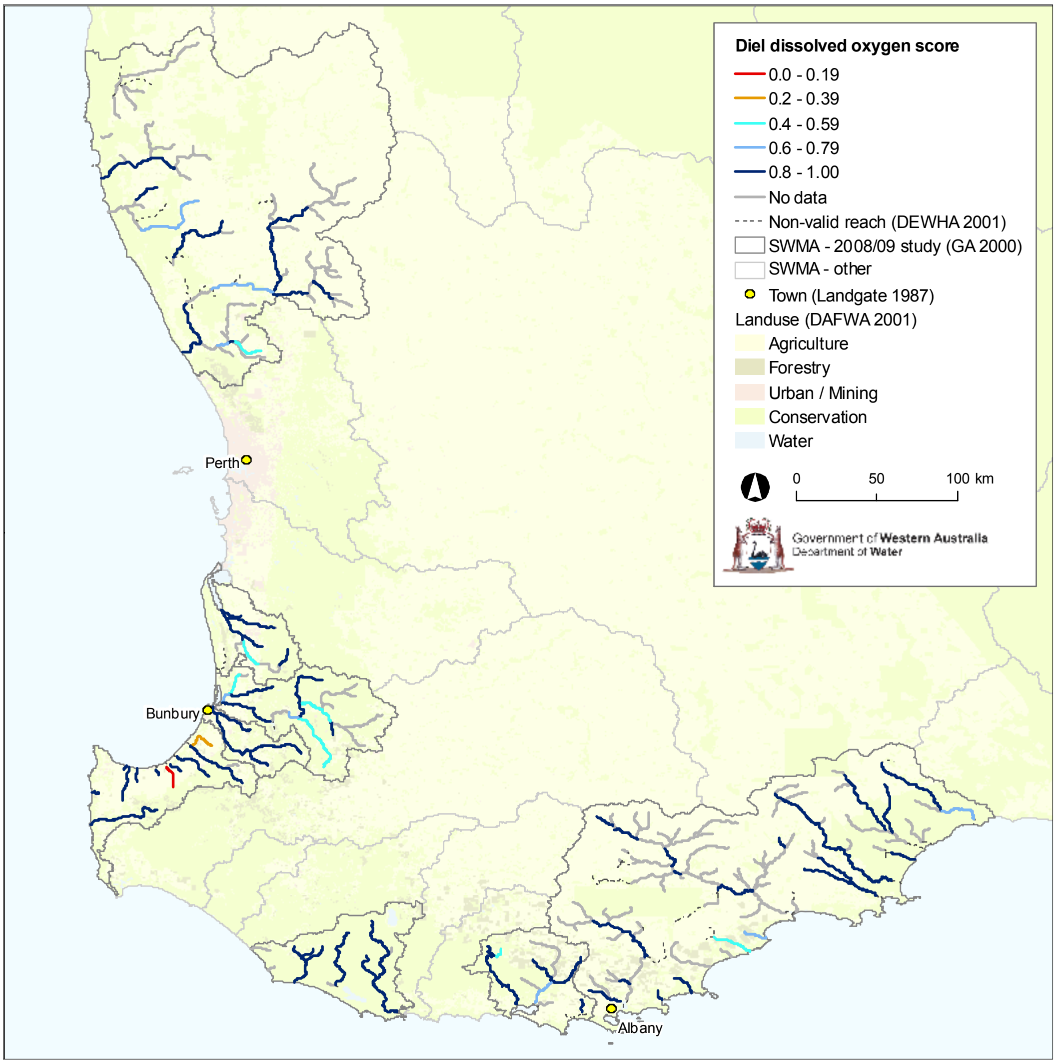


Figure 33 Diel dissolved oxygen sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Diel dissolved oxygen appeared to be within a relatively healthy range across SWWA, with a few localised exceptions. These exceptions were south of Bunbury, with two reaches scoring as substantially and severely modified. These results correlated with poor fringing zones, macroinvertebrates and elements of Hydrological Change scores, and also with phosphorus and turbidity impacts. In addition, field observations recorded anaerobic-smelling sediments.

Diel temperature sub-index

The final scores for the *diel temperature sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are provided in Figure 34.

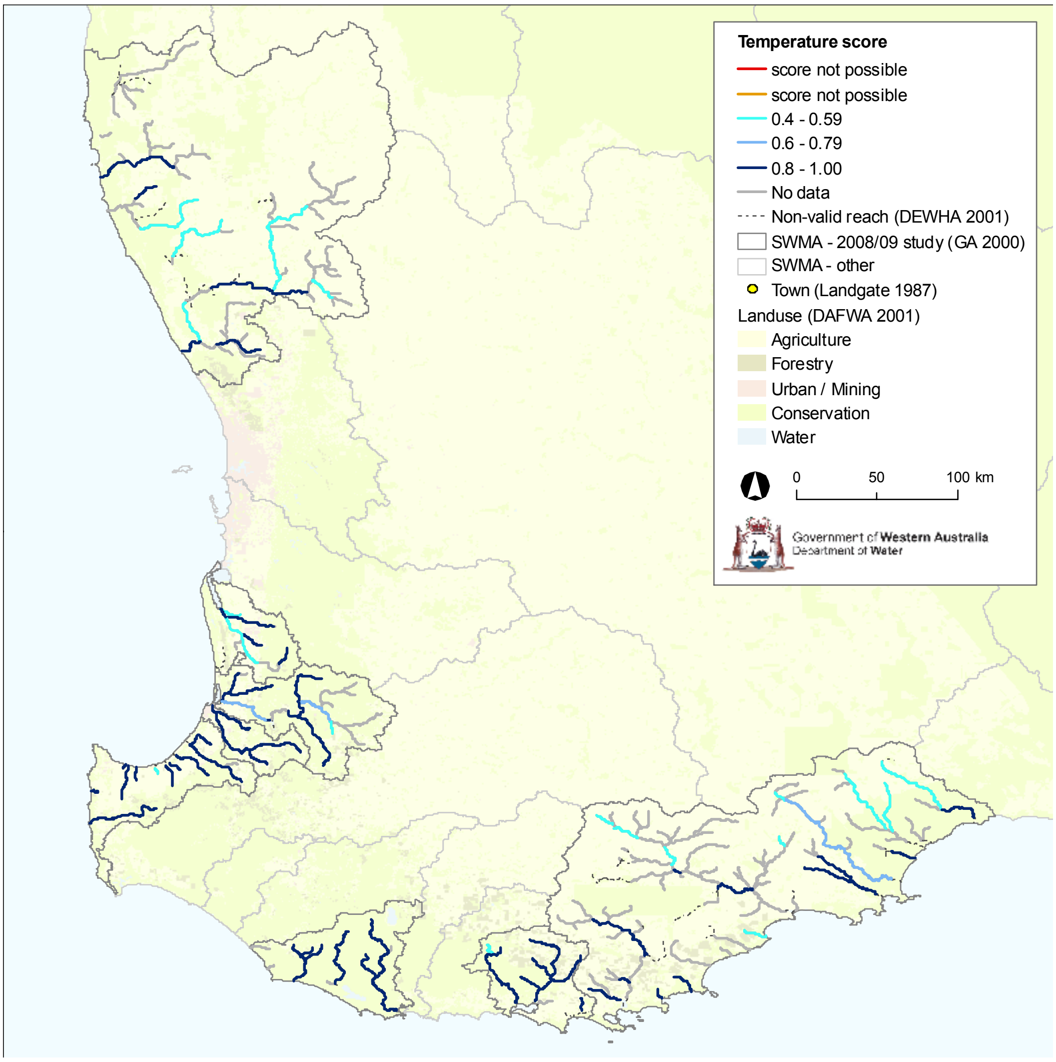


Figure 34 Diel temperature sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Diel temperature provided a relatively coarse indicator of impact, given that only two scores were possible based on range alone. Temperature scores did correlate with reaches in the north and east of SWWA, 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 the taller forests of the south-west corner) and are thus less influenced by shading. Furthermore, the SWMAs to the north and east are generally more extensively cleared than other systems, with greater impacts on riparian vegetation. However, in saying this, ranges used to score temperatures were based on expectations for all systems in the area and similar temperature problems were observed within other SWMAs.

Physical Form

The *Physical Form index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 35.

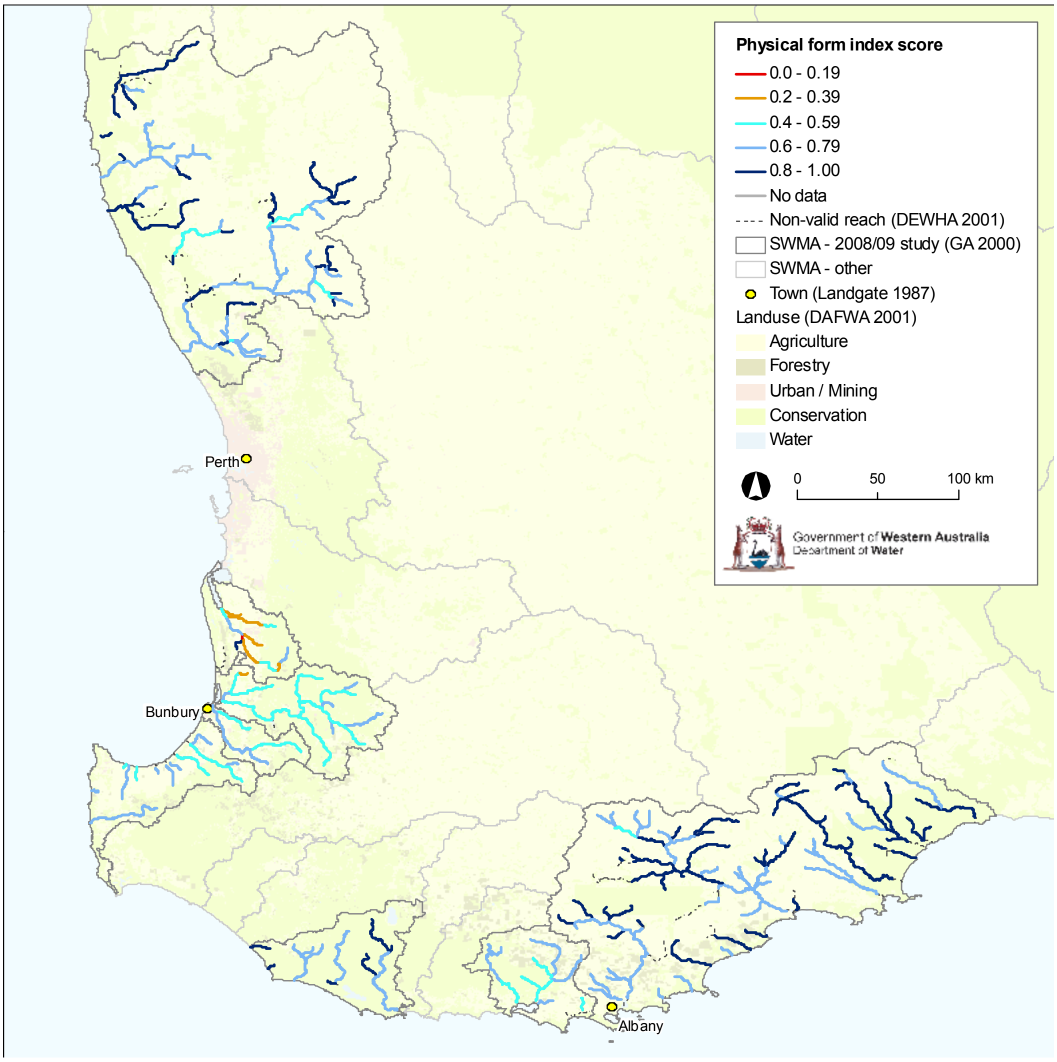


Figure 35 Physical Form index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Note: of the 234 reaches included in the 2008 and 2009 assessments, the *Physical Form index* scores for 60% of reaches were calculated using the *artificial channel sub-index* and *longitudinal connectivity sub-index* scores only, as it was not possible to conduct field work for every reach (the *erosion sub-index* requires site visits for observations). The remaining 40% of reaches were sampled and the *Physical Form index* scores were calculated using all three sub-index scores.

The Moore-Hill Rivers, 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 there was erosion 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 have more dams present. Further, many reaches in the Harvey River SWMA have been modified into drains to help remove water from the agricultural areas.

Longitudinal connectivity sub-index

The *longitudinal connectivity sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 36.

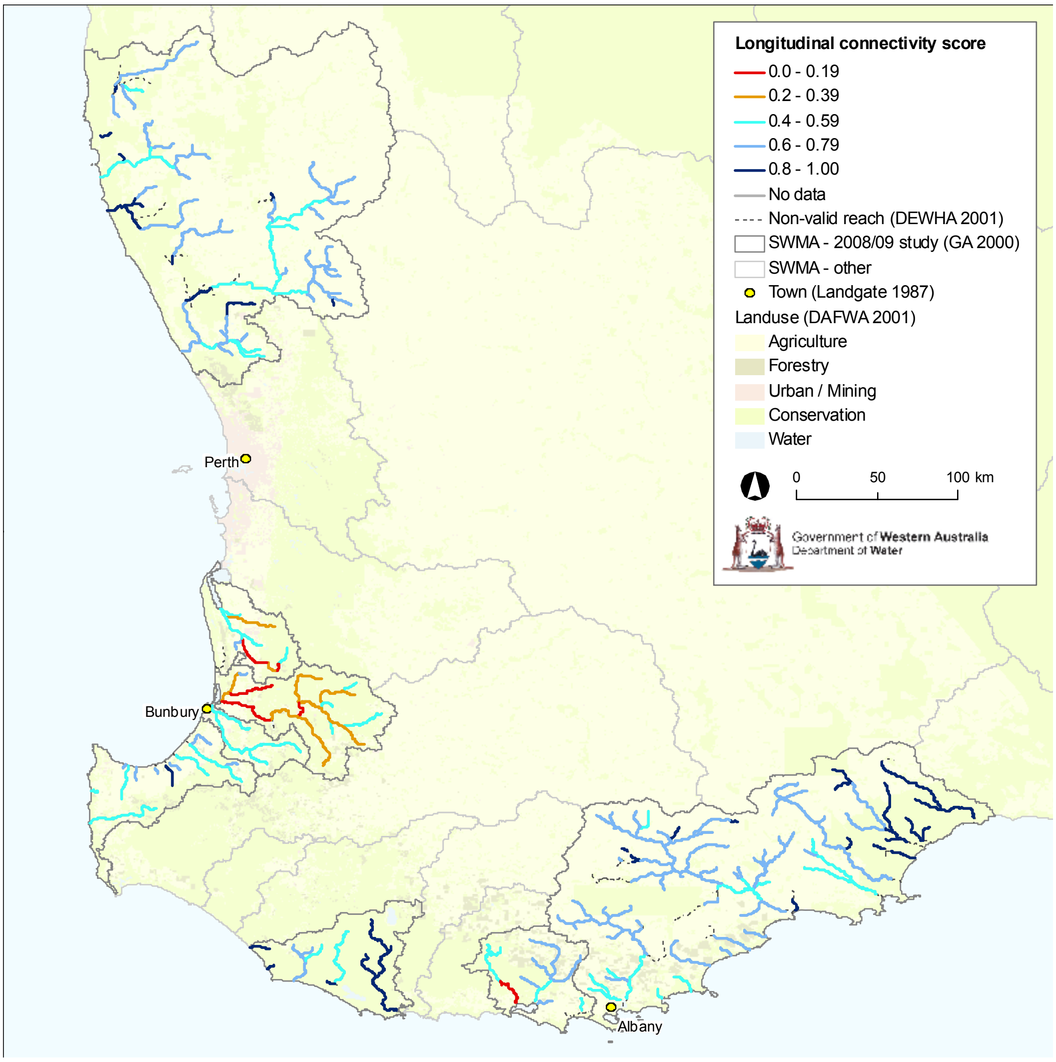


Figure 36 Longitudinal connectivity sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

The lowest scores occurred in the Harvey River and Collie River SWMAs, which matched expectations given both have higher levels of development for agriculture and drinking water sources than the other SWMAs. As such, they have a number of major dams, minor dams and associated gauging stations, plus an extensive network of roads.

In the Collie River SWMA, four major dams are 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 there are 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, four major dams are located on four of the 14 reaches (Harvey Dam, Stirling Dam, Samson Brook Dam and Samson Brook Pipehead Dam), plus there are a number of minor dams (on eight reaches) and gauging stations (on six reaches). Six of the 14 reaches also 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.

Artificial channel sub-index

The *artificial channel sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 37.

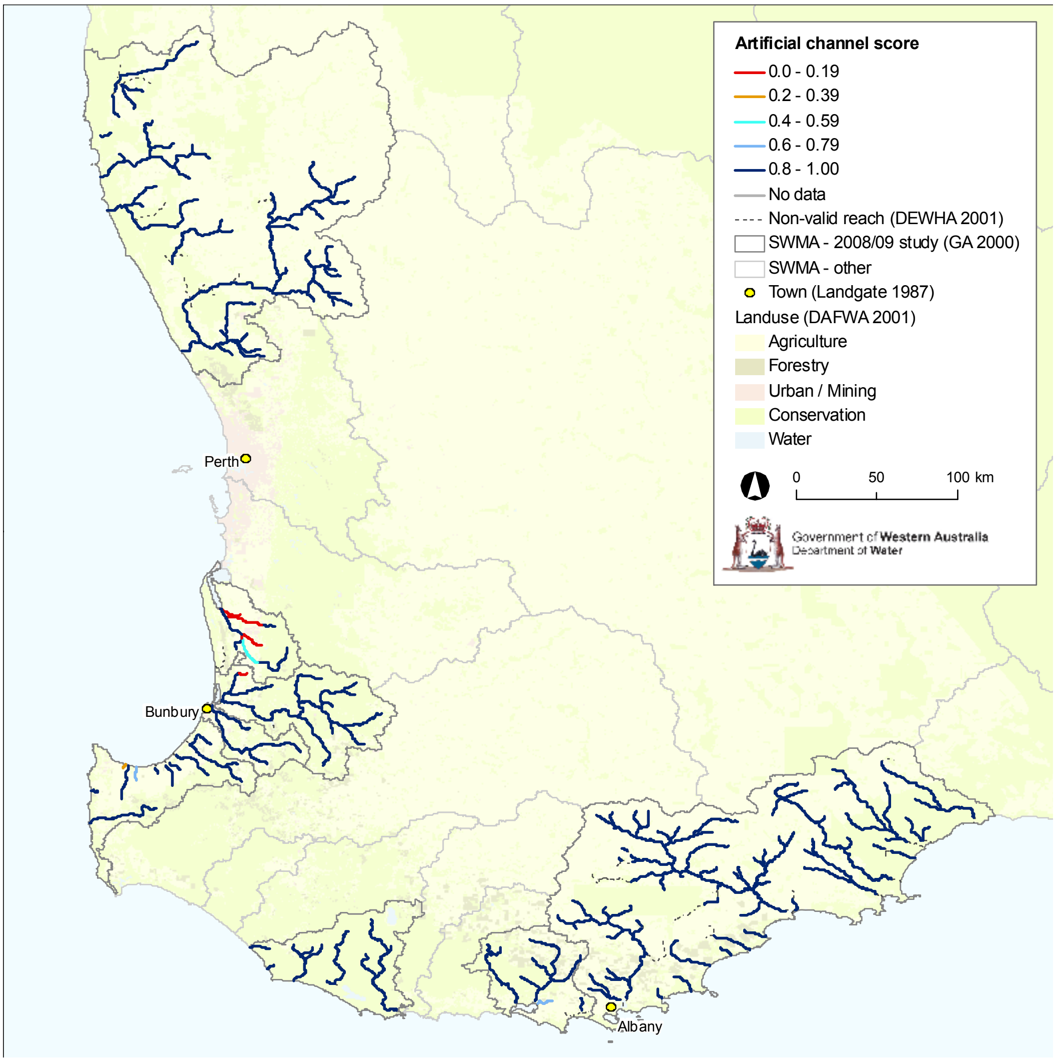


Figure 37 Artificial channel sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

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) that 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 channels.

Erosion sub-index

The *erosion sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 38. Note: the 2008 assessment scores were calculated using different field observations and scoring methods to the 2009 assessment, see Storer et al. (in press b).

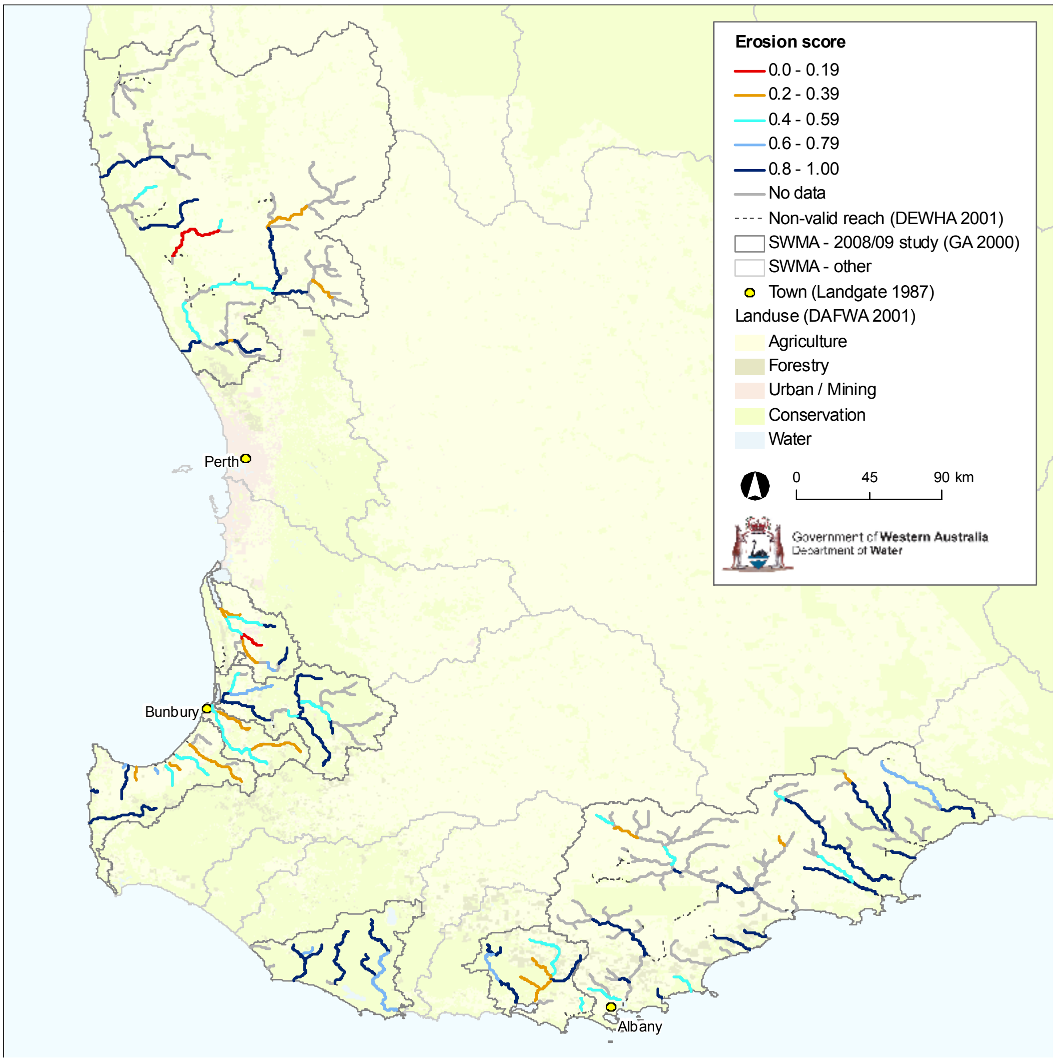


Figure 38 Erosion sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

The reaches with the lowest scores (0.0 to 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 had 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.

Fringing Zone

The final scores for the *Fringing Zone index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 39. Note: scores are available for all reaches as this index was calculated using two sub-indices, one of which (*extent of fringing zone*) was calculated remotely and the other (*nativeness*) relied on field data.

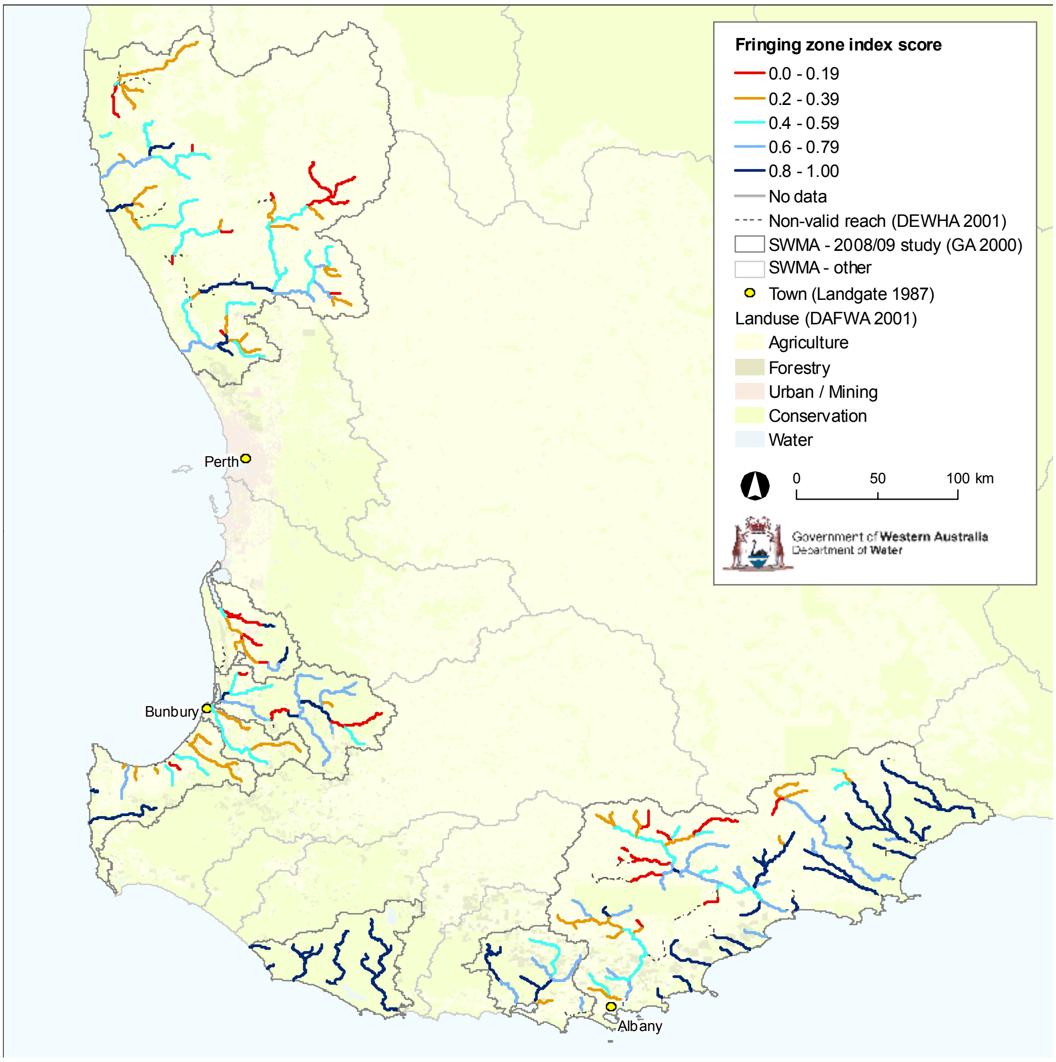


Figure 39 Fringing Zone index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

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 or 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 held by departmental staff and are highly correlated with land uses that typically result in removal of trees and clearing of understorey (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.

Extent of fringing zone sub-index

Two components were calculated for this sub-index, *fringing vegetation length* and *fringing vegetation width* – these are presented individually below.

Fringing vegetation length component

Scores for the *fringing vegetation length component* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 40.

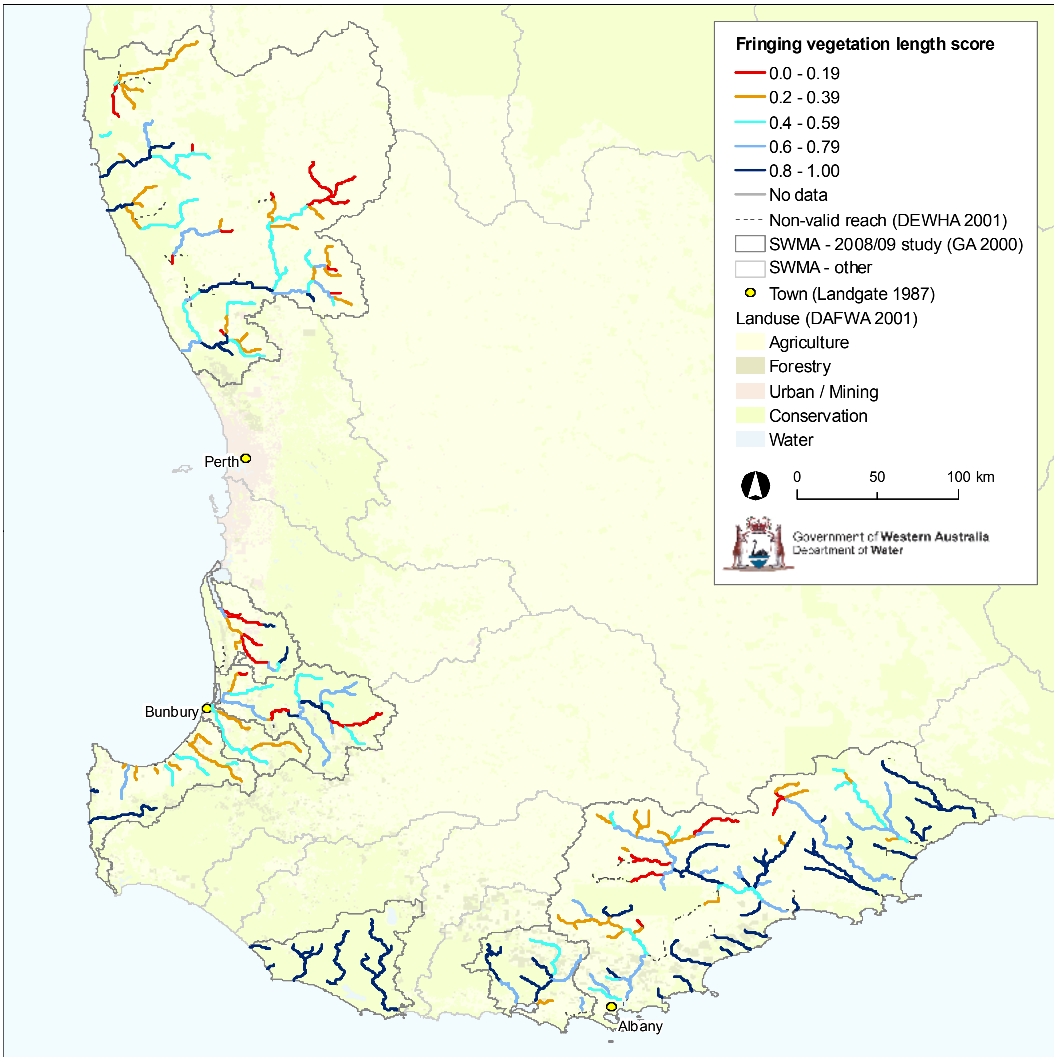


Figure 40 Fringing vegetation length component scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

In general, higher-order streams scored more poorly than lower-order streams. This reflects the extent of clearing that has occurred in these areas, predominantly for agriculture. Many of these streams have had their riparian zones cleared, in some cases completely. The Shannon River SWMA scored very well, which correlates with field observations of this near-pristine system. The scores also correlated well with expected associated impacts such as land use.

Fringing vegetation width component

Scores for the *fringing vegetation width component* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 41.

