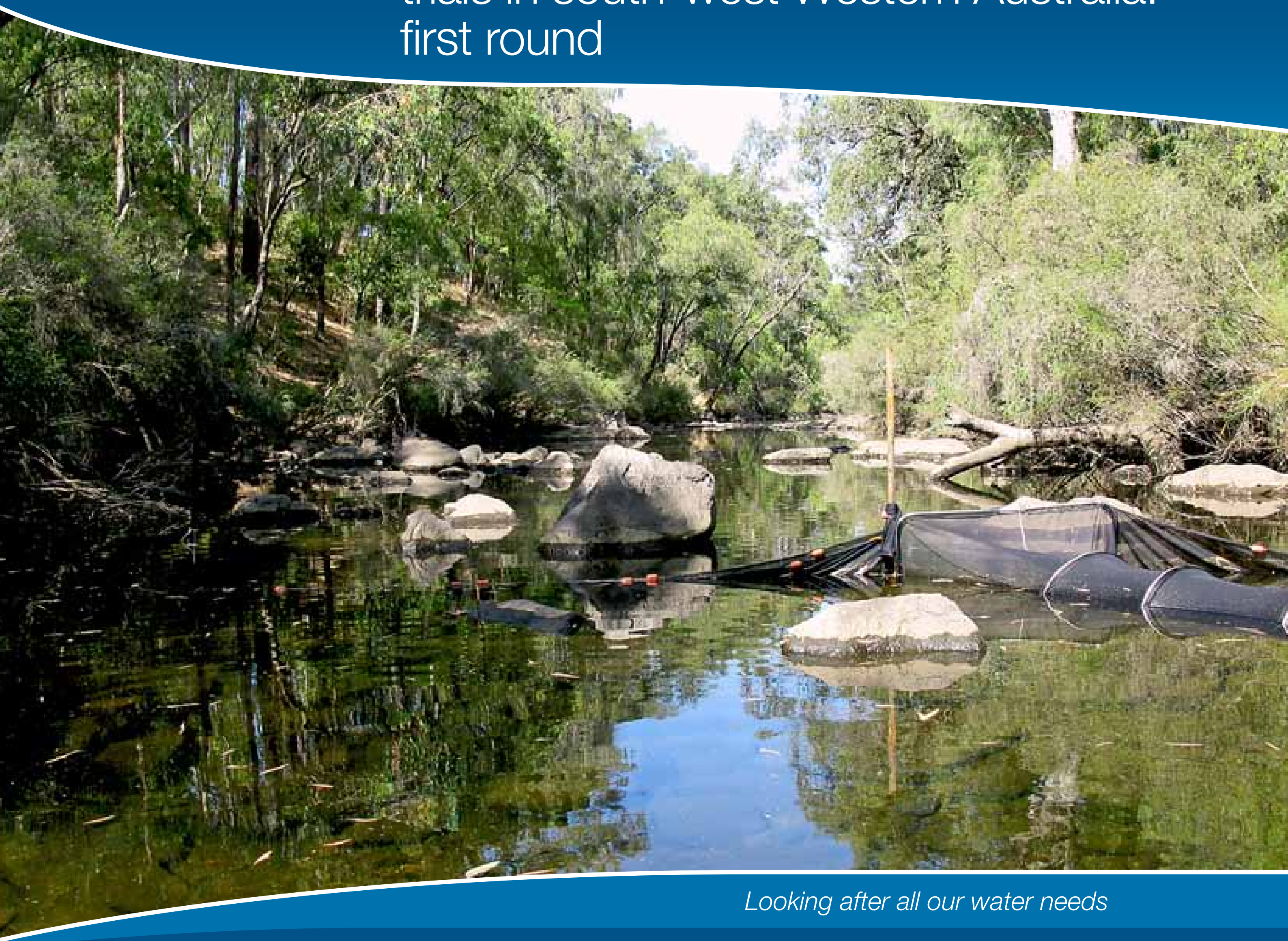
Government of **Western Australia**
Department of **Water**

Report on the Framework for the assessment of river and wetland health trials in south-west Western Australia: first round



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September 2009

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Summary

This project aims to assess the effectiveness of the *Framework for the assessment of river and wetland health* (FARWH) in the flowing waters of the south-west of Western Australia. To do this, two field trials and a series of desktop studies are being conducted. The first trial was conducted in the spring of 2008 (and is the subject of this report), and the second will be conducted in the spring of 2009. As there was no existing river health program across the south-west of Western Australia which could be used for the FARWH, the first round of trials focused on indicator development. The second round of field trials will concentrate on refining indicators.

Five of the six themes recommended by the National Water Commission (NWC 2007a) for undertaking an assessment using the FARWH were investigated in the first round of trials. Three surface water management areas (SWMAs) were sampled within the south-west of Western Australia. These were the Moore Hill, Collie and Albany Coast surface water management areas. A combination of field collected data, spatial data and modelled data were used to conduct the assessments.

Most of the indicators chosen under the five themes were found to perform reasonably well. There was only one indicator – erosion – which was discarded completely and will not be used in the second round of trials. The remainder were deemed worthy of further investigation.

Several new indicators and scoring methods will also be investigated in the second round of trials including SedNet modelling for total nitrogen and total phosphorus concentrations and sedimentation, development of a new spring channel AUSRIVAS model for the south west of Western Australia which incorporates a finer level of taxonomic resolution (genus) for the Plecoptera, Trichoptera, Ephemeroptera and Odonata orders and the Flow Stress Ranking method for scoring hydrology.

The second round of field trials will aim to sample a further five SWMAs, bringing the total sampled during the project to eight. Further, a retrospective 2005 analysis will be conducted for those SWMAs and indicators for which there is data. This will be done after the indicators and scoring protocols are finalised after the second round of sampling. Further, Data from the one existing river health program in Western Australia will be run through the FARWH to provide an assessment for the Swan Coast SWMA. This river health program, the River Health Assessment Scheme (RHAS) has sampled 20 sites in the Swan Coast SWMA in 2007 and 2008 and funding is available to repeat the sampling in 2009. Whilst data will not be available for all of the indicators recommended by the FARWH, this data will allow some assessment of the temporal variability in scoring to be assessed.

1 Background

This project aims to trial the Framework for the Assessment of River and Wetland Health (FARWH) to the flowing waters of the south-west of Western Australia. The geographical extent of the project is roughly from Kalbarri in the north to Esperance in the east. Figure 1 shows the location of the study area.

Figure 1 Geographical extent of south-west Western Australia FARWH project

The project consists of two field trials – the first was conducted in the spring of 2008, and the second will be conducted in the spring of 2009. As there was no existing river health program across the south-west of Western Australia which could be for trialling the FARWH, the first round of trials focused on indicator development. The second round of field trials will concentrate on refining indicators. Once this has been completed a retrospective 2005 assessment will be carried out for those SWMAs and indicators for which there is data. Data from the one existing river health program which is conducted in the Swan Canning system (the River Health Assessment Scheme - RHAS) will also be analysed using the FARWH scoring method.

Sampling in 2008 was carried out in three surface water management areas, the Moore Hill, Collie and Albany Coast. Unseasonal rainfall was experienced whilst conducting the Albany Coast sampling in November. In the Albany town site 226 mm of rain was recorded, the highest since records commenced in 1877. This may have influenced the results obtained.

The FARWH identifies six themes under which indices need to be developed. These are:

1. catchment disturbance
2. hydrological change
3. water quality and soils
4. physical form
5. fringing zone
6. aquatic biota.

Each of these themes are discussed in more detail in the following sections. It is intended that the FARWH will be adopted by regional offices and natural resource management (NRM) groups after the development phase is completed. Therefore, when selecting indicators and sampling methodologies consideration was given to both the ease of undertaking the sampling, and the cost of the equipment required to conduct it.

1.1 SWMA and reach selection strategy

The first round of trials in the south-west Western Australia FARWH project focused on the development and trialling of indicators. To this end, three SWMAs were chosen in which to conduct sampling – Albany Coast, Moore Hill and Collie. These were chosen as they represented a range of climatic conditions and human impacts.

The method used for selecting which reaches to sample is detailed in the project inception report (van Looij & Storer 2009). In summary, reaches were selected in such a way as to represent the geographic extent of each SWMA as well as the topography, rainfall, land-use and geology within it. This strategy was chosen as it ensured that the indicators would be trialled at a range of different sites.

1.2 Reach validation

The reaches used for the first round of trials were developed during the National Land and Water Resource Audit mark I (NLWRA I) (Australia assessment of river condition (Reach) 2001 (DEWHA 2008)). Prior to calculating scores, all reaches in the sampled SWMAs were validated by comparing them to rivers from the National Topographic Map Series 1:250 000 Scale (NATMAP 250K) (GA 1997), and to aerial photography and Departmental hydrolinear datasets. There were instances where large reservoirs and areas of low lying land were defined as reaches, and where streamlines had been incorrectly connected together. Reaches with invalid sections (e.g. flowing through a reservoir) were shortened or split into valid parts. Completely invalid reaches (e.g. low lying land) were deleted, as were estuarine reaches due to the FARWHs focus on freshwater systems. For simplicity's sake the original reach identification codes have been retained with a suffix added to those that have been altered ('x' was added to the identification code of shortened reaches, 'a' and 'b' were added to the codes of split reaches).

1.3 Dealing with ephemeral systems

As many of the streams in the south-west of Western Australia are ephemeral, the timing of sampling is crucial to ensure that winter flows have receded to their base flow level and that the smaller headwater streams have not yet dried out. As 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. During sampling for this round of trials some sites had dried to pools by the time they were sampled. These were still sampled however the results were not included in final scoring as the ecology and processes in a pool are different to those in a flowing river. For the second round of field trials pools will not be sampled.

2 Catchment disturbance index

The catchment disturbance index (CDI) has been included in the FARWH to detect and provide a measure of human induced changes that affect river condition and biota (NWC 2007b).

Three indicators were trialled for the CDI;

- an infrastructure measure
- a land cover change measure
- a land-use measure.

Given that this index applies at the whole-of-SWMA scale, a desktop approach to conducting the assessment was seen as most appropriate. For the purpose of this report the assessments were made at the whole-of-SWMA scale but the intention is that future assessments would be made at a number of smaller scales, namely the reach scale (assessing the CDI for each of the sub-catchments associated with the reaches) and the river system scale.

The methods used for assessing the CDI are based on those given in NWC 2007b.

2.1 Infrastructure measure

The infrastructure measure was calculated by assigning a rank to different infrastructure types, based on their impact on stream health, and using this to calculate an overall weighting. The rankings (and weightings) were based on those give in NWC 2007b with some modifications for local conditions. Table 1 shows the rankings and weightings that have been adopted for the south-west Western Australian FARWH.

Table 1 Rankings of different infrastructure types and resulting weights for south-west Western Australia

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

The only rankings that have been altered from the originals proposed in NWC 2007b are the effect of unsealed roads and vehicle tracks on nutrients. Both of these have been reduced from a ranking of 6 to 4. There has been only limited research carried out in Western Australia regarding the impact of different infrastructure types on river health. However, a 2003 study in a forested catchment showed that whilst suspended solids generated from gravel and unsurfaced roads was much higher than the surrounding catchment, the ratio of suspended solids to total phosphorus varied between roads. On a catchment scale the roads were found to contribute 3.5% of the suspended sediment exported but only 1.5% of the total phosphorus. The total nitrogen contribution was found to be minor (Sheridan & Noske 2007). Given the generally poor nutrient holding capacities of Western Australian soils, and the practice of applying inorganic, water soluble fertilisers to farmland, it was decided to reduce the nutrient ranking of unsealed roads and vehicle tracks.

Four datasets were used to calculate this index. These were:

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

The features in these datasets are represented by polylines, but the infrastructure measure requires the area of catchment covered by the different infrastructure types, so a buffer was placed around each polyline to create polygons. Using aerial photographs, the width of a subset of each infrastructure type was measured to calculate an average buffer width for each infrastructure type (Table 2).

Table 2 Buffer widths for the different infrastructure types

Dataset infrastructure type	FARWH infrastructure type	Buffer width (m)
Trails	Walking track	2.0
Pipelines	Utilities (power, pipes)	0.25
Railways	Railway	13.75
Roads – highway	Main sealed road	11.8
Roads – main road	Main sealed road	8.7
Roads – local sealed road	Other sealed road	7.0
Roads – local road other	Unsealed road	7.7
Roads – track	Vehicle track	4.0
Roads – no classification	Unsealed road	4.0

Any overlap in datasets was removed prior to calculating the area of each of the FARWH infrastructure types.

The assessment was carried out at the whole-of-SWMA scale using Equation 1 below. However, future assessments will also be carried out at the reach and river system scale.

Equation 1 $I = 1 - ((I_1 \times w_1) + (I_2 \times w_2)...)$

where I = infrastructure measure; I_n = fraction of the catchment of infrastructure category n and w_n = the weight for infrastructure category n.

2.2 Land cover change measure

Land cover change was assessed by calculating the percentage of each SWMA where perennial vegetation was cleared during the 2003 to 2007 period. This was done by using a series of vegetation extent datasets produced by the Landmonitor Project in Western Australia, which have a 25 m pixel resolution and are updated annually. The datasets were:

- Lm50_south_VegMask_2003_mga.ers and equivalents to 2007
- Lm50_nwest_VegMask_2003_mga.ers and equivalents to 2007.

The Agricultural Land Cover Change 1990–1995 dataset which measured change in woody vegetation cover between 1990 and 1995 was also investigated, but as it was at a coarser scale (250 m pixel size) and was neither current nor likely to be updated it was not used.

The Land Monitor Vegetation Change product includes algorithms which allow the user to interrogate the datasets in ER Mapper. Using the relevant algorithms (Lm50_south_VegChange_1990-2007.alg and Lm50_nwest_VegChange_1990-2007.alg) the pixels showing loss of perennial vegetation during the period 2003 to 2007 were identified, and the total area of loss calculated.

There was no indication given as to why the vegetation had been lost (that is, the datasets did not distinguish between vegetation loss due to clearing, wildfires or controlled burns). The NOAA fire affected areas 2003, 2004, 2005, 2006 and 2007 dataset (Landgate) were investigated as a means of distinguishing between data loss due to fire and other destructive activities. The pixel size for these datasets is 1 km but due to the methodology used to create the data the minimum detectable burn size area is 4 km^2. Errors occurred when converting the raster data to vector format which could not be rectified, causing a mismatch between the pixel and polygon locations. Further, the dataset did not provide information about the cause of the fire so it was not possible to distinguish between wildfires and those caused by human influence. As a large number of fires in the south-west of Western Australia are not natural it was decided not to use this dataset, so vegetation loss due to fire has not been factored into the final land cover change measure calculations.

2.3 Land-use measure

The land-use measure was calculated by assigning a rank to different land-use types, based on their impact on stream health, and using this to calculate an overall weighting. The rankings (and weightings) were based on those given in NWC 2007b with some modifications for local conditions. Table 3 shows the rankings and weightings that have been adopted for the south-west Western Australia FARWH.

Table 3 Rankings for different land-use types and resulting weightings for south-west Western Australia

Land-use	Rankings: Nutrients	Salinity	Biocides	Hydrological change	Sediment supply	Riparian change	Toxicants	Mean rank	Weight
Urban	5	2	3	6	3	6	6	4.43	0.68
Intensive and irrigated agriculture	6	5	6	5	4	3	4	4.71	0.70
Dryland cropping	4	5	4	3	3	3	2	3.43	0.53
Grazing	2	4	3	1	2	3	1	2.29	0.35
Plantation forestry	1	2	3	2	1	1	1	1.57	0.24
Managed resources	1	1	-	1	1	-	-	0.57	0.09
Conservation	-	-	-	-	-	-	-	0	0

Changes were made to the rankings for salinity and toxicants to better represent conditions in the south-west of Western Australia. Whilst the rankings for toxicants were originally focused on the likelihood of different land-uses to produce spillages of hydrocarbons and other toxicants, the impact of hormones and fertiliser use has also been considered here.

To bolster production of the naturally nutrient poor soils in the south-west of Western Australia, water soluble fertilisers are widely used in agriculture. These fertilisers contain (amongst other things) cadmium, mercury and lead, with literature produced by the Fertiliser Industry Federation of Australia (2008) warning that there is a risk of these metals accumulating in soils and causing the maximum limits for cadmium in food to be exceeded. Bennet-Chambers et al. (1999) estimates that almost 300 t of cadmium has been added to Western Australian soils (50% of which is water soluble) through the application of superphosphate fertilisers between 1982 and 1999. Further, Bennet-Chambers et al. (1999) state that the old maximum permissible concentration for cadmium concentrations of 0.2 mg/kg was frequently exceeded in tissues of the freshwater crayfish *Cherax tenuimanus*. This maximum permissible concentration has since been removed.

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

For these reasons the rankings for intensive and irrigated agriculture (fertilisers and hormones) and dryland cropping (fertilisers) have been increased.

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

A separate land-use category, ‘managed resources’, has been added to the land-use types in Table 3 and given its own ranking. This recognises that those land-uses classified as ‘managed resources’ in the Land Use in WA v5 dataset used for calculating the land-use measure are actually managed as production forests (known as state forests to the Department of Environment and Conservation (DEC)). These are areas of natural bushland managed by DEC that are zoned for logging. Clearing in these areas is usually carried out on a 50-year cycle although this is subject to a number of factors (e.g. location). This clearing frequency is lower than plantation forests which are typically logged every 12 to 15 years (Tasmanian blue gums) or 20 to 30 years (pine plantations). As these areas are periodically logged it is misleading to classify them as conservation (as per NWC 2007b). The impact from this land-use is minimal and tends to be acute, occurring over a short period of time immediately after an area has been logged. Riparian zones are not typically cleared during these logging exercises as they do not generally incorporate the targeted tree species, hence no ranking was assigned to riparian zones. Further, biocides and toxicants are not used in this kind of forestry, again leading to the lack of ranking for these impacts.

To calculate the land-use indicator, the Land Use in WA v5 dataset was used. This shows land-use at a property scale as assessed by field officers between 1996 and 2001. While this dataset is not current it is far more detailed than the most recent national dataset (Land Use of Australia v3 2001/02) which has a pixel resolution of approximately 1 km^2. The assessment was carried out at the whole-of-SWMA scale using Equation 2. However, future assessments will also be carried out at the reach and river system scale.

Equation 2 $LU = 1 - ((F_1 \times w_1) + (F_2 \times w_2)...)$

where *LU* = land-use measure, F_n = fraction of the catchment of land-use category n and w_n = the weight for land-use category n.

2.4 Integration and aggregation

Integration follows the methodology suggested in the FARWH documentation, see Equation 3 (NWC 2007a).

Equation 3 $CDI = I + LC + LU - 2$

where *CDI* = Catchment disturbance index score, *I* = Infrastructure score, *LC* = Land cover change score, *LU* = Land-use measure.

Where Equation 3 returns a negative number the overall CDI score is assigned a zero.

Aggregation is done by calculating the area-weighted average of all reach scores.

During this first round of trials the CDI has only been calculated at the whole-of-SWMA scale. However in future trials it is recommended that the CDI be calculated at the sub-catchment scale to allow an overall FARWH assessment to be made for each reach. Therefore, for this round of sampling integration has been carried out at the SWMA scale rather than the reach scale and aggregation has not occurred.

3 Hydrological change index

The hydrological change index (HCI) has been included in the FARWH to provide a measure of the impact of the water regime (both surface and groundwater) on the functioning of the aquatic ecosystem (NWC 2007a).

Five indicators were to be trialled under the HCI. These were:

- low flow index
- high flow index
- proportion of zero flow index
- monthly variation index
- seasonal period index.

Discussions with Department of Water hydrologists indicated that there should be sufficient data available in most SWMAs to calculate the index set listed above, but not to determine pre-European condition for these indicators.

However, because suitable staff were not available, the HCI was not investigated further as part of the 2008 assessments. Work will commence on this index at the start of the 2009–10 financial year and a retrospective scoring will be calculated for the SWMAs assessed as part of this round of field sampling.

4 Water quality and soils index

The water quality index (WQI) measures the change in water quality features relevant to Western Australia, and relative to reference.

Six indicators were selected for trialling. These were:

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

Data for all of these indicators except salinity was collected in the field using spot measurements (with the exception of diel dissolved oxygen and temperature which were logged over a 24-hour period). Salinity data was scored using a combination of measured and modelled salinities, created by Mayer et al. (2005).

Modelling approaches were also highlighted as worth trialling for parameters other than salinity, but this has not yet been undertaken due to the unavailability of suitable staff. Work will commence on modelling approaches for TN and TP at the start of the 2009–10 financial year. For this round of assessments the field data has been used for scoring.

4.1 Total nitrogen

There is no agreed approach to developing scoring protocols for TN in the FARWH documents. Ideally minimally disturbed reference sites would be used to determine natural TN concentrations, but for the south-west of Western Australia this is not feasible. There is a lack of suitable reference sites available as large areas have been cleared. Whilst there are some rivers which have their entire (or a large proportion) of their catchment uncleared these do not provide suitable reference sites for other systems due to a range of factors such as rainfall gradient, differences in geology and differences in river form and function.

To determine reference condition a number of approaches were investigated. Firstly, all available data for the three surface water management areas was sourced from the Department of Water’s water information network (WIN) database. This was then filtered to only include data collected between August and January inclusive to help remove the effect of seasonality on the data (most systems in the south-west of Western Australia exhibit a positive flow response for nutrient concentrations). This data was then plotted against a number of ‘predictor’ variables (those variables which are unlikely to be influenced by human impact) such as easting, northing, altitude, average annual rainfall and average maximum daily temperature to determine if there were any relationships between the predictor variables and the TN concentrations. No relationships were observed.

The ANZECC guidelines were then consulted to determine their suitability. They recommend two default trigger values, one for lowland rivers (those at less than 150 m in altitude) of 1.2 mg/L and one for upland rivers (those at more than 150 m in altitude) of 0.45 mg/L (ANZECC & ARMCANZ 2000). These trigger values were then compared to the compiled datasets and the recommended cut-off point in altitude of 150 m found not to reflect the collected data. A cut-off point of 25 m would seem to reflect the data more closely (see Figure 2) for the Collie and Albany SWMAs and there is no obvious cut-off for the Moore Hill.

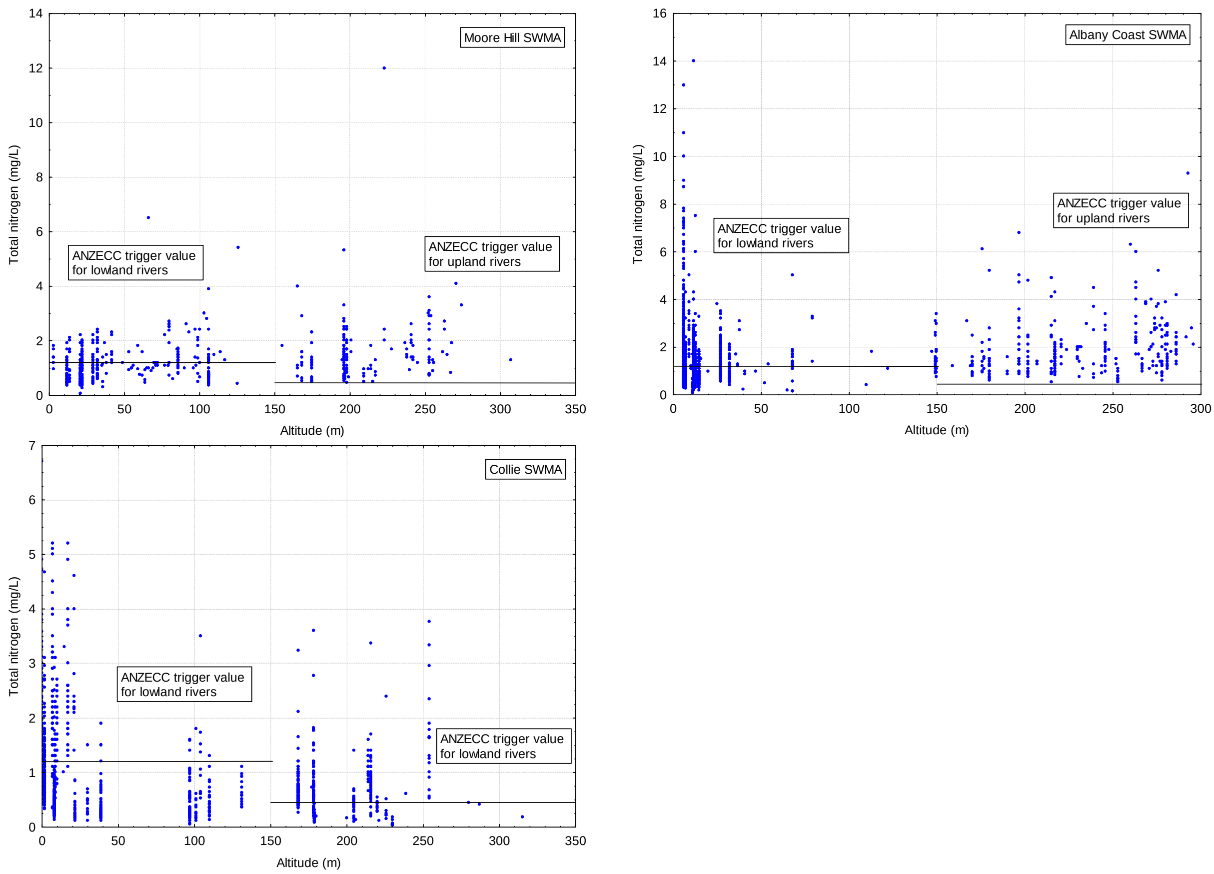

Figure 2 TN versus altitude in the Moore Hill, Collie and Albany Coast SWMAs

An existing TN classification scheme developed for Western Australia has therefore been utilised to develop the scoring protocol for TN. This scheme was developed by the Department of Water to allow comparisons of TN concentration data statewide and was based on all the available TN data in the state. Generally, classifications are assigned using three years of data to remove seasonality. As there were not three years of data available for most of the sites a single point of data has been used. If modelling of TN proves to be successful then modelled data can be used to determine the classifications in future FARWH assessments. This will help reduce the potential bias of utilising point data. The categories, their definitions and their

FARWH scores can be found in Table 4. Note, a zero score was not assigned as it was felt that this was not relevant to nutrients. Even at very high nutrient levels a system will continue to function, albeit differently to how it originally functioned.

Table 4 TN categories and scores

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

4.2 Total phosphorus

The approach taken to develop the total phosphorus (TP) scores was the same as for TN. The resulting categories and scores are in Table 5 below. Note, a zero score was not assigned as it was felt that this was not relevant to nutrients. Even at very high nutrient levels a system will continue to function, albeit differently to how it originally functioned.

Table 5 TP concentrations, categories and scores

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

4.3 Turbidity

The approach taken to develop the turbidity scores was the same as for TN. The resulting categories and scores are in Table 6 below. Note, a zero score was not assigned as it was felt that this was not relevant to turbidity. Even at very high turbidity levels a system will continue to function, albeit differently to how it originally functioned.

Table 6 Turbidity levels, categories and scores

Turbidity (NTU)	Turbidity category	FARWH score
< 5	low	1
5 – 10	moderate	0.8
> 10 – 25	high	0.6
> 25	very high	0.4

4.4 Electrical conductivity (salinity)

Whilst spot measurements of specific conductivity were taken in the field a combination of existing measured and modelled data was used to assign scores. The Salinity and Land Use Management branch of the Department of Water carried out a large scale project, classifying streams by salinity in the south-west of Western Australia (Mayer et al. 2005). This project used data from a number of sources, with a preference for gauging stations with long-term continuous datasets (a minimum of 10 years). The REG6S model (since updated to the REG75 model) was then used to estimate salinity for those streams where there was no available salinity data. The average flow-weighted salinity (1985 to 2002) were presented on a map. Before using this data the map was verified by comparing point data collected during the FARWH field work, as well as other available data, to the results presented. In all cases there was found to be a very good fit.

As the reach definition used in the mapping project of Mayer et al. (2005) was different to that used for the FARWH, there is not 100 % coverage of all the FARWH reaches. For the three SWMAs sampled there was 50% coverage of the reaches for Moore Hill, 79% for Albany Coast and 95% for Collie. The other issue was that the reaches used in the mapping exercise were generally much shorter than those used for FARWH, resulting in numerous classifications for some FARWH reaches (up to 50 per reach). In all cases there was one classification that was more common than the others so the mode of the classification categories was used as the FARWH reach classification.

There is no agreed approach to developing scoring protocols for electrical conductivity (or salinity) in the FARWH documents. Extensive literature searches have found conflicting information, with some reports suggesting that all, or parts, of some rivers in the south-west of Western Australia were naturally brackish or salty (see Hargraves 1863, Bleazby 1917, Schofield et al. 1988) and others suggesting that all rivers were once fresh (see Mayer et al. 2005). Evidence does seem to suggest that there was rapid salinisation after European disturbance. For example, Bleazby (1917) cites the case of a reservoir established near Cranbrook in 1888 for the Great Southern Railway which was salty and unfit for use by 1902.

Mayer et al. (2005) suggest that forested catchments may make appropriate reference sites for salinity. They define forested catchments as those that have less than four percent of their native vegetation cleared. Most catchments that fit this description are in the high rainfall zone (greater than 900 mm of rainfall annually) and therefore may not make good reference sites for low rainfall areas. However, evidence seems to suggest that streams in forested catchments in lower rainfall areas were also once fresh, as both the Canning and Mitchell Rivers which lie in areas of less than 900 mm of rainfall annually are fresh.

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

Ecosystem tolerance to salinity was then investigated and is summarised in Table 7.

Table 7 Summary of salinity tolerances in the literature.

Trigger value threshold (mg/L TDS)	Comment	Reference
62 to 156 [120 – 300 µS/cm]	Recommended trigger value for upland and lowland rivers in south-west Western Australia	ANZECC & ARMCANZ 2000
> 1 000	Direct adverse effects become apparent in aquatic ecosystems.	Mayer et al. 2005
	Below this salinity freshwater ecosystems are subject to little stress.	Nielsen et al. 2003
1 000	Macroinvertebrates: osmoregulatory function starts to fail.	Hart et al. 1991
10 000	Fish: tolerate salinity to this concentration.	
800	Mortality and sub-lethal effects in macroinvertebrates have been found to occur.	Bailey & James 2000
	General salinity thresholds for:	James et al. 2003
1 000 – 2 000	Most submerged macrophytes.	
2 000 mg/L	Macroinvertebrates – lethal effects.	
< 2 000 mg/L	Microinvertebrates – lethal effects.	
2 000 mg/L	Riparian trees – adverse effects.	
8 800 mg/L	Adult fish – most tolerant to this level.	
2 000 – 4 500 mg/L	Juvenile fish (pre hardened eggs).	
3 000 – 50 000 mg/L	Juvenile fish (growth rate, survivorship, sperm mortality).	

As a result, the salinity categories used by the map were scored as shown in Table 8.

Table 8 Salinity bandings, categories and scores

Salinity (mg/L TDS)	Category (from Mayer et al. 2005)	FARWH score
< 500	Fresh	1
500 – 1 000	Marginal	1
1 000 – 1 500	Marginal-brackish	0.5
1 500 – 3 000	High-brackish	0.5
3 000 – 7 000	Low-saline	0.5
7 000 to 14 000	Mid-saline	0.5
14 000 to 35 000	High-saline	0
> 35 000	Brine (seawater)	0

4.5 Diel dissolved oxygen

Twenty-four-hour dissolved oxygen (DO) readings were collected at ten-minute intervals at each site sampled using the open water (whole stream) method. The feasibility of calculating stream metabolic variables (GPP, respiration and P/R) was investigated.

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

The open water metabolism calculation was not found to be effective for the data collected. The calculations did not work at over half the sites. This was discussed with Roger Young from the Cawthron Institute, New Zealand (pers. comm. 2009) and, on further investigation by him, it was found that many sites did not exhibit the typical night/day diurnal pattern, with oxygen levels remaining relatively stable throughout the twenty-four-hour monitoring period. He also noted that many sites exhibited low production. As two loggers were deployed at each site there is confidence in the collected data, so the lack of typical diurnal pattern is real, rather than being due to instrument faults. The conclusion was that the current open system methods will not work for many of our systems.

As stream metabolism variables could not be calculated, the approach used for the River Health Assessment Scheme (RHAS) (Galvin et al. 2009) was used instead. This involves determining the proportion of time that the dissolved oxygen spends in different bands over the twenty-four-hour monitoring period, with each band being assigned a weighting. The bands, concentrations and weighting scores are shown in Table 9.

Table 9 Dissolved oxygen concentrations, bands and weighting scores.

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

Following the precautionary principle, if more than 25% of the 24-hour data were below 2 mg/L the site was assigned a score of zero. If this was not the case (and no sites in the current trial fell into this category) then the overall score for the site was calculated using Equation 4.

Equation 4 $$DO = (1.0 \times B_1) + (0.8 \times B_2) + (0.6 \times B_3) + (0.4 \times B_4) + (0.2 \times B_5) + (0 \times B_6)$$

where *DO* = the DO score for the site, B_1 = proportion of time spent in Band 1, B_2 = proportion of time spent in Band 2, and so on.

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

An upper limit was then selected, also based on literature. The ANZECC guidelines recommend a default trigger value of 80% saturation for lowland rivers and 90% saturation for upland rivers which equates to roughly 6 mg/L (ANZECC & ARMCANZ 2000). Hunt and Christiansen (2000) state that concentrations below 5 mg/L will start to have an impact on fish, with most species actively moving away to more oxygen rich waters. They further define ‘clean’ water as having a DO concentration greater than 6.5 mg/L (Hunt & Christiansen 2000). Waterwatch Australia Steering Committee (2002) states that a minimum of 5 to 6 mg/L is required for fish growth and activity. An upper limit of 6 mg/L was therefore selected.

The bands between the upper (6 mg/L) and lower (2 mg/L) limits were simply determined by evenly dividing the concentrations to provide 4 bands, giving a total of 6 bands (see Table 9).

4.6 Diel temperature

Temperature was logged at ten-minute intervals, over twenty-four hours, at each of the sites sampled. Whilst there is an abundance of information on lethal and sub-lethal effects of temperature on individual species there is only limited information on south-west species, or whole-of-ecosystem effects. Further, there is a lack of suitable minimally disturbed reference sites with which to develop reference condition.

The natural temperatures in streams will vary across the south-west of Western Australia with waterways in the Moore Hill SWMA expected to be warmer than those in the Collie and Albany SWMAs. This is due to a number of factors including;

- the warmer ambient temperatures in the Moore Hill area
- the difference in altitude between the SWMAs
- the difference in rainfall between the SWMAs, Moore Hill being dryer
- the difference between the natural vegetation types in the two areas – tall, dense canopy forests in Collie, more open canopies in Moore Hill.

Therefore, no attempt was made to develop a banding system similar to that used for dissolved oxygen. Instead, the change in temperature over the twenty-four-hour period has been used, with changes of less than 4 °C being considered acceptable and changes greater than 4 °C being considered unacceptable. This is the same approach used by the Environmental Health Monitoring Program in Queensland (South East Queensland Healthy Waterways Partnership 2006). This value is supported by Cox and Rutherford (2000) who showed that when temperature varied diurnally by ± 5 °C a 50% mortality could be expected. This is calculated as the difference between the 95th and 5th percentiles to reduce the effect of any outliers. Table 10 summarises the scoring.

Table 10 Diel temperature scoring

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

4.7 Integration and aggregation

Where there was more than one site sampled per reach the WQI score was calculated individually for each site and then the resulting scores averaged to produce one WQI score per reach.

Integration follows a variation on the methodology recommended in the FARWH documentation (NWC 2007a). Indicators were classified as ‘critical’ (salinity, DO and temperature) and ‘non-critical’ (TN, TP and turbidity). Indicators were split based on the impact they are likely to have on stream function when they deviate from reference. Where extremes of salinity, DO and temperature range are encountered this is expected to have an immediate and catastrophic effect on the biota. High levels of TN, TP and turbidity will have an impact on the biota but the effects will be more chronic. Further, increases in nutrient levels are often coupled with an increase in productivity (up to a certain point). On closer inspection of the temperature data it was found that a 4°C change in temperature was not linked to change in the biota. Therefore, for south-west Western Australian systems a change of 4°C may not be appropriate. In the absence of adequate data it was decided to leave the scoring as it stood but to include diel temperature range in the ‘non-critical’ indicators in the interim.

The average of the four non-critical indicators (TN, TP, turbidity and diel temperature range) was calculated. A precautionary approach was then used. At each site the worst scoring of the two critical indicators (salinity and DO) and the average of the non-critical indicators was selected as the overall WQI score.

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

5 Physical form index

The physical form index (PFI) uses measures of sediment inputs and connectedness to assess the local habitat and its likely ability to support aquatic life (NWC 2007a).

Four indicators were selected for trialling. These were;

- channel pattern
- artificial barriers to fish migration
- presence of farm dams
- sedimentation index.

The intention was that this index would be scored using a combination of spatial and modelled data. However, due to the unavailability of suitable staff the modelled component (sedimentation index) has been delayed and work on it will commence at the start of the 2009–10 financial year. More information regarding the status of each of these indicators is given in the subheadings below.

5.1 Channel pattern

Channel pattern was assessed by calculating what percentage of a reach had been channelised, using the Hydrography Linear dataset (DOW 2006) which is derived from topographic mapping captured between the 1:25 000 and 1:100 000 scales. This dataset includes a category for the type of hydrographic feature, and those categorised as drain (major and minor), levee bank and supply channel were considered to provide evidence of channelisation. The channelised features which aligned with reaches defined in the ARC reach dataset were selected, the length was measured and the percentage of reach channelised was calculated from this. (The total length of the reach was taken as that calculated from the 250K-reach dataset described in Section 6). Scoring was based on percentages (so 100% channelisation would return a score of zero, no channelisation would return a score of 1).

The Hydrography Linear dataset was reasonably complete over the three SWMAs assessed, with the exception of an area of roughly 200 000 hectares in the Albany SWMA near the top of the Gairdner River (equivalent to ~ 10% of the SWMA). This was addressed by not scoring this portion of the SWMA.

A visual comparison was conducted between the Hydrography Linear dataset and appropriate aerial photography to gauge the accuracy of the layer in detecting channelisation. It appeared that there were some sections of reaches that have been straightened but have not been classified as such in the dataset. The magnitude of this discrepancy varied between SWMAs, being in the vicinity of 20% in the Collie SWMA (roughly 16 km of channelised reaches identified using the Hydrography Linear dataset, a further 4 km identified as possibly being channelised from aerial photography), 10% to 20% in the Albany Coast SWMA and about 5% in the Moore

Hill SWMA. These discrepancies were accepted as a limitation of the dataset, in preference to the alternative option of visually assessing channelisation from aerial photography, which would be both time-consuming and have the potential for introducing operator bias.

5.2 Artificial barriers to fish migration

There is currently no broad scale dataset which identifies the location and types of fish barriers present in the south-west of Western Australia. Funding has been sourced through the Department of Fisheries and a project has begun which will ultimately allow the number and severity of barriers by catchment and reach to be identified. This project is compiling information using desktop studies, literature reviews, consultation with regional stakeholders and limited ground truthing. The draft final report and database are due in September 2009 and will be available for use for the FARWH project at this time. This database (GIS based) will allow a scoring system to be developed for FARWH assessments. Scoring is likely to involve assessing the severity of each fish barrier and assigning a score to each reach based on this severity (for example a barrier which allows no fish passage at all will be assigned a very low score). All reaches above an identified barrier will be assigned the score of that barrier (as the effect of the barrier will continue upstream of the reach in which it is located).

Once the database is complete a retrospective analysis will be undertaken for the 2008 FARWH assessment.

5.3 Presence of farm dams

Options for scoring the impact of farm dams were investigated and two main issues identified. The first issue revolved around the availability of suitable datasets and the other around how to score the impact of farm dams.

Three datasets were investigated for suitability; Hydrography Points (DOW 2006), Hydrography Linear (DOW 2006) and Farm Dams (DOW 2008). The first two of these datasets are derived from statewide topographic mapping at between 1:25 000 and 1:100 000 scale, so they were too coarse to capture all of the farm dams visible in aerial photography. The Farm Dams dataset was captured from satellite imagery and aerial photography so it was very detailed and accurate but covered only a very small portion of the south-west (less than an entire SWMA). In addition, to assess the impact of farm dams their surface area needs to be known as this will allow their volume to be calculated (Department of Water 2007). As neither of the Departmental hydrography datasets record the surface area of the dam (they are linear datasets) it is not possible to determine volume. Consequently there was no appropriate dataset available with which to identify farm dams. Licensing databases were investigated as an alternative source of information but, as there are many circumstances in which farm dams do not need to be licensed (e.g. in unproclaimed areas), it was not possible to use these to identify farm dams either.

There was therefore no appropriate dataset available with which to identify farm dams.

A study by SKM (2007) noted three main effects of farm dams in the south-west of Western Australia:

- Changes to low flows. Lower flows are significantly reduced by farm dams and the proportion of zero flow days can be significantly increased.
- Changes to seasonal pattern. Current flow (with dams) can be 30% to 50% of the natural flow in summer and early winter while the dams are refilling. By late winter the impacts are small.
- Changes to annual variability. Farm dam impacts vary with different rainfall years, with the greatest impact in low rainfall years.

Scoring of farm dams would therefore need to incorporate a measure of impact on flow (and in fact, the impact of farm dams should probably be included under the hydrological change index rather than the physical form index). SKM's work suggested there was roughly a 1:1 relationship between farm dam storage and annual impact on streamflow (SKM 2006). If it was therefore possible to identify the location and size (in particular surface area) of farm dams it would be possible to develop a score based on their impact in individual catchments. As it is not possible to identify and measure the surface area of farm dams this indicator has been set aside for the time being. If more accurate mapping of farm dams becomes available in the future it should be re-investigated as a potential indicator.

5.4 Sedimentation

The intention is to score this indicator using modelled data from SedNet. However, as noted previously, the lack of availability of suitable staff means that this modelling has not yet begun. In the interim, scoring has been developed based on field observations. At each site, observations were taken on the severity of bank erosion, as shown in Table 11.

Table 11 Bank erosion categories, definitions and FARWH scores

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

Scores have been assigned to each of the bank erosion categories and these have been used for calculating an interim FARWH score.

5.5 Integration and aggregation

Where there was more than one site sampled per reach the PFI score was calculated individually for each site and then the resulting scores averaged to produce one PFI score per reach.

Integration follows the methodology recommended in the FARWH documentation (NWC 2007a). The standardised Euclidean distance was calculated with the individual indicators being unweighted.

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

6 Fringing zone index

The fringing zone index (FZI) provides a measure of the integrity of the vegetation in the streamside zone (NWC 2007b).

Two indicators were selected for trialling, whilst other techniques such as the ‘greeness index’ were to be investigated. The indicators were:

- longitudinal continuity
- riparian width (fringing zone width).

A number of datasets were investigated to determine their suitability for scoring. Consideration was given to the spatial extent of the datasets, their scale and the update frequency. The Land Monitor vegetation extent 2007 datasets (lm50_south_VegMask_2007_mga and lm50_nwest_VegMask_2007_mga) were selected to assess the indicators. These raster datasets are derived from Landsat 5 Thematic Mapper images and show the extent of perennial vegetation at a 25 m x 25 m pixel scale. They cover the agricultural area of the south-west of Western Australia, from Kalbarri to Cape Arid, and are updated annually by Landgate for the Land Monitor project (see Furby et al. 2008).

To calculate the FZI scores the Rivers from National Topographic Map Series 1:250 000 scale dataset (NATMAP 250K) (Geoscience Australia 1997) was used in preference to the reaches defined in the ARC Reach dataset (DEWHA 2008). This decision was made based on the observation that the reaches presented in the ARC Reach dataset often did not overlie the actual location of streamlines on the ground. As there are vegetation corridors of varying widths along many south-west streams, using the ARC Reach dataset was going to provide an underestimation of the amount of vegetation present along the reaches. Figure 3 shows an example of the disparity between the ARC Reach dataset, the NATMAP 250K dataset and the actual stream location as shown by aerial photography. The disparity between the ARC Reach dataset and the actual streamline was measured in the order of a few kilometres in some areas.

Figure 3 Example of the disparity between the ARC reach *dataset (red line), the NATMAP 250K dataset (blue line) and the actual streamline on the Brunswick River in the Collie SWMA*

To deal with this disparity the reaches, as defined by the ARC Reach dataset, were manually reconstructed using the NATMAP 250K dataset and this 250K-reach dataset was used for calculating the FZI scores.

Investigating the suitability of the 'greenness index' has not yet been undertaken.

6.1 Longitudinal continuity

Longitudinal continuity was measured by overlaying Land Monitor vegetation extent 2007 datasets with the 250K-reach dataset. The total length of each reach that was vegetated was then measured, and converted to a score out of one by dividing by the total modified-reach length. Reference condition was defined as being no longitudinal breaks in the fringing vegetation. The use of a minimum break size of 10 m for reference was investigated, but the scale of the dataset used (25 m x 25 m pixels) meant that this was not feasible to measure. The width of the fringing zone was not taken into account for this indicator as it is measured in the fringing zone width indicator.

6.2 Fringing zone width

Initially it was intended that this indicator be used to score the riparian zone width only. This has been revised and the scoring now relates to the fringing zone. The main reason for this is the natural differences in riparian vegetation width in the south-west of Western Australia. In some areas the riparian vegetation is very wide, for example some lowland rivers, and in others it is very narrow (less than 1 m) for example in small headwater streams with rocky beds in forested catchments. As the purpose of measuring riparian width is to provide an indication of the amount of buffering that the stream has from surrounding land-uses it was decided that measuring fringing zone width was more robust. There is conflicting information available regarding how wide a buffer is needed to help protect rivers from surrounding land-use (see Price et al. 2004, WRC 2000 and Hunter et al. 2006). A fringing zone width of 50 m was selected as being equivalent to reference based on advice in Roberts et al. (2009).

Consideration was given to the appropriate spacing between the 50 m transects along a reach. As the dataset being used has a 25 m^2 pixel size a transect spacing of 25 m was selected as a minimum and the average vegetation width over the length of a number of test reaches calculated. This was repeated for transect widths of 50, 100, 150, 200, 250, 500 and 1000 m to determine the most appropriate transect spacing. Figure 4, below shows the average vegetation widths calculated using the different transect spacings for two reaches.

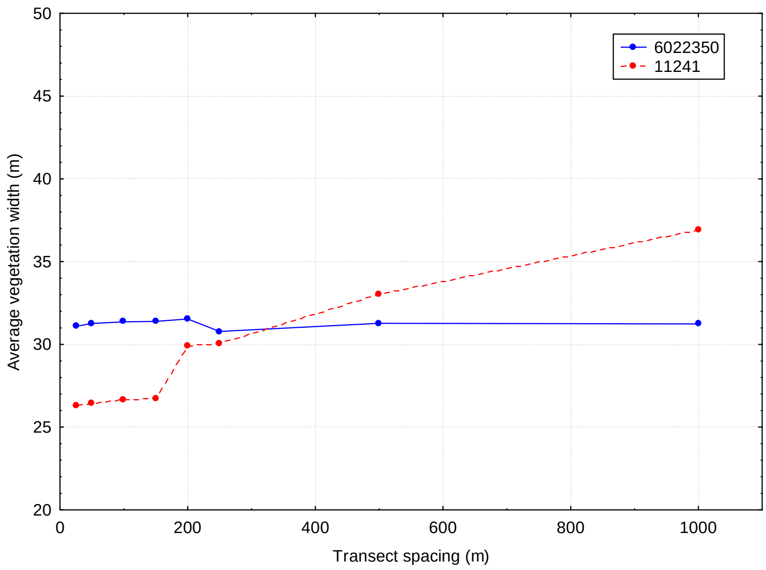

Figure 4 Average vegetation widths (to a maximum of 50 m) for different transect spacings in two reaches

As can be seen from Figure 4, transect spacings up to about 150 m give similar results. The computational time for calculating the average vegetation width varies very little between the transect spacings so this is not a limiting factor. A transect spacing of 50 m was selected for performing the final measurements based on these trial measurements and the observation that a spacing of 25 m led to duplication. This duplication occurs where transects fall near a sharp river bend. As the transects are placed at a 90° angle to the river, where there is a bend in a river it is possible for the transects to overlie each other, resulting in the same area being measured twice. A transect spacing of 50 m reduced this duplication.