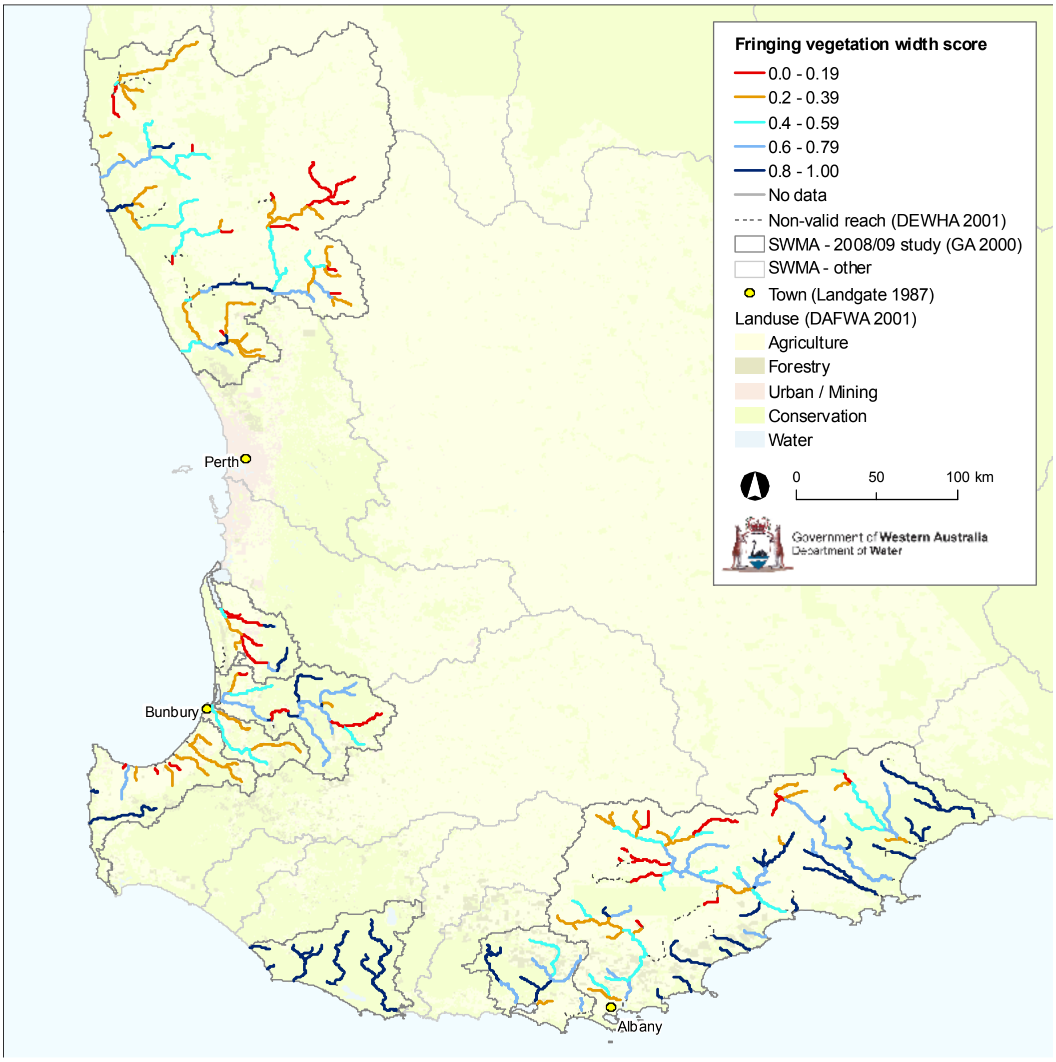


Figure 41 Fringing vegetation width component scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Fringing vegetation width component scores correlated closely with the *fringing vegetation length component* scores. This was expected because clearing generally affects both the width and length of vegetation remaining. Both components are included because ecologically they measure different things.

Nativeness sub-index

Scores for the *nativeness sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 42.

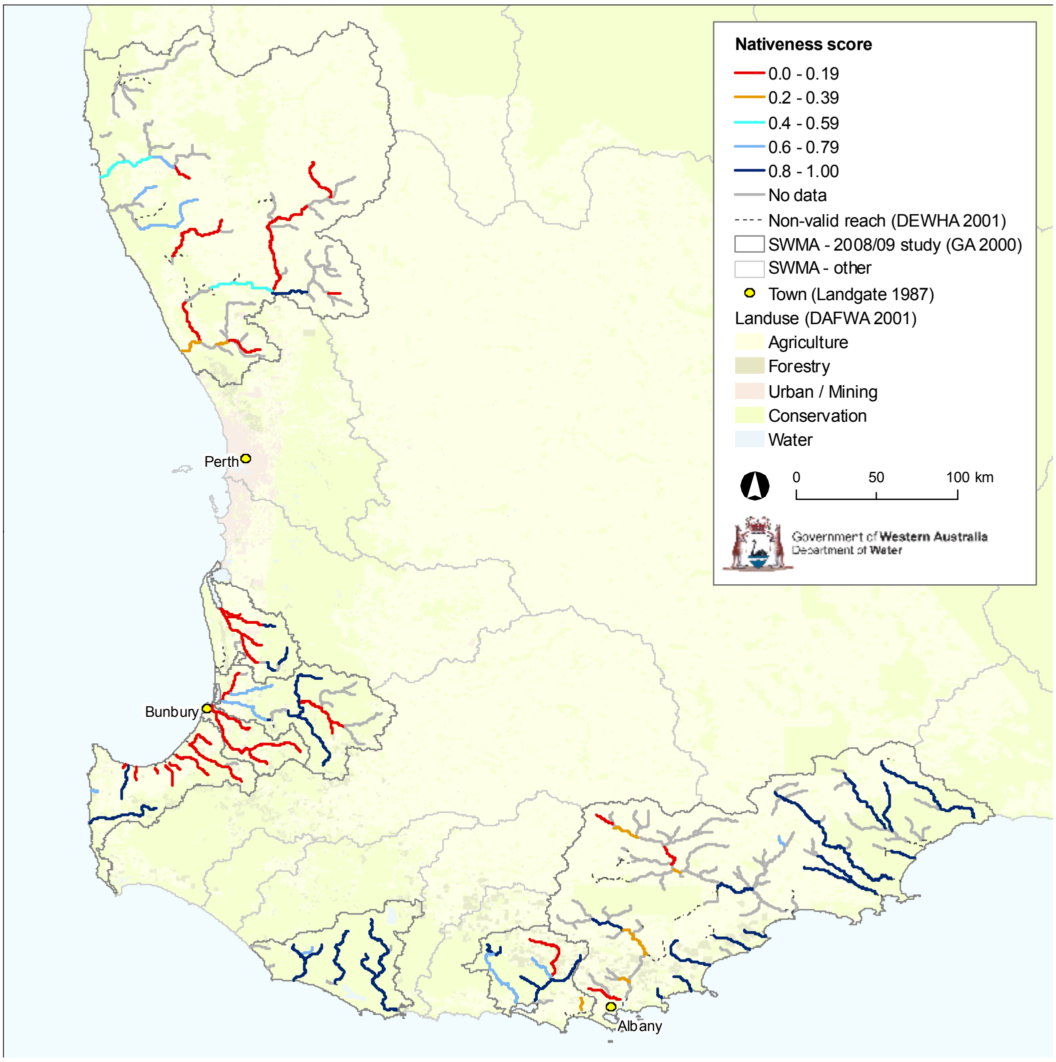


Figure 42 Nativeness sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

The *nativeness sub-index* scores are dominated by extremes (see Figure 42), with most reaches being either largely unmodified or severely modified. This pattern reflects the nature of invasive species: some systems (rare) had no non-native species (predominantly the Wild Rivers located on the eastern edge of the Albany Coast SWMA and the entire Shannon River SWMA that is largely protected for conservation purposes); others had limited exotics (where species have been introduced into systems with a resilient native population); and the remainder were dominated by exotics, primarily grasses (typically agricultural areas such as the Harvey River, Preston River and Busselton Coast SWMAs).

Aquatic Biota

The final scores for the *Aquatic Biota index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 43.

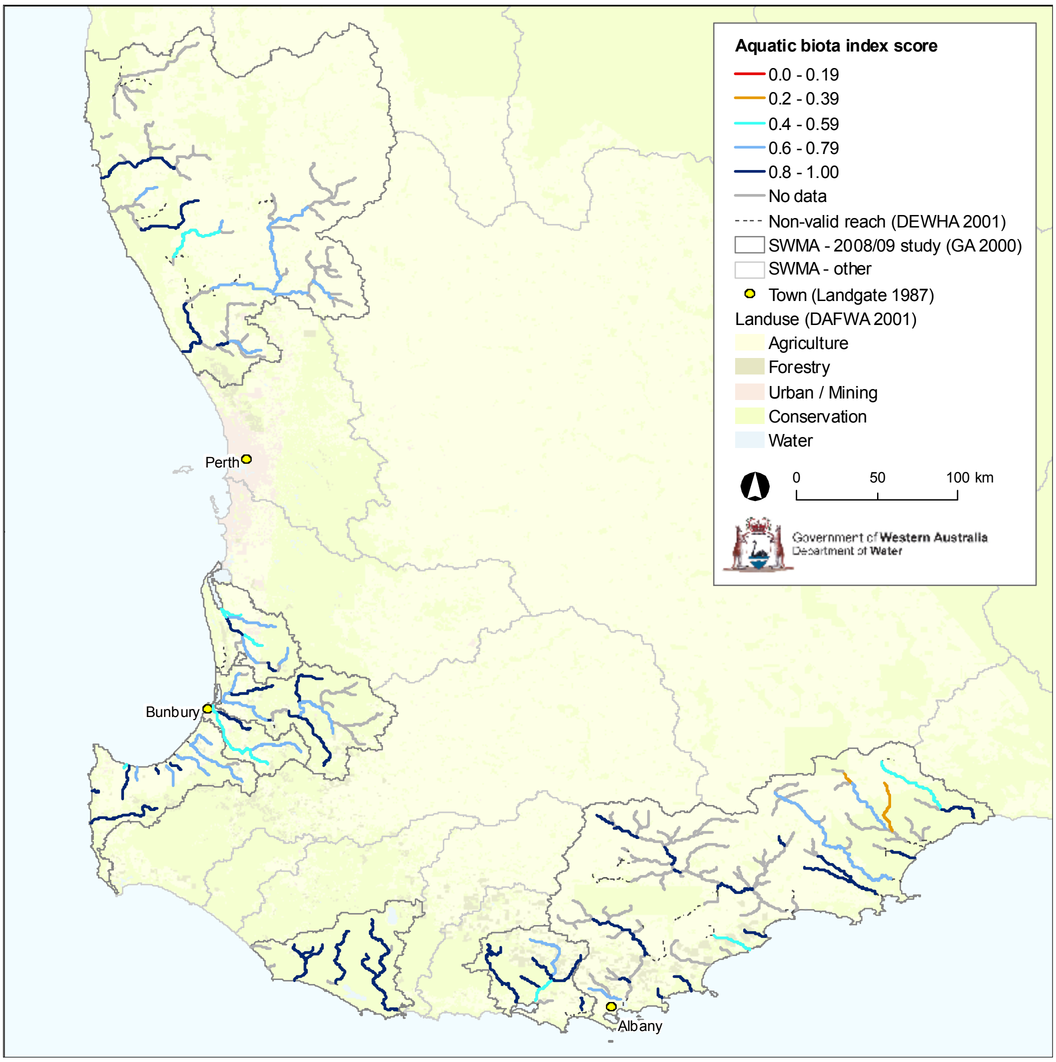


Figure 43 Aquatic Biota index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

The scores returned reflect our general understanding of reach health as determined by field officers and regional environmental managers, with much of SWWA being 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, it is believed that some reaches in the Shannon River SWMA (see Appendix A) have been represented in a worse condition than is actually the case. This may be related to limitations of the *macroinvertebrate sub-index* or indicate a yet-unknown impact (such as climate change). The most significant impacts are found in the eastern rivers of the Albany Coast SWMA, which reflects salinisation of the area.

Fish/crayfish sub-index

The *fish/crayfish sub-index* scores for reaches assessed in the 2008 and 2009 trials are shown in Figure 44.

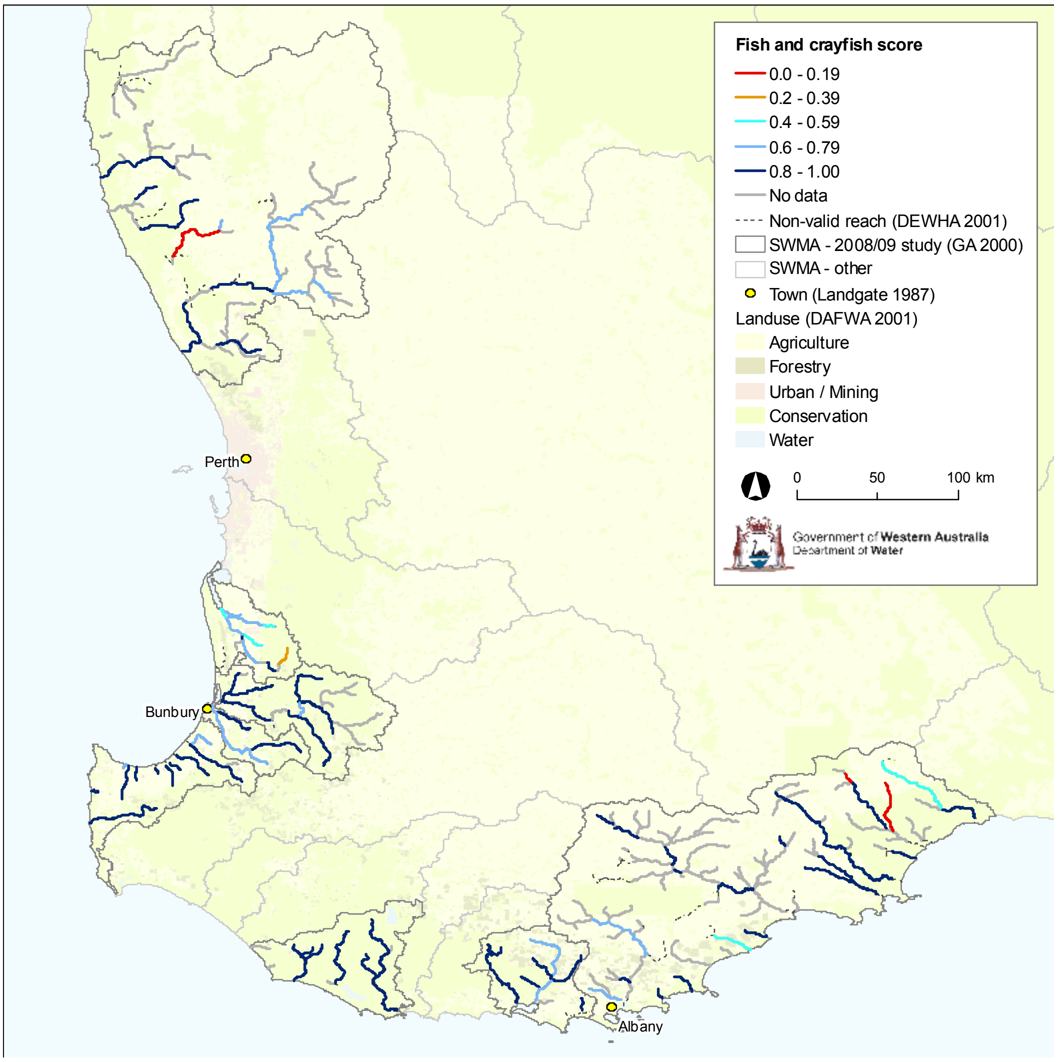


Figure 44 Fish/crayfish sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

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 most of the sites across SWWA (except in the most pristine areas such as the Denmark River and Shannon River SWMAs) but abundance was generally low. The exceptions were two reaches in the Albany Coast SWMA where no fish or crayfish were collected and one in the Moore-Hill Rivers SWMA where only exotic species were collected. All three of these sites were located in agricultural areas where the hydrological regime had been altered, the riparian vegetation was cleared or highly disturbed and erosion was severe. In addition, the sites located in the Albany Coast SWMA were affected by salinity.

Typically reaches with moderate scores (0.4 to 0.59) were found in agricultural areas where riparian vegetation had been cleared or was highly disturbed (e.g. scattered trees, no shrub layer, groundcover dominated by exotic species) and erosion was severe. One site in the Harvey River's upper reaches (above Stirling Dam) was the only exception. This site was located in relatively pristine forest with little to no erosion. The fish assemblage comprised one *Galaxias occidentalis* (western minnow) and two *Salmo trutta* (brown trout) individuals. It is likely the extinction of other native species expected to occur here, as well as the very low abundance of *G. occidentalis,* is due to the presence of *S. trutta,* which are known to consume endemic fish and crayfish (Morgan et al. 2004; Jenkins 1952; Pusey & Morrison 1989).

Macroinvertebrate sub-index

The final scores for the *macroinvertebrate sub-index* for reaches assessed in the 2008 and 2009 SWWA-FARWH trials are shown in Figure 45.

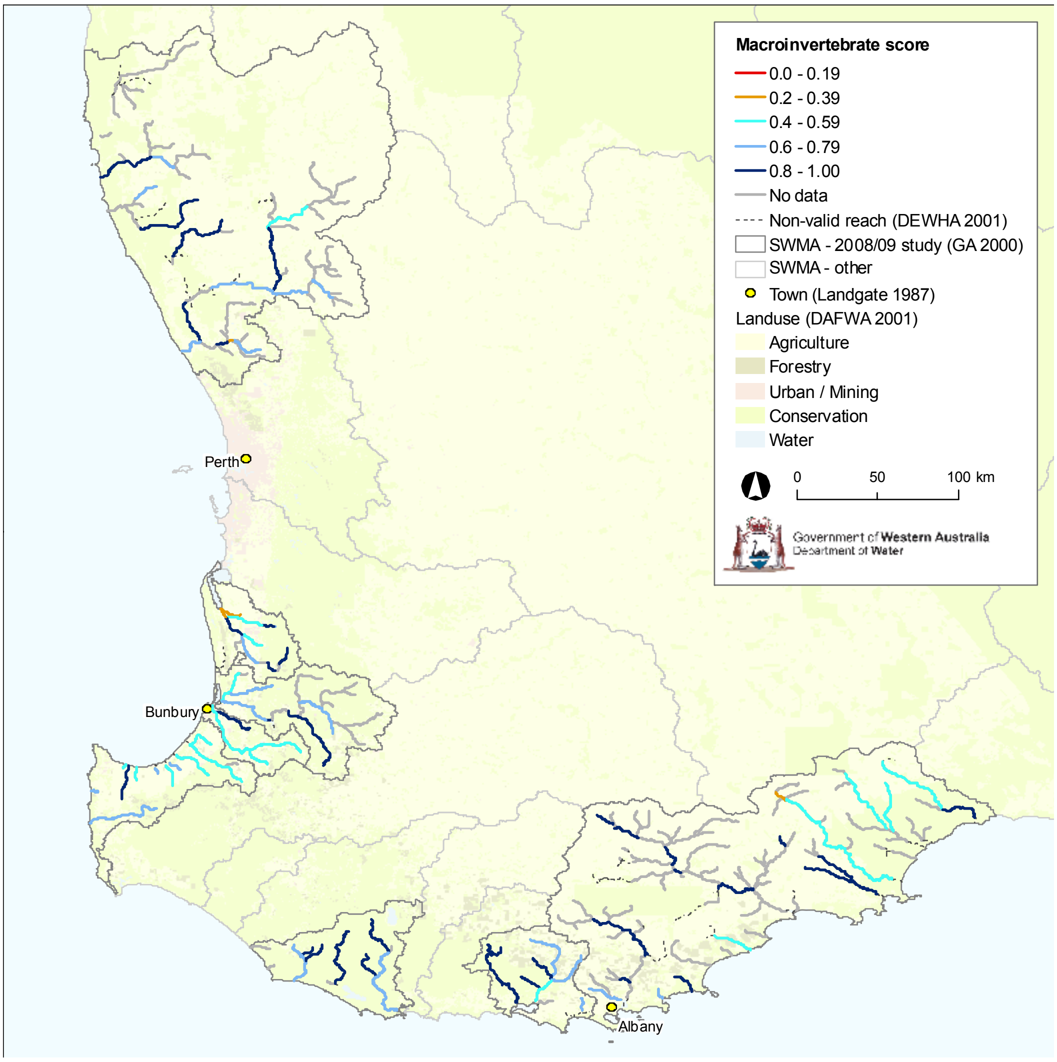


Figure 45 Macroinvertebrate sub-index scores for reaches in SWMAs assessed in 2008 and 2009 within the SWWA-FARWH trials

Comparison of scores across SWWA showed reasonable correlation with land use and hydrological impacts, with moderately modified conditions 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.

There were a couple of unexpected results, 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 and crayfish). This may reflect a short-coming of the AUSRIVAS model (discussed in Storer et al. (in press b)).

5.2 2005 baseline-year assessment

As was introduced in Section 2, the national FARWH was created in response to insufficient data being available to complete an Australia-wide river (and wetland) health assessment for 2005: identified in the AWR (2005) audit. The 2005 baseline year was designed to measure outcomes from actions taken to implement the NWI's objectives.

An extensive data trawling and generation exercise was conducted as part of the SWWA-FARWH trials to compile all available information to generate the 2005 baseline-year assessment. Data assessed was generally confined to 2005 (adjacent years not included), because it was determined that using additional data (e.g. 2003–07) had little influence on scores (no significant effects on spatial coverage or data quality). However, where no data existed for 2005 'the next-best-available' data were used (within reason). Where data used for the 2008 and 2009 assessments were the most appropriate, scores have not been regenerated for the 2005 baseline year.

Due to significant data limitations, only a sub-set of the SWWA-FARWH indicators were able to be assessed for the 2005 baseline year: these are highlighted in Table 4. Many indicators were not scored due to low data confidence or insufficient spatial coverage (see reviews below).

Table 4 Data availability for the 2005 baseline-year assessment

Theme	Sub-indices / *Components*	Data source	Scale	Data period
Catchment Disturbance (CDI)	Infrastructure	Desktop	Reach	2000–2008
	Land cover change	Desktop	Reach	2000–2005
	Land use	Desktop	Reach	1996–2001
Hydrological Change (HCI)	*Flow stress ranking			
	Low flow	Desktop	Reach	2005
	High flow	Desktop	Reach	2005
	Proportion of zero flow	Desktop	Reach	2005
	Monthly variation	Desktop	Reach	2005
	Seasonal period	Desktop	Reach	2005
Water Quality (WQI)	*Total nitrogen	Historical field	Site	2005
	*Total phosphorus	Historical field	Site	2005
	*Turbidity	Historical field	Site	2005
	*Salinity	Desktop	Reach	1985–2002
	Diel dissolved oxygen	Field	Site	Not available
	Diel temperature	Field	Site	Not available
Physical Form (PFI)	Longitudinal connectivity			
	Major dams	Desktop	Reach	2009
	Minor dams	Desktop	Reach	2009
	Gauging stations	Desktop	Reach	2009
	Road-rail crossings	Desktop	Reach	2009
	Artificial channel	Desktop	Reach	2006
	Erosion			
	Erosion extent	Field	Site	Not available
	Bank stabilisation	Field	Site	Not available
Fringing Zone (FZI)	Extent of fringing zone			
	Fringing vegetation length	Desktop	Reach	2005
	Fringing vegetation width	Desktop	Reach	2005
	Nativeness	Field	Site	Not available
Aquatic Biota (ABI)	Fish/crayfish			
	Expectedness	Field	Site	Insufficient data
	Nativeness	Field	Site	Insufficient data
	Macroinvertebrates	Field	Site	Insufficient data

*Note: Sub-indices and components listed in red were not included in the 2005 assessment due to insufficient data. *indicates partial assessment.*

The following summaries discuss data availability and associated confidence for each FARWH theme. SWMA scores for 2005 are provided where appropriate.

Catchment Disturbance

Land use data were only available for the period 1996 to 2001. This is the same data used in the 2008 and 2009 assessments provided in this report; therefore it is not possible to provide a snapshot for 2005, or to detect change between the assessment periods.

Infrastructure data are available for a range of dates between 2000 and 2008, but only data on walking trails were available specifically for 2005. The best-available data for the remaining infrastructure types would therefore be the same as for the 2008 and 2009 assessments, and as above, a 2005 snapshot is not possible.

Land cover change data were available for 2000 to 2005; however as the FARWH document (NWC 2007b) suggests a minimum requirement of land use data and infrastructure data in order to calculate the *Catchment Disturbance index,* the *land cover change sub-index* was not pursued.

Hydrological Change

Hydrology data was available for most reaches for the 2005 baseline-year assessment. Results are shown in Figure 46.

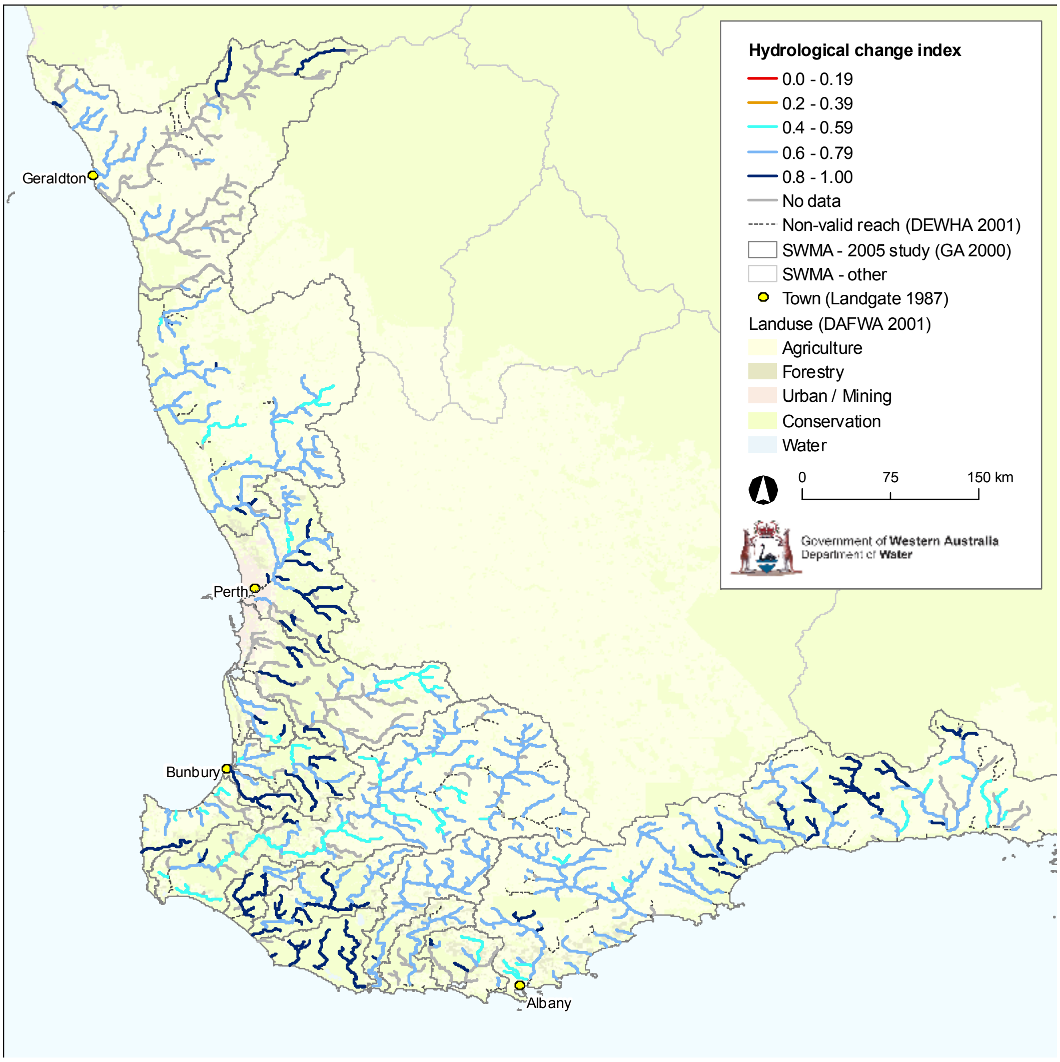


Figure 46 Hydrological Change index scores for 2005, the AWR baseline year

Water Quality

For TN, TP and turbidity, WIN data were used to generate water quality scores. This followed the same scoring method as discussed in the theme description (see Storer et al. (in press b)). Data collected between September 2005 and January 2006 were taken, reflecting the same seasonal period assessed for the 2008 and 2009 trials. Only WIN sites on valid reaches were used, resulting in coverage for 64 (TN and TP) and 50 (turbidity) of 723 reaches across the study area. Where more than one sample was taken per site over the sampling period, a median was calculated; and where there was more than one site on a reach, the scores were averaged (there were 89 WIN sites on valid reaches). The TN, TP and turbidity scores are shown in Figure 47, Figure 48 and Figure 49 respectively.