The vegetation width in each 50 m transect along the reach was measured and then the average of these widths calculated. This was then converted to a score out of one by dividing by 50 (the average width that would be obtained in a reference situation where no clearing of the fringing zone had occurred). See Equation 5.

Equation 5 $$FZW = \frac{1}{50} \times \frac{(W_{T1} + W_{T2} + W_{T3} + ... + W_{Tx})}{n}$$

where *FZW* = fringing zone width score, W_{T1} = width of fringing zone in transect 1, W_{T2} = width of fringing zone in transect 2 and so on. *n* = total number of transects in the reach.

6.3 Integration and aggregation

Integration for the FZI follows the method suggested in the FARWH document (NWC 2007a) – an unweighted reach average is taken of the two indicators used.

Aggregation to the SWMA scale is done by calculating the length-weighted average of all the reach scores, as per NWC 2007a.

7 Aquatic biota index

The aquatic biota index (ABI) was included in FARWH trials for south-west Western Australia as the biota is the ultimate end point of environmental change in waterways and is therefore of critical importance to an assessment of river health (NWC 2007a).

Two components of the biota were selected for trialling, with a number of indicators investigated for each component. These are:

- fish and crayfish
    - a measure of capacity (system yield)
    - a measure of complexity (species diversity)
    - a measure of resilience (ratio of exotics to native species)
- macroinvertebrates
    - AUSRIVAS
    - SIGNAL
    - number of taxa
    - functional feeding groups
    - presence of indicator species
    - EPT

Data for these indicators was collected in the field using a combination of box traps and fyke nets for the fish and crayfish and the AUSRIVAS protocols for macroinvertebrates.

Data analysis was undertaken separately for the two components and the final scores integrated to give an overall site score.

7.1 Fish and crayfish

A number of scoring methods (both existing and newly developed) were investigated for suitability using both data collected in the field and theoretical scenarios. Scoring methods based on trophic dynamics were also investigated as these have been shown to be an effective way of reflecting ecological health, providing additional information on which component of the system is breaking down. These were deemed unsuitable to the south-west of Western Australia due to the low number of native species and their generalist nature in terms of niche occupation. There are only ten species of native freshwater fish (80% endemic) and nine species of endemic freshwater crayfish present. There are also four estuarine fish species typically found in freshwater systems. At any one site it is rare to encounter more than six species and, in some areas, expected species richness may be as low as one.

The final scoring method used was adapted from the Sustainable rivers fish index, a component of the Sustainable River Audit protocols (Davies et al. 2008) developed for the Murray–Darling Basin. These methods were originally developed for the Index of Biotic Integrity in North America (e.g. Karr 1981) and the NSW River Survey (Harris & Gehrke 1997). Table 12 shows the final indicators used for scoring fish and crayfish.

Table 12 Indicators, metrics and scoring protocol for fish and crayfish scoring. Adapted from the Sustainable Rivers Fish Index of the Sustainable River Audit (Davies et al. 2008)

Indicator	Metric	Definition	Weighting
Expectedness *Information on species richness relative to reference condition*	Observed to expected ratio (*OE*)	Compares number of native species predicted to occur in a site based on reference condition and the actual number collected. The number of predicted species is corrected downward for species likely to be rarely sampled*****.	**0.25**
	Observed to predicted ratio (*OP*)	Compares number of native species predicted to occur in a site based on reference condition (without correction for rarity) with the actual number collected.	**0.25**
Nativeness *Information on proportions of abundance and species richness that are native rather than alien*	Proportion native abundance (P_{Ab})	Proportion of individuals that are native species.	**0.25**
	Proportion native species (P_{Sp})	Proportion of species that are native species.	**0.25**
Presence of exotics in absence of natives	Presence of exotics in absence of natives (*Flex*)	Assigns an additional value to system with no native species if exotic species are present	***used if nativeness = 0*** 1 to 2 spp = 0.05 > 3 spp = 0.1

***** protocol for identifying rare species is outlined in ‘reference condition establishment: expert rules’, later in this section.

The individual indicators in Table 12 are combined to provide an overall fish and crayfish score for a site using Equation 6.

Equation 6 $FCI = (OE + OP + P_{Ab} + P_{Sp}) + Flex$

where *FCI* = fish and crayfish score, *OE* = observed to expected ratio, *OP* = observed to predicted, P_{Ab} = proportion native abundance, P_{Sp} = proportion native species and *Flex* = presence of exotics in absence of natives.

Initially the scoring method included all metrics in Table 12, with the exception of ‘Flex’ (presence of exotics in the absence of native species). A number of scenarios were assessed using the initial scoring method, using permutations of observed versus expected/predicted ratios of native species and varying proportions of exotic species or relative abundance. This process demonstrated that the scoring method assigned reasonable scores to the majority of scenarios tested but highlighted no differentiation (in score) between systems devoid of all fish and crayfish and those which contained only exotic species.

A system able to support some fish and crayfish, even if only exotic species, was assumed to be healthier than one unable to support any life. Therefore, a nominal figure was added to the overall fish and crayfish score where the score for ‘nativeness’ and ‘expectedness’ returned a zero but exotic species were present. Where one or two exotic species were present 0.05 was added, and where more than three exotic species were present 0.1 was added (as greater species richness reflects more tolerable conditions and/or more niches supported, therefore greater habitat complexity). The additional metric (Flex) does not significantly alter the overall fish and crayfish scores but does allow those systems that support life to be distinguished from those that do not in the final score breakdown. Note that this method will slightly bias systems without fish that have the ability to support exotic species but have not been exposed to invasion, this scenario is rare in Western Australia.

The ‘OE’ metric within the expectedness indicator was included in the scoring protocol for 2008. However, the identification of rare species was made on limited data and will need to be re-examined into the future as more data becomes available. Certain species in south-west Western Australia naturally exist in low numbers in reference condition, so failure to capture them may be due to chance rather than a decline in river health. The OE metric has been used to account for these ‘rare species’ by not including them. Those species which have been defined as ‘rare’ in the south-west of Western Australia are discussed in the next section. Note that future work will examine assigning a percentage chance of capture to each species however this will be outside the capacity of the current FARWH project.

Reference condition establishment: expert rules

Pre-European reference condition was developed from a combination of existing literature, historical data (e.g. museum collections), minimally impacted reference sites and expert knowledge. Lists of species expected to occur under reference condition have been prepared for each reach. Distribution maps will be developed for the whole of the south-west and will be provided in the final report. Work has begun on these but priority has been given to those SWMAs where the FARWH was trialled in 2008, and the entire south-west has not yet been completed.

Where expert opinion was used to fill knowledge gaps when determining pre-European reference a number of 'expert rules' were created. These are:

- Rare species were separated from commonly caught species within the fish and crayfish score. Rare species are defined as those that naturally exist in low numbers within their distribution, regardless of the extent of their natural range. Species with a high probability of no-capture include *Nannatherina balstoni* (Balstons pygmy perch) and *Galaxiella munda* (Western mud-minnow), as identified from previous studies (Morgan et al. 1998). A percentage capture rate has not been assigned to quantify the differentiation. However, this may be investigated as more data becomes available (though this is likely to be outside the scope of the current project). With the exception of the two mentioned, species were generally caught in large numbers during the field trials providing confidence in the current distinction between 'rare' and 'common' species.
- Some south-west fish species were not included as expected species due to extreme rarity. Based on data from Morgan et al. (1998), these include the *Galaxiella nigrostriata* (black stripe minnow) and *Lepidogalaxias salamandroides* (salamanderfish). Both of these species have been periodically collected in rivers, but typically remain in ephemeral pools and small creeks which are outside the reaches defined by the NATMAP 250K dataset.
- Most of the species known to spend time in marine/estuarine systems (e.g. *Acanthopagrus butcheris* (black bream) and *Leptatherina wallacei* (western hardyhead)), were not included in scoring due to dynamic, and therefore uncertain, temporal/spatial distributions. However *Pseudogobius olorum* (Swan River or blue-spot goby) and *Afurcagobius suppositus* (big-headed goby), were included as these species are commonly caught in large numbers within their known freshwater range. Some species, such as *Geotia australis* (pouched lamprey), were not encountered in the first round of field trials as their natural range was not sampled, and therefore have not featured in current scoring protocols. Decisions on inclusion will be made on a case-by-case basis.
- *Gambusia holbrooki* (mosquito fish, exotic) evaded capture at some sites where they were visually observed as being abundant. As *G. holbrooki* is the most widespread exotic fish or crayfish species in the south-west of Western Australia they were still included in scoring but further work needs to be

carried out regarding the probability of trapping this species. This work is outside the scope of the current FARWH project.

- Natural distributions of *Cherax preissii*, *C. glaber* and *C. crassimanus* were difficult to determine accurately, as they inhabit ephemeral zones and collection success is dependent on sampling time. There is very little literature or historical data with which to determine their pre-European distribution. Hence they have not been included in the expectedness score (they are still included in the nativeness scores where they were found). As the amount of data available increases, distribution maps may become accurate enough to incorporate them into the expectedness indicator, perhaps as a 'rare' species.
- *Cherax cainii* (smooth marron) and other native species that were collected outside their pre-European range have not been included in the expectedness score in these areas (they are still included in scoring in their natural range), as it was deemed improper to count them as either native or exotic in these regions. The presence of native species outside their natural distribution will continue to be recorded during field sampling, as the loss of these species from areas into which they have been introduced may have implications in future health assessments.
- Exotic species present in south-west rivers, including *Salmo trutta* (brown trout), *Oncorhynchus mykiss* (rainbow trout), *Perca fluviatilis* (redfin perch) and others each currently have the same weight applied to them during scoring. That is, one species is not considered to be more damaging to river health than any other. Future work will reconsider this assumption (though it may be outside the scope of the current FARWH trials), based on both the type of species and its residence time within a system.
- Where information on species distribution was general or incomplete, expert opinion was used to fill the gaps. One example is a river system in the Albany Coast SWMA which was suggested to contain both *Galaxias maculatus* (jollytails) and *G. occidentalis* (western minnow) (though these had not both been observed there) (Davies et al. 2001). Coexistion of these species has not been observed in any other system in the state and it is believed that due to conflicting niche occupation they would occupy distinct ranges. As such, the overlapping distribution was believed to be an artefact of generalised distribution data and only one species, *G. occidentalis* (western minnow), was recorded as being expected as this species has actually been captured in this system. Modifications or additions to reported species ranges will be highlighted in the final distribution maps.

7.2 Macroinvertebrates

A number of indicators were investigated for scoring macroinvertebrates and these are discussed under separate subheadings below.

AUSRIVAS

Macroinvertebrate data was run through the existing Western Australian spring channel AUSRIVAS model and scoring was based on the resulting O/E score. It is possible for AUSRIVAS scores to be greater than one (where a site has a richer macroinvertebrate community than reference), and the FARWH requires scores to be between zero and one, therefore a way of scaling scores that were greater than one needed to be developed. As it is not possible to determine if sites with a score of greater than one are natural biodiversity hotspots or are suffering from mild nutrient enrichment it was decided that it was inappropriate to assign these sites a score of one (which would indicate that they were equivalent to reference). Instead, the scores were modified by subtracting the amount by which they were greater than one from one to give a final score less than one. For example, if a site returned an O/E score of 1.08, then 0.08 was subtracted from one to give a final score of 0.92. In reality this had very little impact on the overall classification of the site as the classification bands are in increments of 0.2 and it is highly unusual for a site to score greater than 1.2.

To try and increase the sensitivity of the AUSRIVAS models work is currently underway to develop a new spring channel AUSRIVAS model which will be for the south-west of the state only. This model will require macroinvertebrate identification to the same taxonomic resolution as current models with the exception of Odonata, Plecopterans and Trichopterans which will be identified to genus.

SIGNAL

The SIGNAL index was trialled using data collected in the first round of field sampling. The theoretical maximum and minimum that can be scored using this index are 10 and 1 however most sites will lie between 3 and 7 (Chessman 2003). The actual range of scores returned for sampled sites was between 2.0 and 4.8, with the Collie SWMA ranging between 3.1 and 4.8, Albany Coast ranging between 2.0 and 4.8 and the Moore Hill SWMA ranging between 2.6 and 4.2. This narrow scoring range indicates that the SIGNAL index was not particularly sensitive in detecting impacts on macroinvertebrate communities based on pollution (when compared to the AUSRIVAS scores which ranged between 0.2 and 0.9). Due to the lack of distinction between sites the SIGNAL score was not used in the final scoring.

Number of taxa

The number of taxa is a simple scoring system based on the principle that less impacted sites will have more taxa present than those that are more impacted. Whilst the results obtained appeared to represent what was observed on the ground it was decided not use this indicator due to the difficulty associated with defining reference condition. Reference condition will vary across the south-west of Western Australia as climate, geography, vegetation and other factors all vary naturally across this area. It would, therefore, be necessary to construct reference condition from a range of minimally impacted sites across the whole of the south-west. As there are insufficient reference sites present in the south-west, and sampling a large number of reference sites as well as test sites is beyond the capacity of this project, the number of taxa indicator was not developed further.

Functional feeding groups

Metrics based on functional feeding groups are widely used in North America (see Kelly & Feminella 2006; Barbour et al. 1996 and Barbour et al. 1999). These metrics all require identification at a lower taxonomic resolution than that used for this study. Many of the families collected comprise species with varied feeding habits (Chessman 1986) so it was often not possible to assign a functional feeding group to a taxa. The other difficulty with scoring this indicator was defining reference condition. As for the number of taxa indicator, it would be very difficult to define reference condition for a functional feeding group indicator.

Presence of indicator species

As for the number of taxa and functional feeding group indicators it would not be possible to define reference condition for a presence of indicator species indicator. Further, not enough is known of the biology of most invertebrate species in the south-west of Western Australia to allow such an indicator to be developed.

EPT taxa

EPT (or PET) has been used by other river health assessment programs such as the south-east Queensland Ecological Health Monitoring Program (EHMP 2008) which simply counts the number of genus in a sample belonging to the EPT orders (Ephemeroptera, Plecoptera and Trichoptera). The Sustainable Rivers Audit pilot also tested an EPT index, where the number of taxa in the EPT orders were divided by the number of Chironomid taxa and the EPT abundance (Murray-Darling Basin Commission 2003). This indicator was dropped after the pilot study as it was only found to be useful in upland streams (as this is the habitat preference for most species within the EPT orders). It was decided not to use an EPT indicator in the final scoring for the south-west Western Australia FARWH as it was not possible to define reference condition and, further, the indicator only has the potential to be useful in upland streams.

7.3 Integration and aggregation

Integration follows the methodology suggested in the FARWH documentation (NWC 2007a). That is, the average is taken of the fish and crayfish and the macroinvertebrate score. Where there is only one score present, that is used as the ABI score for the site.

Where there is more than one site on a reach the ABI scores for the individual sites are averaged to give the reach score.

Aggregation to the SWMA scale is done by calculating the length-weighted average of all the reach scores, as per NWC 2007a.

8 Moore Hill SWMA assessment

The Moore Hill SWMA lies north of Perth and has an area of 24 533 km^2 (see Figure 5). It has three main rivers, the Moore, the Hill and the Nambung. There were 94 reaches identified by the NATMAP 250K dataset. After validation this number was revised to 90, ranging from 0.2 to 47.7 km, with an average reach length of 11.6 km. Rainfall varies across the SWMA from approximately 650 mm at the south-western corner to 310 mm in the north-eastern corner. A large proportion of the SWMA has been cleared and the predominant land-use is non-irrigated cropping. Whilst 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, but there are no identified wild rivers.

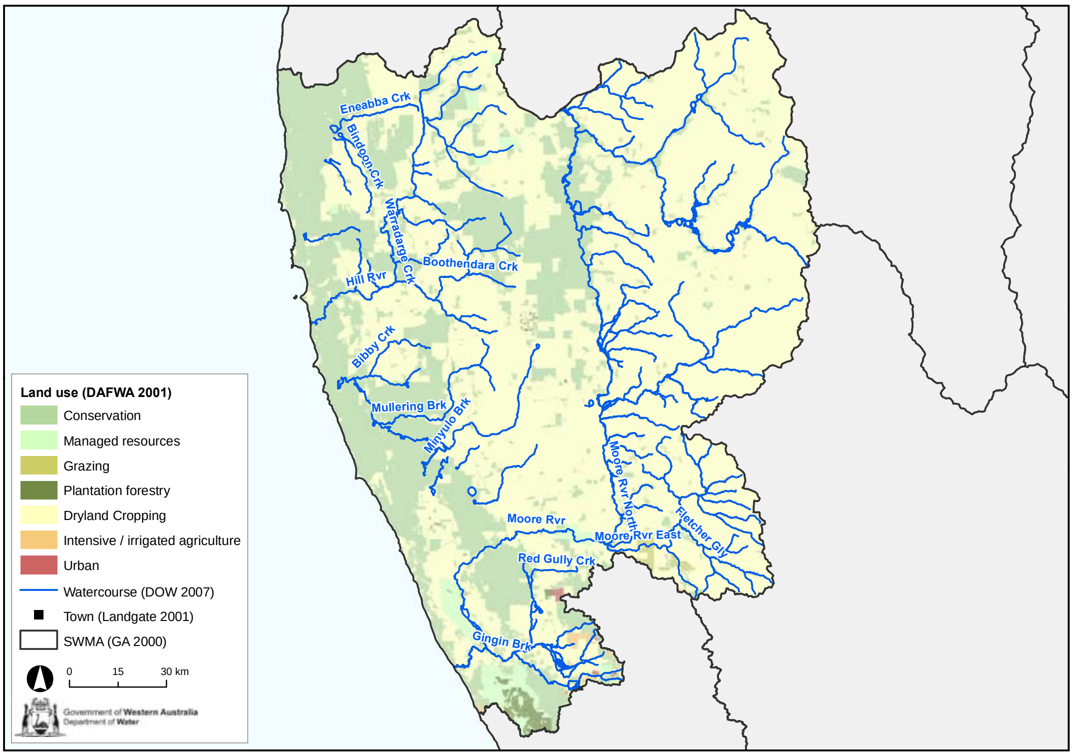

Figure 5 Moore Hill surface water management area

A total of 24 sites were sampled during October 2008. Of these, two were not included in scoring as field staff had sampled pools and one was not included as it was not located on a reach recognised by the NATMAP 250K dataset. Three reaches had two samples collected on them and one had three. Where this occurred, the average of the site scores was taken to determine the reach score. This resulted in a total of 16 reaches sampled, or 18% of the total number of reaches. Eneabba Creek, the most northerly river system in the SWMA was not sampled as it was dry by November. For the same reason many of the first order streams on the eastern edge of the river systems were not sampled either.

To represent the scores graphically the bands recommended in NWC 2007a and shown in Table 13 have been used.

Table 13 Mapping bands and definitions.

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

8.1 Overall assessment

To aggregate the individual index scores to an overall SWMA scale the standardised Euclidean distance with unweighted components was used (as per the recommendation in NWC 2007a). This resulted in an overall assessment for the Moore Hill SWMA of 'slightly modified' (a score of 0.6).

8.2 Catchment disturbance index

The overall CDI for the Moore Hill SWMA was 0.6 (slightly modified). For this round of the trials the CDI has only been calculated at the whole-of-SWMA scale due to issues associated with the sub-catchment definitions.

Infrastructure measure

The infrastructure measure score for the Moore Hill SWMA was 1 (largely unmodified). This is due to the size of the catchment and the comparatively small amount of infrastructure found within it.

Land cover change measure

The land cover change measure score for the Moore Hill SWMA was 1 (largely unmodified). As with the infrastructure measure, this is due to the overall size of the catchment and the limited amount of clearing that has occurred in the 2003 to 2007 period. A large portion of the catchment is cleared, but this clearing pre-dates the time period of interest.

Land-use measure

The land-use measure score for the Moore Hill SWMA was 0.6 (slightly modified). Only three of the land-use categories contributed greater than 1% of the overall land-use. These were dryland cropping (69%), managed resources (2%) and conservation (28%).

8.3 Hydrological change index

As the HCI has not yet been developed there is no score available as yet. Work will commence on this index at the start of the new financial year as appropriate staff become available and a retrospective analysis will be performed for the Moore Hill SWMA once this index is developed.

8.4 Water quality index

The overall WQI score for the Moore Hill SWMA was 0.5 with scores for individual reaches ranging between 0.4 (moderately modified) and 0.9 (largely unmodified). The overall WQI score was mostly driven by the salinity scores with these accounting for the overall score in 12 of the 16 sampled reaches.

Figure 6 shows the overall WQI scores for each of the reaches sampled in the Moore Hill SWMA.

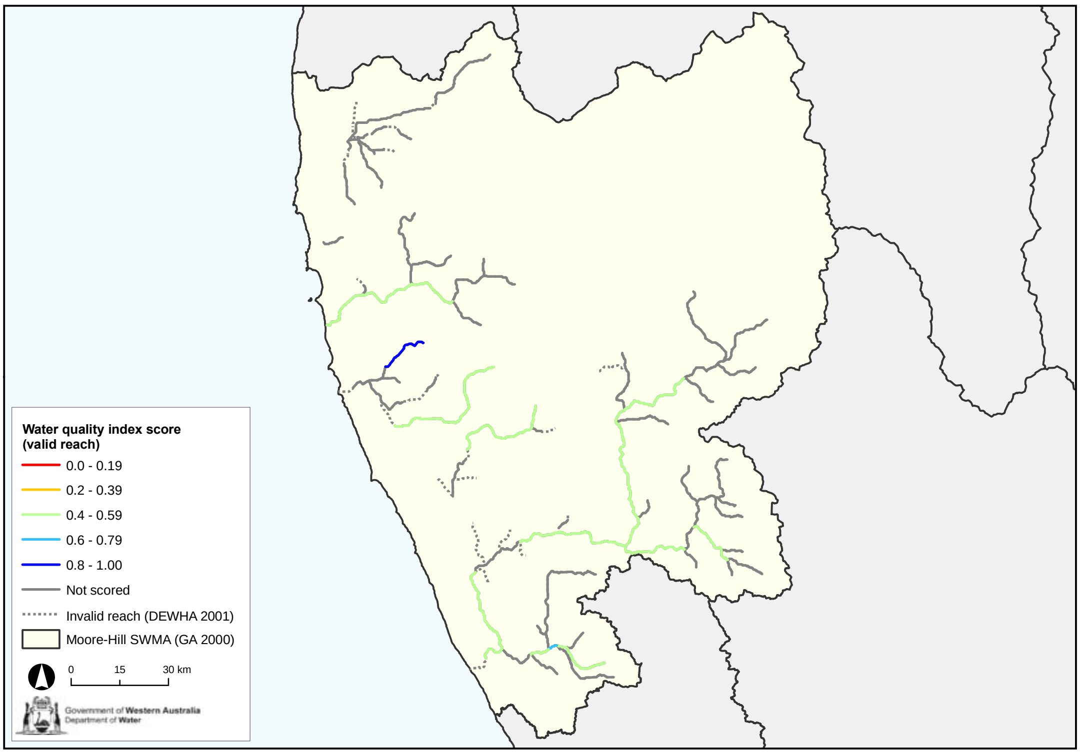

Figure 6 Overall WQI scores for the Moore Hill SWMA

As can be seen from Figure 6, most of the reaches were classified as moderately modified with one reach classified as slightly modified and one as largely unmodified. There was not enough variability within the scores to identify any spatial patterns in the SWMA.

Total nitrogen indicator

TN scores ranged between 0.6 (slightly modified) and 1 (largely unmodified) with none of the sampled reaches returning the worst score possible for TN (0.4). There were no spatial patterns evident in the TN scores.

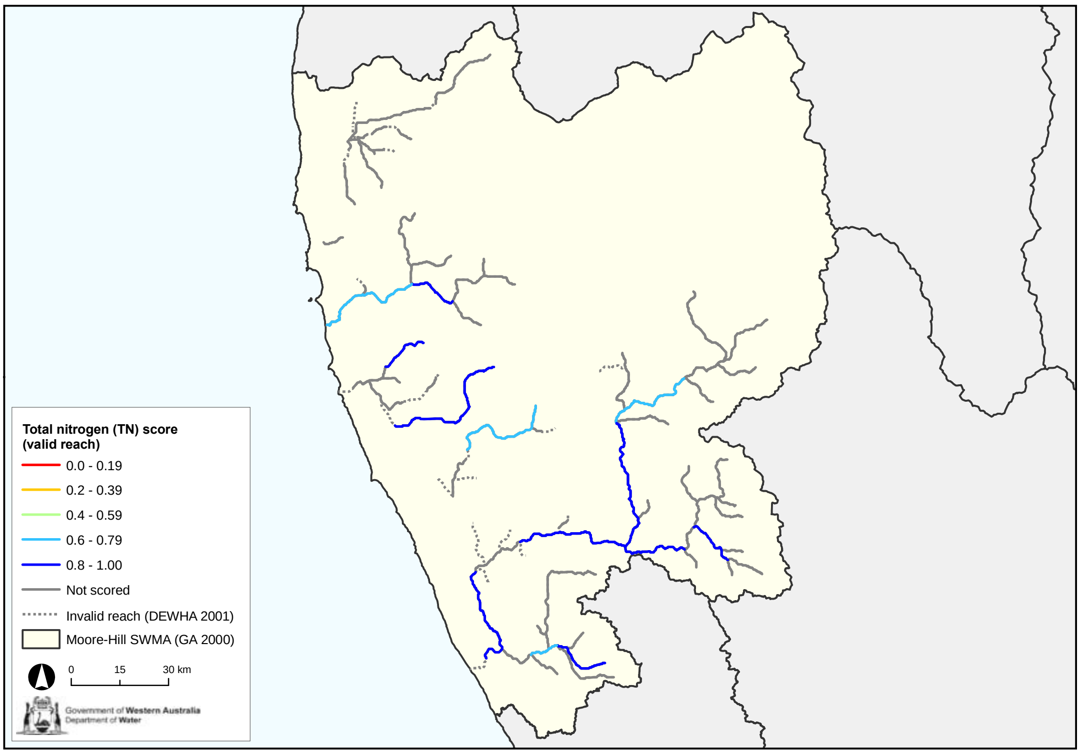

Figure 7 Total nitrogen scores for the Moore Hill SWMA

Total phosphorus indicator

TP scores ranged between 0.4 (moderately modified) and 1 (largely unmodified). There was no spatial pattern evident in the TP scores.

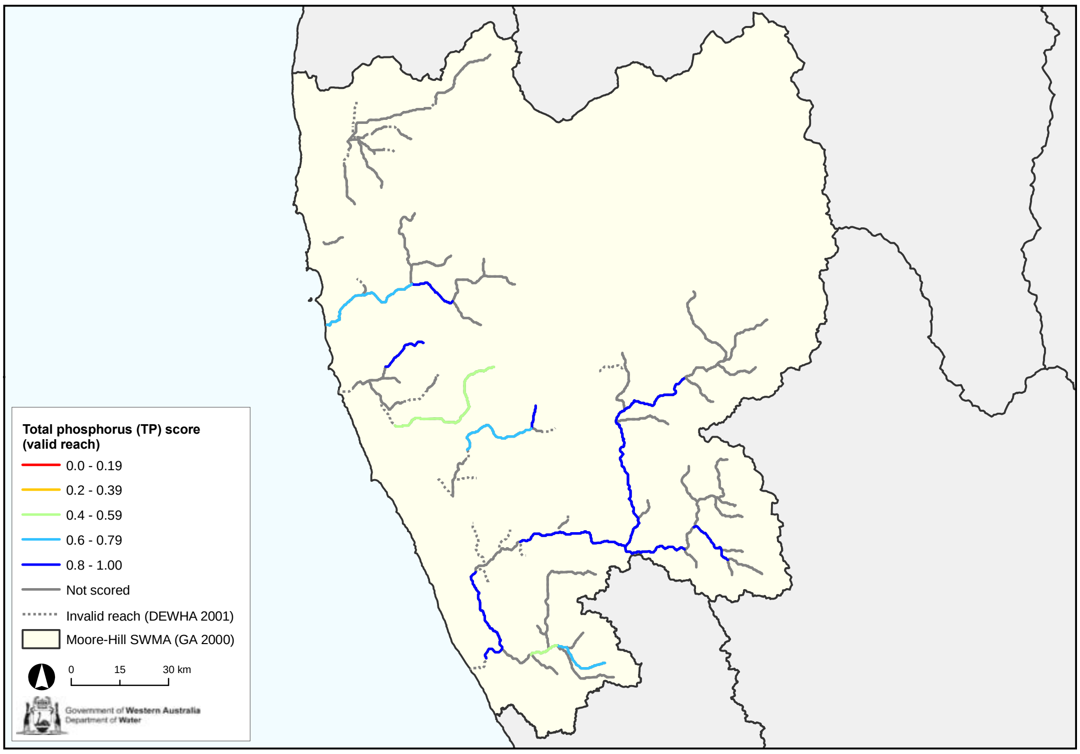

Figure 8 Total phosphorus scores for the Moore Hill SWMA

Turbidity indicator

Turbidity scores ranged between 0.4 (moderately modified) and 1 (largely unmodified). There was no spatial pattern evident in the turbidity scores.

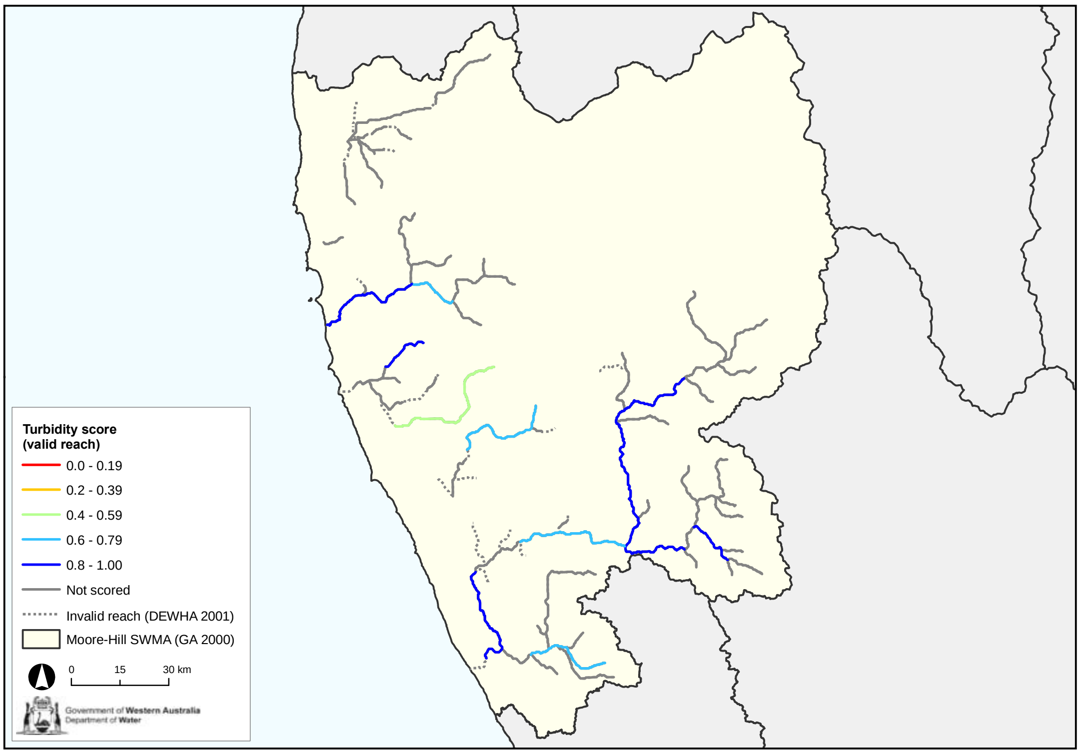

Figure 9   Turbidity scores for the Moore Hill SWMA

Salinity indicator

Salinity scores in the reaches used to develop the overall SWMA score ranged between 0.5 (moderately modified) and 1 (largely unmodified). As salinity scores were modelled there were scores available for a larger number of reaches than those used in the final score. Figure 10 shows all the available salinity scores in the Moore Hill SWMA. The majority of reaches in the Moore Hill were moderately modified. A small area in the south-east was severely modified. No obvious spatial pattern was present.

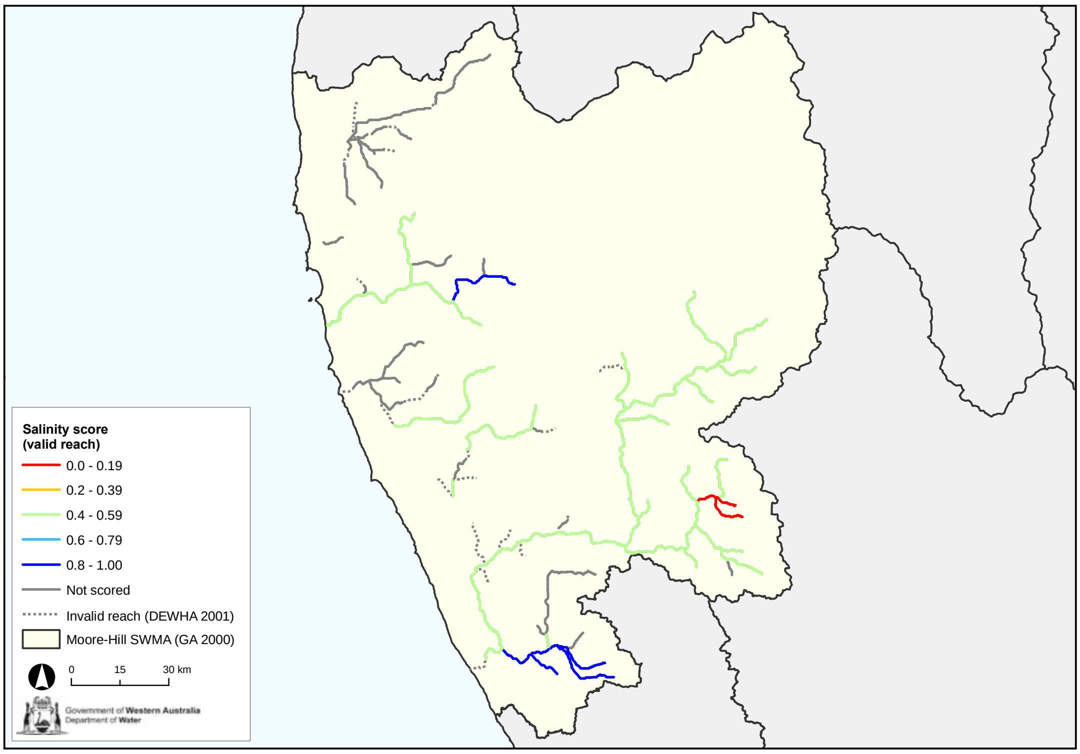

Figure 10 Salinity scores for the Moore Hill SWMA

Diel dissolved oxygen indicator

Diel dissolved oxygen scores ranged between 0.4 (moderately modified) and 1 (largely unmodified). There were no obvious spatial patterns in diel DO scores.

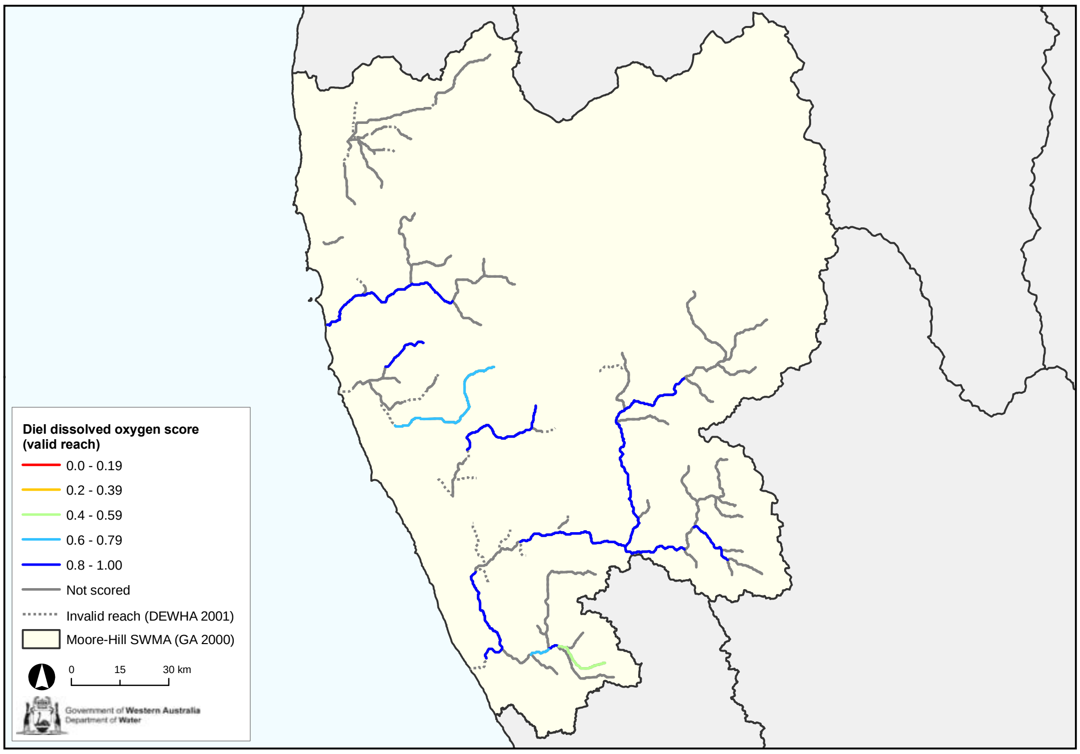

Figure 11 Diel dissolved oxygen scores for the Moore Hill SWMA

Diel temperature indicator

Diel temperature scores ranged between 0.4 (moderately modified – the lowest possible score for this indicator) and 0.8 (largely unmodified – the highest score possible for this indicator). As there were only two scores possible for this indicator there is very little distinction between the different reaches and, not surprisingly, no evidence of a spatial pattern in scores.

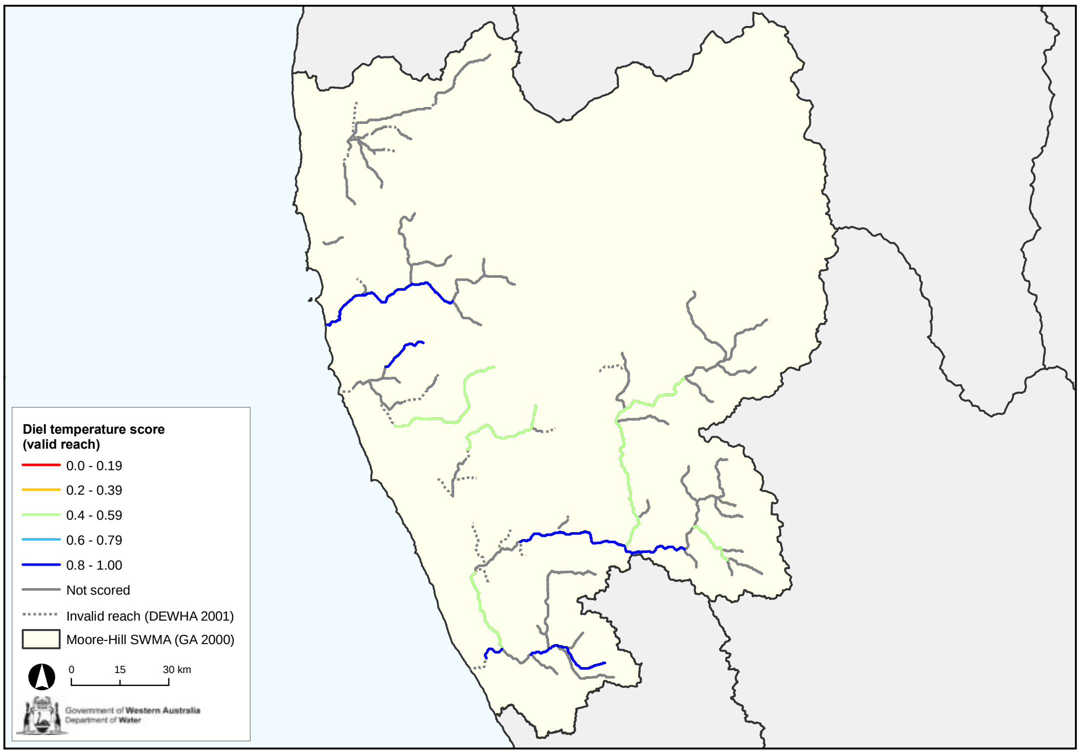

Figure 12 Diel temperature scores for the Moore Hill SWMA

8.5 Physical form index

The overall PFI score for the Moore Hill SWMA was 0.7 with scores for individual reaches ranging between 0.3 (substantially modified) and 1 (largely unmodified).

Figure 13 shows the overall PFI scores for each of the reaches sampled in the Moore Hill SWMA.

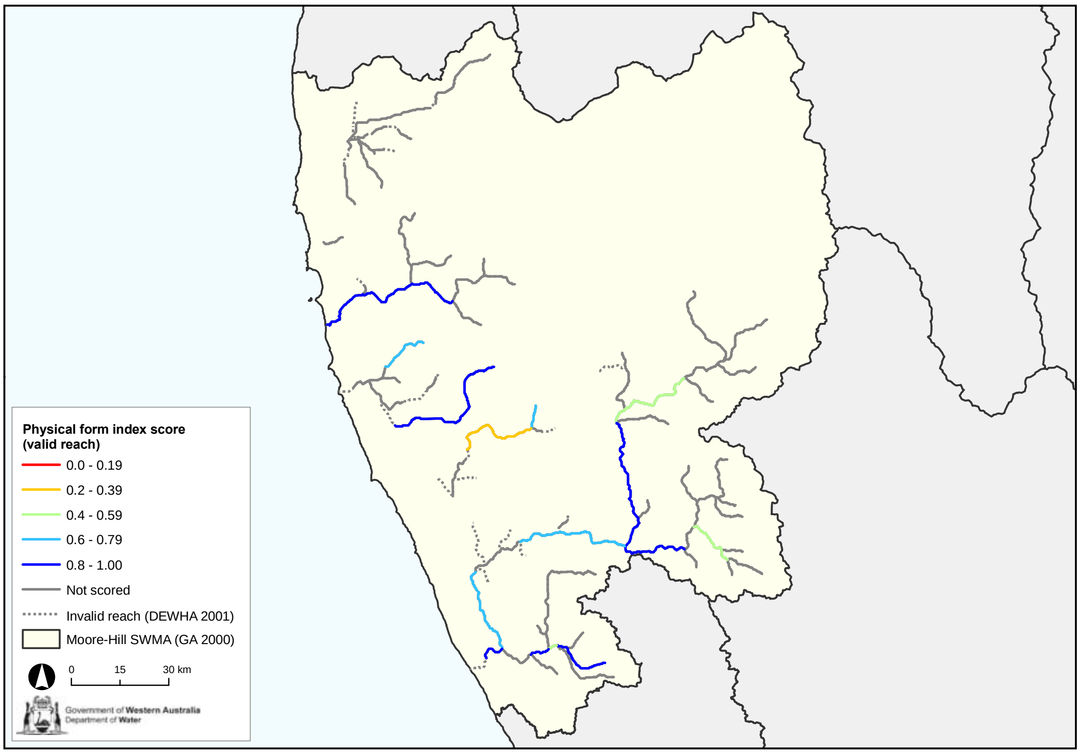

Figure 13 Overall PFI scores for the Moore Hill SWMA

As can be seen from Figure 13, there is no obvious spatial pattern in the PFI scores.

Channel pattern indicator

Channel pattern scores in the reaches used to develop the overall SWMA score ranged between 0.8 and 1 (both largely unmodified). As channel pattern scores were assessed using spatial data there were scores available for almost all of the reaches in the Moore Hill SWMA, as shown in Figure 14. There are no clear patterns evident in the channel pattern scores, with the exception that lower scoring reaches tended to be short and occur nearer the western boundary of the SWMA. As there was not much distinction in channel pattern scores it was decided not to assign an overall WQI score for reaches where there was not also an erosion score present.

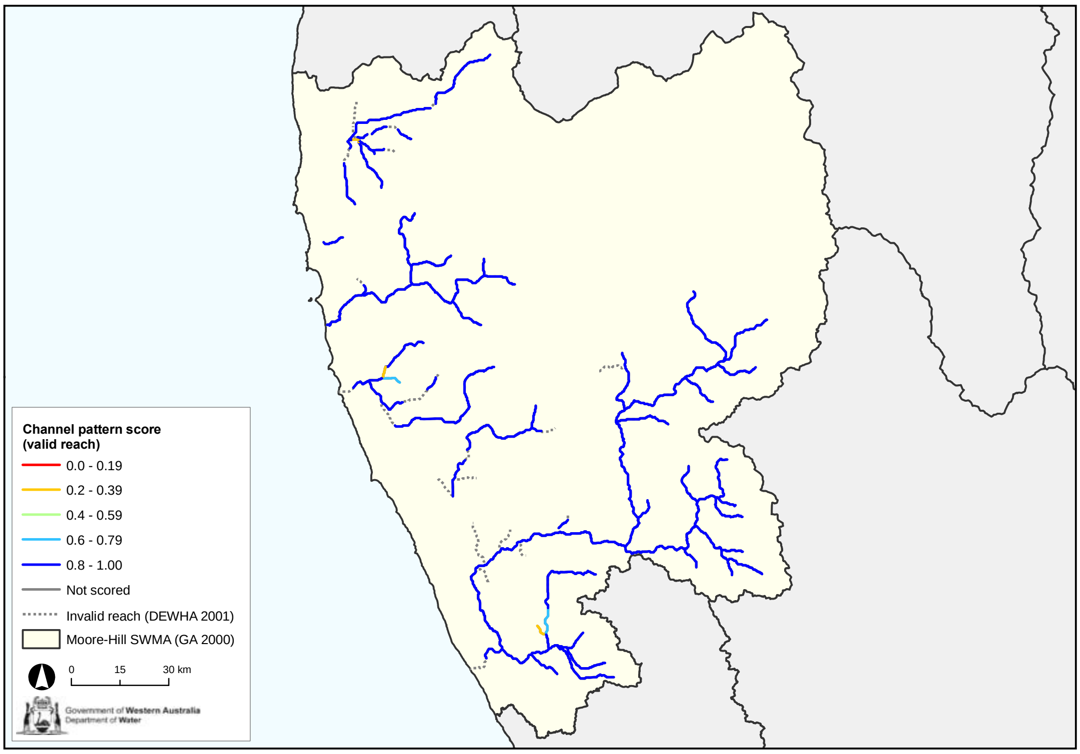

Figure 14 Channel pattern scores for the Moore Hill SWMA

Erosion indicator

Erosion scores ranged between 0 (severely modified) and 1 (largely unmodified). There was no clear spatial pattern present in the erosion scores.