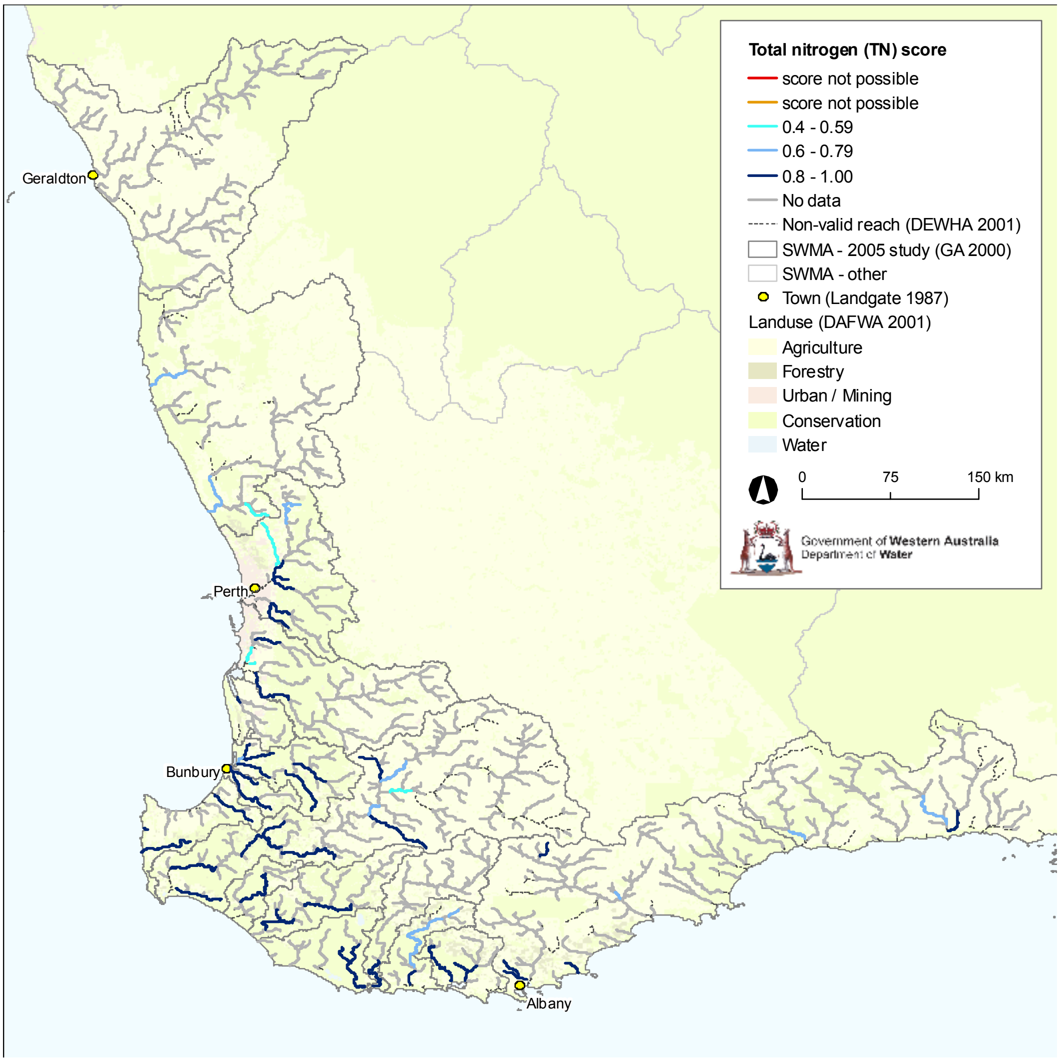


Figure 47 Total nitrogen sub-index scores for 2005, the AWR baseline year

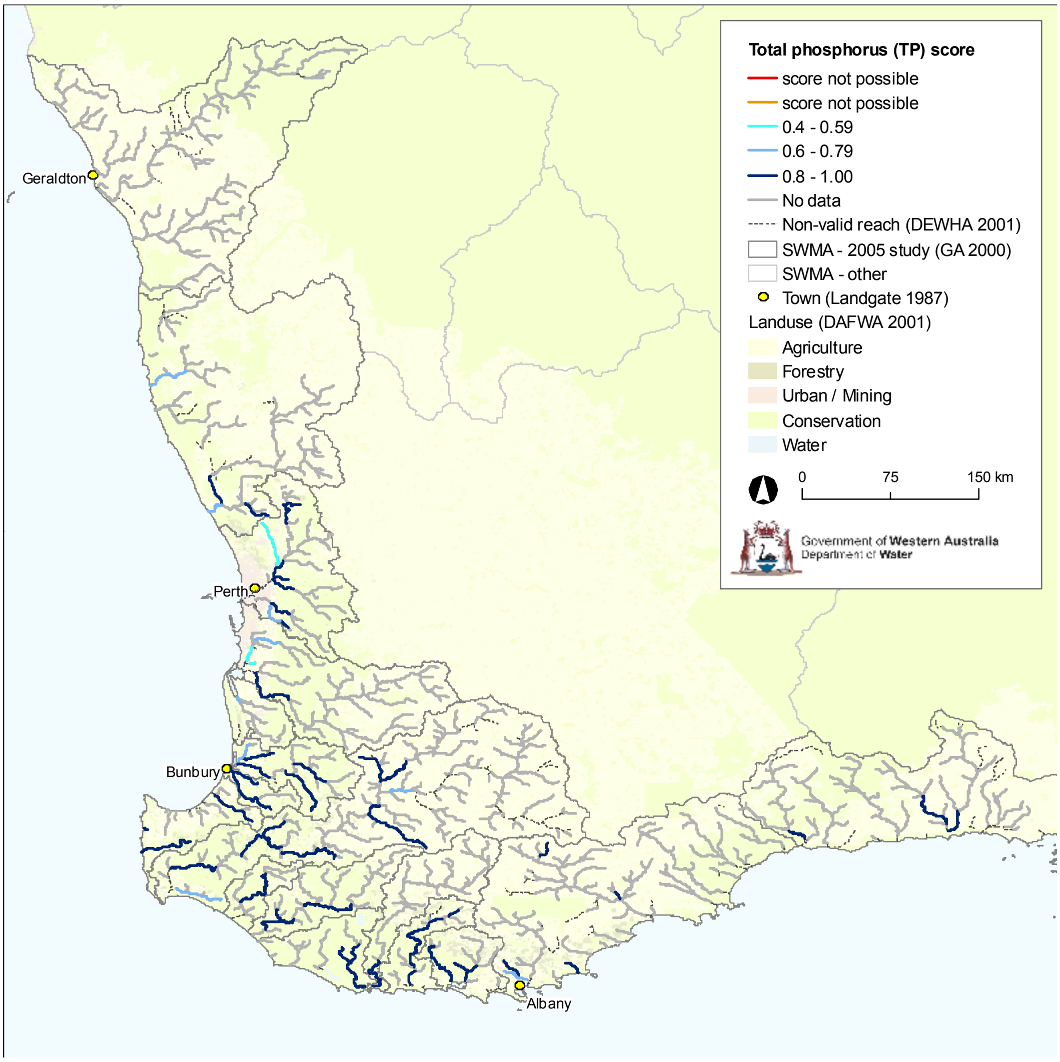


Figure 48 Total phosphorus sub-index scores for 2005, the AWR baseline year

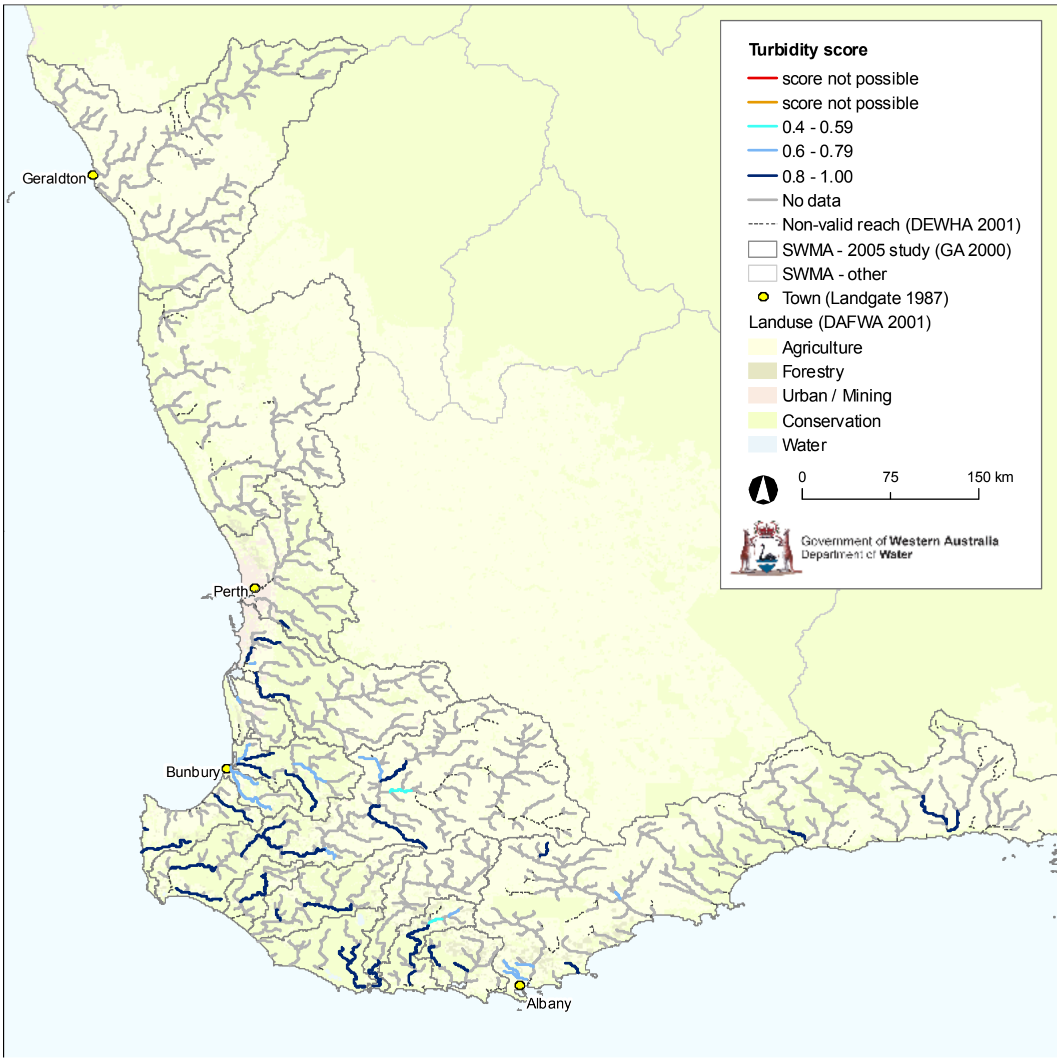


Figure 49 Turbidity sub-index scores for 2005, the AWR baseline year

For the *salinity sub-index*, the Stream Salinity Status dataset (see Table 22), which presents average flow-weighted salinity for the period between 1985 and 2002, has not been updated to cover subsequent years. Thus it was not possible to provide an assessment for 2005 using this data source. The possibility of using spot-sample salinity data collected in 2005 (stored in the WIN database) was investigated but not pursued due to differences in spatial coverage and data collection methods, which would reduce the confidence in any change in scores between 2005 and subsequent assessments.

There were no data available for calculation of the diel dissolved oxygen and diel temperature indicators for the 2005 assessment.

Due to the data availability issues above, overall *Water Quality index* scores were not calculated for the 2005 baseline-year assessment because missing data were deemed too significant to conduct a worthwhile health appraisal. It is recommended that the 2008 and 2009 trial scores be used as the best-available baseline for SWWA systems.

Physical Form

Only the *artificial channel sub-index* was available for scoring for the 2005 baseline-year assessment, with a 2006 dataset available. The data are the same as those used for the 2008 and 2009 assessments, therefore scores have not been re-presented here.

No data were available for the *erosion sub-index* – as this requires specific field observations. The possibility of using observations made for foreshore condition assessments undertaken for river action plans was investigated, however it was not possible to locate the field data collected during 2005 (Brunswick River and Wilyabrup Brook action plans) (Mike McKenna, pers. comm.) and so this idea was not pursued further.

The best-available dataset for the *longitudinal connectivity sub-index* was from 2009, and as this was used for the 2008 and 2009 trials, the scores have not been re-presented here.

It is recommended that a minimum of two out of the three sub-indicator scores are used to calculate the *Physical Form index* for a reach (see Storer et al. (in press b)). As data are only available for one of the sub-indicators, it would not be appropriate to calculate *Physical Form index* scores for the 2005 assessment. As such, the best-available assessment of baseline for this index is represented by the 2008 and 2009 SWWA-FARWH scores provided in this report.

Fringing Zone

Only the *extent of fringing zone sub-index* was available for the 2005 baseline-year assessment. The *nativeness sub-index* requires field assessed data, which were spatially insufficient for the 2005 period and would require interpretation of data collected using various methods and personnel.

The *extent of fringing zone sub-index* was deemed to have an acceptable level of information to assess the health of the fringing vegetation zone for the 2005 baseline. Scores were generated and are shown in Figure 50.

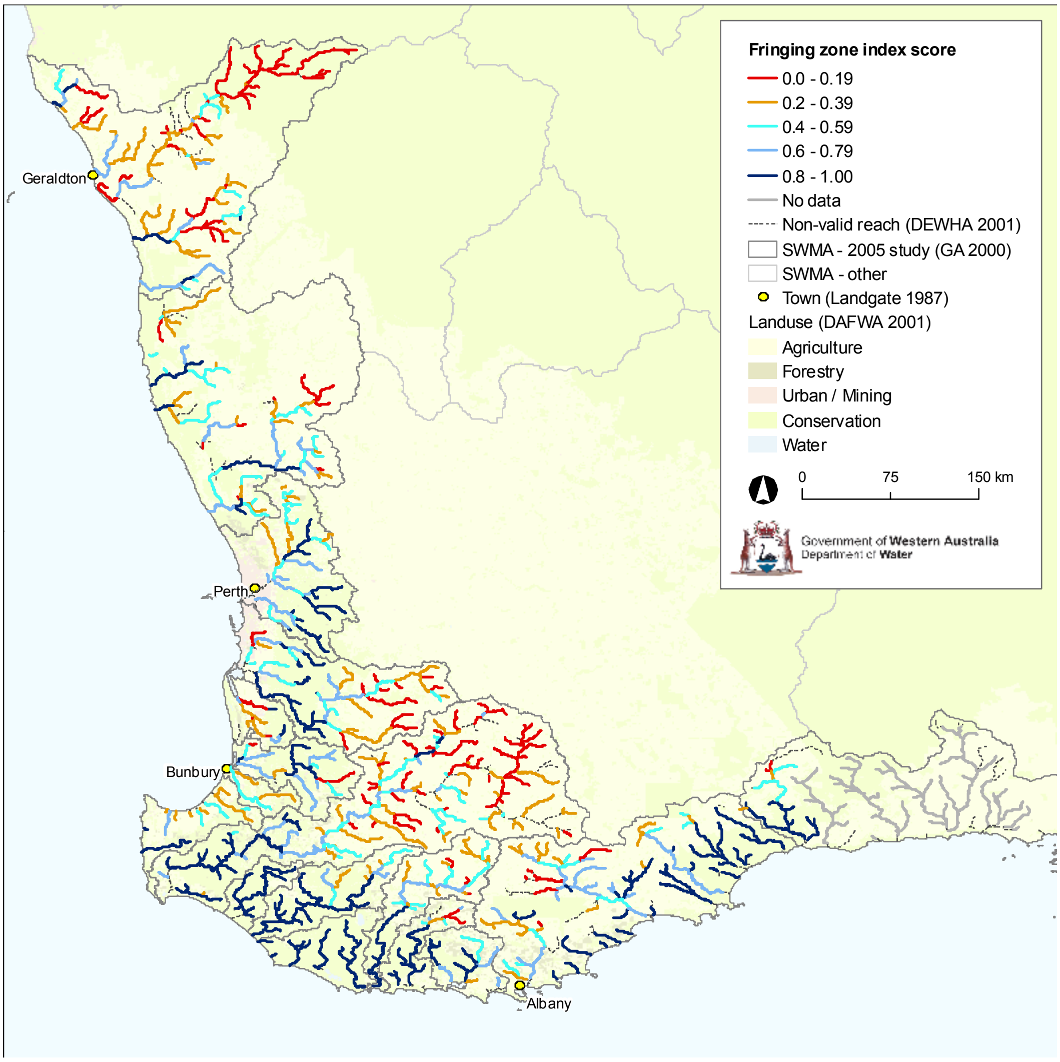


Figure 50 Extent of fringing zone sub-index scores for 2005, the AWR baseline year

By comparing 2005 *Fringing Zone index* scores with scores generated for the SWWA-FARWH 2008 and 2009 trials, a certain degree of change is detected; however, this is attributed to the *nativeness sub-index* being excluded from the 2005 assessment. When comparing the *extent of fringing zone sub-index* between assessment years, little change is observed. This has two ramifications: firstly, that comparison between themes is inappropriate (in this instance) where missing data occurs; and secondly, the degree of change in the *extent of fringing zone sub-index* is not significant – and therefore supports that the *Fringing Zone index* need only be assessed infrequently (five years as per summaries in Section 4.9).

Aquatic Biota

Data available for assessing the *Aquatic Biota index* for the 2005 baseline year were very limited. As shown in Figure 51, only a small percentage of reaches had data for either indicator: 17 reaches for macroinvertebrates and 18 reaches for fish/crayfish.

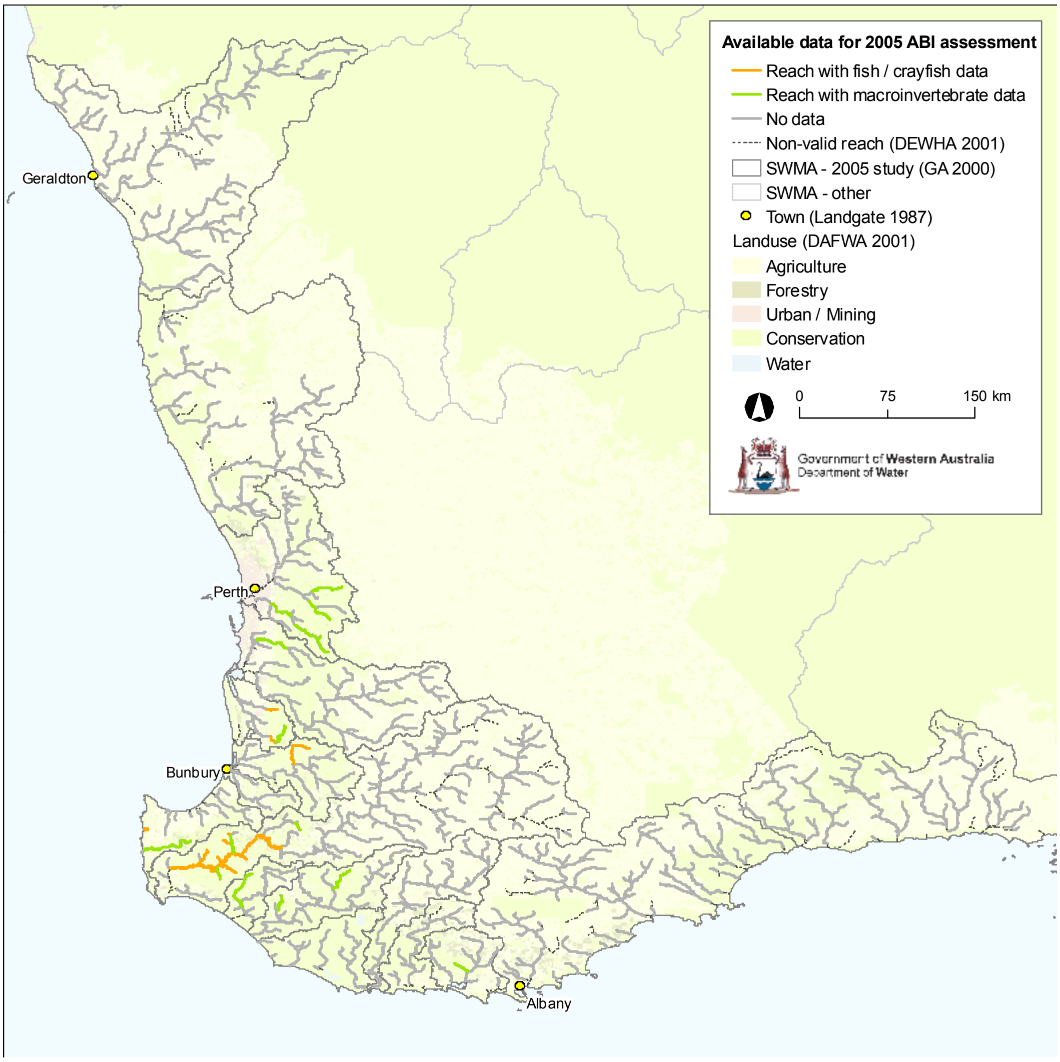


Figure 51 Macroinvertebrate (yellow) and fish/crayfish (orange) data collected during 2005

In addition, available data for the *fish/crayfish sub-index* varied in sampling method (collection techniques and season), making comparative assessments difficult (Table 5). Differences in method are known to produce different species profiles.

Table 5 Fish/crayfish data collected during 2005

Reference	Year collected	Season collected	Type of data	Crayfish collected	Collection method
Morgan and Beatty (2005)	2005	April	Abundance	Y	Variety of seine nets (3 mm woven mesh), composite gill nets, a Smith-Root backpack electrofisher, a portable generator-powered electrofisher, scoop nets and crayfish traps.
Beatty and Morgan (2005)	2004 and 2005	Oct–early Nov 2004; March 2005	Density	Y	Three replicate lengths of up to 100 m of streamline were sampled. Most sampling employed the use of an electrofisher (Smith-Root Model 12-A), which fished over the entire sample area, to temporarily stun the fish and freshwater crayfish to a radius of 2 m. On wider sections of streams, 5 and 10 m seine nets (stretched mesh width of 3 mm) were also deployed. A downstream larval trap (mesh width 1 mm) was also deployed at a selected site in each river section.
Beatty et al. (2006)	2005 and 2006	Sept 2005; March 2006	Density	Y	Each site was sampled over an area of up to 360 m^2 depending on the degree of available habitat. Sampling was primarily undertaken using a backpack electrofisher. A variety of seine nets were also deployed depending on the habitat (suitable, for example, in the wider, shallow reaches of the systems).
Beatty et al. (2006)	2005 and 2006	Spring 2005, all seasons 2006	Graphs, density	N	Only have one dataset – assume that the data collected over multiple seasons were pooled. Seine net and/or electrofisher.

Finally, only one reach had data for both fish and macroinvertebrates. Thus almost all reaches would have had *Aquatic Biota index* scores based on only one indicator. Given these limitations, the index was not used for the 2005 baseline review.

Summary

Due to the significant data limitations described above, it is recommended that the desired 2005 baseline-year river health assessment be disregarded, and that the baseline for measuring NWI objectives (and other programs in the future) uses the scores generated from the 2008 and 2009 trials.

To complete the baseline-year assessment for 2008–09 (for those SWMAs not yet assessed), best-available data up until the period could be sourced. However, available data will still be limited in some areas because many of the critical ecological data have not been assessed in SWWA (at a sufficient spatial scale). As such, a rapid completion of assessments for the remaining SWMAs is recommended.

5.3 Alignment between the FARWH and RHAS

The River Health Assessment Scheme (RHAS) was designed specifically for tributaries of the Swan and Canning river systems, within the Swan Coast SWMA [see Summary Box 7].

RHAS data collected in spring 2008 were put through the SWWA-FARWH scoring protocol to investigate correlation between the local program and the FARWH. Note: as the SWWA-FARWH assessment was not conducted for the Swan Coast SWMA, a direct correlation has not been conducted.

Summary Box 7: the Swan Coast SWMA

The Swan region is the most developed and densely populated area in Western Australia. The two main tributaries of the Swan River Estuary are the Swan (becoming the Avon east of the Darling Scarp) and Canning rivers, with the confluence near Perth's CBD. The Swan River extends for approximately 30 km through urban areas of Perth and into farmland and vineyards of the Swan River valley. Many sections and tributaries of the Swan River have been dammed to supply scheme water to both Perth and the Goldfields, and are strictly managed. The Canning River drains the northern jarrah-marri forest before travelling across the Swan Coastal Plain where land use changes from agriculture to urban. The Canning is also heavily dammed.

The residential and industrial areas of Perth have an extensive network of drains discharging into both rivers and the estuary. Nutrients are a widespread stressor in the Swan Coast SWMA. Salinity and contaminant stress is more localised.

The RHAS was assessed as part of the national FARWH trials to test the ability of existing programs to use the framework. Note: this component was primarily directed at areas with long-term established programs, where it is essential the FARWH can complement (not replace) these existing state-based programs. This was less applicable for SWWA as no state-based integrated ecological assessment programs are in place. RHAS is an ecological health program but is in its infancy and only applies to part of one SWMA (there are no other applicable programs in SWWA).

The RHAS relates to Swan-Canning subcatchments that represent only a portion of the Swan Coast SWMA (Figure 52). The SWMA is approximately 821 350 ha, compared with 211 690 ha of subcatchments currently assessed within the RHAS. There are two entire river systems (Brockman River and Wooroloo Brook) not included in the RHAS study area. The upper reaches of many catchments (above the Darling Scarp) are also not included. The RHAS does, however, assess a number of waterways that are not defined ARC reaches even though they are significant tributaries to the Swan-Canning estuary (van Looij & Storer 2009a). For more background information on the RHAS, see Galvin et al. (2009a; 2009b).

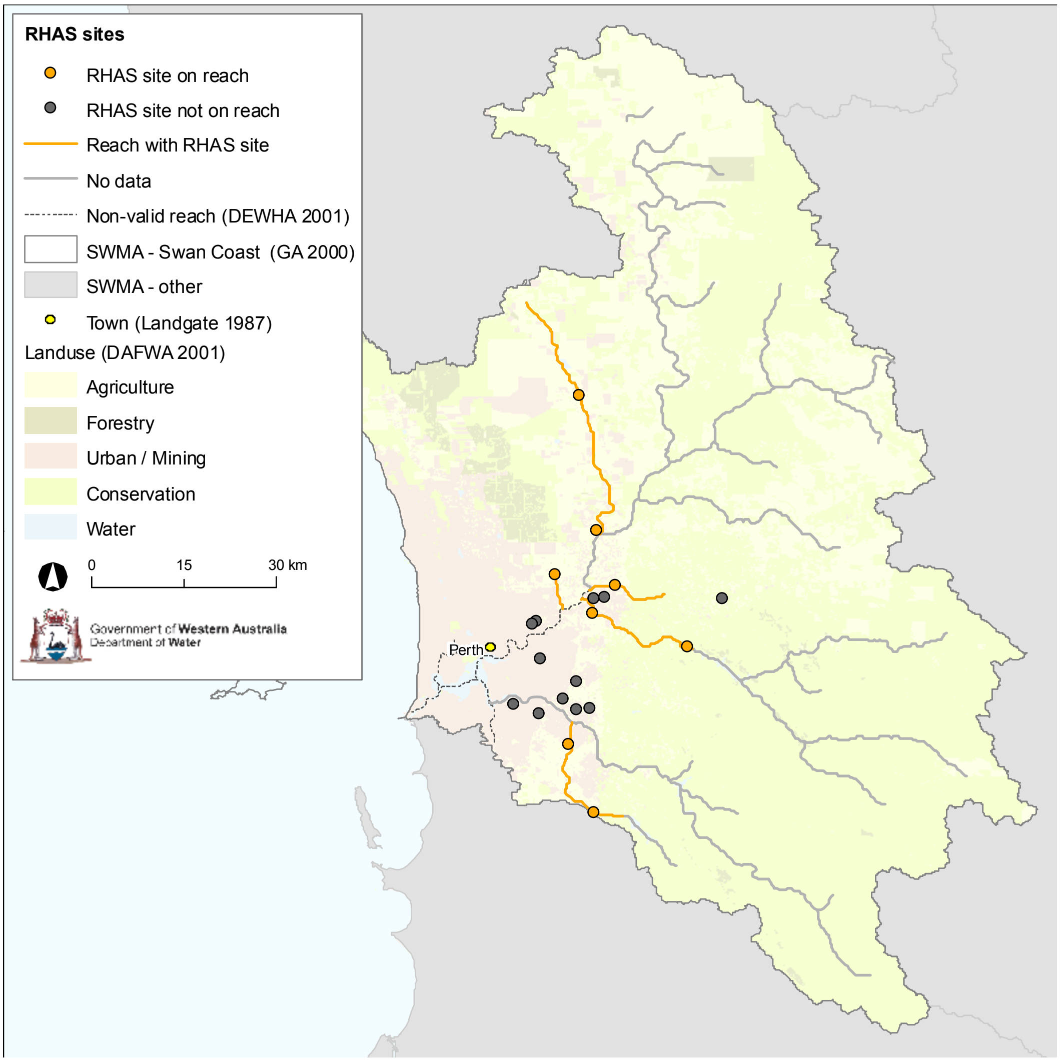


Figure 52 Assessment area for the RHAS, within the Swan Coast SWMA

RHAS site selection was based on targeting priority subcatchments in terms of nutrient concern and included systems of both high and low concentrations. For each subcatchment chosen, two sites were selected on separate rivers or streams. Of the 20 sites assessed for the RHAS, only five Reconstructed (ARC) reaches were captured.

The FARWH aligns well with the RHAS via the underpinning principles of both programs. They both assess river health based on multiple ecological parameters; use linear scoring protocols to compare site scores; use general methods to select indicators; and follow standard protocols for data collection. However, there are significant discrepancies between themes and indicators. These differences are easily explained by scale: RHAS is designed for local management and targets response indicators only. As such, it currently does not incorporate the pressure indicators used in the FARWH (e.g. Catchment Disturbance). Data availability for the FARWH from the RHAS is detailed in Table 6 below.

Table 6 Data availability for the FARWH assessment from the RHAS

Catchment Disturbance	Fringing Vegetation	Hydrological Change	Physical Form	Water Quality	Aquatic Biota
Not included in RHAS	Some data transferable Data collection method varied Reviewed in Table 7	Not included in RHAS	Some data transferable Data collection method varied Reviewed in Table 9	Data available for all FARWH indicators Data collection method varies for some indicators Reviewed in Table 10	Data available for all FARWH indicators Data collection method varied for some indicators Reviewed in Table 17

Catchment Disturbance and Hydrological Change

As discussed, the RHAS focuses on stream condition by assessing response indicators. As such, little information is available for pressure (catchment disturbance). Hydrological indicators are being developed for the RHAS but no data have been collected.

Fringing Zone

Table 7 compares the RHAS and FARWH fringing zone methodologies.

Table 7 Comparability between RHAS and FARWH for Fringing Zone index

Fringing Zone sub-indices	FARWH method	RHAS method	Achievable
Extent of fringing zone sub-index			
Fringing vegetation width component	GIS data Assessed the width of vegetation within a 50 m corridor on either side of the river. Measures perennial vegetation (not limited to riparian species).	Field data Assesses riparian width within a 40 m corridor for one bank only; at three points along 430 m of stream.	Possible More accurate at site, less accurate at reach. FARWH indicator can be scored for reaches based on the three transects used in RHAS.
Fringing vegetation length component	GIS data Assessed the percentage of the reach that is vegetated (looks at the reach as a single line, therefore vegetation only needs to be on one side to be counted). Measures any perennial vegetation (not just riparian species).	Field data Assesses longitudinal continuity (length of continuous vegetation and the length and presence of 'breaks' (> 10 m length) in the vegetation); along 430 m of stream for one bank only.	Possible More accurate at site, less accurate at reach. Only 430 m of a reach would be assessed.
Nativeness sub-index	Field data Assessed the percentage of exotic groundcover (recorded in categories) as a proportion of the total vegetation cover in the fringing zone (10 m from the river edge).	Field data Method similar to FARWH except the percentage categories used are slightly different and it assesses the total vegetation cover (not a proportion as for FARWH).	Yes
Integration of scores	The overall site score is an average of the *extent of fringing zone sub-index* and *the nativeness sub-index* score. (Note: *extent of fringing zone sub-index* is an average of the *fringing vegetation length* and *fringing vegetation width* scores).	The overall site score is obtained by adding together the sub-indicator scores and converting to a score out of 10. RHAS fringing zone sub-indicators are: longitudinal continuity, vegetation width, structural intactness, cover of exotic vegetation, recruitment of native woody vegetation and canopy cover.	Partly Due to reasons outlined above, scores for all sub-indices may not be available.

A direct comparison of the width and length indicator scores was not conducted given the differences in data collection method and variations in scale of assessment. The SWWA-FARWH *nativeness sub-index* and the RHAS cover of exotic vegetation indicator only differed slightly due to scoring bands, having no impacts on final scores. The scoring bands from the two programs are shown in Table 8.

Table 8 Scoring bands assigned for both the FARWH nativeness sub-index and the RHAS cover of exotic vegetation indicator

Cover of exotic vegetation (% total cover) FARWH	FARWH score (out of 1)	Cover of exotic vegetation (% total cover) RHAS	RHAS score (out of 4)
> 75	0.1	> 60	0
50–75	0.2	40–60	1
10–50	0.6	11–40	2
1–10	0.8	1–10	3
0	1	0	4

Note: the FARWH bands were developed from RHAS bands and improved through guidance from literature and field validation exercises.

Whether scores were able to be compared directly or not, the ability for the programs to ‘talk to each other’ has been supported. If both programs were to continue, RHAS data plus GIS data used for the broader-scale width and length indicators would enable the Fringing Zone theme to be generated with little effort.

Physical Form

Table 9 compares the RHAS and FARWH physical form methodologies.

Table 9 Comparability between RHAS and FARWH for Physical Form index

Physical Form sub-indices	FARWH method	RHAS method	Achievable
Longitudinal connectivity	GIS data (potential barriers)	Field data (actual barriers). The measuring site (430 m) takes the lowest score of all the barriers located downstream from it (as this is the barrier that will be having the greatest impact on fish migration at the site).	No Information from the two programs will not necessarily show the same trends (different errors involved).
Artificial channel	GIS data (proportion of straight section of river)	Field/GIS Classifies streams into 'river like' and 'drain like' (not only related to straightness).	No RHAS does not calculate percent of stream channelised and is influenced by other factors (uniform depth).
Erosion			
Erosion extent component	Field data Assess the extent (percentage) of active and recently eroding surfaces on the left and right bank over a 100 m sampling site.	Field data Data collected on bank condition. Combines factors such as severity of erosion exposed roots and bank instabilities (assessed at three 30 m transects over a 430 m site). Does not assign an actual percentage of erosion.	Partly No data on the extent (percentage) of erosion along both banks for the *erosion extent component*. Data available for the *bank condition component.* RHAS has data on percent cover of shrubs and trees at the site. However, the trees are not categorised into < 10 m and > 10 m and the size of the area sampled differs.
Bank condition component	Field data Uses data collected on the percentage cover of vegetation (trees < 10 m, trees > 10 m, shrubs only) over a 100 m sampling site. Provides a measure of the vegetation cover and complexity on the river banks as an indication of how well the bank is stabilised.	Field data Data collected on the percentage cover of trees (> 5 m tall) and shrubs (assessed at three 30 m transects over a 430 m site).	

A direct comparison of scores was not conducted for this exercise given the differences in data collection method and variations in scale of assessment. Similar to the Fringing Zone theme, this exercise has demonstrated that the two programs are closely aligned, supporting the FARWH's relevance to local conditions and providing a valuable comparative resource for any future assessments.

Water Quality

Table 10 compares the RHAS and FARWH water quality methodologies.

Table 10 Comparability between RHAS and FARWH for Water Quality index

Water Quality sub-indices	FARWH method	RHAS method	Achievable
Total nitrogen *Total phosphorus* *Turbidity*	Compared field (site) collected data to guidelines developed by the Department of Water.	Compared field (site) collected data to guidelines developed by the Department of Water. These were slightly modified to be specific for the Swan Coast SWMA (Galvin et al. 2009).	Yes However guideline bands are different between FARWH and RHAS (see Table 12).
Diel temperature	Temperature recorded every 10 mins for 24 hours. Diurnal temperature range compared with guidelines (one value for both upland and lowland rivers).	Temperature recorded every 10 mins for 24 hours. Diurnal temperature range compared with guidelines (different values for upland and lowland rivers).	Yes However, guideline values varied between FARWH and RHAS (see Table 14).
Diel dissolved oxygen	Oxygen recorded every 10 mins for 24 hours. Score based on the percentage of time spent in different dissolved oxygen bands.	Oxygen recorded every 10 mins for 24 hours. Score based on the percentage of time spent in different dissolved oxygen bands.	Yes Same data collection and scoring method used for FARWH and RHAS.
Salinity	Used modelled and actual data developed by Mayer et al. (2005) that classified the salinity (total dissolved salts) of watercourses in SWWA. These classifications were matched to reaches and compared with guidelines based on salt tolerances of aquatic biota (see Table 14).	Compared field (site) collected data (electrical conductivity) to guidelines developed by the Department of Water (see Table 15). These were slightly modified and converted to electrical conductivity to be specific for the Swan Coast SWMA (Galvin et al. 2009).	Yes However, threshold values vary between RHAS and FARWH (see Table 15). Modelled data is available for some of the RHAS reaches. Alternatively, RHAS field collected samples could be compared with FARWH guidelines.
Integration of scores	Used the precautionary principle approach (i.e. the final score is the lowest of the average of the secondary indicators (TN, TP, turbidity and diel temperature indicators) and the primary indicators (salinity and diel dissolved oxygen).	All scores are added together and equally scaled to obtain a final score out of 10.	Yes Can use precautionary principle with RHAS scores (see Table 16). Note: pH is not used in FARWH scoring.

Water quality was highly correlated between the RHAS and FARWH, highlighting the effectiveness of the FARWH methods at a range of scales (useful at local scales targeted by the RHAS). To test the alignment of the two programs, RHAS scores were generated using FARWH protocols, which required two processes:

1 The RHAS site/reach scores were converted to a score out of 1 to make them comparable with the FARWH.
2 The RHAS sites were scored using FARWH scoring techniques. Where there were two sites on the reach, an average was taken.

Summary: total nitrogen, total phosphorus and turbidity sub-indices

Reach scores generated using RHAS and FARWH protocols generally scored within the same category – most likely a result of similar thresholds being used for scoring. These thresholds were sourced from an existing Department of Water classification scheme for comparing data statewide (DoW 2004). The RHAS further modified the scheme's classifications specifically for the Swan Coast SWMA (Galvin et al. 2009a). The major difference between the two programs is that the lowest score able to be assigned to a site is zero using RHAS protocols and 0.4 using FARWH protocols.

RHAS and FARWH scores for TN, TP and turbidity are compared in Table 11.

Table 11 Reach scores for total nitrogen, total phosphorus and turbidity – generated from both RHAS and FARWH scoring protocols

River system	Reach	Total nitrogen		Total phosphorus		Turbidity	
		FARWH	RHAS	FARWH	RHAS	FARWH	RHAS
Ellen Brook	6160553	0.50	0.25	0.40	0.00	0.50	0.25
Jane Brook	6160569	1.00	1.00	1.00	1.00	1.00	1.00
Bennett Brook	6160571	0.60	0.50	0.80	0.75	0.40	0.00
Helena River	6162041	1.00	1.00	0.90	0.88	0.90	0.88
Wungong/ Southern Rivers	6161640	0.80	0.75	0.80	0.63	0.80	0.75

Table 12 Comparison of RHAS and FARWH scoring thresholds for total nitrogen, total phosphorus and turbidity

TN concentration (mg/L)	TP concentration (mg/L)	Turbidity (NTUs)	FARWH score (out of 1)	RHAS score (out of 4)
< 0.75	< 0.02	< 5	1	4
0.75–1.2	0.02–0.08	5–10	0.8	3
> 1.2–1.7	> 0.08–0.14	> 10–16	0.6	2
> 1.7–2.00	> 0.14–0.20	> 16–25	0.6	1
> 2.0	> 0.20	> 25	0.4	0

Summary: diel temperature, diel dissolved oxygen and salinity sub-indices

Diel temperature

The temperature scores varied between the RHAS and FARWH, with the RHAS assigning reaches higher scores (one or two categories higher) than the FARWH. There are two reasons for this. Firstly, the difference in possible scores (the RHAS only assigns scores of 0 or 1 whereas the FARWH assigns scores of 0.4 or 0.8). Secondly, the RHAS differentiates between upland and lowland rivers when calculating scores (with a larger temperature range being considered acceptable in lowland rather than upland rivers), whereas the FARWH uses the more precautionary of these two temperature ranges (see Table 14). This is summarised in tables 13 and 14.

Table 13 Reach scores for diel temperature, salinity and diel dissolved oxygen – generated from both RHAS and FARWH scoring protocols

River system	Reach	Temperature		Salinity		Diel DO	
		FARWH	RHAS	FARWH	RHAS	FARWH	RHAS
Ellen Brook	6160553	0.60	1.00	1.00	0.88	0.68	0.68
Jane Brook	6160569	0.80	1.00	no data	0.75	1.00	1.00
Bennett Brook	6160571	0.40	1.00	no data	0.50	0.33	0.33
Helena River	6162041	0.80	1.00	1.00	0.88	0.82	0.82
Wungong/ Southern Rivers	6161640	0.60	1.00	1.00	1.00	0.90	0.90

Note: Some FARWH reaches have missing data for salinity as data were not provided by the model.

Table 14 Comparison of RHAS and FARWH scoring thresholds for diel temperature

Diel temperature range (°C) upland rivers*	Diel temperature range (°C) lowland rivers*	FARWH score (out of 1) Note: uses upland rivers scoring only	RHAS score (out of 4)
< 4°C over 24 hours	< 5.5°C over 24 hours	0.8	1
> 4°C over 24 hours	> 5.5°C over 24 hours	0.4	0

**RHAS uses different diel temperature ranges for upland (those at more than 150 m in altitude) and lowland rivers; FARWH uses the upland temperature ranges only.*

Diel dissolved oxygen

The RHAS and FARWH use the same scoring method for diel dissolved oxygen, therefore the reach scores did not differ.

Salinity

Despite some variation in the salinity scoring methods and thresholds for the RHAS and FARWH, there was little difference between the final salinity scores (see Table 13). This correlation was mostly due to RHAS sites having low salinity levels (all were below 1000 mg/L) and therefore receiving high scores. Assigned threshold levels for scores above 1000 mg/L are less similar between the two programs (Table 15).

Table 15 FARWH and RHAS scoring thresholds for salinity

Salinity (mg/L TDS)	Category	FARWH score (out of 1)	RHAS score (out of 4)
< 500	Fresh	1	4
500–1000	Marginal	1	3
1000–1500	Marginal-brackish	0.9	2
1500–3000	High-brackish	0.8	2
3000–7000	Low-saline	0.5	1 (3000–5000)
7000–14 000	Mid-saline	0.2	0 (> 5000)
14 000–35 000	High-saline	0	0 (> 5000)
> 35 000	Brine (seawater)	0	0 (> 5000)

RHAS salinity thresholds were adapted from existing Department of Water (2004) guidelines (the RHAS used electrical conductivity, thus data required conversion to salinity). The FARWH thresholds were developed based on literature relating to salt tolerances of aquatic biota and are thus viewed as an improvement on those of the RHAS. Further, RHAS scores were based on spot measurements, whereas the FARWH scores were based on field and modelled data. See Storer et al. (in press b) for more detail on the development of sub-indices for the Water Quality theme.

Overall Water Quality theme score

Overall the RHAS scoring technique assigned a slightly higher *Water Quality index* score than that of the FARWH (see Table 16). This may be due to differences in the integration method as the RHAS equally weights sub-indicators, whereas the FARWH uses the precautionary principle and categorises each indicator as ‘primary’ or ‘secondary’ (see Storer et al. (in press b) for more information on scoring protocols for the Water Quality theme). In addition, the final RHAS score included field measurements of pH whereas the FARWH did not. However, based on an assessment of the scores, this is unlikely to have a significant impact on the overall *Water Quality index* score.

Although the RHAS did not use ‘primary and secondary indicators’ to integrate the water quality sub-indicators, the authors recommend this concept be investigated for future RHAS assessments (Galvin et al. 2009b). This was tested by applying the precautionary approach to the original RHAS data (see Table 16). For three of the reaches this lowered the RHAS scores, making them more comparable with the scores generated by the FARWH.

Table 16 Overall Water Quality index score for RHAS and FARWH

River system	Reach	Overall *Water Quality index* score		
		FARWH	RHAS (actual)	RHAS (precautionary)
Ellen Brook	6160553	0.38	0.58	0.38
Jane Brook	6160569	0.95	0.96	1.00
Bennett Brook	6160571	0.33	0.40	0.63
Helena River	6162041	0.82	0.90	0.79
Wungong/ Southern Rivers	6161640	0.71	0.86	0.77

It is clear that generation of FARWH scores from RHAS data would produce a useful assessment. However, as data for only five FARWH reaches were available from the RHAS there is little point in attempting to score water quality for the SWMA.

In the future, the authors recommend the RHAS program be updated to include a number of the new indicators developed through the SWWA-FARWH trials. Additional assessments should be added to the program to enable future FARWH assessments, while also maintaining indicators for local management purposes.

Aquatic Biota

The following table compares the RHAS and FARWH aquatic biota assessment.

Table 17 Comparability between RHAS and FARWH for Aquatic Biota theme

Aquatic Biota sub-indices	FARWH method	RHAS method	Achievable
		Fish/crayfish	
Expectedness component	Consists of two measures which compare the species composition of the observed native assemblage of fish species to that predicted at a site under unimpacted or reference conditions (expected), based on reference lists of species at site and subcatchment scales. OP measure does not correct for rare species; hence it does not take into account species which occur in seasonal river systems and migratory species.	Complexity component − based on the number of native fish species present, compared with the number of native fish species expected to occur under unimpacted (or pre-European) conditions. This method does not take into account rare or seasonal species as in the FARWH. $Co_r = 4 \times (nSp_n/nSp_e)$ Where Co_r = complexity score, nSp_n = number of native species collected, nSp_e = number of native species expected.	Yes RHAS sampling methods provide data that can be used to calculate the expectedness indicator.

Aquatic Biota sub-indices	FARWH method	RHAS method	Achievable
	OE measure accounts for these 'rare species' by not including them in the observed/expected scoring.		
Nativeness	The *nativeness component* integrates two measures (proportion of native abundance and proportion of native species); contains information on the proportions of abundance and species richness that is native rather than exotic.	Resilience component: proportion of native fish/crayfish abundance compared with the total number of fish/crayfish collected.	Yes, RHAS sampling methods provide data that can be used to calculate the nativeness indicator.
Expert rule for scoring fish/crayfish	A cap of 0.05 is applied to sites where only exotic fish/crayfish species are present (i.e. *nativeness component* score equals zero). Sites with no fish score zero.	No rules used	Yes
Score calculation for fish/crayfish	$FCSI = OE + [(2 \times OP_r)+OP_s]+ P_{Ab} + P_{Sp}$ Where FCSI = fish/crayfish sub-index score, OE = observed to expected ratio, OP_r = observed to predicted ratio (includes rare species), OP_s = observed to predicted ratio (includes seasonal species), P_{Ab} = proportion native abundance, P_{Sp} = proportion native species.	$FC_{ms} = CC_r + Co_r + R_r$ Where FC_{ms} = fish/crayfish index score; CC_r = carrying capacity score; Co_r = complexity score; R_r = resilience score. Extra indicator used in RHAS: carrying capacity. The carrying capacity component provides a score based on the total number of individuals (native and exotic fish/crayfish) that are collected.	Yes
Sampling method for fish/crayfish	Combination of box traps and fykes set for a 24-hour period. One fyke is set at the top of site facing upstream and the other is set at the bottom of site facing downstream. The 10 box traps (five large and five small) are set in all habitats present.	Fourteen box traps (four large and 10 small) set over a 24-hour period. No fykes are used due to the accessibility of sites to the general public.	Yes. Probability of capture may change for some species, such as *Galaxias occidentalis* (western minnow) which are not frequently collected in box traps.

Aquatic Biota sub-indices	FARWH method	RHAS method	Achievable
		Macroinvertebrates	
Observed/expected (AUSRIVAS)	WA Spring channel model used to generate O/E score. O/E 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.	WA Spring channel model used to generate O/E score. A score is assigned based on the AUSRIVAS condition bands.	Yes
Sampling method for macroinvertebrates	Standard AUSRIVAS protocol. Scores for both the overall theme and individual indicators are 0–1.	Standard AUSRIVAS protocol. Overall theme scores are calculated out of 10. Individual indicators are scored out of 4.	Yes
Score calculation for macroinvertebrates	MI = O/E Where MI = macroinvertebrate score; O/E= AUSRIVAS observed/expected	MI = M_{ms} = 10/12 x [AUS_{ms} + SIG_{ms} + FR_{ms}] M_{ms} = macroinvertebrate theme; AUS_{ms} = AUSRIVAS indicator score; SIG_{ms} = SIGNAL indicator Score; FR_{ms} = family richness indicator score. Extra indicators used in RHAS – family richness and SIGNAL indicators.	

Given the similar sampling techniques used in the RHAS and FARWH, scores generated were compared. The RHAS site/reach scores were converted to a score out of one (to enable comparison with the FARWH scores).

An initial assessment was conducted using all RHAS sites (regardless of the relationship with recognised reaches for the SWWA-FARWH). This highlighted a reasonable correlation but did identify a standard error: combining the macroinvertebrate and fish themes using RHAS scoring protocols results in lower *Aquatic Biota index* scores when compared with the FARWH scoring method. Eleven sites (out of 20) were placed one condition band lower using RHAS scoring protocols compared with the FARWH. Note: one site in Helena River was classified as pristine using FARWH methods and moderately disturbed using RHAS methods.

Follow-up assessments were done using the five valid FARWH reaches in the RHAS study area. Scores for the *Aquatic Biota index* and associated indicators were calculated using FARWH and RHAS scoring methods (see Table 18). RHAS scores tended to be lower than the FARWH scores, with reaches rarely scoring within the same FARWH condition band, although they typically fell into the next condition band (as with the initial assessment).

Table 18 FARWH and RHAS scores for the macroinvertebrate sub-index, fish/crayfish sub-index and Aquatic Biota theme

River system	Reach	Fish/crayfish score		Macroinvertebrate score		Aquatic Biota score	
		FARWH	RHAS	FARWH	RHAS	FARWH	RHAS
Ellen Brook	6160553	0.89	0.79	0.75	0.54	0.82	0.67
Jane Brook	6160569	0.80	0.82	0.75	0.75	0.78	0.79
Bennett Brook	6160571	0.67	0.56	0.28	0.28	0.47	0.42
Helena River	6162041	0.81	0.71	0.89	0.71	0.85	0.71
Wungong/ Southern Rivers	6161640	0.68	0.75	0.49	0.42	0.59	0.58

The fish/crayfish indicator assessed in the RHAS is similar to the FARWH as it includes an observed/expected assessment (Complexity metric) and measures the proportion of individuals that are native rather than exotic (Resilience metric). The third metric used in the RHAS is the total abundance of individuals (includes natives and exotics) found at a site – a measure of the system's capacity to support life (Carrying capacity metric).

The FARWH method is an improvement on the RHAS, through new information and field testing. The FARWH method is also less limited by scale. As such, the RHAS scoring method for fish/crayfish will be updated to include the expectedness (OE) and nativeness indicators developed as part of the FARWH. More work is necessary to determine whether the Carrying capacity metric currently used in the RHAS should remain.

Summary

The RHAS and FARWH programs align closely. For the FARWH this highlights that its methods are effectively representing the finer scale targeted by the RHAS, while remaining relevant at the SWMA scale.

As discussed above, the RHAS is still being developed and is localised to one portion of one SWMA in SWWA. As such, the requirement of the FARWH to align closely is less important than in other states, which have long-term statewide programs.

Finally, in many cases it was shown the FARWH methods were an improvement on those of the RHAS, and it has been determined that the RHAS will be updated accordingly. It was always the intent to update the RHAS as new research and data became available.

6 Discussion of results

6.1 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 (see Storer et al. (in press b) for results of these analyses).

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 4.2: *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 53, which generally align with the understanding of river health in SWWA.

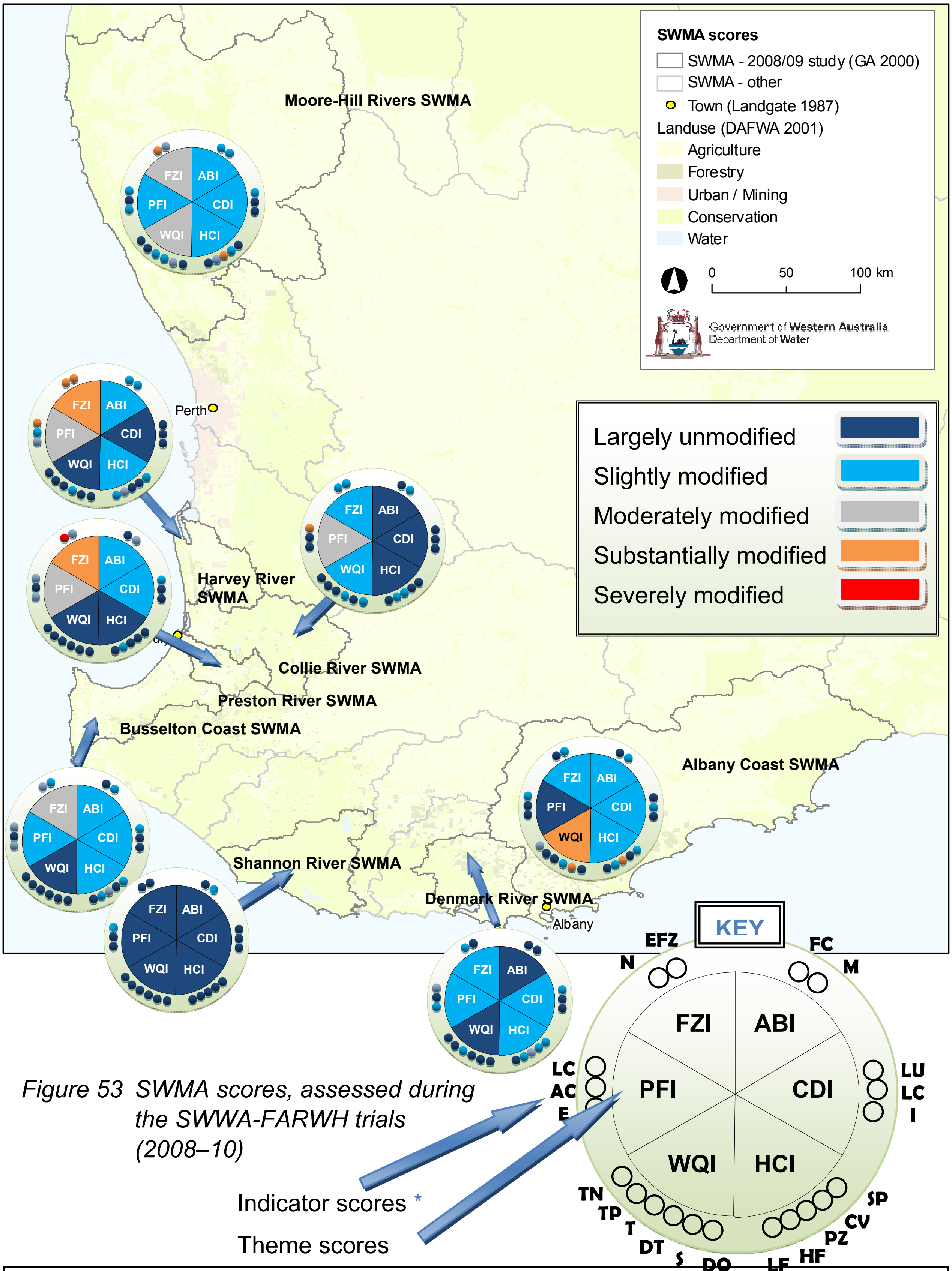


Figure 53 SWMA scores, assessed during the SWWA-FARWH trials (2008–10)

*** 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).

As shown in Figure 53, 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. Most 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 scores compared with the 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 Storer et al. (in press b)). 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 for the *Water Quality index* to be effective using primarily point-source data. This situation has been addressed in Section 8.1: *Recommendations* (use of logging equipment to capture longer-term data across multiple parameters).

Physical Form theme

SWMA scores for the *Physical Form index* ranged 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. 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 54), whereas SWMA boundaries extend from lowland to upland zones.

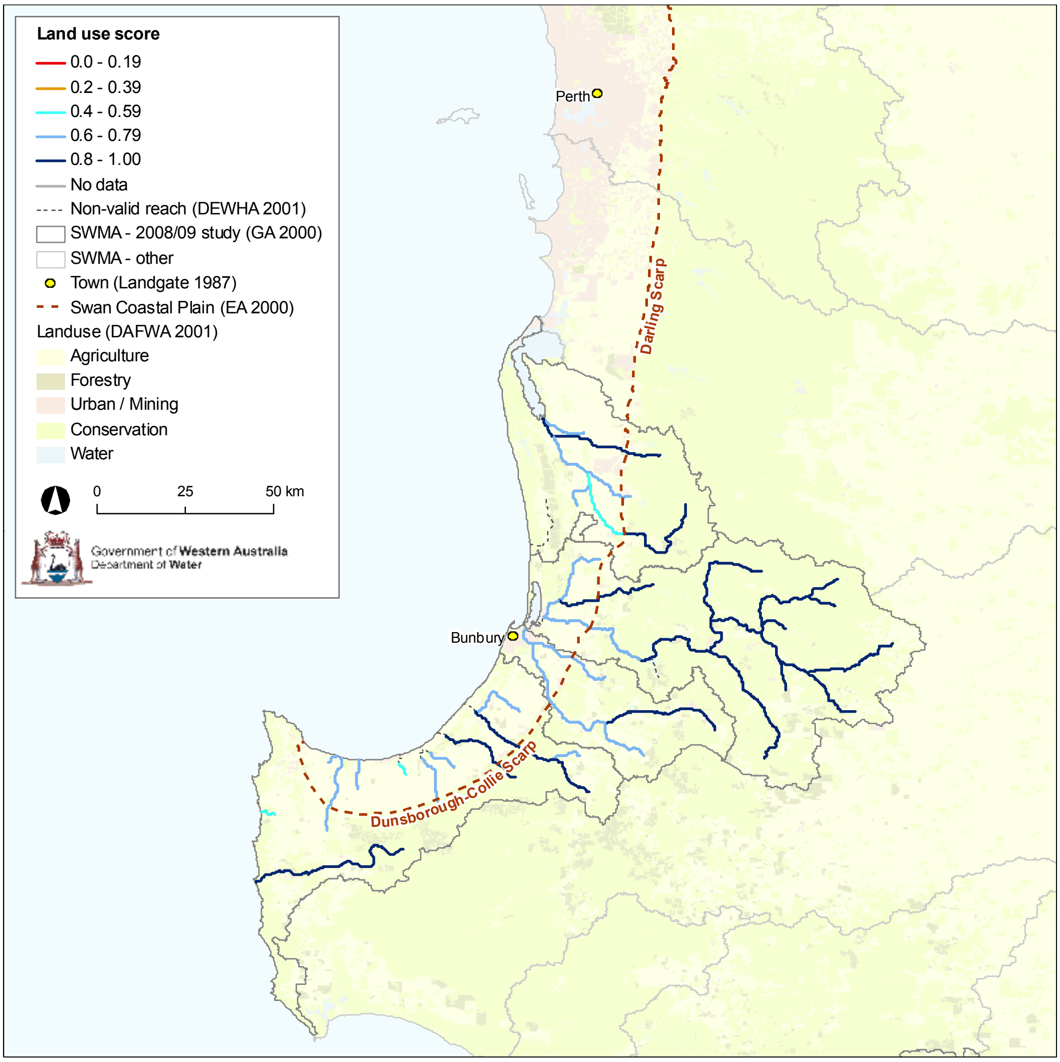


Figure 54 Land uses in SWWA, encompassing Harvey River, Collie River, Preston River and Busselton Coast SWMAs. The division between conservation-dominated upland areas and agriculture-dominated coastal lowland areas (west of Darling Scarp)

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).

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.

6.2 Discussion and analysis on integration of data

This section examines the integration of data: incorporating weighting of indicators to generate themes and dealing with missing data at the reach and SWMA scale.

Weighting at reach level (combining indicators)

The combining of indices to calculate theme scores followed a range of methods within the SWWA-FARWH, based on applying weights to each indicator associated with the respective influence on the health of the theme. In most cases, insufficient information was available to assign specific weights – as this required rigorous statistical and field validation outside of the time available for the SWWA-FARWH trials. As such, an unweighted average of component indicator scores was applied for Catchment Disturbance, Aquatic Biota, Hydrological Change and Fringing Zone (a standard position in the absence of information). The Physical Form theme followed a similar principle, however Euclidian Distance was employed as the theme indicators represented mutually exclusive conditions (connectivity, erosion and channelisation). Note: averages were used where indicators measure similar attributes of the same condition, such as within the Aquatic Biota theme.

A slightly different approach was taken for the *Water Quality index*, where a precautionary principle was adopted. This was done to represent a distinct difference in water quality parameters, between those resulting in mortality or impairment of growth and reproduction at specific levels (salinity and dissolved oxygen), and those with no discernible threshold limit (TN, TP, turbidity, temperature). In this instance, the Water Quality theme score was selected as the lowest score from either dissolved oxygen, salinity or the average of the four secondary parameters. Note:

temperature will have specific thresholds for different species, but due to limited knowledge on species tolerances, appropriate thresholds could not be identified.

In some cases, weighting was applied in generating theme indicators (e.g. integrating components and metrics) where an obvious trend was observed. For instance, in generating the *longitudinal connectivity sub-index,* weights were applied to the four components: major dams, minor dams, gauging stations and river crossings. In this case, the specific contributions of the different data were unknown, however the four components could be ranked in terms of impacts. To represent the different impacts a linear scaling factor was applied, this being: major dams weighted 1 (highest impact); minor dams 0.75; gauging stations 0.5; and river crossings 0.25 (lowest impact).

Literature was also used where available to inform weightings. This was particularly effective for the *land use* and *infrastructure* sub-indices. For example, land use categories were broken down into the elements of each land use that are known to impact on river health, such as nutrients, contaminants and sedimentation. Weightings for each land use were then calculated based on the relative contribution of each component (see Storer et al. (in press b)).

Development or improvement of appropriate weightings for all indicators is an important next stage in developing the SWWA-FARWH, requiring additional field data (to validate existing patterns) and information about species tolerances and associated statistical analysis to quantify influence.

Weighting at SWMA scale

Although suggested in the FARWH guidelines (NWC 2007a), combining themes together at the SWMA scale was not conducted. Themes were reported separately at the SWMA level to allow interpretation of specific impacts, and further, it was deemed inappropriate to combine themes representing different levels of ecological information.

Finally, most SWMAs assessed in the SWWA-FARWH contained a range of conditions, from near pristine through to severely impacted (a situation exacerbated by large SWMAs existing in SWWA, where boundaries cross significant scales of altitude and climate – and accordingly large differences in land use and associated impacts). As such, combining themes de-sensitises scores; effectively masking any impacts against the pristine areas and producing a moderate health rating.

Missing data

There are missing data at the indicator, theme and reach level, and these must be accounted for in terms of integration and appropriateness to represent health. From this there are two issues:

1. the minimum level of information required to generate a theme score for a SWMA (number of reaches/sites)

2 the level of information required to discuss health at the SWMA scale (how many and which themes are required).

There is no single solution for the first issue, as the level of information required to represent a theme is relative. That is, different indicators within each theme require different sample sizes, and operate at different scales. This issue was discussed at a national workshop for the FARWH, where it was confirmed that site parity was not important (while the workshop reports were not publicly released, the NWC can be contacted for the information gained). For each indicator within each theme an analysis of power is required to determine sampling requirements (see Storer et al. (in press b)). From trials conducted for the SWWA-FARWH, significant differences were found not only between the various indicators, but also between SWMAs. In summary, a minimum level of samples has been prescribed for each component of the SWWA-FARWH, after which a certain level of error is accepted.

The issue of the number of samples required for each indicator has to be considered in terms of efficiency; that is, it is often logistically favourable to complete the entire sampling suite at each site (maintaining site parity).

The FARWH guidelines (NWC 2007a) suggest a minimum standard for the number of reaches per SWMA of 5%. The Victorian ISC uses 25%. To some degree this goes against the theory of required power, however it highlights the requirement to consider sampling efficiencies, and also recognises the importance of collecting complex information at each site to maximise the ability to interpret for a range of management scales. The following figure shows the percentage of coverage for SWMAs assessed in the SWWA-FARWH trials.

Table 19 The proportion (%) of reaches sampled in each SWMA assessed during SWWA-FARWH trials

SWMA	Total no. of reaches	No. of valid reaches	No. of partially valid reaches	No. of sites sampled	No. of reaches sampled	% of reaches sampled
Albany Coast	154	86	9	27	24	25
Denmark River	21	11	0	10	10	91
Shannon River	12	11	0	7	7	64
Busselton Coast	18	12	0	11	11	92
Preston River	3	3	0	3	3	100
Collie River	22	20	0	17	11	55
Harvey River	18	13	1	11	11	79
Moore-Hill Rivers	94	59	9	21	16	24
Total	342	215	19	107	93	40*

** average*

The number of reaches sampled within the SWWA-FARWH trials exceeds expectations based on standards employed within other programs (e.g. ISC) and recommendations from the FARWH.

The final issue for missing data is the level of information required to interpret health. The FARWH documents suggest that data need to be available for three of the six indices to allow an overall assessment to be made (NWC 2007a). An objective of this work was to examine whether this was appropriate for Western Australia, or if some themes/indices were more critical to an accurate assessment than others.

In conclusion, there is not enough information to be confident of the residual variation remaining when removing different themes. However, based on current results and the general understanding of ecology, we can say the *Catchment Disturbance index* is critical because it differentiates the broad pressures influencing the environment, and the *Fringing Zone index* is important because it provides information on the buffering capacity of rivers to withstand land use pressures (the effect of management – e.g. agriculture impacts in areas with protected river corridors versus no protection). Finally, the *Aquatic Biota index* is critical because this is the primary indicator of system health and has the potential to respond to impacts not highlighted remotely (with the *Catchment Disturbance* and *Fringing Zone* indices). The effectiveness of the *Hydrological Change index* is unknown and requires more work in terms of including allocation and farm dams, however there is likely to be a strong link with the *Catchment Disturbance index*. In saying this, hydrology data are critical for management of a system as they can be a good indicator to gauge environmental flows. *Physical Form* appears strongly correlated with the *Catchment Disturbance* and *Fringing Zone* indices (combined), and would likely only leave a small residual variation in describing river health. Water quality is important for interpretation of the

Aquatic Biota index, and is also linked with the *Catchment Disturbance* and *Fringing Zone* indices. The use of spot measurements for most indicators carries a low confidence in terms of validity in scoring at a SWMA scale (except for salinity). However, it is assumed that most health issues highlighted by water quality data would either be detected in biota or be related to the *Catchment Disturbance* and *Fringing Zone* indices.