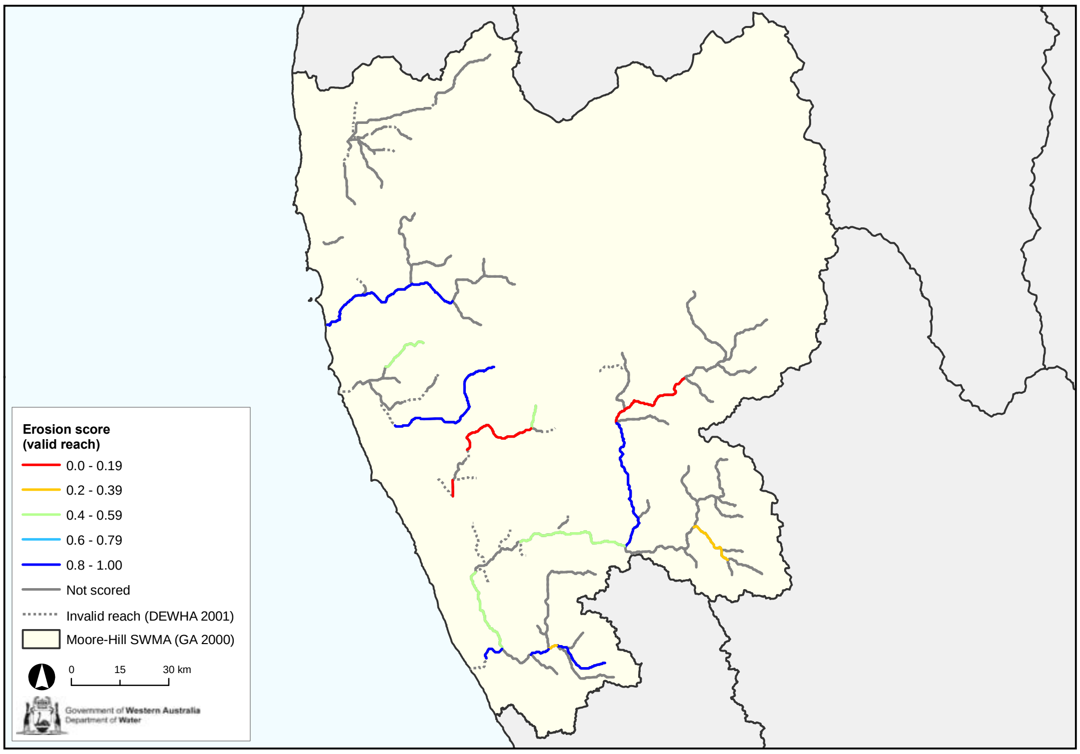

Figure 15 Erosion scores for the Moore Hill SWMA

8.6 Fringing zone index

The overall FZI score for the Moore Hill SWMA was 0.5 with scores for individual reaches ranging between 0 (substantially modified) and 1 (largely unmodified).

Figure 16 shows the overall FZI scores for all of the reaches in the Moore Hill SWMA (as this indicator was scored using remotely sensed data there are scores available for every reach).

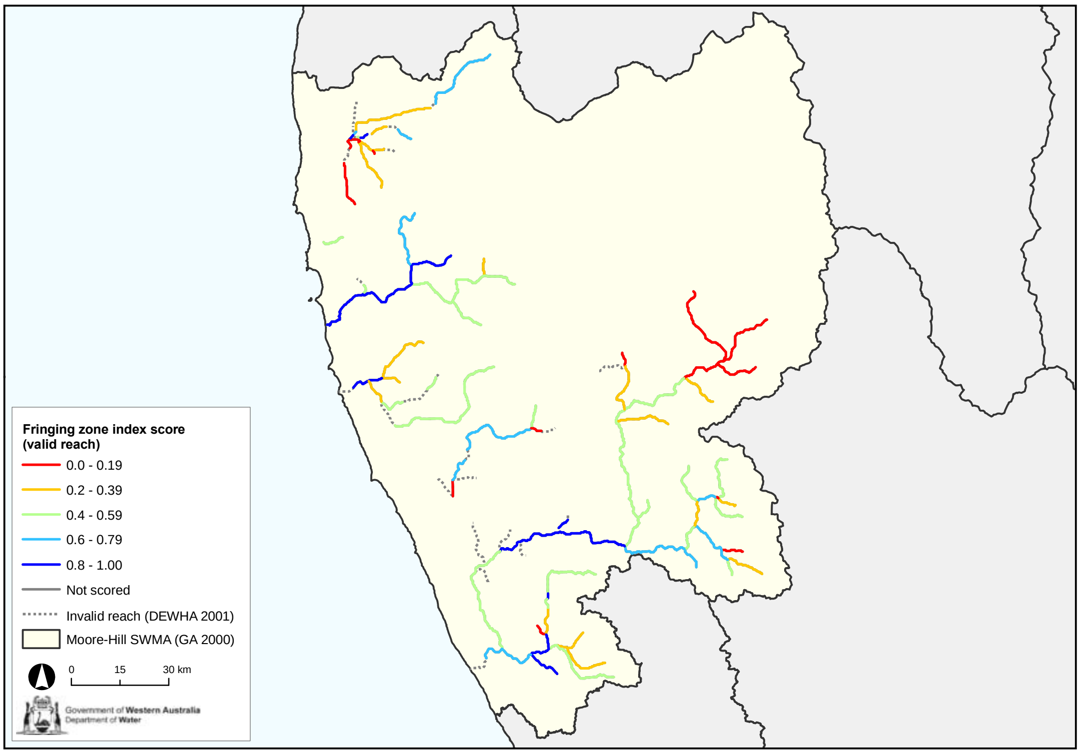

Figure 16 Overall FZI scores for the Moore Hill SWMA

As can be seen from Figure 16, there is a general pattern in FZI scores with reaches lying at the eastern edges of river systems, in their upper catchments, generally scoring the worst. These reaches tend to lie in areas of farmland.

Longitudinal continuity indicator

Longitudinal continuity scores ranged between 0 (substantially modified) and 1 (largely unmodified). As was the case with the overall FZI scores, those reaches lying at the eastern edges of river systems, in their upper catchments, generally scored the worst.

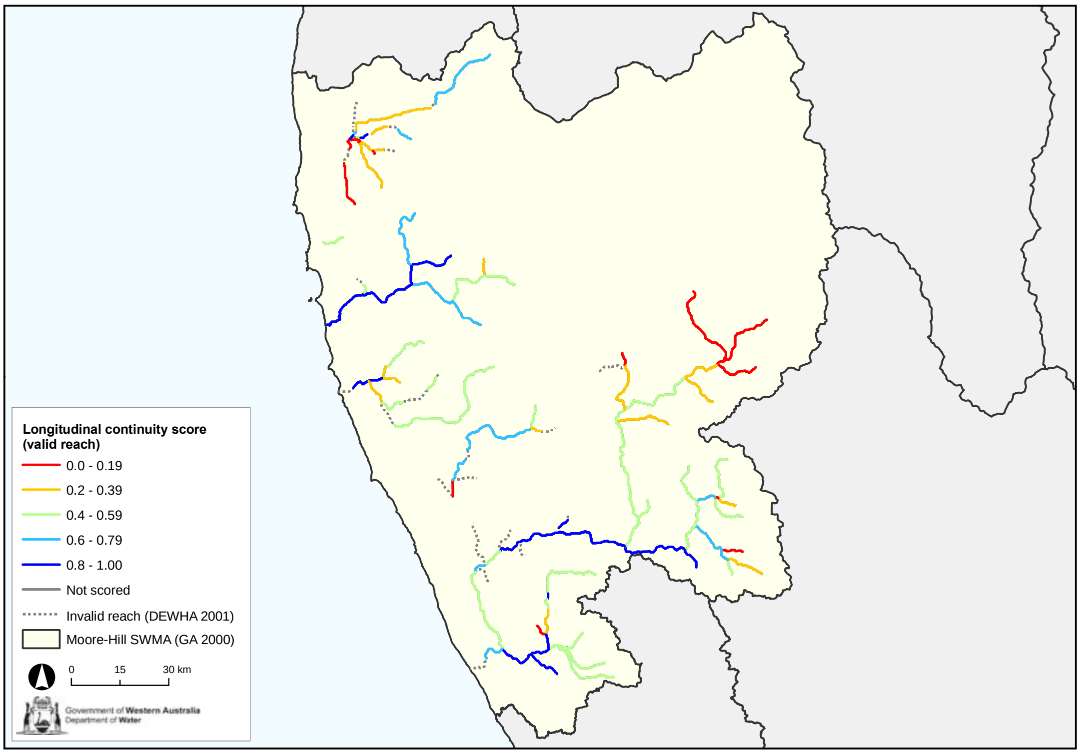

Figure 17 Longitudinal continuity scores for the Moore Hill SWMA

Fringing zone width indicator

Fringing zone width scores ranged between 0 (substantially modified) and 1 (largely unmodified). A similar spatial pattern to the overall FZI score and the longitudinal continuity score was observed, with reaches in the upper catchments of rivers (on the eastern side of the SWMA) generally scoring the worst.

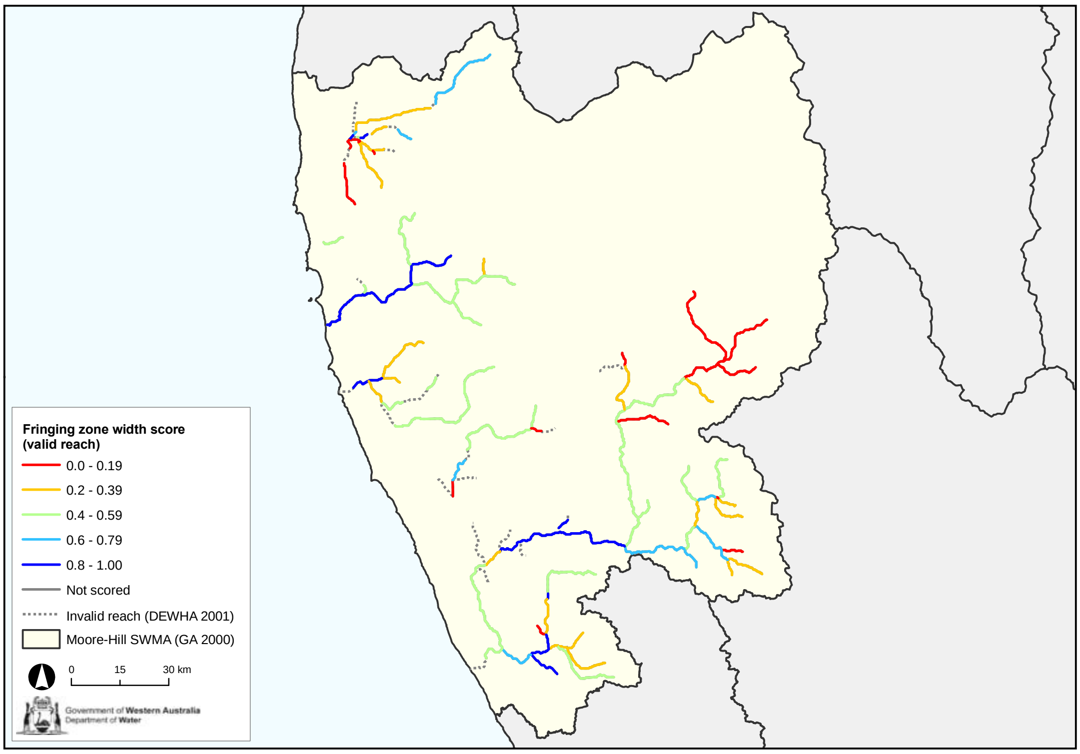

Figure 18 Fringing zone width scores for the Moore Hill SWMA

8.7 Aquatic biota index

The overall ABI score for the Moore Hill SWMA was 0.7 with scores for individual reaches ranging between 0.4 (moderately modified) and 0.9 (largely unmodified).

Figure 19 shows the overall ABI scores for each of the reaches sampled in the Moore Hill SWMA.

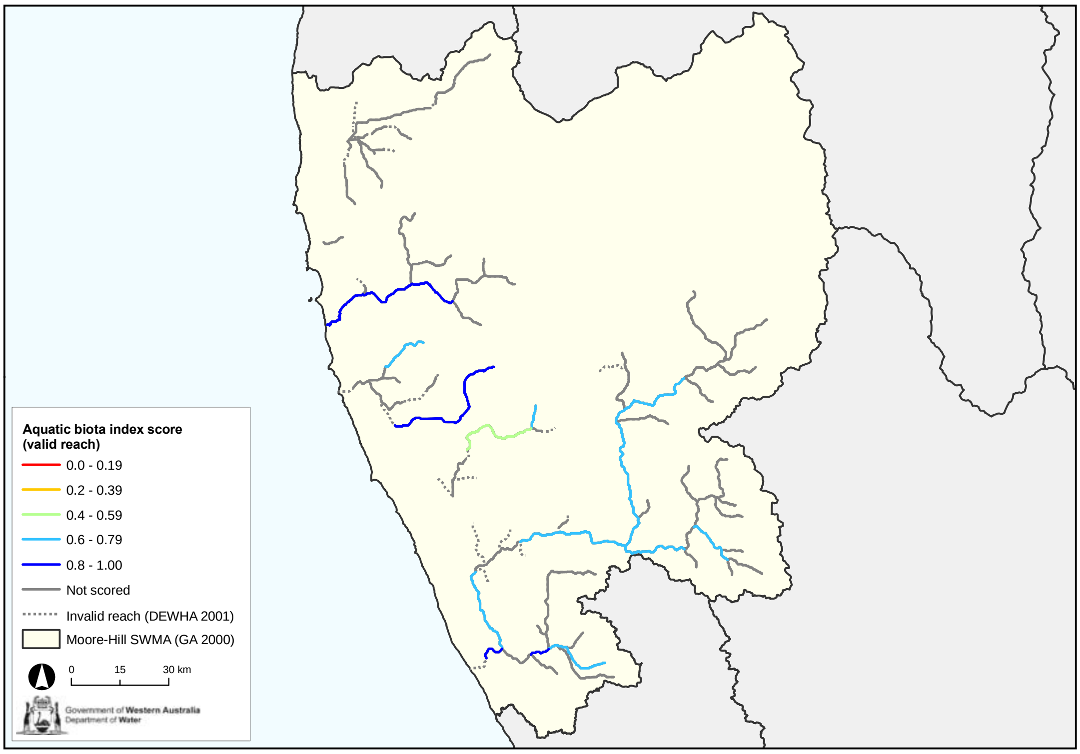

Figure 19 Overall ABI scores for the Moore Hill SWMA

As can be seen from Figure 19, most reaches fell into the slightly modified category. There were no distinct spatial patterns in the ABI scores.

Fish and crayfish indicator

Fish and crayfish scores ranged between 0.1 (severely modified) and 0.9 (largely unmodified). As for the overall ABI scores, there were no obvious spatial patterns to the scores.

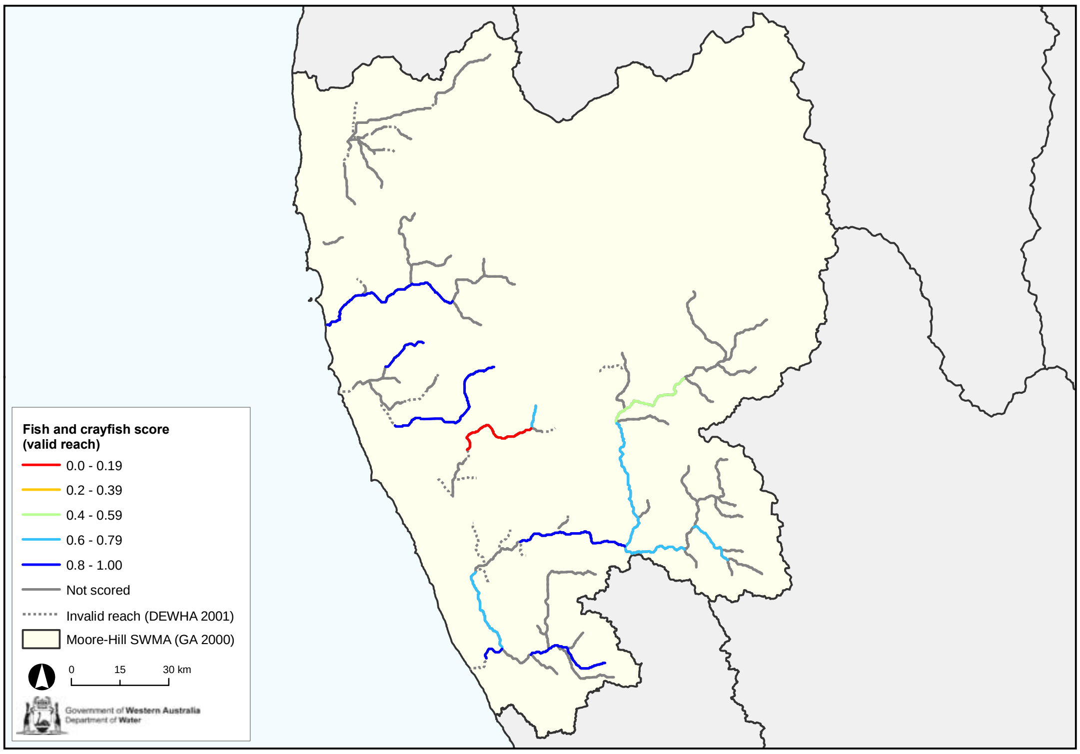

Figure 20 Fish and crayfish scores for the Moore Hill SWMA

Macroinvertebrate indicator

Macroinvertebrate (AUSRIVAS) scores ranged between 0.2 (substantially modified) and 0.9 (largely unmodified). It was not possible to calculate AUSRIVAS scores for all sites sampled as some were outside the experience of the model. There were four such sites, one was located outside the recognised reach network and so would not have been included in the overall score anyway, two were located on reaches with multiple sites so there was still an AUSRIVAS score available for the reach and one was on a reach with a single site and so the ABI was calculated from the fish and crayfish score only. Overall, the macroinvertebrate scores were lower than the fish and crayfish scores however there were instances where fish and crayfish scored poorly but macroinvertebrates scored well and vice versa.

There were no obvious spatial patterns in the macroinvertebrate scores.

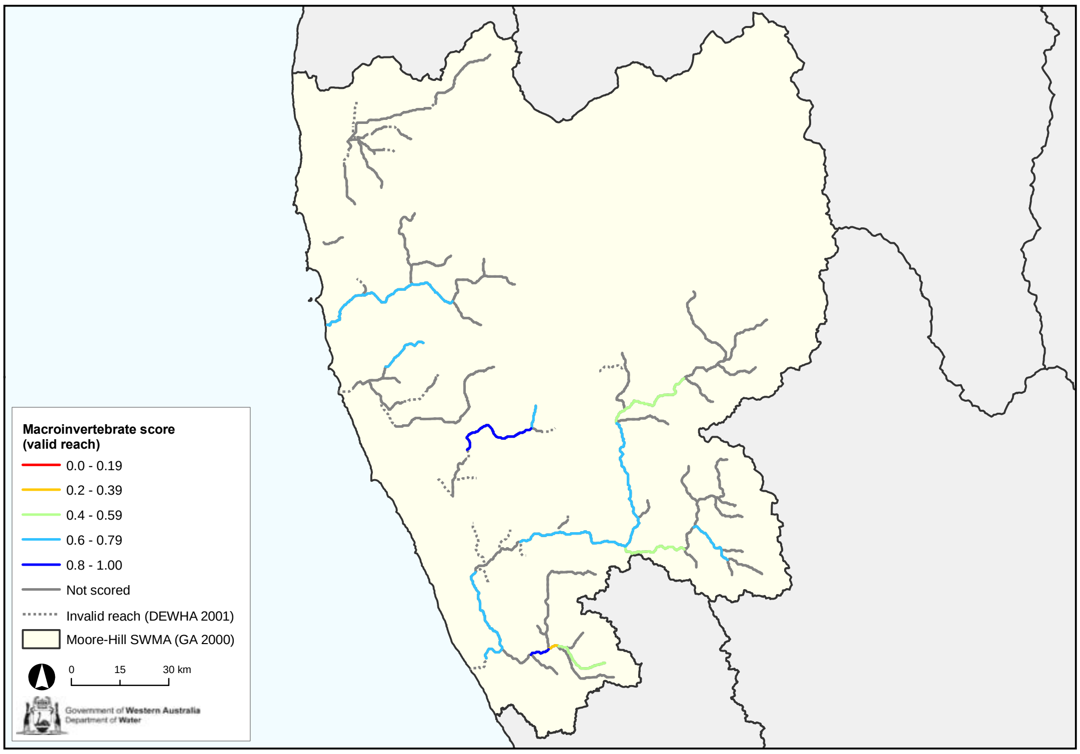

Figure 21 Macroinvertebrate scores for the Moore Hill SWMA

9 Albany Coast SWMA assessment

The Albany Coast SWMA lies on the south coast of Western Australia and extends roughly from Albany to Bremer Bay (see Figure 22). It is 19 604 km^2 and has approximately 15 river systems in it, the largest of which is the Pallinup River. Rainfall varies from around 900 mm annually at the western point on the coast to 400 mm along the northern boundary. There were 154 reaches identified by the NATMAP 250K dataset which was revised to 101 after validation. Reach length varied from 0.9 to 100 km with an average length of 13.5 km. Cropping constitutes the major land-use. There is a large nature conservation area in the south-eastern portion of the SWMA and another, small area, in the central west. There are also areas of plantation forestry present in the south-western corner (mostly Tasmanian blue gums). There are no large dams present (though there are many farm dams). Two wild river catchments (the Saint Mary and the Dempster rivers) are present, both in the nature conservation areas in the south-east of the management area SWMA.

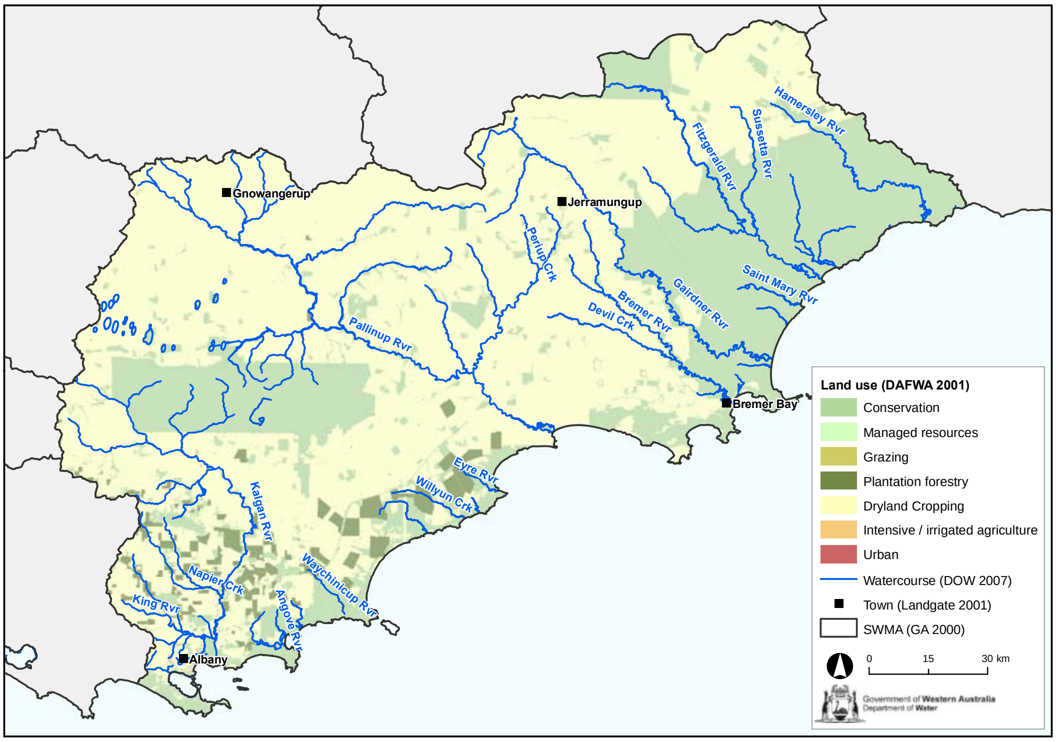

Figure 22 Albany Coast surface water management area

A total of 29 sites were sampled during November 2008. Of these, two were not included in scoring as they were not located on a reach recognised by the NATMAP 250K dataset. One of these, located on the Goodga River, was sampled as a special interest site due to the presence of *Galaxias truttaceus* (trout minnow). Three reaches had two samples collected on them and, where this occurred, the average of the site scores was taken to determine the reach score. This resulted in a total of 24 reaches being sampled, or 24% of the total number of reaches. All the major river systems were sampled, as were all except three of the smaller systems (Dempster River and Mullocullop and Wongerup creeks).

Unusual weather conditions were encountered while sampling the Albany SWMA. The highest November rainfall since records commenced in 1877 (226.1 mm at Albany townsite, where the November average is 44.7 mm). This will have had some influence on the field scored indicators in this SWMA.

9.1 Overall assessment

To aggregate the individual index scores to an overall SWMA scale the standardised Euclidean distance with unweighted components was used (as per the recommendation in NWC 2007a). This resulted in an overall assessment for the Albany Coast SWMA of 'slightly modified' (a score of 0.6).