6.3 Alignment with other programs

Alignment of techniques between the SWWA-FARWH and other FARWH programs is inherent in the adoption of guidelines outlined in the FARWH documents (NWC 2007b). As such, indicator selection, data handling and analysis, and scoring protocols were standardised where possible and appropriate – in theory resulting in national comparability. Whether final scores are comparable is largely a function of decisions made around weighting for integration, and to some degree this level of alignment is the responsibility of the national technical steering committee, which has been established to synthesise the results of the state FARWH programs.

Alignment was promoted through a series of workshops convened by NWC to discuss key topics for evaluating the FARWH (representatives from all FARWH programs along with state experts attended). Three topics were covered: data analysis and reporting, sampling design and applying the referential approach. While the workshop reports were not publicly released, the NWC can be contacted for the information gained in these sessions. See Section 7.1 for a list of these workshops.

This alignment process is particularly important in Western Australia because two distinct FARWH programs are being developed within the state: one for SWWA (this project) and one for tropical northern Australia. Alignment is being supported by establishment of an online forum (CSS 2010) and collaboration within training components being developed by eWater for both projects (CSS 2010). Further, cross-representation exists between the SWWA-FARWH and the wet-dry tropics FARWH steering committees (incorporating northern Western Australia).

Note: at inception meetings involving all FARWH programs from around Australia a commitment to interstate and cross-jurisdictional cooperation was made.

A number of river health programs exist within Australia, including the ISC, TRCI, EHMP and SRA. Alignment of the FARWH to these programs, along with other programs identified by the NLWRA, the most recent *State of the environment report* and the AWR 2005 (e.g. CFEV, NNRMM&EF) is particularly important both for comparability and to optimise efficiency in generating FARWH scores without additional data collection. The SWWA-FARWH was developed via review of these programs and input by associated representatives.

Alignment of the SWWA-FARWH with the other programs around Australia has been achieved in a number of ways. Firstly, the methods and indicators used by these programs were reviewed in developing appropriate techniques for testing, and secondly, the steering committees for the SWWA-FARWH and national FARWH programs included representatives from each of the programs listed above.

A summary of how the SWWA-FARWH and other Australian river health programs align (including other FARWH trials and existing state programs) has been provided in Table 20. This table examines the various indicators used by each program within the broad ecological themes prescribed by the FARWH. This shows that regional FARWH programs are closely aligned and hence, that a high level of comparability is expected. There are some differences in regard to alignment with state programs, which is expected given that program design is led by various management objectives and system-specific conditions. However, given all programs are following the same fundamental approach, the basis for a FARWH-style assessment is supported.

Table 20 Alignment of indicators across river health programs within Australia, including regional FARWH programs

	FARWH (south west WA)	CFEV (TAS)	TRCI (TAS)	ISC (VIC)	SRA (Murray Darling Basin)	SEAP (Central bioprovince, QLD)	EHMP (SE QLD)	FARWH (tropical AUS)
Physical form	Longitudinal connectivity Artificial channel Erosion	n/a	Bed material Erosion	Fish barriers Large wood Bank stability	n/a	Bank stability Substrate heterogeneity	Habitat heterogeneity Presence of large woody debris Bank stability	Bank stability Connectivity
Fringing zone	Extent of fringing zone Nativeness	Vegetation Context	Streamside Zone Extent of vegetation Organic litter Logs Weeds (high threat) Recruitment Canopy cover No. species Cover Longitudinal continuity Large trees Patch size (GIS) Neighbourhood (GIS) Distance to core area (GIS)	Width • Large trees • Understorey Lifeforms • Recruitment • Longitudinal Continuinty • Tree canopy • Litter • Logs • Weeds	n/a	Pest plant species in riparian zone	n/a	Spatial integtrity Nativeness Structural integrity Age structure Debris
Water Quality	Total nitrogen Total phosphorus Turbidity Salinity Diel dissolved oxygen and stream metabolism Diel temperature	Nutrients	n/a	Total phosphorus Turbidity Electrical Conductivity pH	n/a	Turbidity	pH Conductivity Diel (24hr) range and maximum temperature Diel range and minimum dissolved oxygen Ratio of 15N to 14N stable isotopes Ratio of 13C to 12C stable isotopes Respiration (R24) Gross Primary Production (GPP)	EC pH DO Turbidity FRP TP Nitrate TN
Catchment disturbance	Infrastructure Land cover change Land-use	Land use	n/a	n/a	n/a	Land use	Land-use Infrastructure Land cover change	Landuse Fire
Hydrological disturbance	FSR Including: High flow Low flow Proportion of zero flow Monthly variation Seasonal period	Hydrological regime Stream order Fluvial geomorphology	Mean annual flow Flow duration Variation Seasonal amplitude Seasonal period High flow High flow spells Low flow Low flow spells Proportion of zero flows Overbank flow Overbank spells	FSR	Median annual flow Mean annual flow Amended APFD Seasonal period Seasonal amplitude Yearly variation Low flow event number Low Flow Event duration Zero flow days difference 1:2 yr ARI Flood Event Number 1:5 yr ARI Flood Event Number 1:10 yr ARI Flood Event Number	IQQM modelled no flow spells	n/a	FSR
Aquatic Biota	Fish and Crayfish Macroinvertebrates	Fish and crayfish Macroinvertebrates Macrophytes	Macroinvertebrates Algae Fish	Macroinvertebrates	Fish Macroinvertebrates	Macroinvertebrates	Fish Macroinvertebrates	Macroinvertebrates Fish Aquatic weeds

One particularly important and critical outcome from the FARWH trials has been the establishment of a national river health network (linking all the above programs together in one form or another). This network has resulted in rapid development of methods, through optimising knowledge sharing and providing a forum for discussion.

This network, along with the national reporting mechanism (discussed later), should be a priority to maintain momentum in river health assessment in Australia.

7 Outcomes of the FARWH trials

The SWWA-FARWH trials have produced a number of important outcomes relating to general assessment methods, knowledge of systems, resource condition and capacity building.

These outcomes have been communicated through a variety of mediums, including workshops (regional, state and national level), online resources (Department of Water and NWC websites), conferences (a number of state and three national conferences, including two ASL conferences and the River Symposium), and through published reports on all aspects of the SWWA-FARWH program, including data collected, analysis and interpretation methods, and levels of data confidence.

All reports have or will be published through the Department of Water <www.water.wa.gov.au>, National Water Commission <www.nwc.gov.au> and Australian Water Resources <www.water.gov.au>. This includes mapping outputs of reach and SWMA scores from the 2008 and 2009 SWWA-FARWH trials.

Outcomes of the FARWH trials are described in detail below.

7.1 Capacity building and training

Capacity building and training have been essential parts of this project to support future implementation of the FARWH. This was particularly important for SWWA given that ecological assessments of river health had not previously been conducted at the state level: not only was there a need to develop sufficient capacity within SWWA, but confidence among resource managers in relation to the program's benefits also needed to be fostered.

This objective was met on a number of levels: through high-level training of core project staff, meetings (internal and inter-agency), workshops (regional, state and national), conferences (local and national), publications (including posters, reports and online information), development of training materials, collaboration within and across agencies with field work and data analysis, communication with landholders and training days for regional staff. These areas are expanded below:

Meetings (internal and inter-agency)

- Active consultation has taken place within the Department of Water to ensure the outcomes of the FARWH will have a broad application across the department, hence improving its uptake. To date, SWWA-FARWH progress and developments have been reported to the department through meetings of the:
  - Drainage and Waterways Branch
  - Allocation and Planning Branch
  - Environmental Water Planning Branch
  - Water Science Branch.

- SWWA-FARWH project officers have also met with representatives of local natural resource management (NRM) groups, community groups, Aboriginal corporations, the Department of Environment and Conservation (DEC) and the Water Corporation.

Through this process, development of the SWWA-FARWH methods has been aligned with agency requirements. Further, a number of the techniques developed are being reviewed for updating regional monitoring requirements, including implementation of ecological assessments into allocation plans for two systems (discussed later).

At a water resource management level, the SWWA-FARWH has and will continue to improve the efficiency of river health assessment and monitoring in SWWA.

Workshops (regional, state and national)

- Workshops were held in each of the regions where FARWH trials were undertaken. These served as a knowledge-sharing exercise (in determining appropriate sampling methods and site selection for different regions) and to advise relevant stakeholders about the project, including its aims and objectives, methods being used and final products to be delivered. Presentations on the FARWH and its development in Western Australia were conducted at a number of separate workshops for environmental managers throughout the state.
- Workshops conducted include:
  - Three national FARWH workshops evaluating different aspects of the FARWH program (these workshops were run in conjunction with other states trialling the FARWH)
    - sampling design workshop – facilitated by Wayne Robinson (University of the Sunshine Coast) – CSIRO Long Pocket Laboratories, Indooroopilly, Queensland, 27 November 2008
    - data analysis and reporting workshop – facilitated by Wayne Robinson (University of the Sunshine Coast) – Department of Water, Perth, 26 February 2009
    - referential approach workshop – Marque Hotel, Canberra, 15 September 2009.
  - Mid-West region workshop: Geraldton (Department of Water staff from Moore-Hill, Greenough and Murchison regions, along with local NRMs and government agencies).
  - South-West region workshop 1: Bunbury (Department of Water staff from Collie and Brunswick regions, along with local NRMs and government agencies).
  - South-Coast region workshop 1: Albany (Department of Water staff from Albany region, along with local NRMs and government agencies).

- South-Coast workshop 2: (Department of Water staff from Shannon and Denmark regions, along with local NRMs and government agencies).
- Kwinana-Peel and South-West region workshop (Department of Water staff from Harvey, Busselton Coast and Preston regions, along with local NRMs and government agencies).
- River Rats workshop (Geraldton): annual workshop of environmental managers (various agencies) and community groups. Discussion of principles and practices of maintaining environmental health.
- Waterways workshop (Perth): annual workshop of Department of Water staff within waterways health assessment areas from throughout Western Australia. Discussions on policy and management priorities for waterway health.
- Northam workshop (Northam): workshop with regional Department of Water staff on applying river health assessment (SWIRC) to the Avon River.

Conferences

- Australian Society of Limnology 2008 (Mandurah), conference poster and presentation.
- Australian Society of Limnology 2009 (Alice Springs), conference poster and FARWH session presentation.
- River Symposium 2010 (Perth) – presentation.
- Australian Society of Limnology 2010 (Thredbo), presentation.

Publications

- Posters: two ASL posters (2008 and 2009), two promotional posters for use in Department of Water meetings and workshops.
- Reports: inception report (van Looij & Storer 2009a; 2009b), trials report (van Looij et al. 2009), final report (Storer et al. (in press a) and technical report (Storer et al. (in press b). Discussion reports (from each trial and Perth FARWH workshop) in trials report.
- Online information, Department of Water website <www.water.wa.gov.au>.
- Two-page summary flier – provided to all relevant regional staff, community groups, inter-agency staff, and landholders.
- Report cards and associated methodology overview; in preparation.
- SWWA-FARWH methods (separate guide for field sampling techniques and desktop analysis) – in preparation.

Development of training materials

- An important component of the project is the development of training and implementation products and tools for the assessment of river health and the application of FARWH in SWWA. This is being done at a national level in conjunction with the wet-dry tropics FARWH trials to ensure the products are compatible and to help unify the projects, enhancing the FARWH's applicability as a national approach. Training materials are being developed by eWater and will be prepared in conjunction with this report. See Appendix C for the Draft FARWH training and result publication website delivery report.

- Fundamental training materials (including field sheets) have been prepared for training staff. Training days have been held throughout the project for various personnel (discussed below).
- A three-day training session was conducted for staff in the Department of Water's Avon Region on FARWH field and scoring methods. This training session was unique as it focused on applying the FARWH to river pools, which was not undertaken during the SWWA-FARWH trials. Avon staff have borrowed a full set of FARWH field equipment (e.g. trailer, boat and water quality loggers) and will conduct further FARWH-style assessments in the coming months. Further training days will be conducted as needed to build capacity for the regions to implement FARWH methods.
- A training day was also conducted for all staff of the Department of Water's Water Science Branch (approximately 40 people). This was designed to update all staff on the techniques developed through the FARWH trials to better align future work.

Collaboration within and across agencies (field work and data analysis)

- Numerous staff from a range of areas within the department, outside of the Water Science Branch's core project team, have been involved in sampling. This includes regional and head office staff – including field officers, environmental scientists, data management officers and managers. This was done to enhance understanding and appreciation of the project and its usefulness across a wide range of water resource management applications. This has increased the capacity of regions to undertake FARWH-style assessments in future. At least one member of non-core staff was involved in almost all field activities.

Communication with landholders and stakeholders

- Throughout the FARWH trials 117 sites were assessed, and many more visited. Many of these sites were on private land or land governed by other agencies. Through field communications, awareness of the FARWH project was significantly expanded. This included, as previously discussed, the distribution of project information fliers to all stakeholders. In many cases, there were opportunities for field activities to involve landholders, staff from the Water Corporation and DEC, and representatives of local NRM and Aboriginal groups. This has increased awareness and in some cases improved local management actions. For example, fish data collected for the Gingin Brook (Moore-Hill Rivers SWMA) were used by the Department of Water to assess fish passage on the barrier located near the Gingin townsite.

- Field data were also used to supplement existing data (as part of a desktop assessment) of ecological values as part of two reports prepared to support the *Upper Collie water allocation plan* (DoW 2009), which were the:
  - *River action plan for the Upper Collie catchment* (Macgregor et al. 2010)
  - *Identification and mapping of groundwater-dependent ecosystems associated with the Collie River* (SKM 2010).

As mentioned under the publications dotpoint above, the Department of Water will endeavour to develop materials for relevance at local scales. This will focus on methods for data collection and analysis and templates for reporting river health, with the goal to report relevant data at finer scales.

In addition to the areas covered below, capacity was also developed via establishing resources. Through funding from the Raising National Water Standards program, two trailers with all the required sampling equipment to conduct a complete river health assessment were set up. This has further extended to the capacity to undertake future assessments given the simple outcome of site identification and contacts throughout each region. The Department of Water's Avon region is already using one trailer for ecological surveys. Results of these surveys will be added to datasets developed through the FARWH trials.

Through these outputs (including the synthesised FARWH report, associated communications and continued work in the area) the importance of delivering a nationally based river and wetland health reporting framework has and will be demonstrated to the Australian public.

7.2 River health assessment and monitoring

Outcomes of the SWWA-FARWH trials in terms of the status of river health assessment in SWWA can be divided into four areas:

1. improvements to methods
2. increased awareness and acceptance
3. application of methods outside of the FARWH
4. guidance for future development.

These elements are discussed below.

Method improvements

The SWWA-FARWH trials have adapted, improved and developed new methods and indicators for assessing the health of SWWA rivers through an extensive review of the literature; guidance from existing local, national and international methods for assessing river health; data collation from throughout SWWA and subsequent analysis; and field validation.

Previously, river health assessment at a state or regional scale in SWWA was largely based on water quality and quantity indicators – relating data to a general understanding of land use characteristics. The SWWA-FARWH has improved on this by providing of a suite of indicators capable of quantifying and drawing comparisons between aspects of the broader ecological elements of aquatic ecosystems (Catchment Disturbance, Water Quality (new parameters), Physical Form, Fringing Zone, Hydrological Change and Aquatic Biota).

The improvement to methods is not only critical for applications such as the FARWH, but also greatly improves our ability to understand and interpret system health and impacts at local management scales. The specific application of methods developed through the SWWA-FARWH trials is discussed later.

Finally, the SWWA-FARWH project facilitated development of supporting data, which in turn improved the overall capacity for river health assessment. For example, a fish barriers dataset was created to highlight potential barriers to fish migration throughout Western Australia (Storer & Norton in press, Norton & Storer in press).

Increased awareness around river health assessments

A significant outcome for water resource management in SWWA was communication and engagement with a wide range of audiences. Through meetings, workshops and collaborations, project development and results were able to be discussed – showcasing the value, and increasing the support of, multi-parameter ecological assessments. Ultimately, adoption of the techniques discussed in this report requires support from the range of stakeholders involved in water resource management in SWWA.

Specific aspects of this outcome have been discussed within Section 7.1: *Capacity building and training*.

Application of methods outside of the FARWH

Many of the methods and indicators developed as part of the SWWA-FARWH trials were shown to be sensitive at local scales. As such, a number of these methods have been adopted for existing programs being conducted by the Department of Water. Further, through communicating project results, the benefit of this type of assessment for management has led to the request for similar assessments (or use of specific indicators/methods) for a range of specific needs.

Examples of current projects using methods or indicators developed through the SWWA-FARWH include:

- updating methods within the RHAS (the existing Perth-based program)
- adapting the SWWA-FARWH suite for health assessment of river pools along the Avon River – pre- and post-assessment relating to removal of sediment (NRM funded program)
- use of the general health assessment, with a specific focus on fish indicators, for assessing the Kent Street Weir (Canning River, Perth) as a potential fish barrier (Department of Water and Swan River Trust program)

- assessment of *Aquatic Biota index* (fish/crayfish and macroinvertebrates) at several sites along the Canning River (Perth) to elucidate the effects of releasing water to maintain environmental flows (Department of Water funded program)
- assessing the fringing zone vegetation in the Murray River SWMA to determine if remnant vegetation possesses some degree of ecological value
- use of the indicator suite to form the basis for integrated assessment of aquatic ecosystems as part of trials for the High Conservation Value Aquatic Ecosystem project: work being conducted on the Walpole-Nornalup system (Department of Environment, Water, Heritage and Arts funded program)
- potential: ecological data available to determine river typologies in SWWA and potential trial of the application of the Australian National Aquatic Ecosystem (ANAE) classification framework
- general: use of methods and indicators to evaluate Department of Water remediation/rehabilitation activities throughout the SWWA (development of ‘living streams’, riffle restoration, healthy waterways program, bank restorations, assessment of fish barriers) – potential ongoing application
- general: use of ecological indicators in Department of Water’s water allocation plans (and associated licence requirements); for example, the requirement for ecological assessment is being incorporated in the Gingin Brook (Moore-Hill Rivers SWMA) allocation plan, where SWWA-FARWH indicators will be used to determine environmental flow requirements
- development of an Index of River Condition for SWWA (discussed below).

Guidance for future development

As discussed in this report’s recommendations, one of the more useful outcomes of the SWWA-FARWH trials has been identification of knowledge gaps for conducting river health assessments. There is now a good approach to improving water resource management in SWWA following a prioritised list of requirements against each science area.

Finally, the Department of Water has begun development of the SWIRC (South-West Index of River Condition), which will provide a suite of indicators for a range of river health assessments at various scales/purposes. The SWIRC will include recommended indicator sub-sets tailored to specific management needs, from small-scale assessments (e.g. determining impact of fish barriers or effects of river restoration) to broad assessments (e.g. state-based river health programs and any ongoing national reporting requirements). Using standard methods across a broad range of programs will maximise comparability for all users. The SWIRC is founded by indicators developed within the SWWA-FARWH trials, with inclusion of indicators for finer-scale assessment – developed or adapted from existing programs.

7.3 Resource condition knowledge

The knowledge of water resources in SWWA has been significantly improved through the SWWA-FARWH project, particularly within the areas assessed in field trials.

Before the FARWH trials, knowledge at a state-wide scale was limited spatially. What was known was primarily restricted to water quality and quantity information (outside of a number of localised ad-hoc assessments). The FARWH trials collected a complete ecological profile of 117 sites, with each site assessed over two days. This dataset is spatially robust, for the SWMAs assessed, and directly comparable between SWMAs (a weakness of previous assessments for broadscale reporting, given varying methods, project objectives and scales). Further, the SWWA-FARWH trials collected information in many areas not previously assessed for river health. Data from 20 RHAS sites was also collected and added to the FARWH database.

Note: information collected was significantly more extensive than has been reported to this point, as a broad range of supplementary data was collected (refer to field sheets provided in Appendix B).

The SWWA-FARWH trials have provided health scores for each indicator at a reach level (in theme reviews) and overall SWMA scores for each theme/indicator (see Section 6.1, *Performance of the FARWH*). For the first time, at this scale, assessments included an analysis of the interplay between pressure, stressor and response.

The trials have also resulted in the generation of data (compiled, collated, created) that can be used to assess health outside of areas directly targeted by the trials, and will be a valuable resource in the future. A list of these datasets along with access information is provided in Table 22, which also includes existing datasets used or reviewed within the scope of the SWWA-FARWH project.

Resource condition knowledge has been directly improved through the reported health assessments and generation of environmental datasets applicable across the entire region. To complete knowledge of resource condition in SWWA, the remaining SWMAs (those not sampled in the SWWA-FARWH trials) require assessment to ensure natural and anthropogenic variability is understood, while the sampling/analysis/scoring method requires associated validation and subsequent improvement.

The associated understanding of how SWWA systems behave is discussed in the following section.

7.4 Scientific knowledge of systems and methods

Scientific knowledge of SWWA systems has been greatly improved through the SWWA-FARWH trials, however this is still in its infancy given significant gaps in knowledge in terms of reference condition and thus our ability to comprehend and quantify departure from reference. Further, because this was only a snapshot of environmental health and condition, natural variability is poorly understood and, as such, there is a varied (indicator dependent) degree of uncertainty with reported assessments.

Scientific knowledge is only improved through understanding cause and effect, and given data limitations it is, in reality, only possible to elucidate the associated interactions for SWWA systems. The ability to interpret responses of SWWA systems to stressors and pressures has been greatly improved through both the compilation of environmental data across SWWA and collection of consistent information across the eight SWMAs assessed. For instance, interaction can now be studied between broad ecological aspects, such as hydrology and ecology, and between more specific questions, such as biotic response to various land use activities within different climatic regions or with varying levels of fringing vegetation health. The improved interpretive power (due to comparability of data) has both identified apparent links and also highlighted factors having little influence on health (e.g. the secondary water quality indicators described).

The knowledge of SWWA systems, in terms of responses of form and function to various catchment pressures or in-stream stressors, has been presented. However, given the limitations previously discussed (spatial coverage and uncertainty around degree of variability), it is not considered appropriate to further interrogate information at this stage. This will be the primary aim for the next stage of work in this area, which will target the establishment of environmental thresholds and associated prioritisation of management.

Note: multivariate analysis of environmental data collected through the SWWA-FARWH is ongoing and will continue to elucidate system responses to environmental impacts – improving rigour and thus adding confidence to the scientific knowledge.

In terms of methods, scientific knowledge has been improved through the use of sensitivity and power analysis, in that a robust suite of indicators with associated methods for sampling, analysis and scoring have been tested.

As mentioned in previous sections, one of the most critical outcomes for river health assessment in SWWA has been the identification of knowledge gaps – in data as well as scientific knowledge (understanding of system variability). Targeting these will greatly improve the efficiency of future work (prioritised research and monitoring) and result in a rapid increase in knowledge of system function. For example, one immediate priority, which has been greatly overlooked in the past, is the need to understand species tolerance levels across a range of conditions to determine appropriate indicators and set thresholds for management. Understanding general species biology would also enable determination of expected and required habitat (general and reproductive), and determination of species-specific barriers to migration (based on swimming capabilities).

Summary

The SWWA-FARWH program and associated development of the SWIRC have greatly improved the capacity of resource managers in SWWA. They are now in a better position to provide:

- an understanding of the nature of SWWA river systems
- information about the condition of SWWA river systems
- a baseline or reference condition from which changes can be monitored
- an assessment tool for evaluating NRM activities
- monitoring impacts of human activity
- prioritisation for investment based on the above
- strategic direction for future management.

However, building on the advances made through the SWWA-FARWH trials will require significant investment into the future to ensure the momentum is not lost and the capacity to conduct assessments is maintained.

8 Synthesis of key findings and recommendations

Although many uncertainties with the SWWA-FARWH exist at a fine scale (coarse resolution, gaps in information, lack of historical knowledge – all resulting in over-use of expert opinion), these appear to result in a relatively low level of residual variation at the SWMA scale. When viewed at the scale intended, the SWWA-FARWH appears to provide a good representation of the major pressures, stress levels and general condition of the resource (represented by response indicators) of south-west systems.

Prioritisation of broad-level management requirements is significantly improved by using the results of the SWWA-FARWH trials, while attention to the knowledge gaps identified in the project will provide benefits into the future (see recommendations). Further development will increase the relevance of river health assessments for local management.

Specific discussion of findings from the SWWA-FARWH trials is provided in Section 6.1: *Performance of the FARWH*. This section responds to a number of key questions that NWC has posed in relation to the applicability of the FARWH approach, these being:

- relevance of FARWH in meeting state-level requirements for monitoring and assessment
- assessment of whether one river-health approach can be used to provide both state and national needs
- presentation of a picture of water management and its relationship to river health for each trial region.

Responses are provided below.

Relevance in meeting state-level requirements for monitoring and assessment

Alignment of the SWWA-FARWH with existing state-level river health programs, and thus meeting state requirements, is not a question easily answered for SWWA given no existing programs are available for comparison. As such, monitoring and assessment capability is exceeded by development of the SWWA-FARWH.

State-level requirements for monitoring and assessment from a Department of Water perspective include the ability to gauge impacts from water use, and thus support allocation and licensing processes. The SWWA-FARWH provides the opportunity to greatly improve this aspect of water resource protection, by being able to compare hydrological health indicators against both pressures and responses.

One of the most important attributes of FARWH-style assessments is consistency in data collection and scoring – providing the ability to explore cause and effect, and maximise comparability across regions. The high-level of comparability of FARWH results is a function of standardisation of the key underpinning rules, such as range-standardised and linear scoring. One of the greatest weaknesses in ecological monitoring activities in SWWA is a history of ad-hoc assessments, making interpretation of results across programs extremely challenging and attracting a high degree of uncertainty. Ongoing attention to standardisation of methods for monitoring is essential for management of SWWA systems, however this will require careful planning by water resource managers.

The SWWA-FARWH has provided a number of new techniques for assessment of aquatic systems, as well as improvements to existing methods through results from sensitivity analyses.

Assess whether one river health approach can be used to provide both state and national needs

Due to scale issues the current FARWH protocol for SWWA cannot completely meet both needs. For instance, assessment of vegetation extent (width and length) is not sensitive enough to assess/prioritise at state level. This is not so much a limitation of the FARWH, as all available data with reasonable spatial coverage and confidence are used in the reported assessments. The limitation lies with an inability to currently assess water resources at a state level.

That is, available data have a reasonable resolution and spatial coverage for application at a national level, but at finer scales any assessments would have insufficient quality. Obviously this refers to assessing river health from an ecological standpoint. Assessments are still possible for different objectives.

In future, as more data become available, a FARWH-style assessment can be adapted to be useful for a national-level assessment, while still being relevant locally.

Present a picture of water management and its relationship to river health for each trial region

The SWWA-FARWH has identified broad water management issues in SWWA, with often varied conditions operating in the different SWMAs, due to different pressures operating under different natural conditions (e.g. climate). For example, Albany Coast SWMA is characterised by a significant rainfall gradient from east to west, with eastern systems becoming increasingly seasonal. The most significant pressure in this SWMA is cropping and extensive agriculture. This has resulted in serious environmental stress due to salinity and habitat destruction, especially in the eastern half of the SWMA. This situation appears exacerbated in areas where rainfall is most limited. Water management in this area requires significant effort in re-establishing streamside protection zones and attention to the wider catchment salinisation problems. However, this is a significant challenge given the extent of problems and will not be easily remedied. In the short term, many of the smaller coastal systems, including those representing the range of the rare and endangered trout minnow (*Galaxias truttaceus*) should be protected.

A review of management issues identified through river health assessments will be discussed in detail in report cards produced subsequent to this report.

One reassuring observation is that where stream management is in place, even amid otherwise degraded sections of river, overall river health scores appear to reflect improvement in condition. Given the scale of reporting here, most of this differentiation is lost. It does indicate, however, that the FARWH/SWIRC is applicable at the finer scale, which is important for local management.

8.1 Recommendations

Recommendations of the SWWA-FARWH project to address the various identified challenges and knowledge gaps are provided in the table below. Note: recommendations are listed in decreasing scale: from general and overarching comments through to specific site or indicator requirements. These are not meant to reflect a priority scale (see Section 9 for priority recommendations).

Table 21 Knowledge gaps, challenges and recommendations from the SWWA-FARWH project

Category	Knowledge gap and challenges	Recommendation
Increasing applicability of FARWH to SWWA conditions	Current assessment protocol not designed for dry systems (seasonal, ephemeral).	Design a protocol for dry systems (at time of sampling).
	Current assessment protocol not designed for river pools (no flow).	Design a protocol for river pools (no flow).
Increasing applicability of FARWH in Western Australia	Current assessment protocol not designed for Rangelands (e.g. mid-west) [outside of wet-dry tropics scope].	Design a protocol for Rangelands (outside of SWWA and wet-dry tropics study areas).
Spatial limitations	SWMAs not assessed during trials; thus natural variability cannot be confirmed, especially for Aquatic Biota and other indicators requiring field assessment.	Assess remaining nine SWMAs in SWWA – define health scores and use data to inform reference condition.
Temporal limitations	Availability of temporal replicated data: difficult to determine temporal variability and thus inform both reference and current condition.	Temporal monitoring and increase in frequency of data used for GIS-based assessments (e.g. land use mapping), where required (potential to develop trend indicators).
New datasets to improve ability to perform health assessment	Modelled data (to overcome bias with field monitoring for some data).	Investigate and assess models needed and associated datasets required for these (e.g. SedNet input datasets such as gully erosion need to be remapped).
	Ability to assess health remotely due to lack of appropriate data (e.g. coarse-scale data, insufficient coverage of study area, lack of currency).	Trial technologies such as LIDAR (e.g. for aquatic habitat – large wood, and understorey assessment).

Category	Knowledge gap and challenges	Recommendation
Reach dataset	Some current reaches do not represent homogeneous environment (cross distinct natural strata shown to change form/function/behaviour).	Redefine reaches based on topographic conditions (e.g. finer DEM) relevant to scales occurring in SWWA. Examine use of strata (such as geology and natural vegetation zones) to separate reaches.
	Reaches do not line up with river line. Reduces accuracy of many indicators which use conditions along river lines to assess health.	Redefine reaches using a fine-scale DEM and incorporate techniques to ensure reaches align with mapped watercourses.
Site/reach selection	Sites/reaches currently chosen based on representativeness; random selection required to prevent bias.	Use random allocation of sites in future assessments (a network of 'known sites' would need to be established via extensive ground-truthing).
Scale	Reporting and prioritisation is currently relevant at the SWMA scale, however the results are less representative at the reach or site.	Generation of higher-resolution data for sites and reaches to make assessments sensitive at these finer scales.
River typology/regionalisation	Difficulty in tailoring scoring protocols based on river function (regionalisation) as there is limited knowledge of boundaries of river types/styles.	Conduct assessment of typology (e.g. implement ANAE framework). This includes differentiating upland/lowland characteristics and development of conceptual models. This will inform reference condition for areas without historical data.
Improvement of river health assessment protocol	Lack of comparability due to spatial limitations in data and inconsistency in associated methods (existing data).	Complete assessments on all SWWA systems. Validate existing and trial new indicators based on the more complete dataset.
Aquatic Biota theme	Paucity of information on species tolerances (to define impact thresholds, habitat requirements and determine species-specific impact of elements such as barriers to migration).	Assessment of species dynamics across a wider range of systems. Includes understanding of general biology and reproductive requirements. Targeted ecotoxicological studies to determine tolerance levels (to assign indicator thresholds).
	Reference distributions	Complete assessment of rivers in SWWA to

Category	Knowledge gap and challenges	Recommendation
		elucidate expected natural ranges (in conjunction with tolerances studies above).
	Understanding the impact of exotics (species specific).	Complete literature review and assess impacts in SWWA systems. Develop weightings against certain species based on ecological impact and time in systems (e.g. established exotic species such as trout, where stable states have now been reached, may be of lesser concern than newly introduced species).
	Understanding catchability of species to improve ‘expected’ metric.	More data required, including new systems, to determine the percentage chance of catching each species. Incorporate chance of capture in expectations component of O/E scoring protocol.
	Reference condition for macroinvertebrates (existing AUSRIVAS model limited by reference sites – significant residual variation).	Conduct sampling to increase reference data and improve model for SWWA systems.
	Reference condition for fish.	Sampling across wider range of areas required to inform expectations of species distributions (limited historical data available).
	New indicators recommended for testing.	Assess validity of using aquatic weeds, macrophytes, water-dependant terrestrial fauna, turtles and frogs to represent stream health.
Hydrology	Account for the effect of farm dams.	Trial CHEAT model to determine the differences in flow caused by the presence of farm dams within the catchment. Alternatively an additional index relating to farm dam density and farm dam development can be created. Both would require more detailed farm dam mapping then currently exists.

Category	Knowledge gap and challenges	Recommendation
	Effect of allocation on FSR.	Quantify water extraction (Department of Water) data and incorporate into FSR.
Water Quality	Natural variability of water quality parameters (system-specific) poorly understood.	Trial equipment that can log water quality data for a wider range of parameters over a longer time period than what was trialled in the SWWA-FARWH – conduct power analysis to determine required assessment to provide indicator of health. Investigate scoring protocols for these additional parameters.
	New indicators recommended for testing.	Stream metabolism (trial new methods from those assessed in report – e.g. using light data).
	Threshold values assigned for most water quality parameters based on expert opinion or data from outside of Western Australia.	Revise thresholds as more data is collected, and specifically targeted studies on aquatic biota tolerance (see *Aquatic Biota index* recommendations).
Physical Form	Erosion indicator prone to human bias (field assessed).	Expert panels to evaluate scoring and assessment methods.
	Lack of data on pre-European reference condition for *erosion sub-index*.	Define reference condition using geomorphic benchmarks approach adopted in TRCI.
	Lack of data on pre-European reference condition for coverage of tree and shrub layers, used for the bank stabilisation indicator.	Define pre-European reference condition for vegetation based on literature review and expert opinion.
	Data source used for *longitudinal connectivity sub-index* scores is at pre-publication stage and requires extensive verification.	Verify data (clean data points and ground-truth potential barriers) in Fish Barriers database.
	Lack of knowledge about fish characteristics to quantify impact of potential barrier structure.	Conduct research into fish migration patterns, lifecycle and swim characteristics in relation to potential barriers in SWWA.
	Lack of knowledge about occurrence of modification of channels for management, for calculation of artificial channel indicator scores.	Gather information from local management agencies regarding management activities (e.g. dredging).

Category	Knowledge gap and challenges	Recommendation
Fringing Zone	Datasets used to assess vegetation extent limit sensitivity of the data.	New datasets should be assessed e.g. LIDAR (Light Detection and Ranging data) (which may also allow assessment of understorey complexity).
	Reaches are spatially mis-located compared with mapped watercourses.	Redefine reaches using a fine-scale DEM and incorporate techniques to ensure reaches are aligned with mapped watercourses.
	Lack of data on pre-European reference condition for vegetation extent and structural complexity.	Define pre-European reference condition for vegetation based on literature review and expert opinion.
	Use of 50 m buffer as reference condition may not be relevant to all rivers.	Investigate tailoring buffer zones based on stream width.
Catchment Disturbance	Lack of currency of land use data and infrastructure for associated indicators.	Map land use and infrastructure at regular temporal intervals.
	Lack of spatial sensitivity in *infrastructure sub-index* and *land cover change sub-index.*	Refine scoring protocols to increase the differentiation between disturbance levels in catchments.

General recommendations

The communication network established through the national FARWH program was critically important, especially for supporting states without long-term assessment programs. This collaboration of states and program leaders at a national level demonstrated significant efficiencies, whereby techniques were rapidly improved, problems solved quickly, and consistency in methodologies was generally ensured – thus maximising comparability. It is recommended this network be nurtured into the future to maintain momentum and maximise development of river health assessment in Australia.

An ongoing national river health network would be a valuable outcome of this program; and an associated health reporting mechanism and discussion forum is recommended.

Key recommendations for improving the SWWA-FARWH

Finalising the SWWA-FARWH requires assessment of the health of the remaining SWMAs not targeted in current trials, including widening the scope of current protocols to include non-flowing and dry systems. Inherent in this is the validation of current indicators spatially (as above), but also temporally (capturing natural variability).

For national reporting, SWMA scores appear to broadly represent river health when viewed at a theme scale. However, if a single score is required for each SWMA (to meet national reporting requirements) then a precautionary approach is recommended. That is, the lowest theme score for each SWMA is used to represent overall health. If scores are reported nationally across all states, then the FARWH is only endorsed on the proviso that SWMA definition is standardised across jurisdictions. At present any comparisons would be biased.

For local reporting, interpretation of theme- and indicator-level information at reach and SWMA scales will provide valuable information to inform state management of water resources – and direct targeted works where required.

9 Taking key recommendations forward and next steps

9.1 A refined FARWH for undertaking a national assessment

The FARWH is endorsed as an effective method for undertaking a national-level assessment, and is only limited in SWWA by state deficiencies in underpinning data. Specific refinements to the SWWA-FARWH protocol are discussed in the following section.

Consistency and comparability between states is enabled through the core principles of the FARWH (e.g. standard scoring protocols and reporting requirements). Adherence to these principles, along with associated weighting, is largely the responsibility of the national technical steering committee. As such, refining the FARWH for undertaking a national assessment is a perceived outcome of this committee.

9.2 Planned outline for further development, implementation and adoption of the FARWH, including costing

As discussed in the previous sections, the work conducted in the SWWA-FARWH trials requires consolidation and collection of additional data to refine techniques (see Section 8.1: *Recommendations*). For the FARWH to be effective as an ongoing national-level river health assessment tool, the data quality and quantity has to be maintained at a state level. For SWWA, continued monitoring of river health (using FARWH methods) and acceptance of results presented nationally requires endorsement by water resource managers. This endorsement and adoption requires more work in linking health assessment to management, allowing prioritisation and recommendations for system requirements to ameliorate identified impacts.

For SWWA, the development of FARWH methods and determination of management thresholds will require initial support so their importance to the state is recognised, and thus sustainable levels of funding provided. The vision is that river health assessment outputs will be integrated into state water resource management policy, ensuring monitoring and assessment techniques are standardised and therefore data are sufficient for national river health assessments. Further, adoption will be greatly improved by appropriate communication of methods and results (such as community report cards).

Development, implementation and adoption of the FARWH requires:

- Completion of the baseline year (suggested 2008–12) and assessment of remaining SWMAs, capturing natural spatial variability and thus informing reference condition and associated validation of scoring protocols.

- Development of management thresholds for reaches/SWMAs (e.g. assigning thresholds of potential concern and limits of acceptable change) based on river health scores – proving the FARWH's usability for local management and relevance to Department of Water core business.
- Maintenance of existing river health networks.

Once the SWWA-FARWH has been validated for the entire region (from above), a rolling river health assessment is suggested. This would be valuable for meeting many of the state's water resource protection requirements, and would therefore be funded internally.

At this stage, delivery of this program can only be suggested, but would broadly entail frequent assessments of key variables, particularly response indicators, and less frequent assessment of others; for example, pressure indicators that change on much longer time scales. Based on the current river health team's capacity, response indicators (and supplementary data) could be measured for the entire SWWA region every two to three years (rotating through a sub-set of SWMAs annually). An annual assessment could be facilitated with the use of regional officers. Indicators such as hydrology and land use need only be assessed every five years or more (as shown in Table 3) and can generally be done remotely.

A costing for both stages of the FARWH's development in SWWA (consolidation and validation of SWWA-FARWH protocol, and the river health assessments required for a complete assessment of state river health every three years) is provided below:

COSTING: Finalising the SWWA-FARWH protocol

Time required: Two years

Funding source: State and Commonwealth

Scope:

1. Complete development of protocol for flowing rivers, which requires assessment of remaining SWWA SWMAs (those not assessed in current trials) and validation and development of indicators.
2. Develop FARWH protocol for dry and non-flowing systems.

Salary and operating costs:

- Three full-time salaries and four part-time (0.25 FTE) regional staff (at specified calling level 2) and $100 000/yr operating.

  This includes all associated costs; for example, analysis of water quality, identification of macroinvertebrates, travel and equipment maintenance. Note: all required equipment has been sourced through the current FARWH program.

  Total: $500 000/yr

This initial work is critical for SWWA river health assessment, and thus the ability for ongoing national reporting. This work would not only consolidate methods, but allow the incorporation of river health assessment into state-level policy. It is this last point that will ensure sustainability. Simply put, river health assessment is nearing critical mass (due to the FARWH trials): once this is reached, which requires the local management link, ongoing work should be supported by core state-level funding.

This final development period is a short-term requirement to ensure that existing capacity and momentum is not lost, while also protecting the network that has been developed as part of the FARWH program.

COSTING: Assessing river health for future national reporting

Funding source: State

Scope:

1 Assessment of river health across all SWMAs every three years (rolling assessment). Note: could be done annually using regional staff.

Salary and operating costs:

- Three full-time salaries and four part-time (0.25 FTE) regional staff (at specified calling level 2) and $100 000/yr operating.

  This includes all associated costs; for example, analysis of water quality, identification of invertebrates, travel and equipment maintenance. Note: all required equipment has been sourced through the current FARWH program.

  Total: $500 000/yr

Use of the FARWH for reporting river health nationally is in itself not a costly exercise assuming the data are available to generate the indicators prescribed here. Based on this, scoring and reporting would take a few weeks by two trained staff.

9.3 Concise step-by-step guide to undertaking the FARWH for a national assessment

Guidance for undertaking the FARWH for a national assessment, in terms of the SWWA component, is currently covered within this and the accompanying technical report (Storer et al. in press b) (based on final indicator suite and background information existing in theme summaries), the river health assessment field sheets (Appendix B) and the trials report (van Looij et al. 2009a) which contains an overview of most data collection/analysis methods required for the FARWH assessment. Note: any altered methods from the trials report are covered in the technical report (Storer et al. in press b).

A concise step-by-step guide, designed for use by regional Department of Water staff and for future users of the FARWH, will be developed in line with preparation of report cards by the department, following final reporting. In addition, all methods and results will be developed into online training and implementation products and tools by eWater. This is being carried out in conjunction with other jurisdictions where FARWH trials are being conducted, in particular the wet-dry tropics FARWH team.

Note: any prescribed methods for conducting a FARWH assessment will have associated caveats on data confidence and appropriate application.

Appendices

Appendix A Complete final scores for SWWA-FARWH: indicators/themes for reaches/SWMAs

Appendix B SWWA river health assessment field sheets

Appendix C Draft FARWH training and result publication website delivery report

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
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

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
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
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

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
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
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
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

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
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
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

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
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
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
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

Catchment Disturbance theme

Reach	CDI	ISI	LUSI	LCCSI
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
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

Catchment Disturbance theme				
Reach	CDI	ISI	LUSI	LCCSI
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

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6021038	0.6	1	0.7	0	0.7	0.7
6021042	0.6	1	0.7	0	0.7	0.6
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
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

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
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
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						

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
6061119						
6061120	0.9	1	1	0.9	1	0.9
6061124	0.9	1	0.8	0.8	1	0.7
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
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

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
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						
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

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
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
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
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

Hydrological Change theme						
Reach	HCI	LF	HF	PZ	CV	SP
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
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

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
DENM-03	60315402	0.9	0.8	1.0	0.8	0.8	0.9	1.0	1.0
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
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

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
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
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
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

Water Quality theme									
Site	Reach	WQI	TN	TP	Turbidity	Diel Temp	Mean secondary	Salinity	Diel DO
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			
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			

Physical Form theme

Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
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			
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			
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			

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
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		
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

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
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
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			
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		

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
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			
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			

Physical Form theme										
Reach	PFI	ACSI	LSCI	MjD	MnD	GS	RRC	ESI	EE	BS
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		
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			
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
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

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
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
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
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

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
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
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

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
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
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
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

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
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
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

Fringing Zone theme				
Reach	EFZ	FVL	FVW	NAT_{FZ}
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
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	

Aquatic Biota theme										
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

Aquatic Biota theme										
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

Aquatic Biota theme										
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 ______________

Government of Western Australia
Department of Water

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

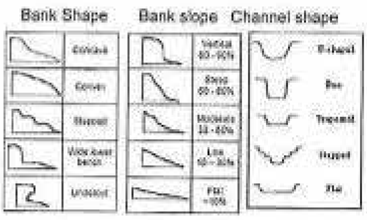
CROSS SECTION DIAGRAM

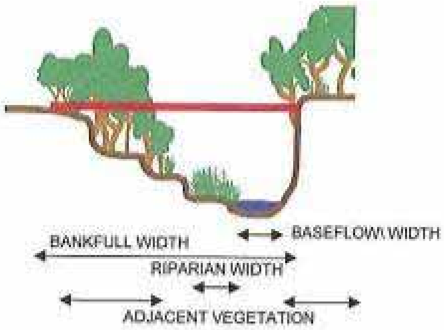
Representative of sampling region (where high variability exists draw two cross-sections).

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





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			Width of riparian zone Left bank ______m Right bank ______m
Ground layer (i.e. sedges, rushes)	yes	no	reduced	Dominant riparian species (if unknown write: refer to photographs):
Shrub layer (woody)	yes	no	reduced	
Tree layer	yes	no	reduced	

* 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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Date ______________ Site code ______________

Government of Western Australia
Department of Water

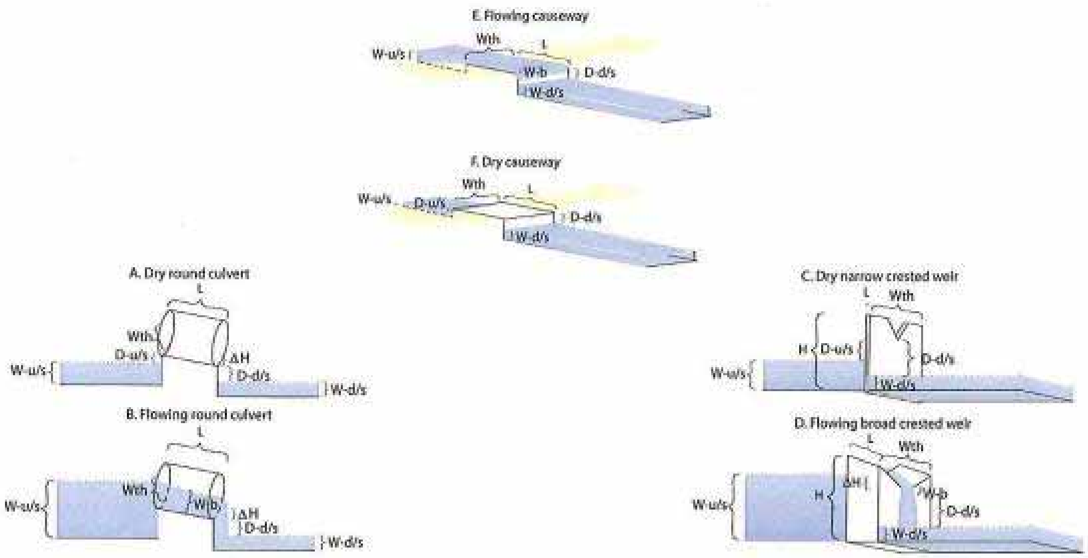
SW-WA RIVER HEALTH ASSESSMENT - FIELD SHEETS
BARRIER ASSESSMENT - 100m sampling site

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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Date ______________ Site code ______________

Government of Western Australia
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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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Date ______________ Site code ______________

Government of Western Australia
Department of Water

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 989 902

________ 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 989 902

________ 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) • staining, parasites, disease, injury • smallest size gravid individual • size of largest individual *Note size of marron over 76mm*
	Fish	0-20	20 - 50	50 - 100	100 +	Other	none	
	Crayfish	0-20	20 - 50	50 - 76	76 - 100	100+	✓ (few)	
	Large fish	0-100	100-200	200-400	400+	Other	✓✓ (many)	

**Evidence of reproductive condition includes gravid females &/or charecteristic 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 Draft FARWH training and result publication website delivery report

FARWH Training and Result Publication
Website Delivery Report

TRaCK and DoW

DRAFT

Revision 2
January, 2011

FARWH TRAINNG AND RESULT PUBLICATION WEB APPLICATION DELIVERY REPORT

REVISION / REVIEW HISTORY

Revision #	Description	Prepared by	Reviewed by
1	Delivery Report Draft	Chris Ryan	Richard Norris
2	Delivery Report Draft	Chris Ryan / Emma Betts	Richard Norris

DISTRIBUTION

Distribution List	Date Issued	Number of Copies
Team Members	01-02-2011	softcopy

Catchment Simulation Solutions (Sydney Office)
Suite 1902
109 Pitt Street
Sydney, NSW, 2000
Tel: (02) 9232 7337
Fax: (02) 9233 8666
Email: dtetley@csse.com.au
Website: www.csse.com

TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

This report documents the delivery of the FARWH training and result publication website. This website is an important component of the Application of the Framework for the Assessment of River and Wetland Health (FARWH) to southwest WA and rivers in the wet/dry tropics of northern Australia.(Website URL: http://farwh.csse.com.au/)

This website is based on the FARWH training and result publication web application concept design report that was published in April 2010. As outlined in this report the site was developed to serve 3 main objectives.

- Education of the general public about the FARWH
- Provide training materials for Agency staff and volunteers
- FARWH result publication and mapping

The concept design also outlined the major technical components of the site to be a flexible group based login/authentication system, a Content Management System (CMS), a Learning Management System (LMS) and an online mapping portal.

The users of the website were considered to include members of the general public that require brief educational material on the FARWH, a range of training participants at different levels and stakeholders wishing to analyse the FARWH results using a range of tabular and mapping tools.

As part of the concept design of the website, several alternative branding and website designs were proposed. After discussions with the TRaCK and SW WA teams, a branding design was adopted.

The draft website has now been developed. This report presents the website and described each of the major sections in the following chapters.

2 PUBLIC FACING PAGES

The public facing pages are an introductory section designed to inform members of the public regarding what the FARWH is, and how the results presented on the site should be (and should not be) interpreted. This section is developed around a simple content management framework to allow easy editing in the future. The emphasis is on streamlined and interesting content targeted at a low level of ecological expertise.

2.1 Home Tab

The public facing pages are predominantly found in the Home tab and can be navigated by a menu in the left hand column and consists of 4 main pages, Introduction, What is FARWH?, Why FARWH and FARWH Interpretation.

2.1.1 Introduction Page

The landing page for the FARWH website (currently http://farwh.csse.com.au) is shown below.

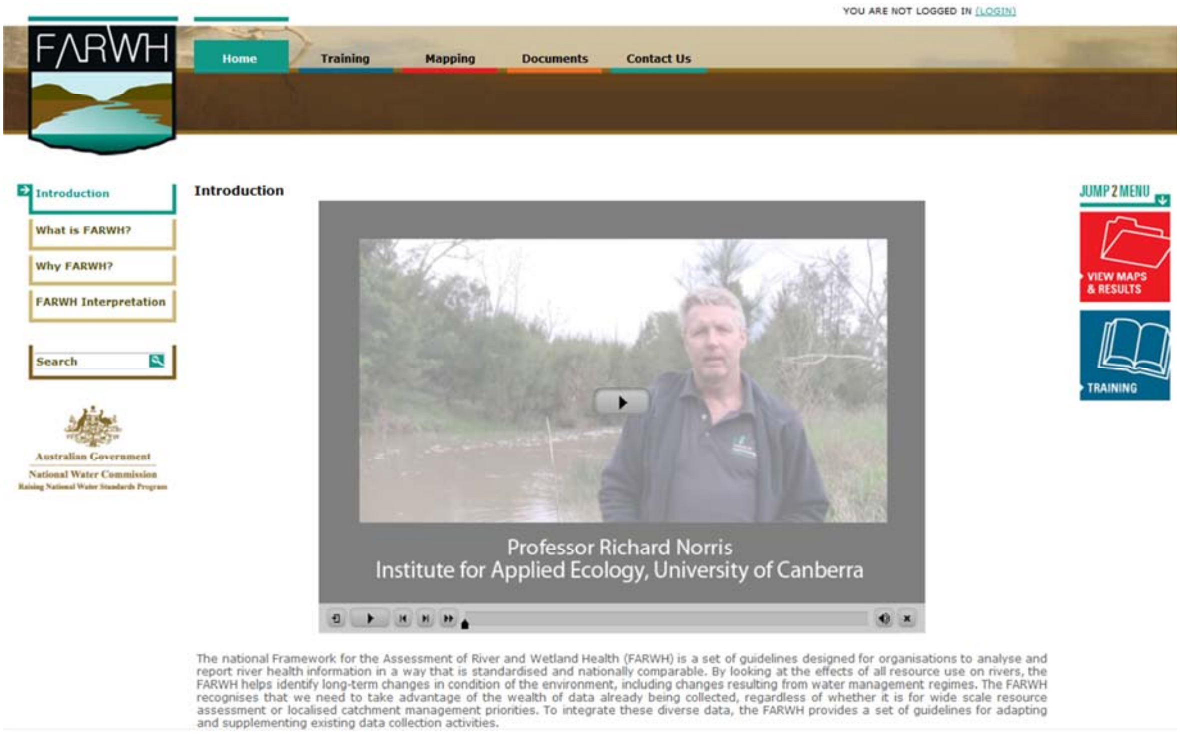


Figure 1: Landing Page

The first piece of content on the landing page is a video of Dr Richard Norris giving an introduction to the website and FARWH in general. The video was shot near Coppins Crossing in the ACT. It includes subtitles in the case of the user not having audio capabilities.

Figure 2: Introductory Video

The public facing page also includes an overview video of the website to help users navigate the site.

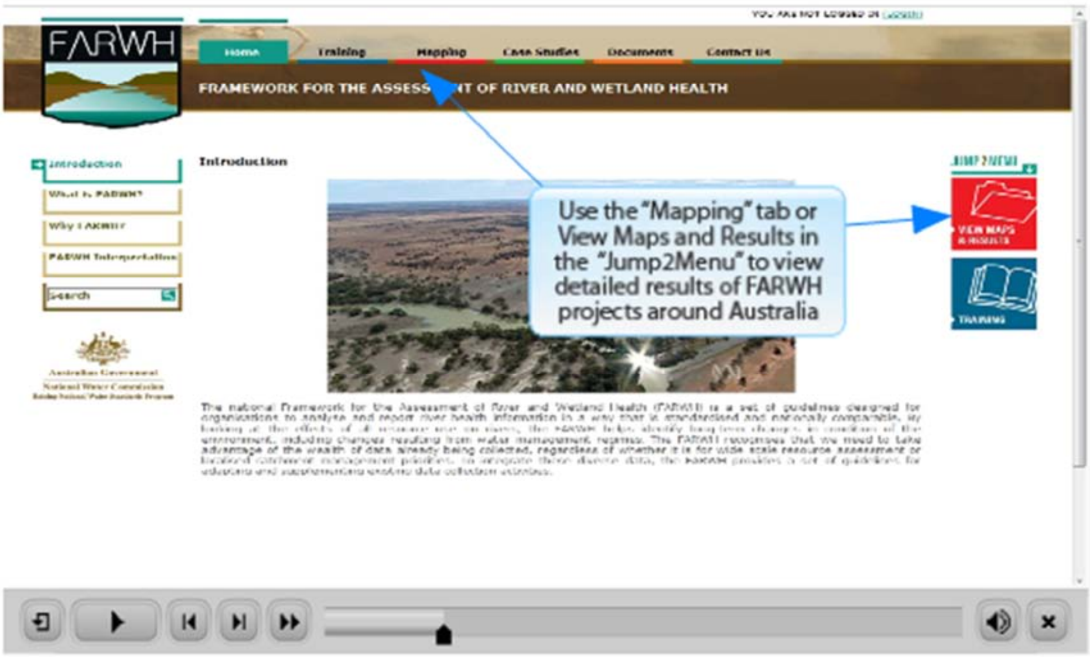


Figure 3: Overview Video

2.1.2 What is FARWH Page?

The ‘What is FARWH’ page includes an interactive animation designed to give a simple introduction to each of the FARWH themes.

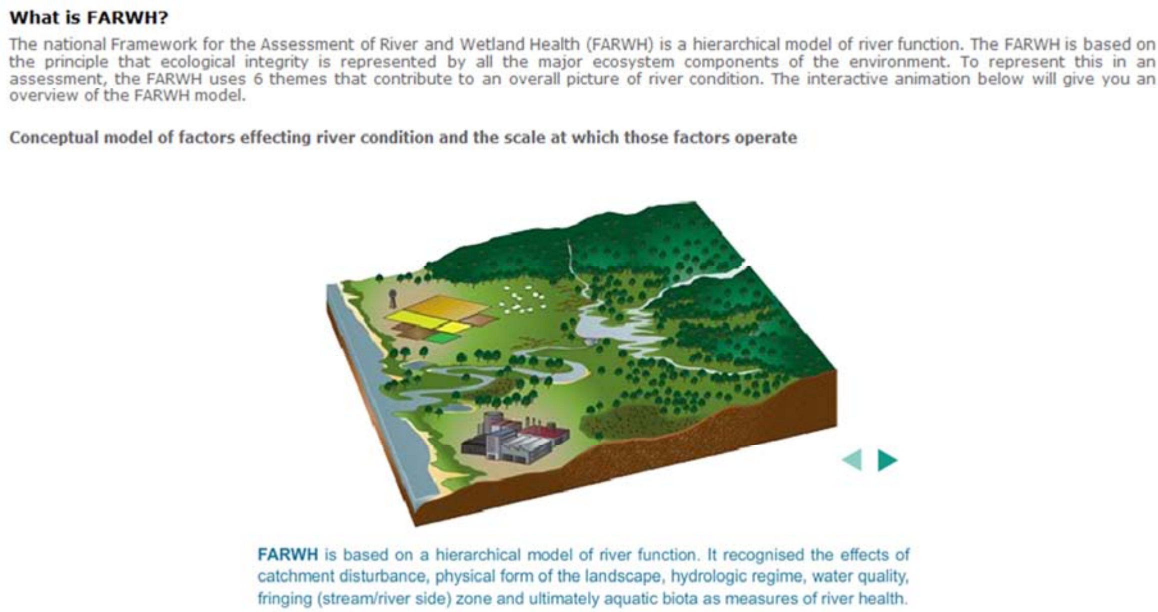
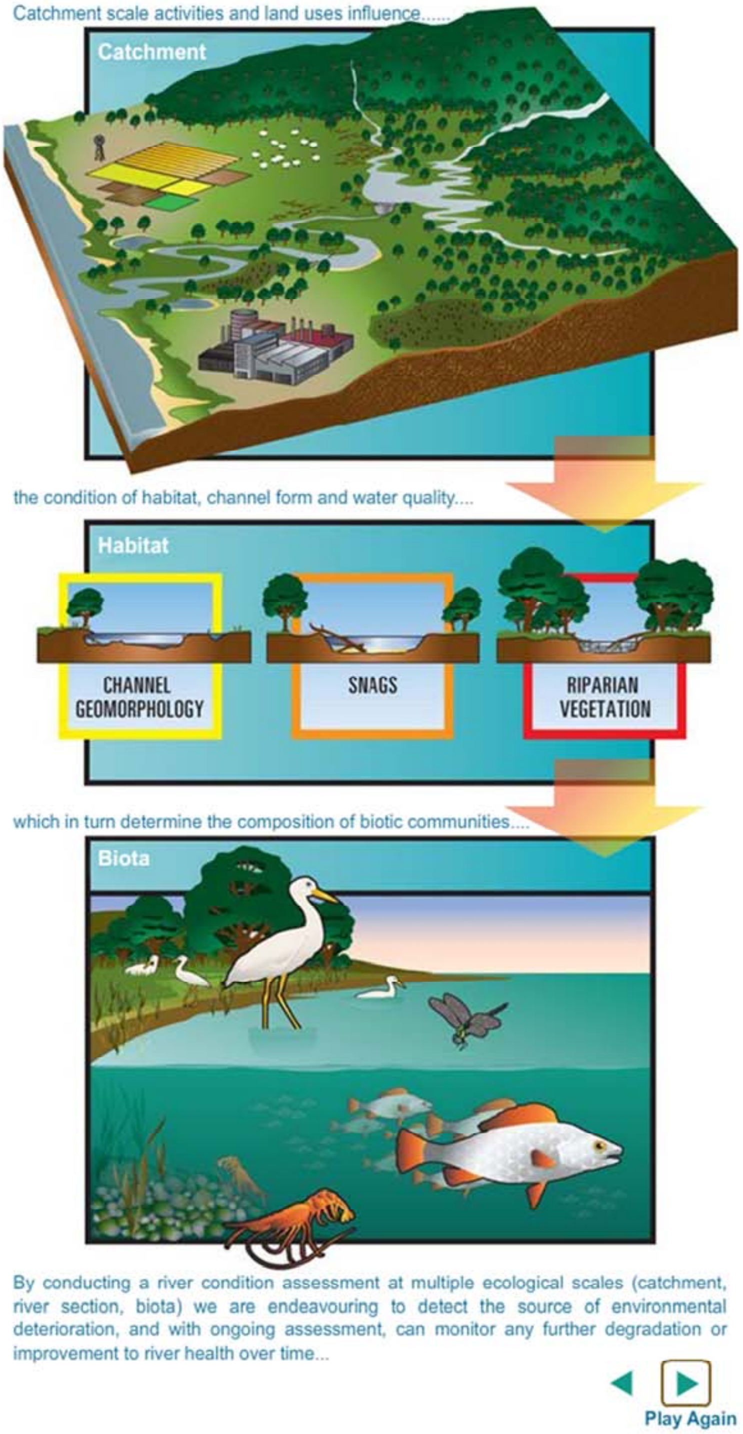


Figure 4: Interactive FARWH Animation

After the user clicks through the animation reading the commentary, the final slide presents the full FARWH diagram which is based on the original diagram by Dr Richard Norris. This slide and the original diagram are presented in Figure 5.



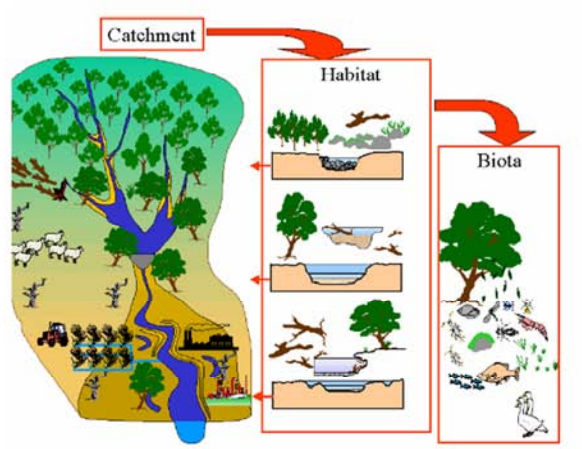


Figure 5: Final Slide of Interactive Animation and original diagram

2.1.3 Other Pages (Home Tab)

The final pages of 'Why FARWH' and 'FARWH Interpretation' display some easy to understand commentary related to why FARWH is useful and how it should be interpreted.

2.2 Training Tab

The Training tab links to the Moodle training portal outlined in Chapter 3.

2.3 Mapping Tab

The Mapping tab links to the mapping site outlined in Chapter 4.

2.4 Documents Tab

The documents section links to a document repository which includes the original FARWH manual plus all other relevant documents. The documents are arranged in categories and each includes a searchable summary. Part of the document repository is shown in Figure 6.