9.2 Catchment disturbance index

The overall CDI for the Albany Coast SWMA was 0.6 (slightly modified). For this round of the trials the CDI was only calculated at the whole-of-SWMA scale due to issues associated with the sub-catchment definitions.

Infrastructure measure

The infrastructure measure score for the Albany Coast SWMA was 1 (largely unmodified). This is due to the size of the catchment and the comparatively small amount of infrastructure found within it.

Land cover change measure

The land cover change measure score for the Albany Coast SWMA was 1 (largely unmodified). As with the infrastructure measure, this is due to the overall size of the catchment and the limited amount of clearing that occurred in the 2003 to 2007 period. A large portion of the catchment is cleared, but this clearing pre-dates the time period of interest.

Land-use measure

The land-use measure score for the Albany Coast SWMA was 0.6 (slightly modified). Only three of the land-use categories contributed greater than 1% of the overall land-use. These were dryland cropping (65%), plantation forestry (3%) and conservation (32%).

9.3 Hydrological change index

As the HCI has not been developed there is no score available as yet. Work will commence on this index at the start of the new financial year as appropriate staff become available and a retrospective analysis will be performed for the Albany Coast SWMA once this index is developed.

9.4 Water quality index

The overall WQI index score for the Albany Coast SWMA was 0.2 with scores for individual reaches ranging between 0 (severely modified) and 1 (largely unmodified). The overall WQI score was mostly driven by salinity scores with these accounting for the overall score in 19 of the 24 sampled reaches.

Figure 23 shows the overall WQI scores for each of the reaches sampled in the Albany Coast SWMA.

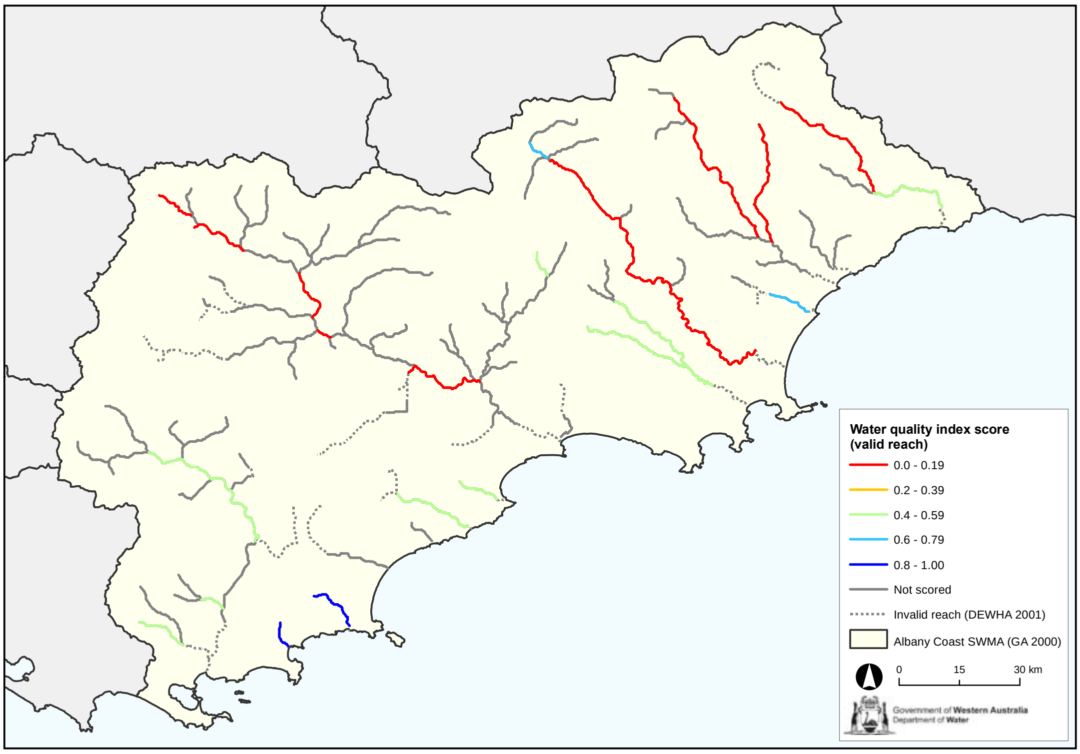

Figure 23 Overall WQI scores for the Albany Coast SWMA

As can be seen from Figure 23, most of the reaches were classified as either severely modified or moderately modified. Those reaches located on the western side of the SWMA tended to score better than those in the east. This is due to the higher rainfall in these areas producing increased flushing and hence lower salinity concentrations. Smaller systems also tended to score better than larger ones.

Total nitrogen indicator

TN scores ranged between 0.4 (moderately modified) and 1 (largely unmodified). The only reaches which scored 1 were small river systems located on the southern edge of the SWMA. There was a general trend evident with scores for the western systems generally being higher than scores for the eastern systems.

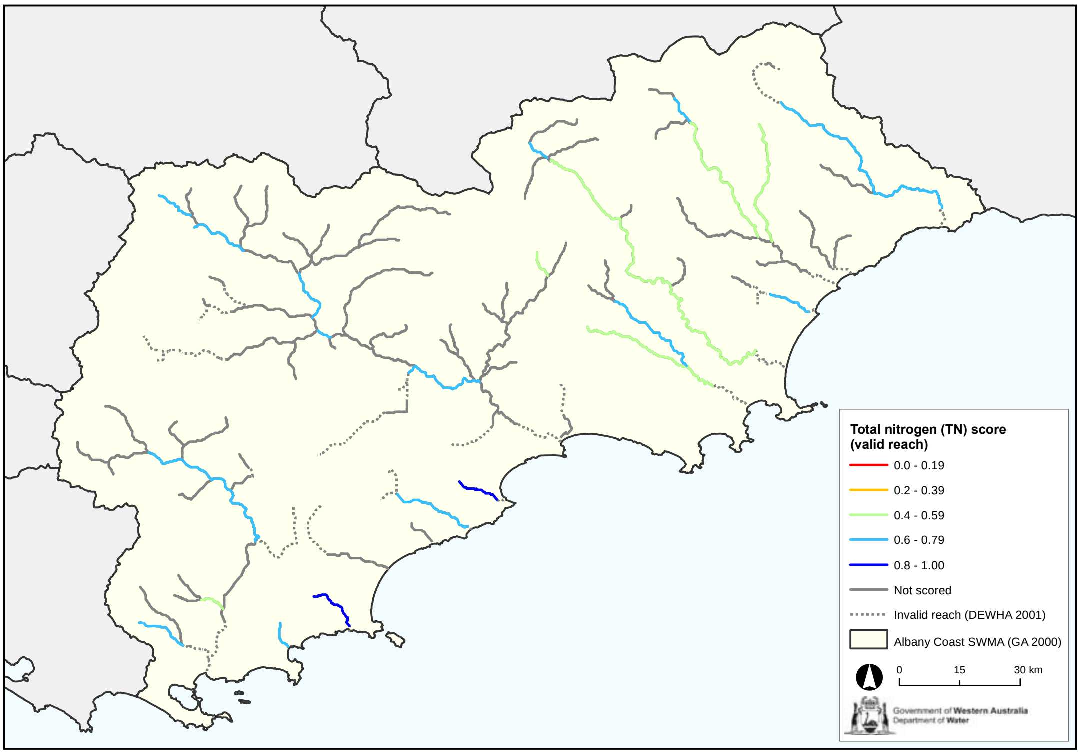

Figure 24 Total nitrogen scores for the Albany Coast SWMA

Total phosphorus indicator

TP scores ranged between 0.4 (moderately modified) and 1 (largely unmodified). The west to east distinction in TN scores was not evident with the TP scores, with the lowest TP score being found on the western edge of the SWMA. Nor was there evidence of any south to north gradient in scoring.

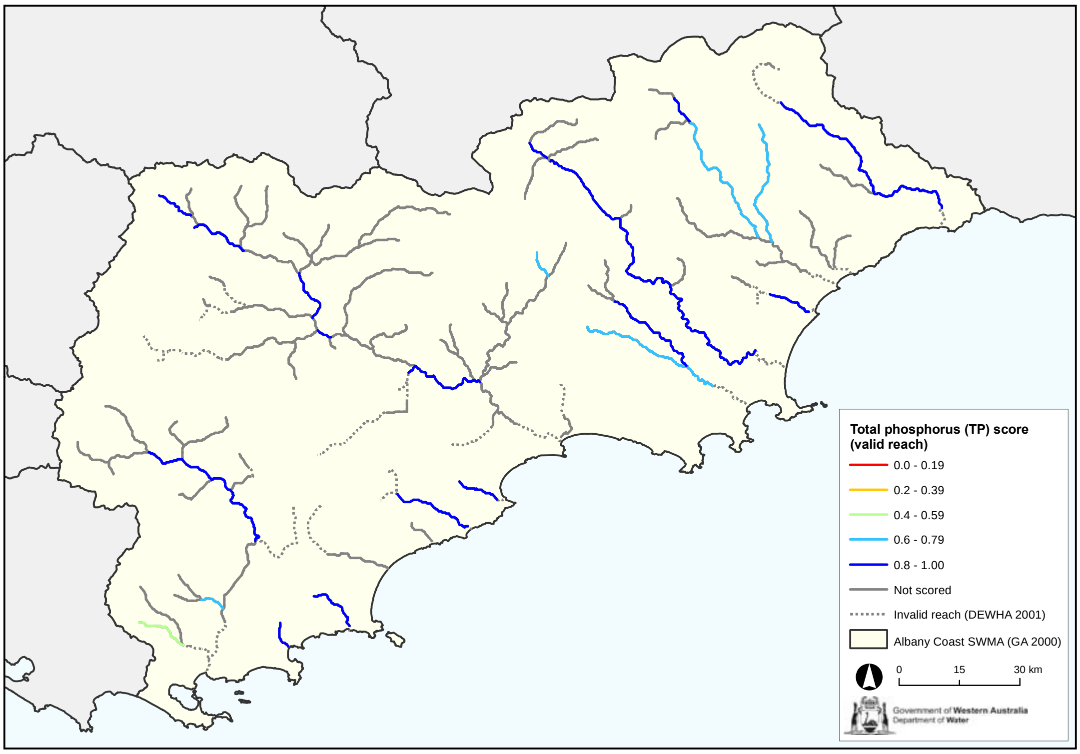

Figure 25 Total phosphorus scores for the Albany Coast SWMA

Turbidity indicator

Turbidity scores ranged between 0.4 (moderately modified) and 1 (largely unmodified). Both reaches which returned the lowest score (0.4) were on small river systems near the coast (Cordinup River and Saint Mary's River). There were no other distinct gradients in scores apparent.

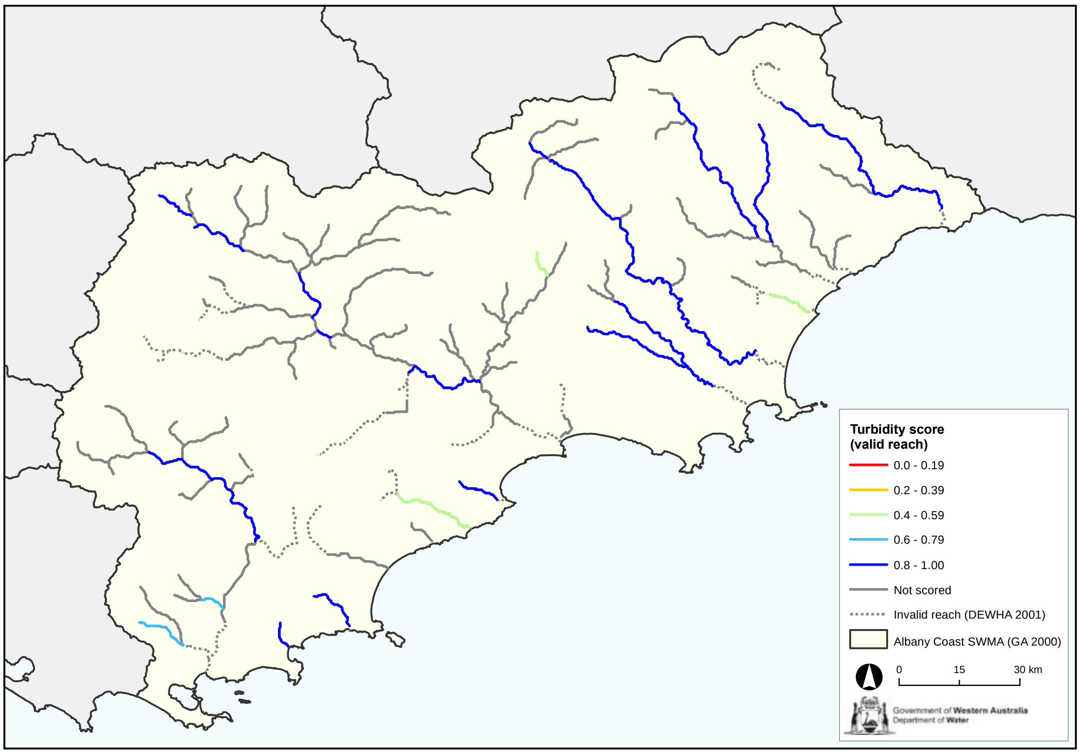

Figure 26 Turbidity scores for the Albany Coast SWMA

Salinity indicator

Salinity scores in the reaches used to develop the overall SWMA score ranged between 0 (severely modified) and 1 (largely unmodified). As salinity scores were modelled there were scores available for a larger number of reaches than those used in the final score. Figure 27 shows all the available salinity scores in the Albany Coast SWMA. Generally the systems in the western portion, and smaller systems, scored better than the larger and more eastern systems. The Pallinup and Gairdner Rivers scored particularly poorly.

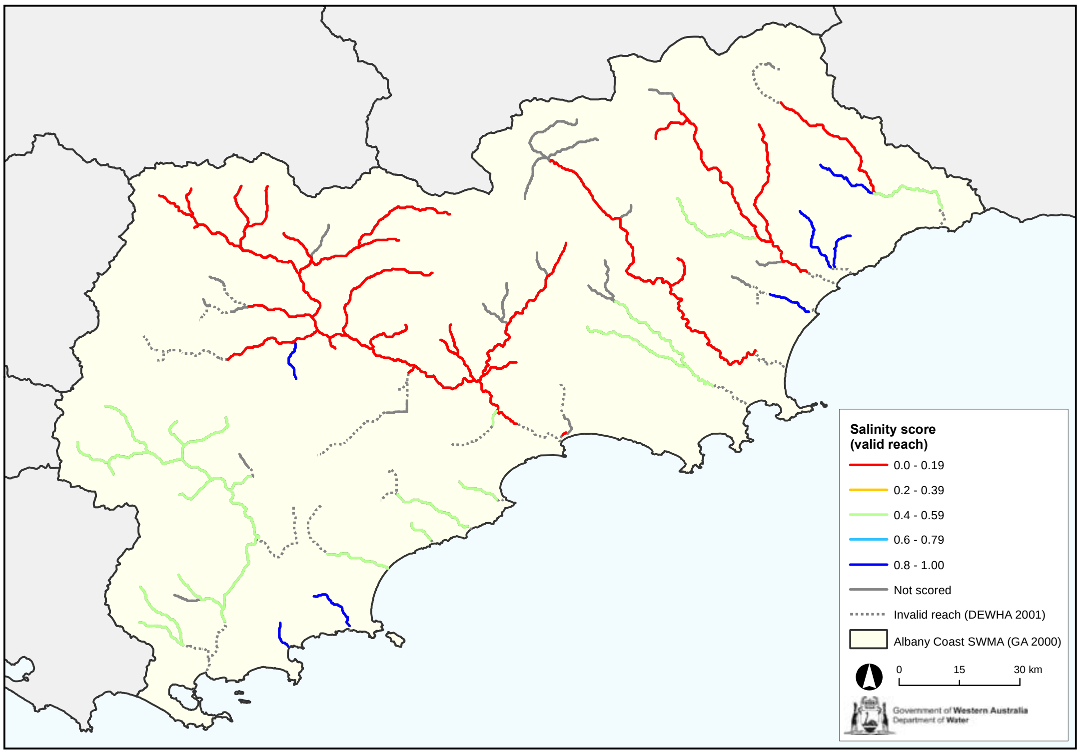

Figure 27 Salinity scores for the Albany Coast SWMA

Diel dissolved oxygen indicator

Diel dissolved oxygen scores ranged between 0.6 (slightly modified) and 1 (largely unmodified). Only two reaches were in the slightly modified category (bottom of the Hammersley River and the Eyre River), the remainder were in the largely unmodified category. Thus there was no spatial pattern evident in diel DO scores.

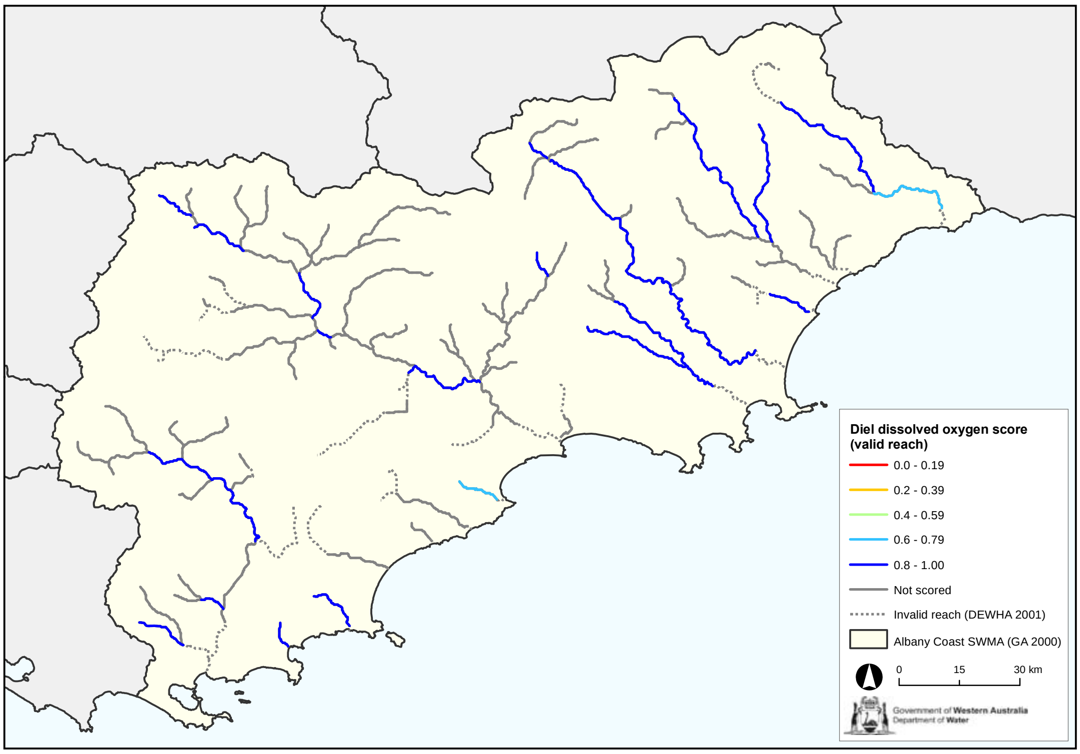

Figure 28 Diel dissolved oxygen scores for the Albany Coast SWMA

Diel temperature indicator

Diel temperature scores ranged between 0.4 (moderately modified – the lowest possible score for this indicator) and 0.8 (largely unmodified – the highest score possible for this indicator). As each site could be assigned only one of two scores for this indicator there is very little distinction between the different reaches (the reaches that are shown with a score other than 0.4 or 0.8 are those which had more than one site on them. For these reaches the average of the sampled site scores was used for the reach score). Generally the reaches in the north of the SWMA and to the east are those with the poorest scores.

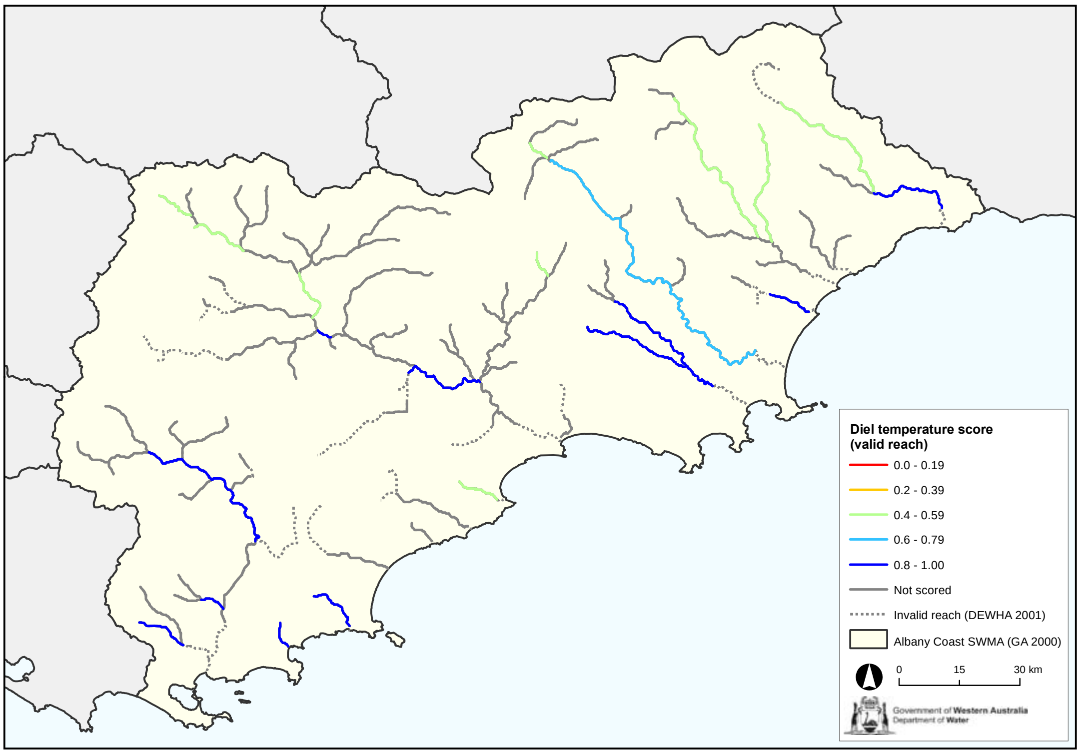

Figure 29 Diel temperature scores for the Albany Coast SWMA

9.5 Physical form index

The overall PFI score for the Albany Coast SWMA was 0.7 with scores for individual reaches ranging between 0.5 (moderately modified) and 1 (largely unmodified).

Figure 30 shows the overall PFI scores for each of the reaches sampled in the Albany Coast SWMA

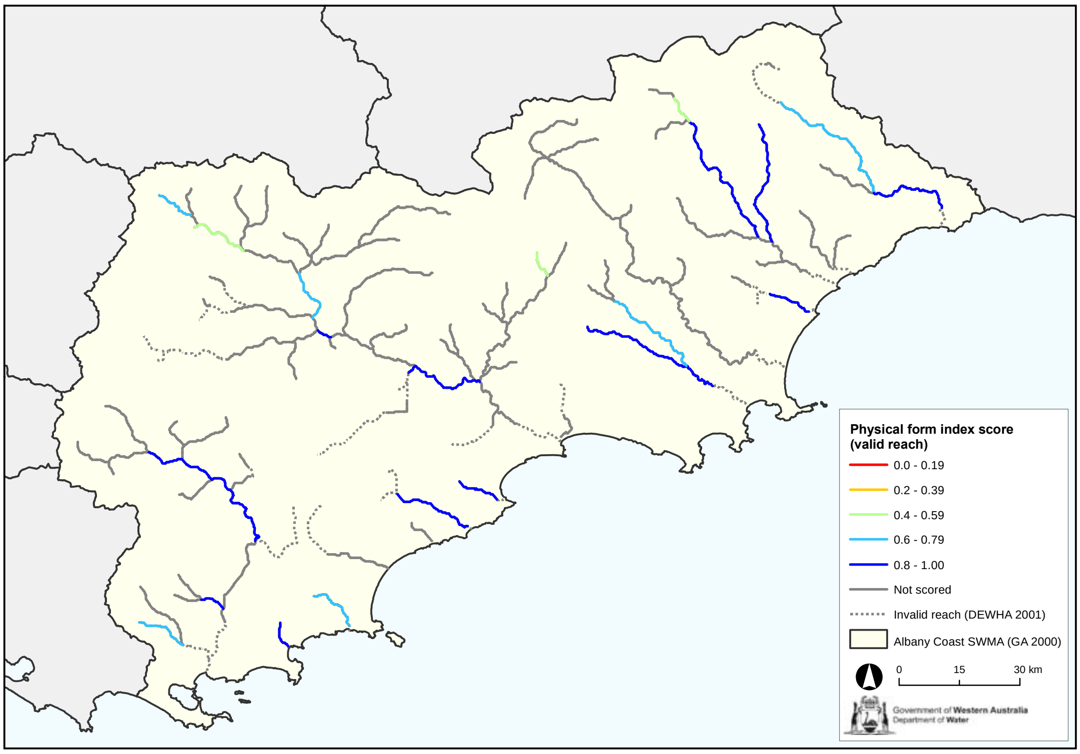

Figure 30 Overall PFI scores for the Albany Coast SWMA

As can be seen from Figure 30, the reaches near the northern boundary of the SWMA tended to score more poorly than those nearer the coast.