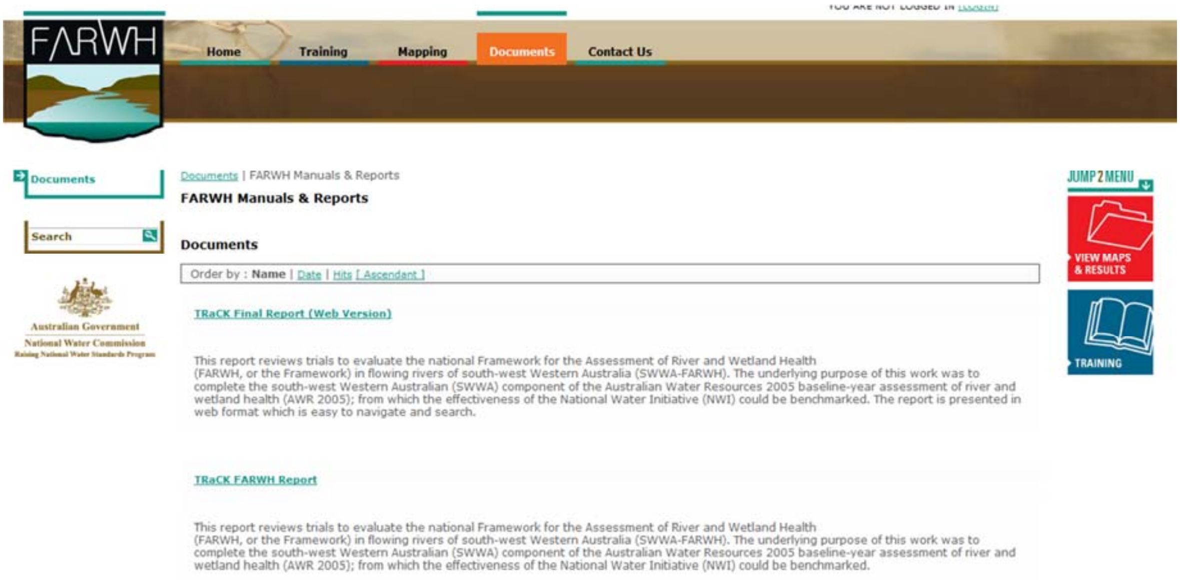


Figure 6: Documents Tab

2.5 Contact Us Tab

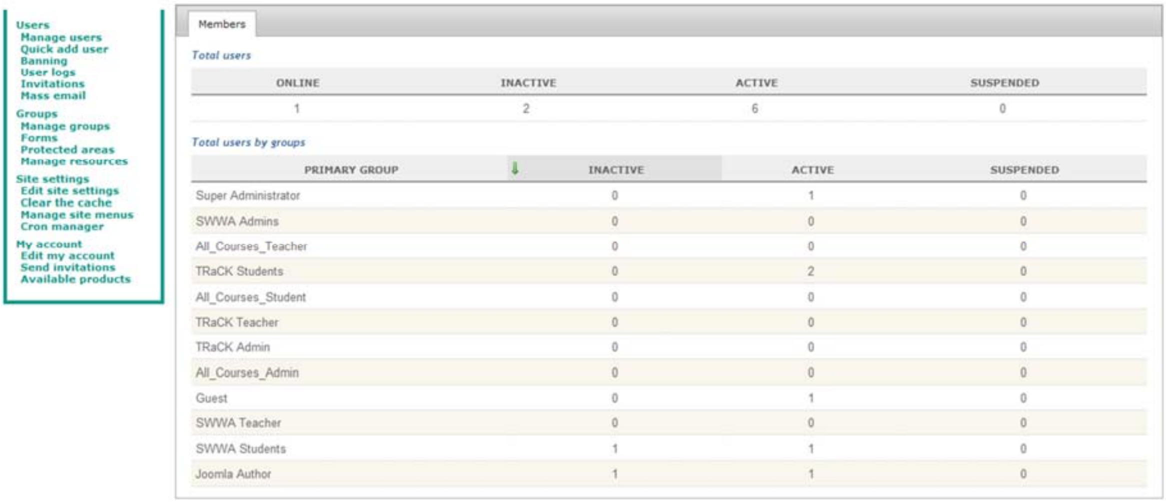
The Contact Us tab displays contact details for the custodians of the website. At present, we have used our contact details but these can be replaced once a permanent custodian is arranged.

3 TRAINING PORTAL

The training portal is based on the Moodle Learning Management System (LMS). Moodle has been integrated with a customized access control system to simplify the enrolment process. This allows administrators and teachers to automatically invite and enrol participants in all relevant courses.

3.1 Access Control System

The Access Control List (ACL) system is based on categorizing users into groups. A screenshot of the current groups is shown in Figure 7.



ONLINE	INACTIVE	ACTIVE	SUSPENDED
1	2	6	0

PRIMARY GROUP	INACTIVE	ACTIVE	SUSPENDED
Super Administrator	0	1	0
SWWA Admins	0	0	0
All_Courses_Teacher	0	0	0
TRaCK Students	0	2	0
All_Courses_Student	0	0	0
TRaCK Teacher	0	0	0
TRaCK Admin	0	0	0
All_Courses_Admin	0	0	0
Guest	0	1	0
SWWA Teacher	0	0	0
SWWA Students	1	1	0
Joomla Author	1	1	0

Figure 7: ACL System

Some of the important groups (and their features) in the ACL are:

- **Super Administrator**
  - Total control over all users and groups and site administrator access to Moodle.
  - Ability to send bulk emails to members of any or all groups including variables such as username, email, last_seen etc.
  - Ban users, or IP ranges.
  - View user access logs.
  - Add new courses or edit which groups can access Moodle courses with which roles.
- **TRaCK Administrator**
  - Administrator access to all TRaCK Moodle courses.
  - Ability to invite users to join groups TRaCK_Teachers and TRaCK_Student.
- **SW WA Administrator**
  - Administrator access to all SW WA Moodle courses.
  - Ability to invite users to join groups SWWA_Teachers and SWWA_Student.
- **TRaCK Teacher**
  - Teacher access to all TRaCK Moodle courses.
  - Ability to invite users to join group TRaCK_Student.
- **SW WA Teacher**
  - Teacher access to all SW WA Moodle courses.

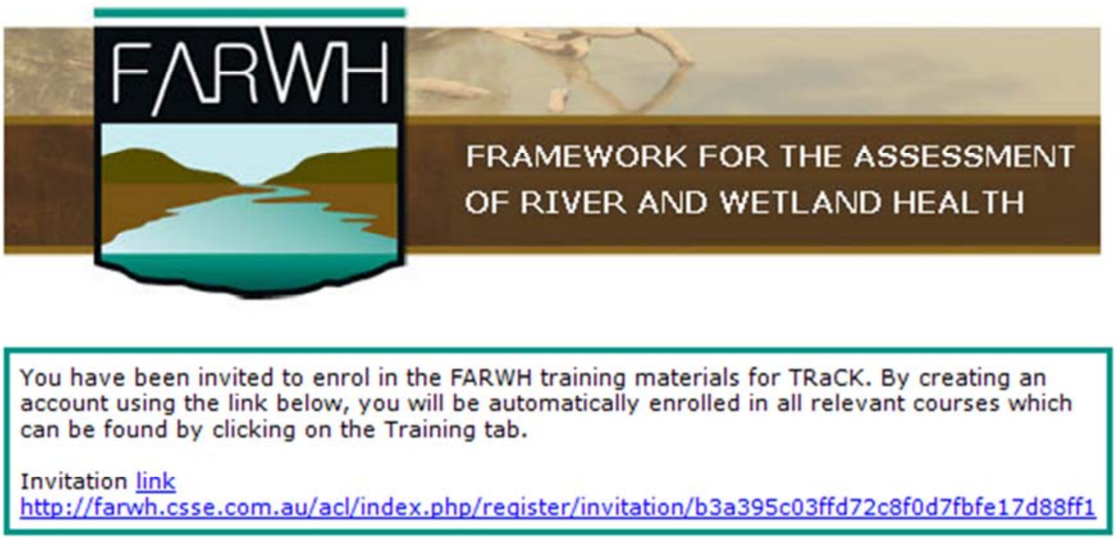
    - Ability to invite users to join groups SWWA_Student.
- **TRaCK Student**
    - Student access to all TRaCK Moodle courses.
- **SW WA Student**
    - Student access to all SW WA Moodle courses.

For testing purposes, users can login to these groups with the accounts track_admin, swwa_admin, track_teacher, swwa_teacher, track_student, swwa_student. The password for all these accounts is available on request.

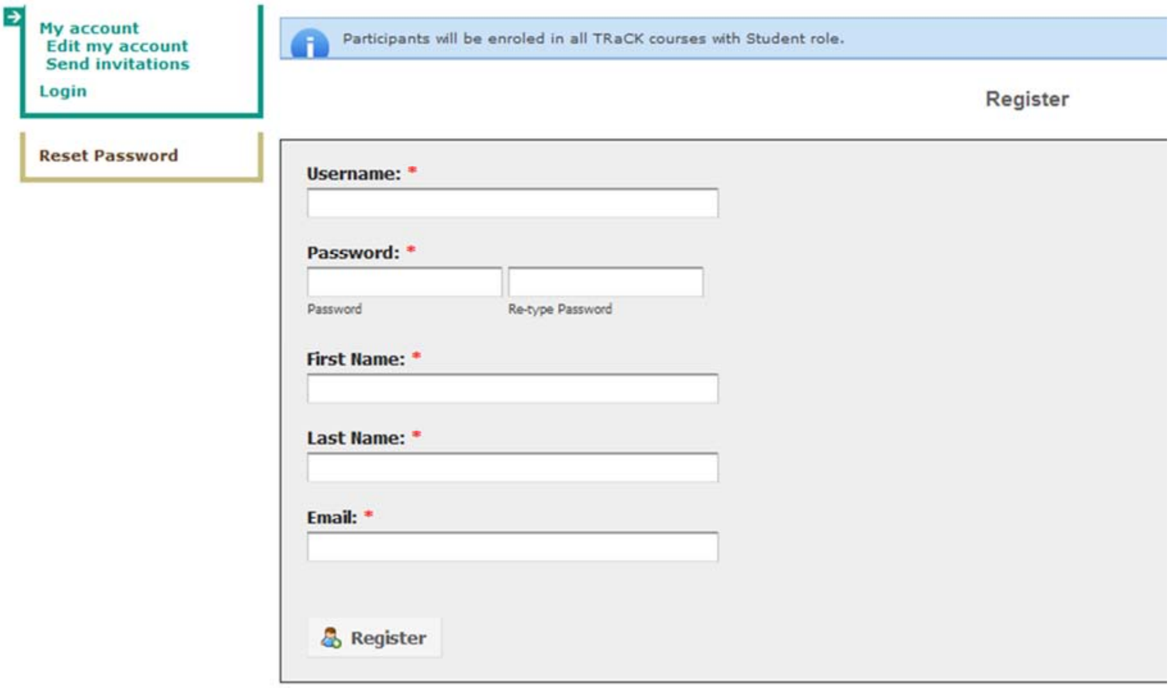
An example workflow for adding a new user to training system via the ACL might be:

- A new employee commences at TRaCK
- The TRaCK teacher logs into the ACL system by clicking on the Training tab.
- The TRaCK Teacher clicks on My Account, then Send Invitations.
- The TRacK Teacher fills in the email address of the new employee, edits the default message if appropriate and clicks Send.

- The employee will receive the following email.



- After clicking on the embedded link, the user will be prompted to setup their account including selection of a username and password.



- At this point, the new employee can click on Training and they will automatically be enrolled in all relevant TRaCK Moodle courses.

The assistance of a Super Administrator may be required to perform certain functions, such as:

- Change the group(s) of existing users
- Edit the courses and roles associated with existing groups.
- Send bulk emails to group members.

These requests can be forwarded to farwh_administrator@csse.com.au

3.2 Training Materials

When a user clicks on the Training tab they will be prompted to login as shown in Figure 8.

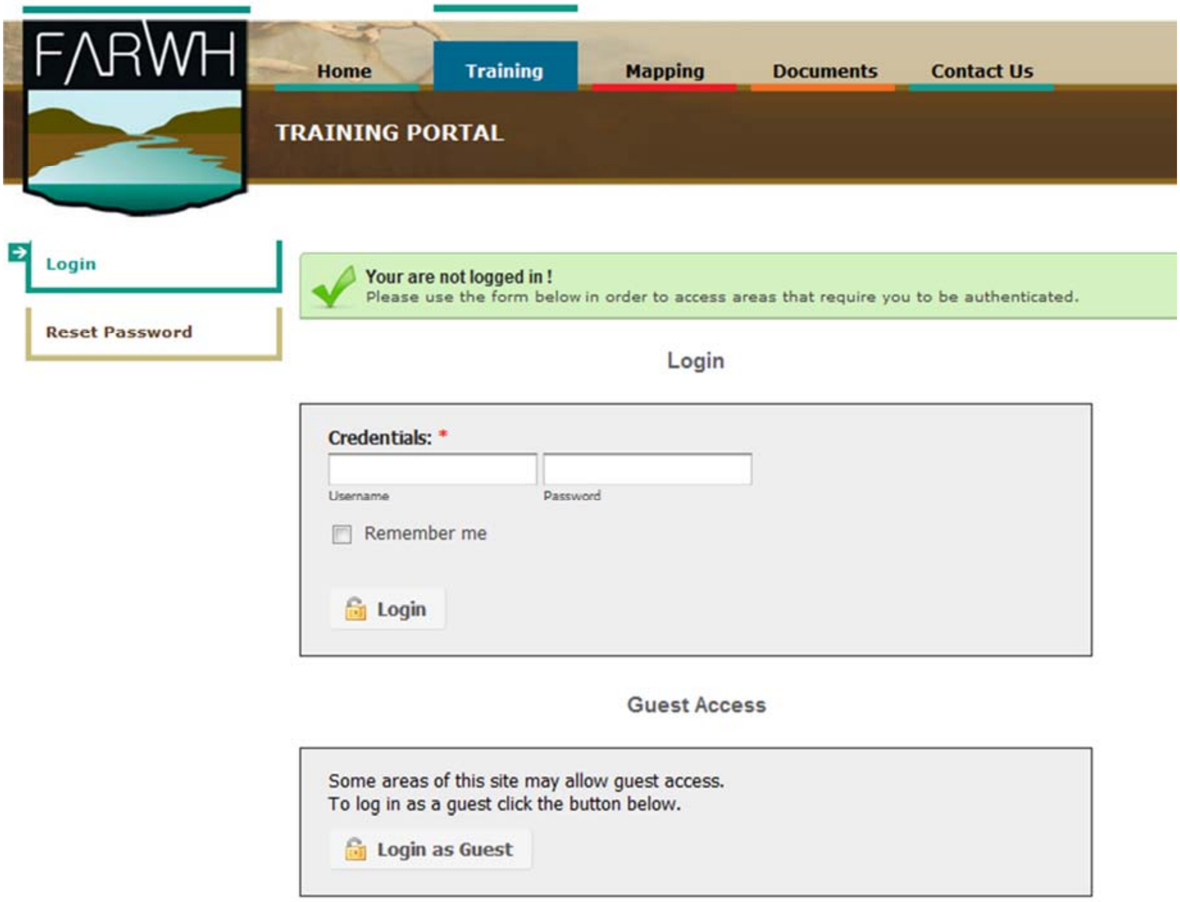


Figure 8: Login Screen

Once the user enters their username and password, they will be forwarded to their My Moodle page. This is a customisable page and the user can set it up as they see fit including Moodle blocks, RSS feeds and other features. The My Moodle page is depicted in Figure 9.

Users that are not registered can click the Login as Guest button. This will give them access only to courses that are setup for public access. Presently, there are no training materials available for the public. However, this feature can be used for publically accessible training materials in the future such as volunteer training.

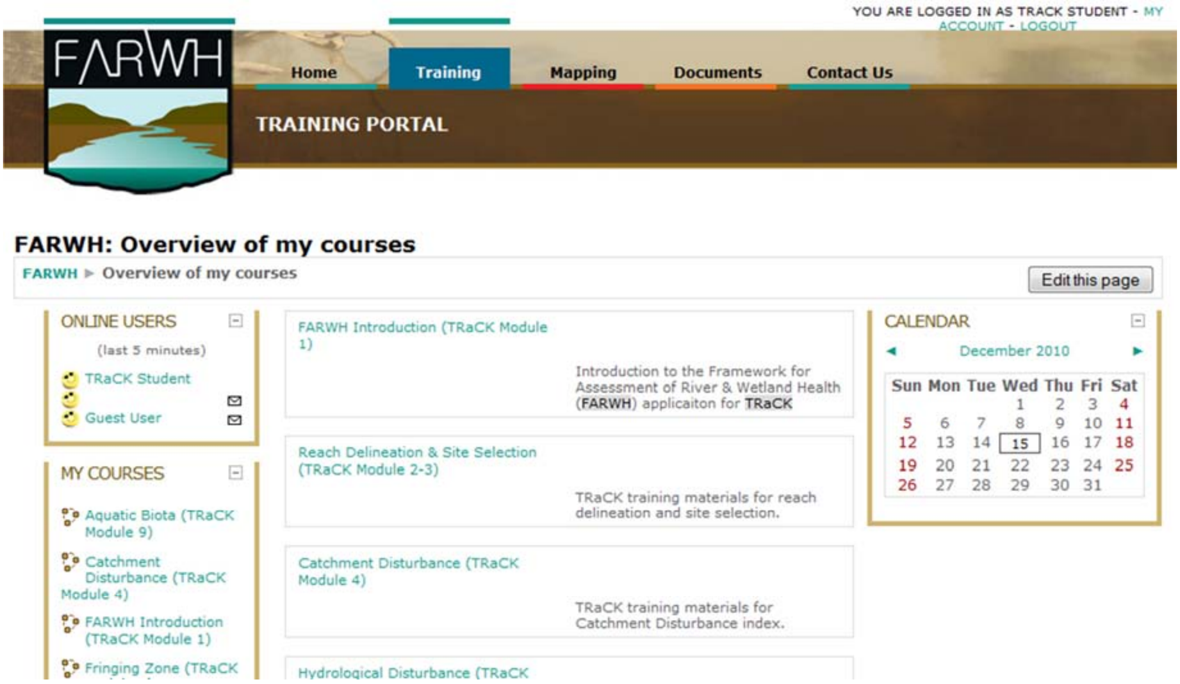


Figure 9: My Moodle Page

After a user clicks on one of their courses, they will be delivered to the course homepage as shown in Figure 10.

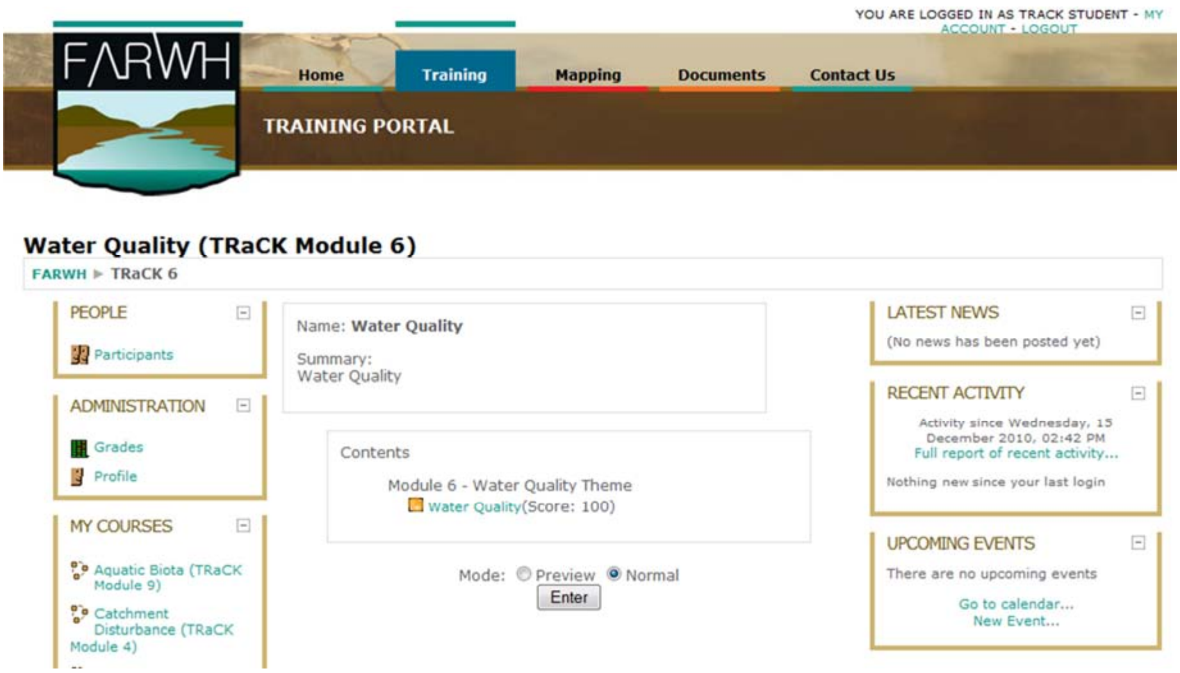


Figure 10: Course Homepage

The course homepage gives users access to the training material as well as any news, forums, grades and a calendar (if required). The Contents block lists the learning module in the course. From a technical perspective, this is a SCORM compliant eLearning module developed in Lectora. SCORM is an industry standard for eLearning materials. Developing content in a SCORM compliant tool will ensure compatibility with all modern eLearning systems. By clicking on the Module name, the user is directed to the training content. Moodle will allow advanced features such as taking the users to the place in the material where they have previously been up to and recording all their interactions with the material. These trainee interactions can then be viewed by all users with Teacher or Administrator privileges. An example of the training content can be seen in Figure 11.

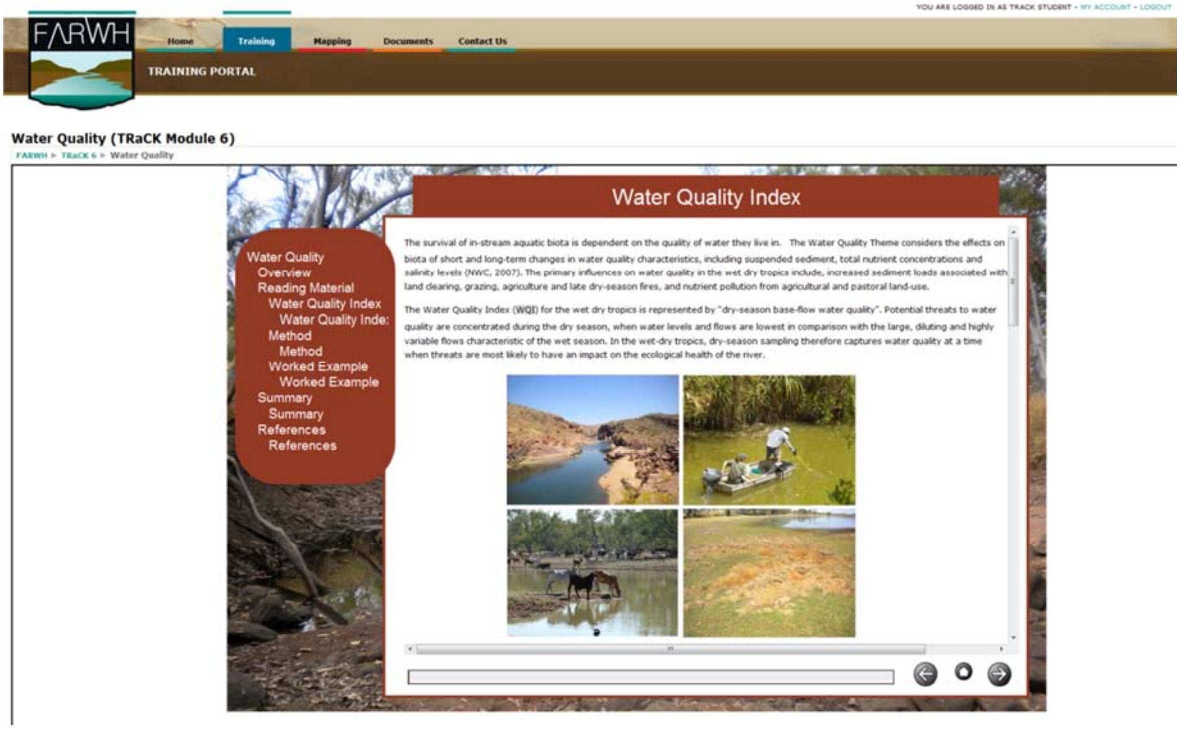


Figure 11: Course Training Material

Each training course includes a self-test quiz at the end of the module. Once the user has completed the quiz, they will receive their score and get feedback related to incorrectly answered questions. Administrators and Teachers can also view results from all quiz attempts.

The training material currently covers 9 topics, or modules:

- FARWH Introduction (Module 1)
- Reach delineation and site selection (Modules 2 and 3)
- Catchment disturbance (Module 4)
- Hydrological disturbance (Module 5)
- Water quality (Module 6)
- Physical form (Module 7)
- Fringing zone (Module 8)
- Aquatic Biota (Module 9)

The training modules do not include all information presented in the FARWH project reports; instead, they present recommended methods for future FARWH assessment. For complete information on FARWH trials and development of methods trainees are directed to the project reports, also available on the website.

Modules 1-3 cover general FARWH concepts including the purpose, role and structure of FARWH, and site and reach selection for assessment. The remaining 6 modules cover the 6 FARWH themes. Included in each theme module is:

- a detailed method for completing desktop and field assessment
- all required equations and scaling information (bands, weightings etc)
- worked examples demonstrating score calculation and index integration and aggregation
- self-test quiz
- printable PDF summary of all equations, bands and weightings etc for practioner reference (as shown in Figure 12).

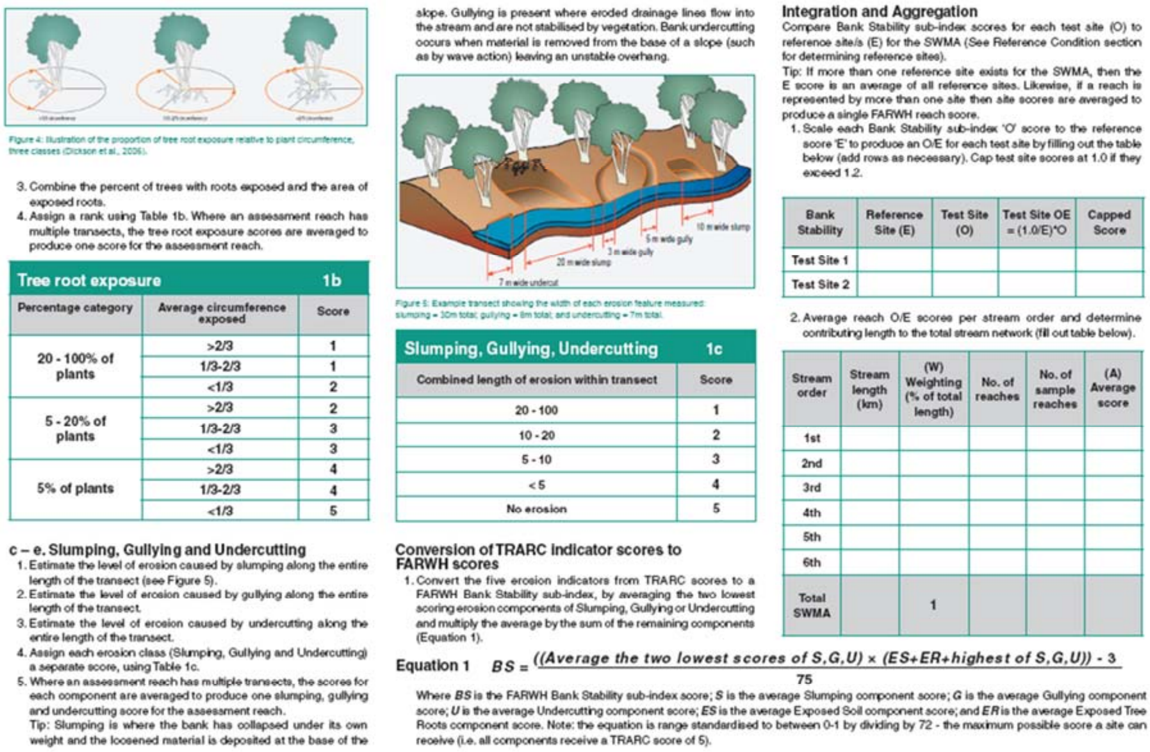


Figure 4: Illustration of the proportion of tree root exposure relative to plant circumference, three classes (Dickson et al., 2006).

3. Combine the percent of trees with roots exposed and the area of exposed roots.
4. Assign a rank using Table 1b. Where an assessment reach has multiple transects, the tree root exposure scores are averaged to produce one score for the assessment reach.

Tree root exposure		1b
Percentage category	Average circumference exposed	Score
20 - 100% of plants	>2/3	1
	1/3-2/3	1
	<1/3	2
5 - 20% of plants	>2/3	2
	1/3-2/3	3
	<1/3	3
5% of plants	>2/3	4
	1/3-2/3	4
	<1/3	5

c – e. Slumping, Gullying and Undercutting

1. Estimate the level of erosion caused by slumping along the entire length of the transect (see Figure 5).
2. Estimate the level of erosion caused by gullying along the entire length of the transect.
3. Estimate the level of erosion caused by undercutting along the entire length of the transect.
4. Assign each erosion class (Slumping, Gullying and Undercutting) a separate score, using Table 1c.
5. Where an assessment reach has multiple transects, the scores for each component are averaged to produce one slumping, gullying and undercutting score for the assessment reach.

Tip: Slumping is where the bank has collapsed under its own weight and the loosened material is deposited at the base of the slope. Gullying is present where eroded drainage lines flow into the stream and are not stabilised by vegetation. Bank undercutting occurs when material is removed from the base of a slope (such as by wave action) leaving an unstable overhang.

Figure 5: Example transect showing the width of each erosion feature measured: slumping = 30m total; gullying = 8m total; and undercutting = 7m total.

Slumping, Gullying, Undercutting	1c
Combined length of erosion within transect	Score
20 - 100	1
10 - 20	2
5 - 10	3
<5	4
No erosion	5

Conversion of TRARC indicator scores to FARWH scores

1. Convert the five erosion indicators from TRARC scores to a FARWH Bank Stability sub-index, by averaging the two lowest scoring erosion components of Slumping, Gullying or Undercutting and multiply the average by the sum of the remaining components (Equation 1).

Equation 1 $BS = \frac{((\text{Average the two lowest scores of } S,G,U) \times (ES+ER+\text{highest of } S,G,U)) - 3}{75}$

Where *BS* is the FARWH Bank Stability sub-index score; *S* is the average Slumping component score; *G* is the average Gullying component score; *U* is the average Undercutting component score; *ES* is the average Exposed Soil component score; and *ER* is the average Exposed Tree Roots component score. Note: the equation is range standardised to between 0-1 by dividing by 72 - the maximum possible score a site can receive (i.e. all components receive a TRARC score of 5).

Integration and Aggregation

Compare Bank Stability sub-index scores for each test site (O) to reference site/s (E) for the SWMA (See Reference Condition section for determining reference sites).

Tip: If more than one reference site exists for the SWMA, then the E score is an average of all reference sites. Likewise, if a reach is represented by more than one site then site scores are averaged to produce a single FARWH reach score.

1. Scale each Bank Stability sub-index 'O' score to the reference score 'E' to produce an O/E for each test site by filling out the table below (add rows as necessary). Cap test site scores at 1.0 if they exceed 1.2.

Bank Stability	Reference Site (E)	Test Site (O)	Test Site OE = (1.0/E)*O	Capped Score
Test Site 1				
Test Site 2				

2. Average reach O/E scores per stream order and determine contributing length to the total stream network (fill out table below).

Stream order	Stream length (km)	(W) Weighting (% of total length)	No. of reaches	No. of sample reaches	(A) Average score
1st					
2nd					
3rd					
4th					
5th					
6th					
Total SWMA		1			

Figure 12: Sample from PDF Summary Sheet

A FARWH glossary has also been integrated into the training portal. The glossary contains definitions for all acronyms, initialisms and technical terms used in the FARWH documents and training material. The glossary is interactive with the training contents, with all terms included in the glossary hyperlinked.

3.2.1 TRaCK FARWH Training

Training material for the TRaCK FARWH project includes all of the listed above. Content has been reviewed by FARWH project staff and is ready to be used by staff and volunteers as required. It is envisaged that no changes will need to be made to the TRaCK training content until the FARWH method is modified.

3.2.2 South west Western Australia Training

The south west Western Australia (SWWA) FARWH training material consists of 9 modules that each include the following:

- method for completing field and desktop methods
- some equations and scaling information (bands, weighting etc)
- some worked examples demonstrating score calculation and index integration and aggregation

Training content was developed using the July 2010 SWWA FARWH Trials Report and has not yet been reviewed by FARWH project team members. To align the SWWA training website and content with project needs the following should be completed:

- update training material to match 2011 SWWA FARWH Trials Report (when released)
- create printable PDF summary of each module
- ensure all equations, bands and scales are provided
- complete thorough worked examples for each module
- complete self-test quizzes for module 4-9
- Review of all materials by SWWA FARWH project team.

As the TRaCK program includes tropical northern Western Australia, government staff from this state should access the TRaCK FARWH training website.

4 RESULT MAPPING & PUBLICATION

4.1 Introduction

The result mapping and publication component of the website allows the public and any other participant to generate maps and interrogate FARWH results. The main features that are mapped are Surface Water Management Areas (SWMAs) and river reaches. These features are by nature polygons and polylines respectively. Each feature has a large amount of non-visual data associated such as an overall FARWH score as well as scores associated with each index and the individual sub-indices that contributed to them. The mapping component of the website is specifically designed to provide easy to use, yet powerful tools to interrogate the attached data.

4.2 Mapping Introduction Page

When a user clicks on the Mapping tab, they will be shown an overview map that lists all agencies with data on the mapping site and displays the locations of their SWMAs. When a user scrolls over their logo or their catchments, the SWMA labels will be shown and the Agency logo will be highlighted. By clicking on the logo or SWMAs, the user will be directed to the mapping pages with the map automatically setup to focus on these regions. This page also includes a link to map all data and watch a video demonstrating the functionality of the entire mapping site.

This video provides a good overview of the mapping functionality can be viewed at: http://farwh.csse.com.au/mapping/how_to_mapping_site.html.

Figure 13: Mapping Introduction Page

4.3 Mapping Interface Page

Once a user has clicked on a SWMA on the mapping overview page, they will be directed to the mapping interface with the SWMAs of interest in the centre of the screen. An example of the mapping interface is shown in Figure 14.

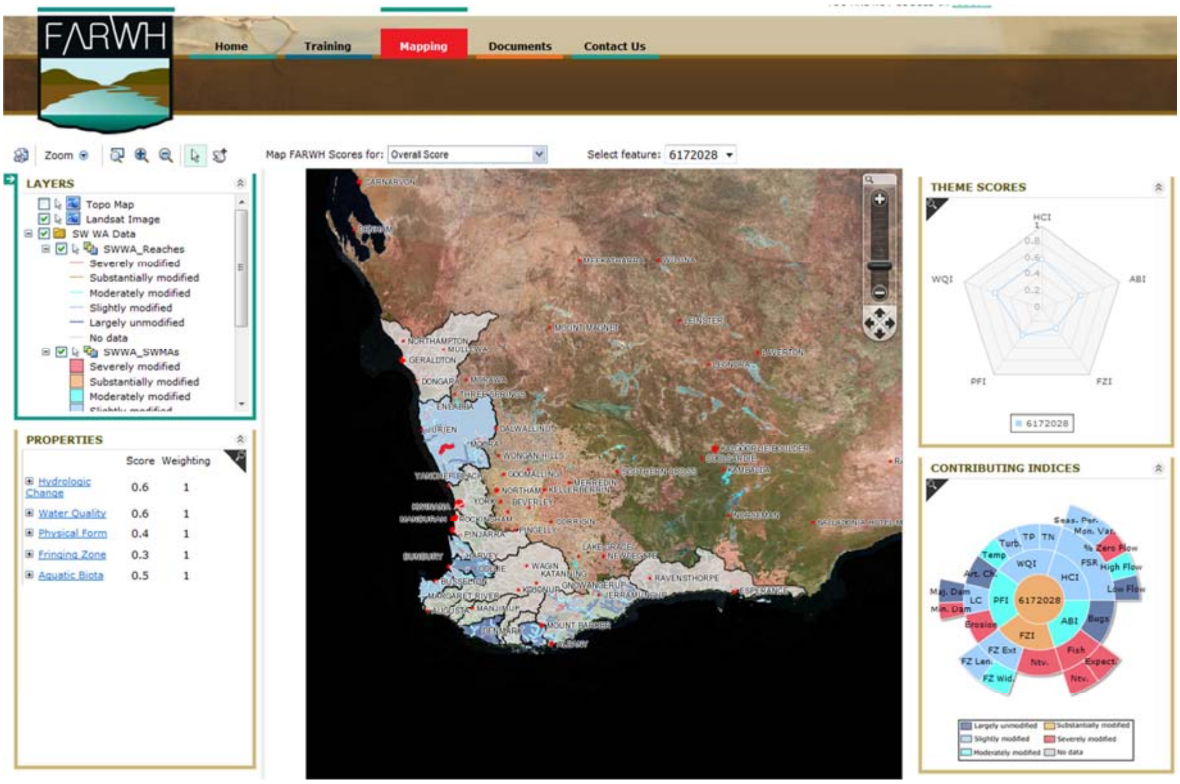


Figure 14: Mapping Interface

The mapping interface consists of 4 main components:

- Layer Control including toolbar and dropdown boxes
- Properties Block
- Theme Scores Block
- Contributing Indices Block

The Properties, Theme Scores and Contributing Indices block all operate in both a sidebar and maximised style. They will update automatically based on selections made in the mapping interface but full functionality can be obtained by clicking the magnifying glass icon to enlarge the block.

All of these blocks are described in detail in the following sections.

4.4 Map Control

The map control component allows users to manipulate the mapping display in the centre of the screen. The Layers Block allows individual layers to be turned on or off. The Toolbar includes many controls to zoom the map, print the map and select one or more reporting units (typically SWMAs or river reaches).

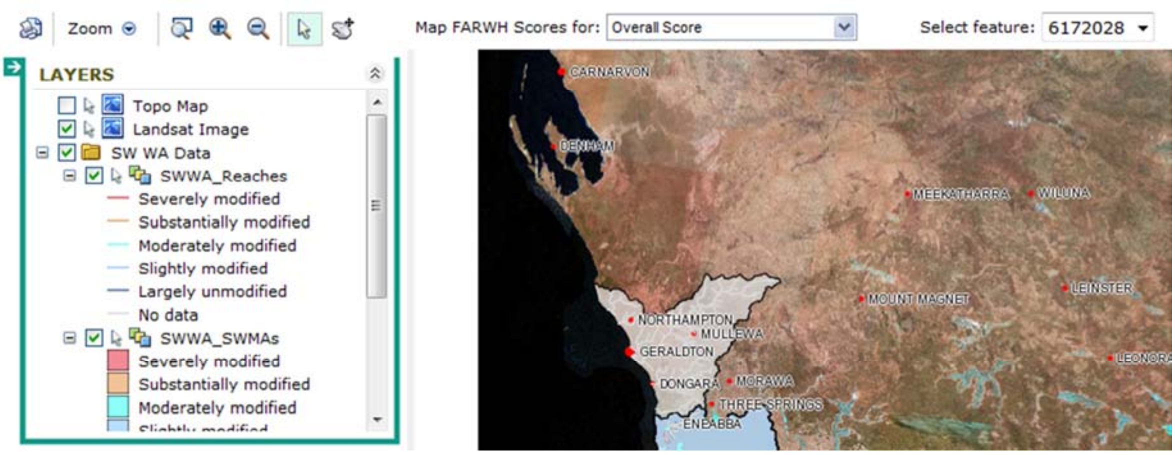


Figure 15: Map Control

By default, the map displays both SWMAs and river reaches (reporting units) colour coded by their Overall FARWH Score (this is the minimum of all reported index scores for the feature). However, the map can be customised to colour code the SWMAs and reaches by the score for any index, sub-index or component using the 'Map FARWH Scores for' control. An example of using this control is shown in Figure 16.

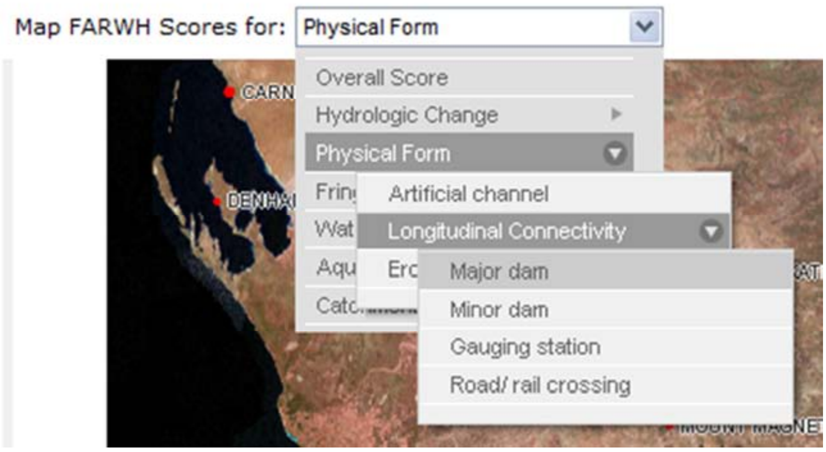


Figure 16: 'Map FARWH Scores for' Control

After using the 'Map FARWH Scores for' control, you will see that the map is refreshed and only those SWMAs and reaches with data available for the selected index, sub-index or component will be shown. The colour of these features will then represent the feature scores for the selected index, sub-index or component. The tooltip displayed when users hover over an available feature will also reflect the selected index, sub-index or component. This is shown in Figure 17.

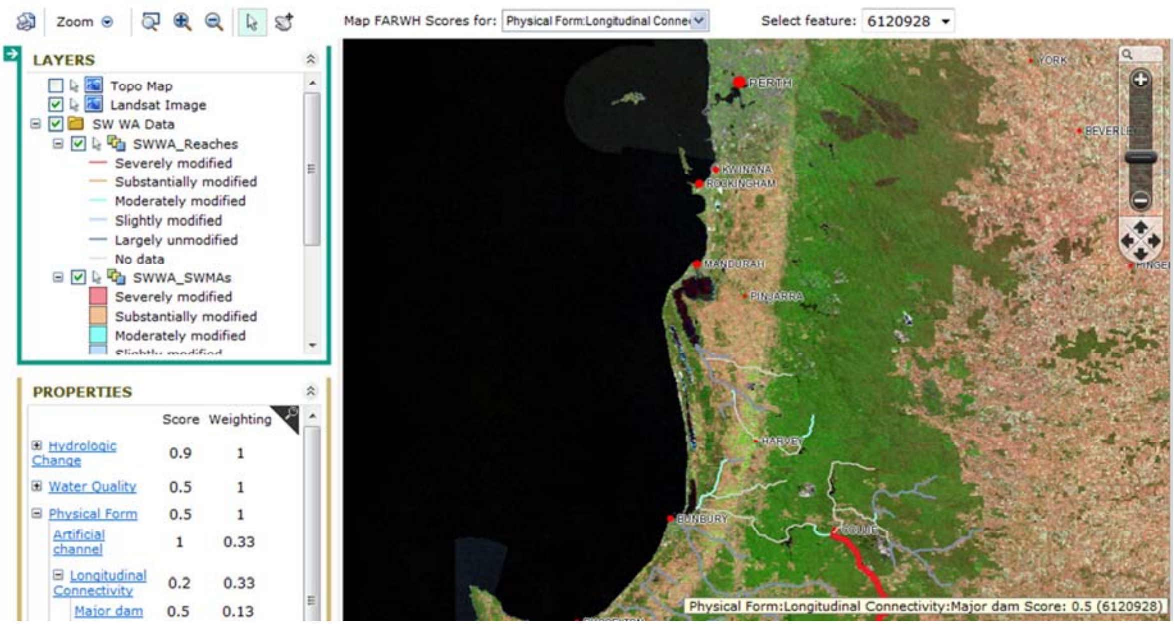


Figure 17: Customisation of Results using 'Map FARWH Score for' control

Several of the mapping components, particularly the Properties Block and Theme Scores Block, provide functionality for comparing the scores for multiple reporting units. To select multiple SWMAs or river reaches, users can hold down the SHIFT or CTRL buttons while clicking on individual reporting units, or drag a selection rectangle around multiple reporting units.

For the Contributing Indices Block which can only display the result for one feature at a time, the Select Feature drop box can be used to select which feature is being reported.

4.5 Properties Block

The Properties Block provides a tree style grid based analysis of the FARWH scores for one or more selected reporting units. It includes the following features:

- The tree can be expanded to show each level of index, sub-index and component that contribute to the parent indexes.
- The method statement from the relevant report can be viewed by clicking on the name of the measurement (eg., Diel Dissolved Oxygen).
- The score for the index, sub-index or component is shown in blue and the background colour is indicative of the extent modified.
- The length of the bar underneath the score is indicative of the proportion contribution of the measurement to parent index score.
- If the user hovers the mouse over a grid cell, a tool tip will display the exact score and percentage contribution.

A sample of the Properties Block is shown in Figure 18.

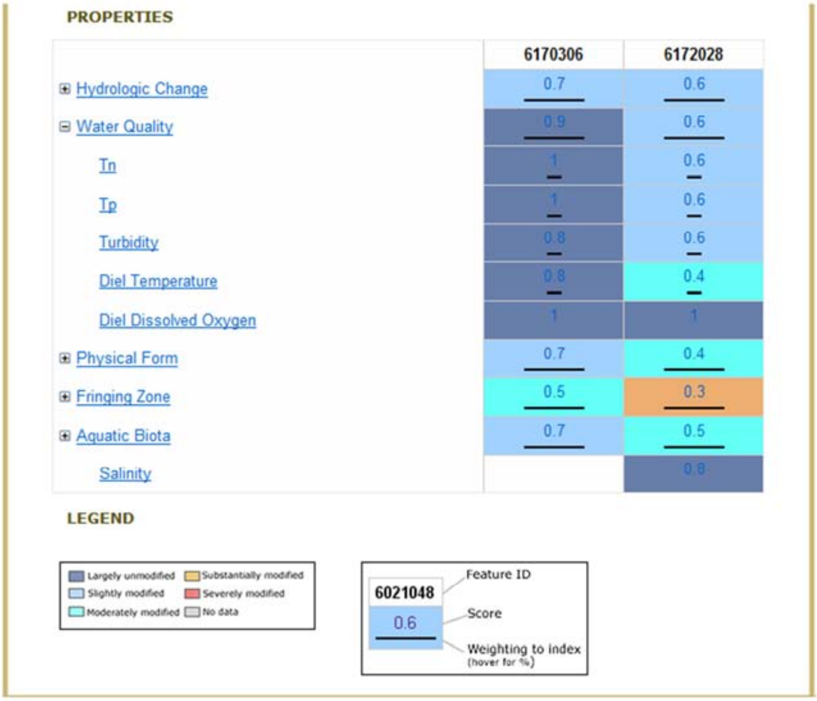


Figure 18: Properties Block

4.6 Theme Scores Block

The Theme Scores block provides a radar chart illustrating the results for each index reported for the selected reporting unit. An example of the Theme Score Block is shown in Figure 19.

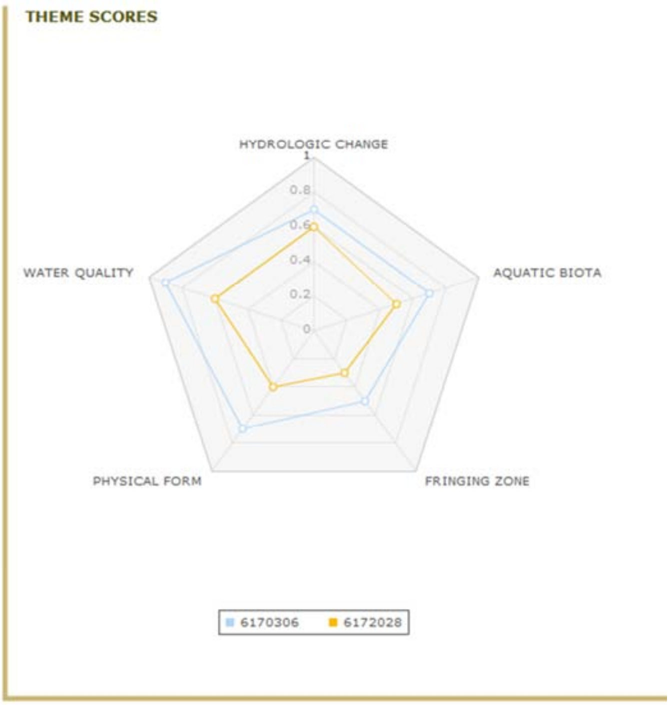


Figure 19: Theme Scores Block

Arguably, the area enclosed by the shape of the radar chart can provide some insight into the overall health of the selected reporting unit(s). For example, for the features presented, the orange series scores poorly in comparison to the blue series for all 6 reported indexes.

4.7 Contributing Indices Block

The Contributing Indices Block visually represents all measurements that have contributed to the selected FARWH reporting unit as a multi-level pie chart. The size of the pie segment reflects the percentage contribution of the measurement to its parent index score. The colour of the pie segment reflects the score (extent modified) of the measurement. An example of the Contributing Indices Block can be seen in Figure 20.

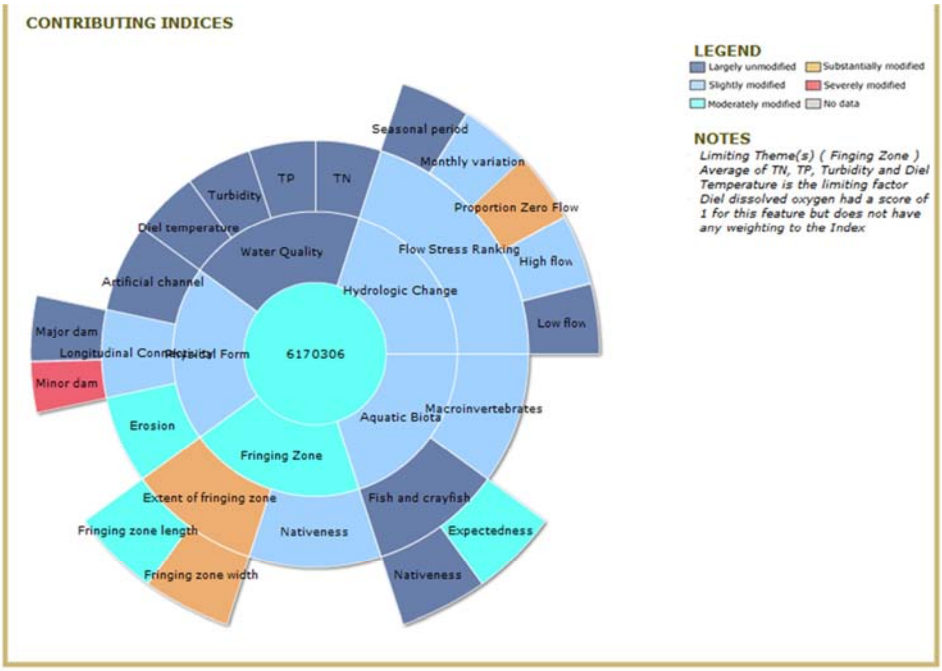


Figure 20: Contributing Indices Block

Similarly to the Properties Block, a user can view the method statement associated with a measurement by clicking on the pie segment.

The notes associated with the pie chart will include all measurements conducted as part of that index, regardless of whether they are incorporated in the final index score. Some measurements may be excluded from the final score by procedures such as the Precautionary Approach for the Water Quality Index in which only a subset of the measurements taken will actually contribute to the final Water Quality Index score. The notes will also indicate the minimum reported index score which informs the overall score which is shown in the centre of the pie chart.

4.8 Data Management

The mapping interface has a complex database structure that is needed to facilitate the powerful tools described in the preceding sections. A key challenge involved with adding new data to the system is conversion from the Client data specification to the required database format. The development team has developed several Excel macros tailored to TRaCK and SW WA data formats. However, these macros will likely need to be revised whenever new data is provided or new data custodians wish to displays results within the mapping interface.

5 NEXT STEPS

The website is currently being hosted on a temporary domain http://farwh.csse.com.au. In the future, it is anticipated that the website will need to be moved to a government domain such as http://farwh.water.gov.au. This domain will need to be acquired in due course.

The website is currently hosted on two virtual servers, a Window MapGuide Enterprise server for the mapping interface and a Linux webserver for all other components of the website. CSS is currently hosting these services and is happy to continue to do so for the immediate future of the project. However, at some stage, plans will have to be put in place to provide hosting and maintenance resources for the website. Some basic hosting and maintenance forecasts have been reproduced below from the concept design report.

5.1 Hosting

There will be hosting costs associated with the website. These cannot be accurately quantified until the site traffic is better known but an amount of $400-$800 per month (for the centralised and mapping servers) would be a reasonable starting point for budgeting.

5.2 Maintenance

Regardless of the exact nature of the hosting setup, there will be maintenance required to keep the website operational. These maintenance requirements can be broken down in to data / content maintenance, software maintenance and hardware maintenance (unless hardware is leased via VPS or dedicated server).

5.2.1 Data / Content Maintenance

The content including the training and public facing pages will need to be kept up to date and developed as FARWH techniques evolve. The mapping data will also need to be updated as new results are generated.

The updating and management of this data will probably be the most significant cost associated with keeping the website operational. A rough estimate might be that this may require 3 person days per month from each Agency.

5.2.2 Software Maintenance

Each of the software packages used in the site (Joomla, Moodle, MapGuide, LDAP etc) as well as the underlying server architecture (PHP, IIS, MySQL, Windows Server etc) will need to be kept current to ensure the site security and function. Testing will also need to be carried out to ensure site features are not affected by updates to any of the installed packages. A rough estimate would be 1.5 person days per month for fully managed software maintenance.

It is possible that there may also be some software/data lease requirements for the commercial products used in the solution, particularly Fusion Charts and MapGuide Enterprise.

5.2.3 Hardware Maintenance

In the case that the server is owned by the project, it may need to be replaced towards the end of its lifecycle. We propose to utilise a Hypervisor (VMWare) to ensure the site can be easily migrated as a Virtual Machine however the migration process and server hardware costs will need to be factored in. If the hardware is leased then the hosting costs will likely be higher to allow for server replacement and migration to be undertaken by the hosting provider. A rough estimate would be 0.5 person days per month for hardware maintenance.

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 near-permanent	Predictably filled [flows] although water levels may vary. Annual inflow > minimum annual loss in 90% of years. During extreme droughts,

(perennial)	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 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
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

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 phosphorus
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
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 22 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 nine-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 nine-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).
Spot Elevation	GA	2001	1998	Vector dataset, points of known elevation from the TOPO-250K Series 2 Relief layer. 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).

Dataset name	Custodian	Metadata year (for GIS data)	Period covered by dataset	Data used or reviewed/ comments
				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.
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 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 and illustration (maps)
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.
Statewide River Quality Assessment (SRWQA) 2004 & 2008	DoW	2009	1998–2007	Vector dataset, points where data was analysed for water quality status and trends. Data used for site selection and for illustration (maps).
Ecology				
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.
EWR and EWP Groundwater and Surface Water Areas	DoW	2009	1986–2007	Vector dataset, locations where ecological water requirement (EWR) and environmental water provision (EWP) studies have been completed. Used for site selection and illustration (maps).
Australian River Assessment System (AUSRIVAS) sites	DoW, Water Science Branch (using DEC data)	Unpublished, contact Water Science Branch	Unknown	Spreadsheet of site locations where macroinvertebrate samples were collected for construction of the AUSRIVAS model. Used for site selection and illustration (maps).
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.

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\

References

ACIL Tasman 2007, *Water Reform and industry – Implications of recent water initiatives for the minerals, petroleum, energy, pulp and paper industries,* report prepared for the Department of Industry, Tourism and Resources.

Allen, GR 1982, *A field guide to inland fishes of Western Australia*, Western Australian Museum, Perth.

Austin CM & Knott B 1996, 'Systematics of the freshwater crayfish genus Cherax Erichson (Decapoda: Parastacidae) in south-western Australia: electrophoretic, morphological and habitat variation', *Australian Journal of Zoology,* vol. 44, pp. 223-58.

Bailey, RC, Norris, RH & Reynoldson, TB 2004, *Bioassessment of freshwater ecosystems, using the reference condition approach*, Kluwer Academic Publishers, Massachusetts.

Beatty, S & Morgan, D 2005, *Monitoring the adequacy of environmental water provisions for fish and crayfish communities of Samson Brook, Harvey River and Harris River,* report to the Water Corporation of Western Australia, Centre for Fish and Fisheries Research, Murdoch University, Perth.

Beatty, S & Morgan, D 2004, *Monitoring the Lion's Weir fishway, Hotham River, Western Australia,* report to the Department of Environment, Centre for Fish and Fisheries Research, Murdoch University, Perth.

Beatty, S, Morgan, D, Jury, C & Mitchell, J 2006, *Fish and freshwater crayfish in streams in the Cape Naturaliste region & Wilyabrup Brook*, report to the Cape to Cape Catchments Group and Geocatch, Centre for Fish and Fisheries Research, Murdoch University, Perth.

Boulton, AJ & Brock, MA 1999, *Australian freshwater ecology processes and management,* Gleneagles Publishing, Glen Osmond.

Bunn, SE & Davies, PM 1990, 'Why is the stream fauna of south-western Australia so impoverished?', *Hydrobiologia* vol. 194, pp. 169-176.

Bussemaker, P, Kelsey, P, & Zammit, C 2004, *Nutrient status and trend in the waterways of the Peel-Harvey catchment*, unpublished report, Department of Environment, Perth.

Clarke, KR & Gorley, RN 2006, Primer v6 :User Manual/Tutorial, PRIMER-E Ltd, Plymouth, UK.

Costanza, R 1992, 'Toward an operational definition of ecosystem health', in R Costanza, BG Norton BD & Haskell, *Ecosystem health: New goals for environmental management,* Island Press, Washington, DC.

Catchment Simulation Solutions (CSS) 2010, FARWH Project Management [Online], available at <www.csse.com.au/projects/farwh/> Catchment Simulation Solutions.

Davies, P 2005, *Assessment of habitat and hydrology of importing tributaries of the Blackwood River associated with Yarragadee, Briefing Report CENRM 17/05, vol. 2*, Centre of Excellence in Natural Resource Management, the University of Western Australia, Albany.

Department of Water 2004, State-wide river water quality assessment, available at: <www.water.wa.gov.au > (accessed 14 April 2010).

— 2009, *Upper Collie water allocation plan,* Water resource allocation planning series, report no. 20, Department of Water, Perth.

Galvin, L, van Looij, E & Storer, T 2009a, *River Health Assessment Scheme for the sub-catchments of the Swan Canning, user's manual,* Water Science Technical Series, report no. 8, Department of Water, Perth.

— 2009b, *River Health Assessment Scheme for the sub-catchments of the Swan Canning, project summary,* Water Science Technical Series, report no. 7, Department of Water, Perth.

Geoscience Australia 2006, *GEODATA TOPO 205K Series 3 user guide*, Geoscience Australia, Canberra.

Jenkins, CFH 1952, 'The food of trout in Western Australia', *The Western Australian Naturalist,* vol 3, pp. 139-141.

Macgregor, C, Speldewinde, P, Farrell, C, Tunbridge, D & Janicke, G 2010, *River action plan for the Upper Collie catchment,* Centre of Excellence in Natural Resource Management, University of Western Australia, report prepared for the Department of Water, Bunbury.

Mayer, XM, Ruprecht, JK & Bari, MA 2005, *Stream salinity status and trends in south-west Western Australia*, Salinity and land use impact series, report no. 38, Department of Environment, Perth

Merrick, JR & Schmida, GE 1984. *Australian freshwater fishes. Biology and Management*, Griffin Press, South Australia.

Morgan, D & Beatty, S 2005, *Baseline study on the fish and freshwater crayfish fauna in the Blackwood and its tributaries receiving discharge from the Yarragadee aquifer*, report to the Department of Environment, Centre for Fish and Fisheries Research, Murdoch University, Perth.

Morgan, DL, Gill, HS, Maddern, MG & Beatty, SJ 2004, 'Distribution and impacts of introduced freshwater fishes in Western Australia'. *New Zealand Journal of Marine and Freshwater Research*, vol. 38, pp. 511-523.

National Water Ccommission 2007a, *Assessment of river and wetland health: A framework for comparative assessment of the ecological condition of Australian rivers and wetlands*, National Water Commission, Canberra.

— 2007b, *Assessment of river and wetland health: Potential comparative indices*, National Water Commission, Canberra.

— 2007c, *Assessment of river and wetland health: Testing the framework*, National Water Commission, Canberra.

— 2007d, *Assessment of river and wetland health: An Australian snapshot,* National Water Commission, Canberra.

Norris, RH, Prosser, I, Young, B, Liston, P, Bauer, N, Davies, N, Dyer, F, Linke S, & Thoms, M 2001, *The assessment of river conditions (ARC), an audit of the ecological condition of Australian rivers*, report to the National Land and Water Resources Audit Office, Cooperative Research Centre for Freshwater Ecology, University of Canberra and CSIRO, Canberra.

Norton, S & Storer, T in press, *Decision tool: Barrier prioritisation to aid the installation of fishways,* Water Science Technical Series (in press), Department of Water, Perth.

Pusey, BJ & Morrison, PF 1989, 'The diet of rainbow trout in Wungong Dam, Western Australia', *Western Australian Naturalist,* vol. 18, pp 37–40.

Riek, EF 1969, 'The Australian freshwater crayfish (Crustacea: Decapoda: Parastacidae), with descriptions of new species', *Australian Journal of Zoology*, vol. 17, pp.855-918.

Sinclair Knight Merz 2010, *Identification and mapping of groundwater dependent ecosystems associated with the Collie River*, SKM, Perth.

South East Queensland Healthy Waterways Partnership Office 2009, *Ecosystem Health Monitoring Program (EHMP),* available at <www.ehmp.org/> (accessed 1 September 2009).

Storer, T & Norton, S in press, *Decision tool: An introduction to fish barriers and fishways for Western Australia*, Water Science Technical Series (in press), Department of Water, Perth.

Storer, T, White, G, Galvin, L, O'Neill K, van Looij, E & Kitsios, A in press a, *The Framework for the Assessment of River and Wetland Health for flowing rivers of south-west Western Australia: project summary and results, Final report*, Department of Water, Western Australia.

— in press b, *The Framework for the Assessment of River and Wetland Health for flowing rivers of south-west Western Australia: method development, Final report,* Department of Water, Western Australia.

Sutcliffe, K 2003, *The conservation status of aquatic insects in south-western Australia*, PhD thesis, Murdoch University Perth.

van Looij, E & Storer, T 2009a, *Inception report – volume 1: SWWA-FARWH, Department of Water, Perth.*

van Looij, E & Storer, T 2009b, *Inception report – volume 2*: *SWWA-FARWH*, Department of Water, Perth.

van Looij, E, Storer, T, White, G, O'Neill, K, Galvin, L & Heald, D 2009, *Report on the Framework of the Assessment of River and Wetland Health trials in south-west Western Australia: first round*, Department of Water, Perth.

Wallace, JB, Eggert, SL, Meyer, JL & Webster, JR 1997, 'Multiple trophic levels of a forest stream linked to terrestrial litter inputs', *Science,* vol. 277, no. 5322, pp. 102-104.

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