Channel pattern indicator

Channel pattern scored 1 (largely unmodified) in all of the reaches used to develop the overall SWMA score. As channel pattern scores were assigned using spatial data there were scores available for almost all of the reaches in the Albany Coast SWMA, shown in Figure 31. There is only a small portion of the SWMA, in the upper reaches of a tributary to the Pallinup River, which scored poorly for channel pattern. As there was not much distinction in channel pattern scores it was decided not to assign an overall PFI score for reaches where there was not also an erosion score present.

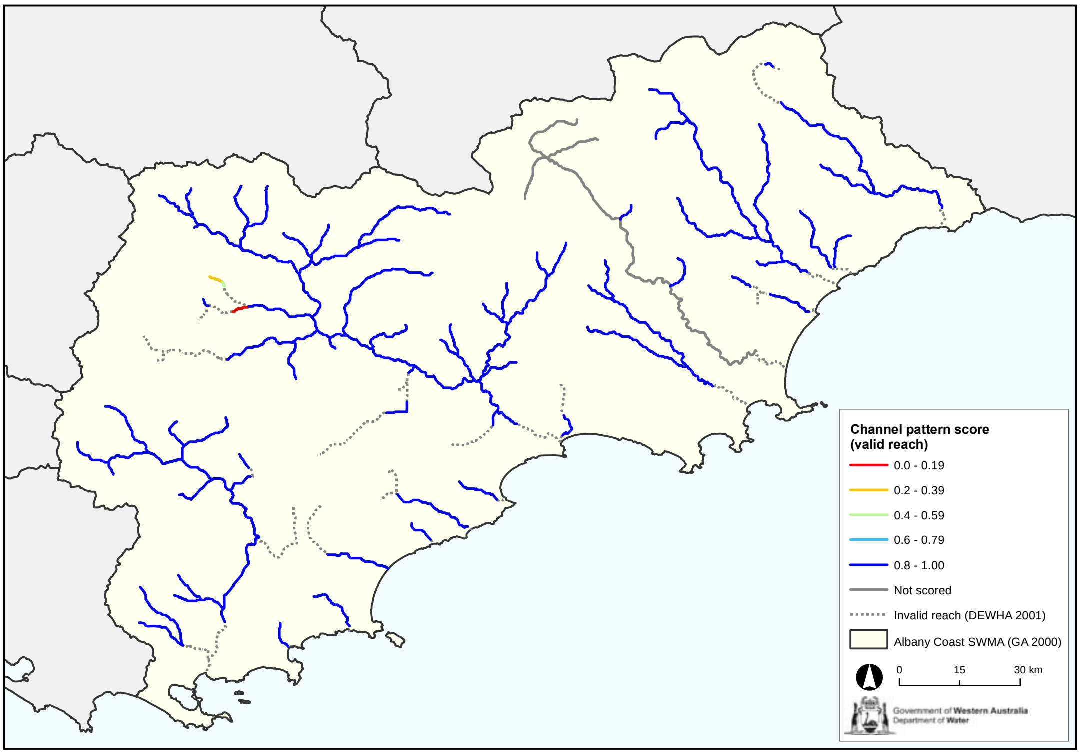

Figure 31 Channel pattern scores for the Albany Coast SWMA.

Erosion indicator

Erosion scores ranged between 0.3 (substantially modified) and 1 (largely unmodified). Reaches on the northern boundary of the SWMA ended to score more poorly than those nearer the coast.

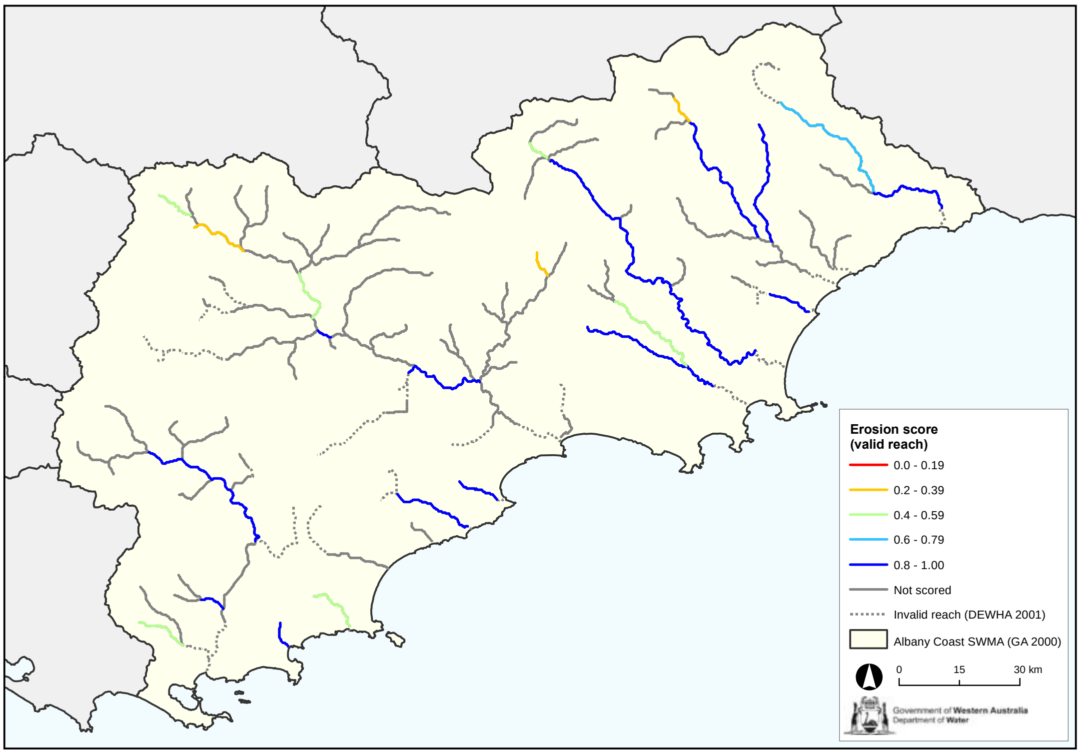

Figure 32 Erosion scores for the Albany Coast SWMA

9.6 Fringing zone index

The overall FZI score for the Albany Coast SWMA was 0.5, with scores for individual reaches ranging between 0 (substantially modified) and 1 (largely unmodified).

Figure 33 shows the overall FZI scores for all of the reaches in the Albany Coast SWMA (as this index was scored using remotely sensed data there are scores available for every reach).

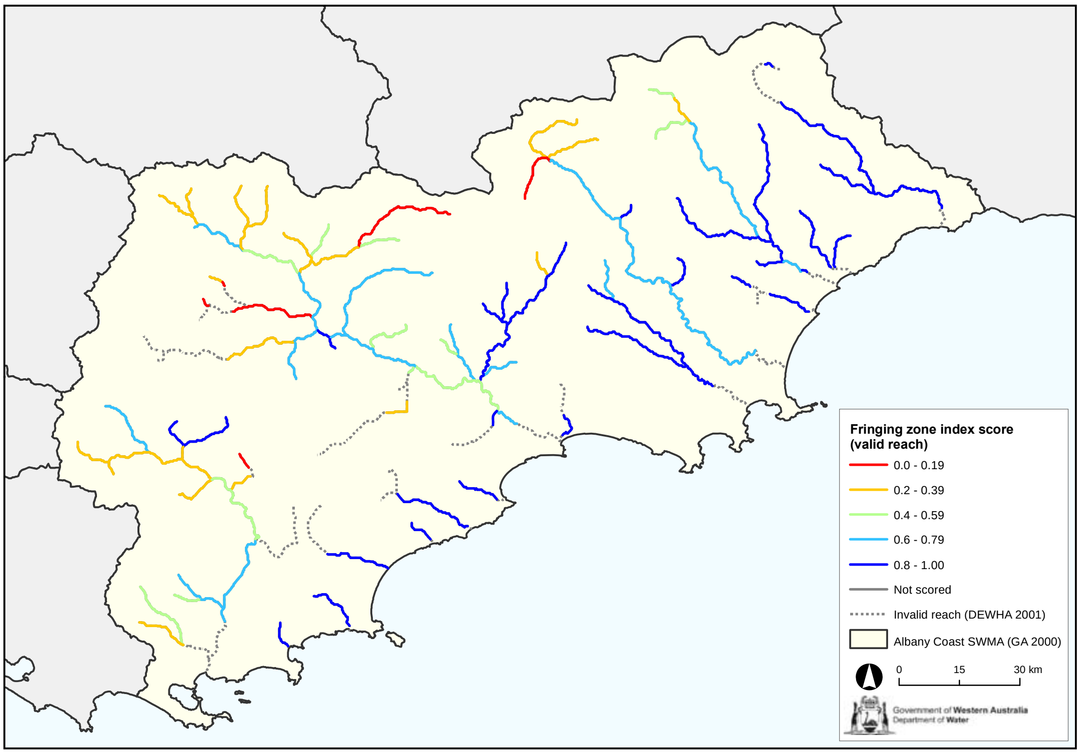

Figure 33 Overall FZI scores for the Albany Coast SWMA

As can be seen from Figure 33, reaches located in the upper catchments of the larger river systems (near the northern boundary of the SWMA) tended to score worse than those near the southern boundary. There was also a west to east trend evident with rivers in the eastern portion scoring better than those in the western portion. All the small systems located near the coast scored well.

Longitudinal continuity indicator

Longitudinal continuity scores ranged between 0 (substantially modified) and 1 (largely unmodified). The spatial pattern observed was very similar to that seen for the overall FZI score.

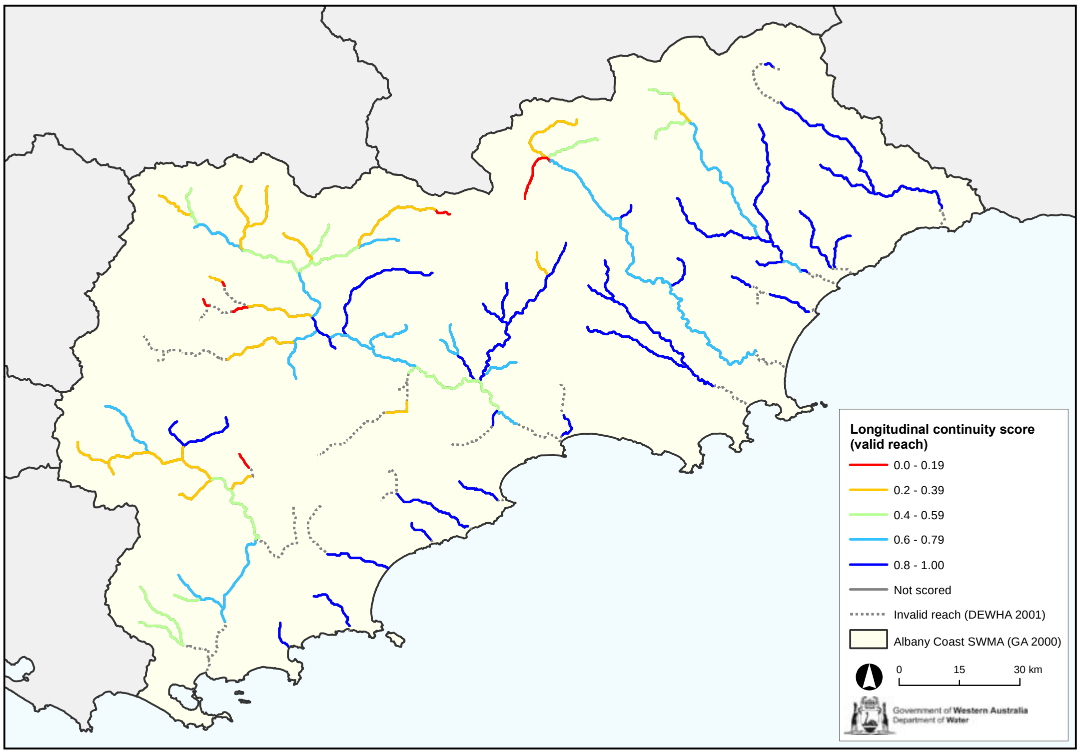

Figure 34 Longitudinal continuity scores for the Albany Coast SWMA

Fringing zone width indicator

Fringing zone width scores ranged between 0 (substantially modified) and 1 (largely unmodified). The spatial pattern observed was very similar to that seen for the overall FZI score and the longitudinal continuity indicator.

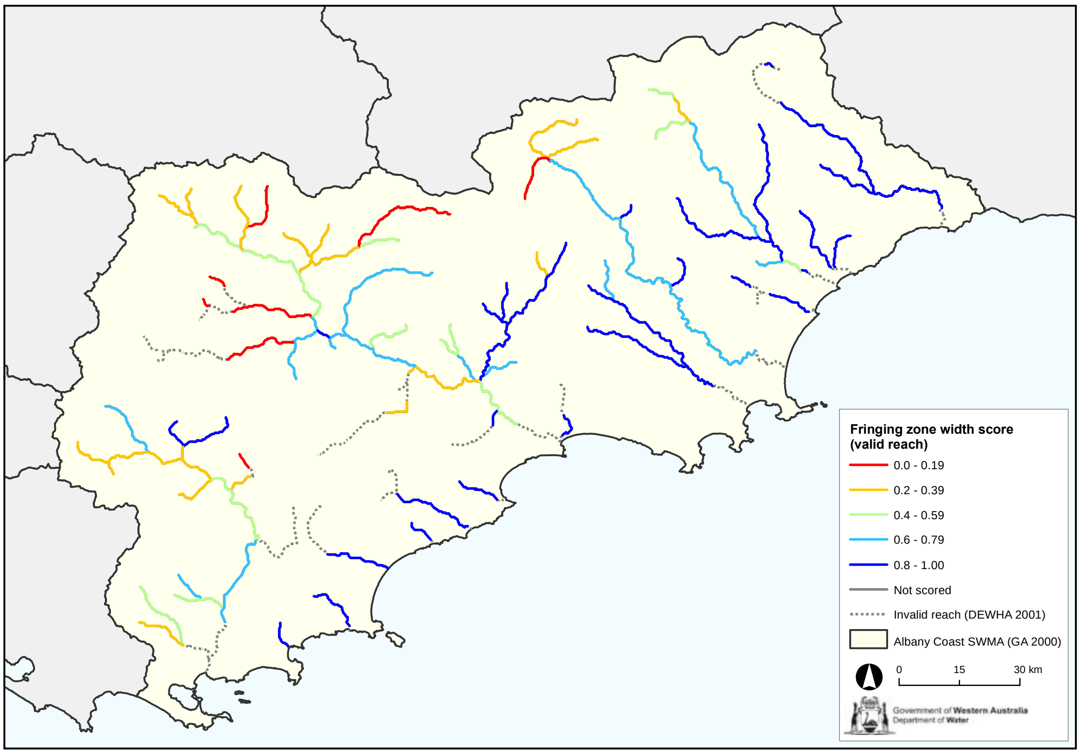

Figure 35 Fringing zone width scores for the Albany Coast SWMA

9.7 Aquatic biota index

The overall ABI score for the Albany Coast SWMA was 0.7, with scores for individual reaches ranging between 0 (severely modified) and 1 (largely unmodified).

Figure 36 shows the overall ABI scores for each of the reaches sampled in the Albany Coast SWMA.

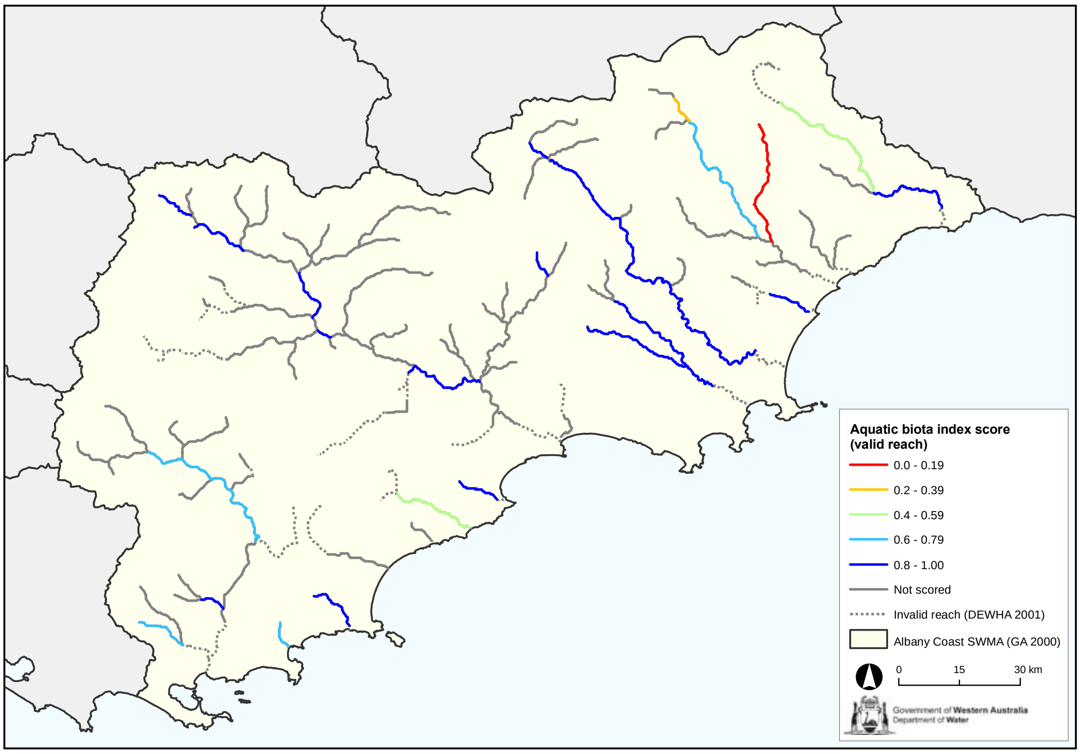

Figure 36 Overall ABI scores for the Albany Coast SWMA

As can be seen from Figure 36, there was a general west to east trend (lower scores occurring in the eastern systems). Small systems tended to score well, returning scores in either the slightly modified or largely unmodified categories with the exception of the Cordinup River which was moderately modified.

Fish and crayfish indicator

Fish and crayfish scores ranged between 0 (severely modified) and 1 (largely unmodified). As for the overall ABI scores, there was a general trend of rivers in the eastern portion of the SWMA scoring more poorly than those in the western portion. The general trend observed was very similar to that for the overall ABI though the categories for reaches did vary.

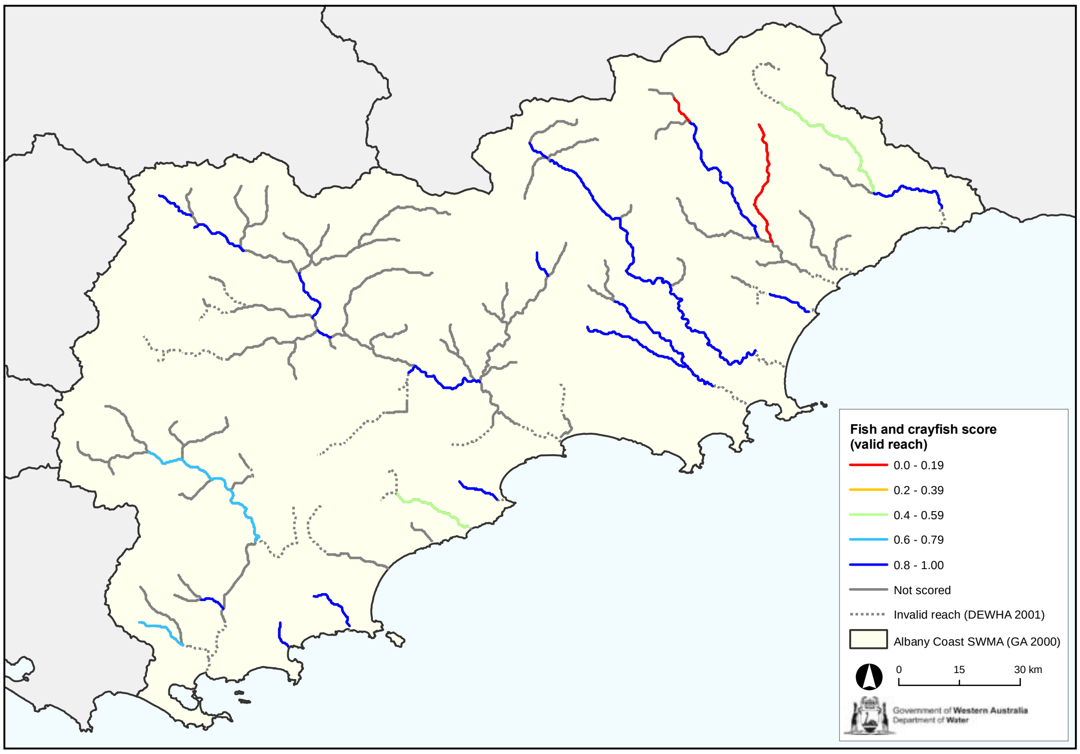

Figure 37 Fish and crayfish scores for the Albany Coast SWMA

Macroinvertebrate indicator

Macroinvertebrate (AUSRIVAS) scores ranged between 0.4 (moderately modified) and 0.9 (largely unmodified). It was not possible to calculate AUSRIVAS scores for nine of the sites sampled as they were outside the experience of the model. Further, due to sampler error at one site, and excessively deep water at another, two sites did not have macroinvertebrate samples collected. The sites for which it was not possible to calculate AUSRIVAS scores mostly occurred on reaches where there was only one site sampled. In one reach where there were two sites sampled they were both outside the experience of the model. For these reaches the ABI was calculated from the fish and crayfish score only. Overall, the macroinvertebrate scores were similar to or higher than the fish and crayfish scores, and the same general pattern of river systems at the eastern edge of the SWMA scoring more poorly was evident.

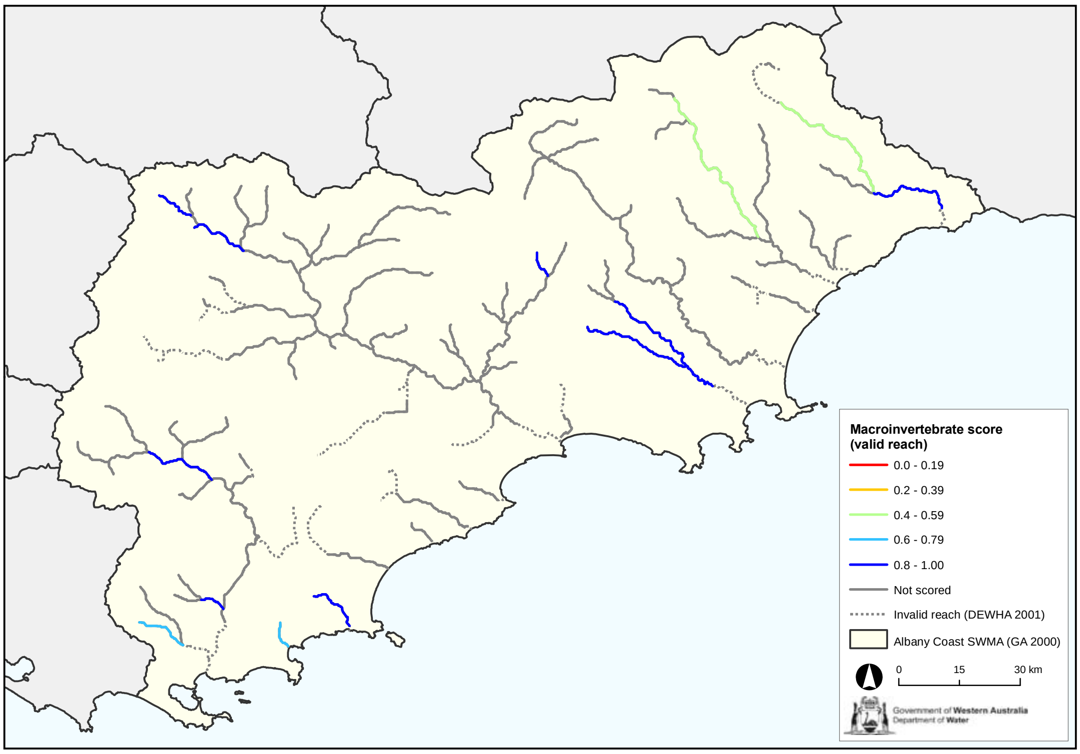

Figure 38 Macroinvertebrate scores for the Albany Coast SWMA

10 Collie SWMA assessment

The Collie River SWMA lies south of Perth and covers 3 717 km^2 (see Figure 39). The NATMAP 250K dataset identified 22 reaches which did not change following validation. Reach lengths varied from 1.0 to 28.8 km with an average length of 13.4 km. There is one main river system in the SWMA, the Collie River. Rainfall near the coast is approximately 820 mm annually, increasing to 920 mm over the Darling Scarp and then decreasing again to approximately 520 mm on the eastern boundary. 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 (the Wellington Reservoir – used for irrigation) and one on the Harris River (Harris Reservoir – used for potable water) as well as numerous smaller ones. There are no wild rivers present in this SWMA.

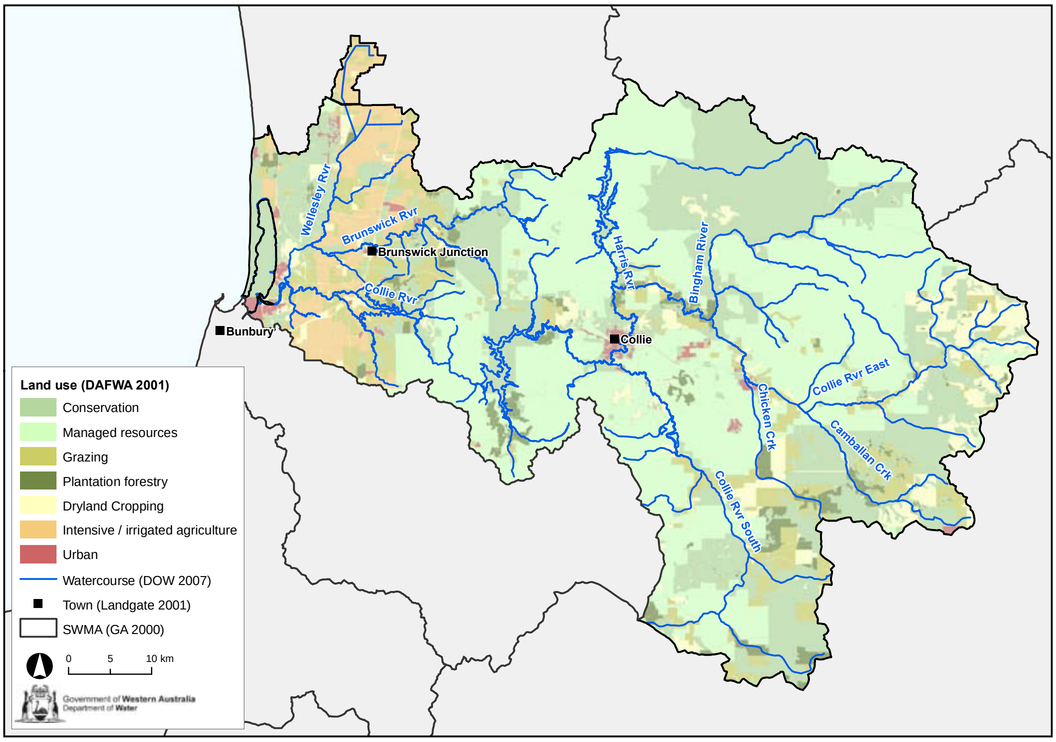

Figure 39 Collie surface water management area

A total of 18 sites were sampled during January 2009. Of these, one was not included in scoring as it was located in a pool rather than a flowing river. Two reaches had three samples collected on them and one had two samples collected. Where this occurred, the average of the site scores was taken to determine the reach score. This resulted in a total of 12 reaches being sampled, or 50% of the total number of reaches. Reaches located on the eastern edge of the catchment were generally not sampled as they were dry at the time of sampling.

10.1 Overall assessment

To aggregate the individual index scores to an overall SWMA scale the Standardised Euclidean distance with unweighted components was used (as per the recommendation in NWC 2007a). This resulted in an overall assessment for the Collie SWMA of 'slightly modified' (a score of 0.7). This was the highest scoring of the three SWMAs sampled in the first round of the trials.

10.2 Catchment disturbance index

The overall CDI for the Collie SWMA was 0.8 (largely unmodified). For this round of the trials the CDI has only been calculated at the whole of SWMA scale due to issues associated with the sub-catchment definitions.

Infrastructure measure

The infrastructure measure score for the Collie SWMA was 1 (largely unmodified). This is due to the small proportion of infrastructure present, compared to the relatively large size of the overall SWMA.

Land cover change measure

The land cover change measure score for the Collie SWMA was 1 (largely unmodified). As with the infrastructure measure, this is due to the overall size of the catchment and the limited amount of clearing that occurred in the 2003 to 2007 period. Much of the Collie SWMA remains uncleared.

Land-use measure

The land-use measure score for the Collie SWMA was 0.8 (largely unmodified). All seven of the land-use categories contributed 1% or greater of the overall land-use, urban (1%), intensive and irrigated agriculture (5%), dryland cropping (8%), grazing (10%), plantation forestry (3%), managed resources (42%) and conservation (32%).

10.3 Hydrological change index

As the HCI has not been developed there is no score available as yet. Work will begin on this index at the start of the new financial year as appropriate staff become available and a retrospective analysis will be performed for the Collie SWMA once this index is developed.

10.4 Water quality index

The overall WQI score for the Collie SWMA was 0.6 with scores for individual reaches ranging between 0.4 (moderately modified) and 1 (largely unmodified). The overall WQI scores were not clearly driven by any one indicator with diel dissolved oxygen and salinity having the greatest impacts.

Figure 40 shows the overall WQI scores for each of the reaches sampled in the Collie SWMA.

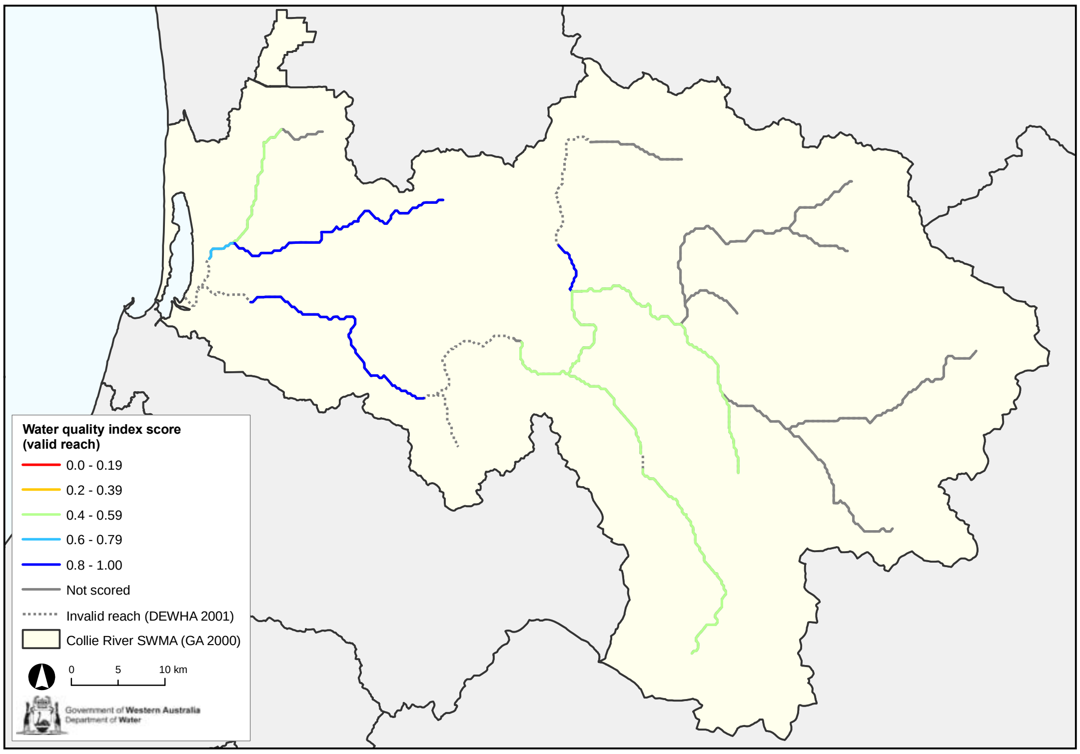

Figure 40 Overall WQI scores for the Collie SWMA

As can be seen from Figure 40, most of the reaches were classified as either moderately or largely unmodified. Generally, the water quality was poorer in the south eastern portion of the SWMA.

Total nitrogen indicator

TN scores ranged between 0.6 (slightly modified) and 1 (largely unmodified). Only one reach was classified as slightly modified, the rest were largely unmodified. Due to the homogeneous scores there were no spatial patterns evident.

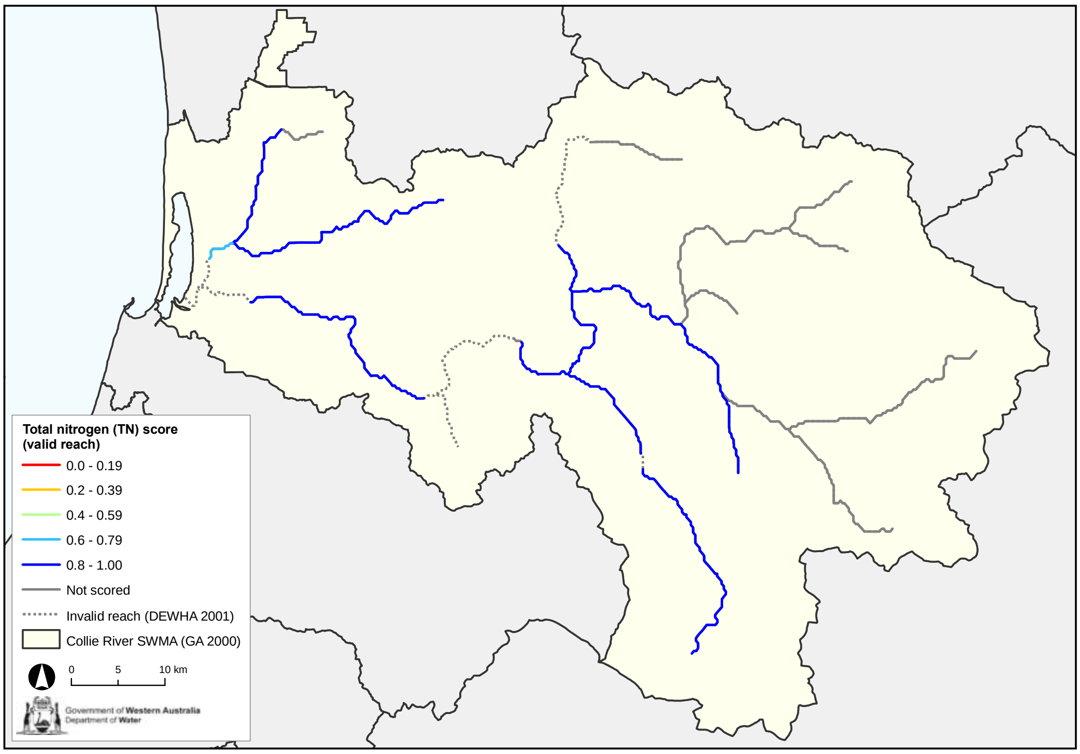

Figure 41 Total nitrogen scores for the Collie SWMA

Total phosphorus indicator

As with TN, TP scores ranged between 0.6 (slightly modified) and 1 (largely unmodified). Both reaches which scored as slightly modified were in the north-western portion of the catchment, on the Wellesley River.

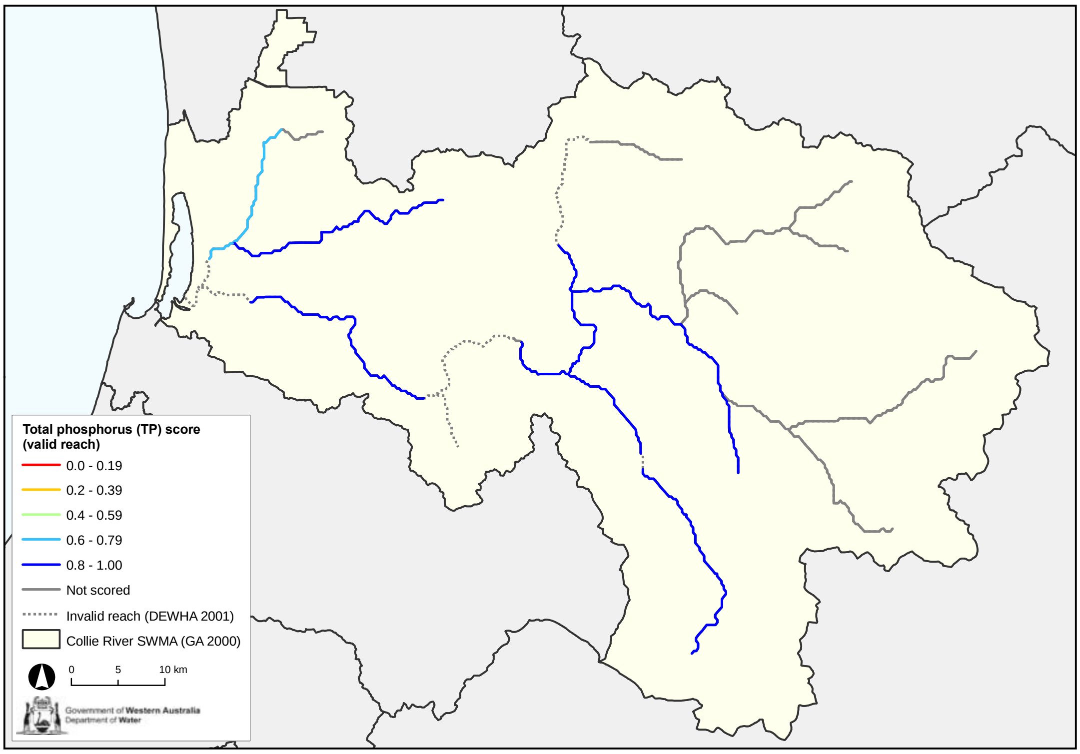

Figure 42 Total phosphorus scores for the Collie SWMA

Turbidity indicator

Turbidity scores ranged between 0.7 (slightly modified) and 1 (largely unmodified). Those reaches which scored in the slightly modified category were the most north-easterly of the reaches sampled.

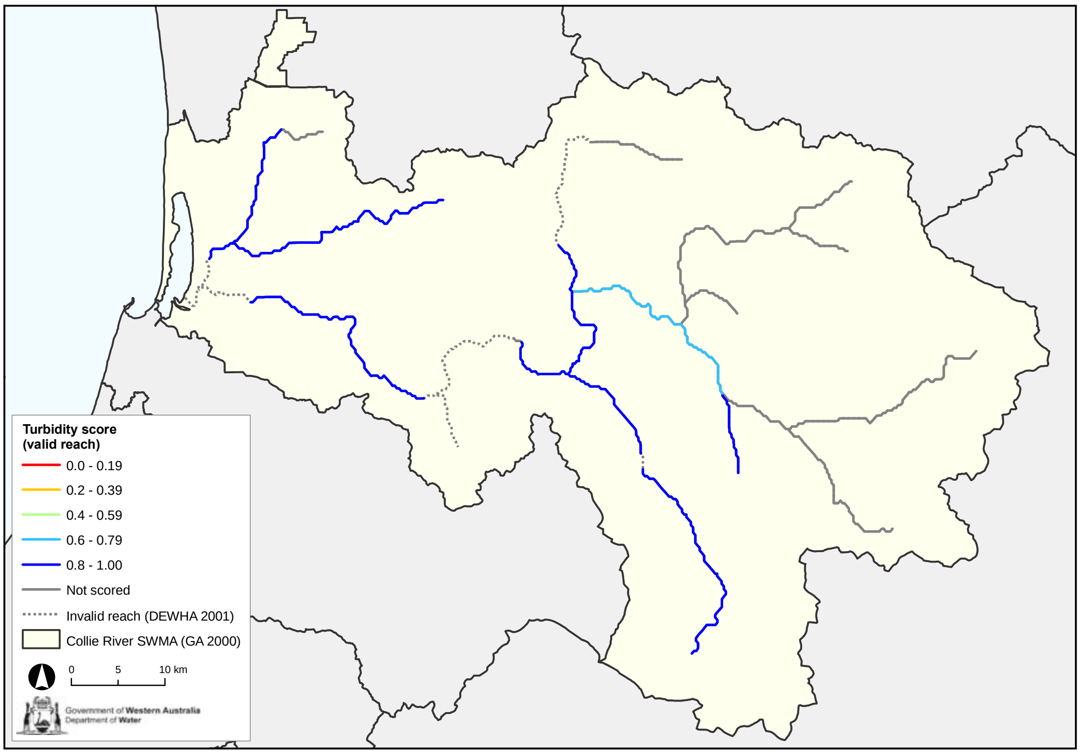

Figure 43 Turbidity scores for the Collie SWMA

Salinity indicator

Salinity scores in the reaches used to develop the overall SWMA score ranged between 0.5 (moderately modified) and 1 (largely unmodified). As salinity scores were modelled there were scores available for a larger number of reaches than those used in the final score. Figure 44 shows all the available salinity scores in the Collie SWMA. There was a general west to east trend in salinity scores with reaches in the south eastern portion scoring the worst.

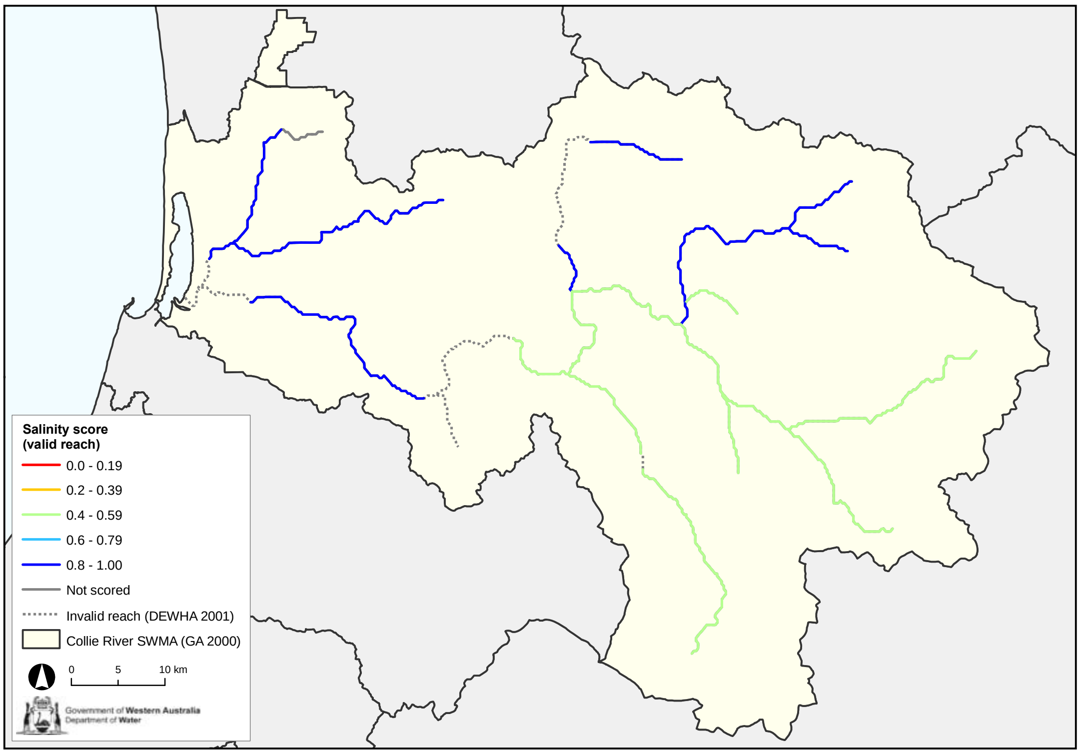

Figure 44 Salinity scores for the Collie SWMA

Diel dissolved oxygen indicator

Diel dissolved oxygen scores ranged between 0.4 (moderately modified) and 1 (largely unmodified). There was no apparent spatial pattern in the diel DO scores.

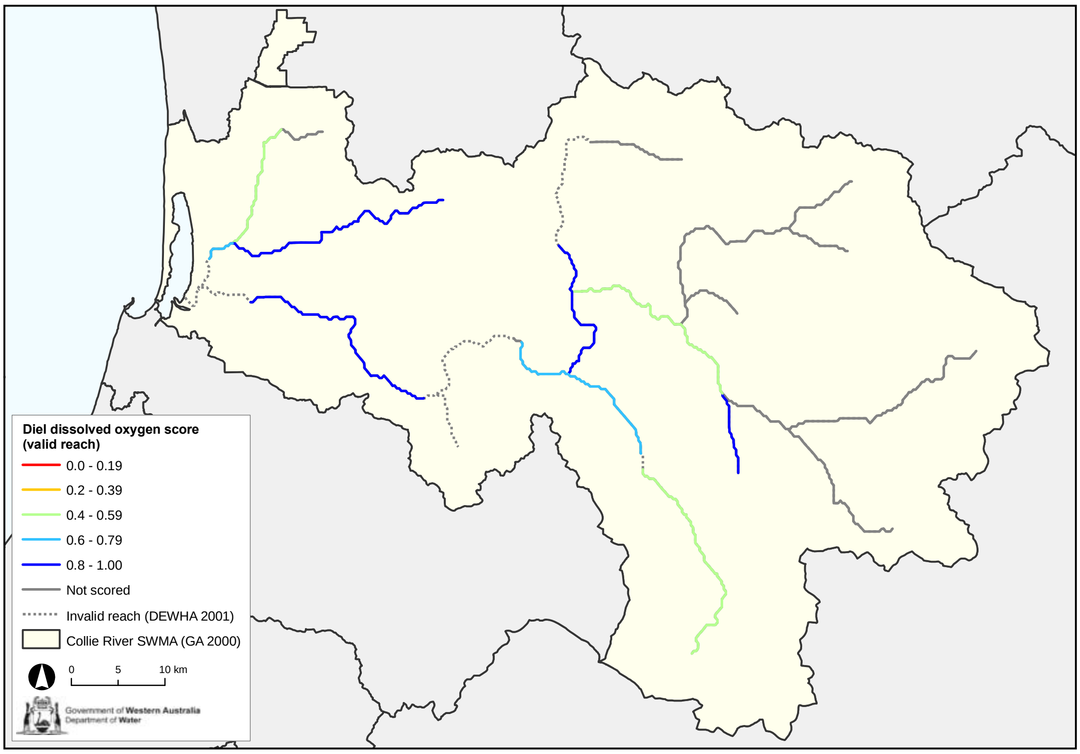

Figure 45 Diel dissolved oxygen scores for the Collie SWMA

Diel temperature indicator

Diel temperature ranged between 0.4 (moderately modified – the lowest score possible for this indicator) and 0.8 (largely unmodified – the highest score possible for this indicator). As there were only two scores possible for this indicator there is very little distinction between the different reaches, those reaches that returned a score other than 0.4 or 0.8 are those which had more than one site sampled on them. For these reaches the average of the site score was used for the reach score. There is no obvious spatial pattern in diel temperature scores.

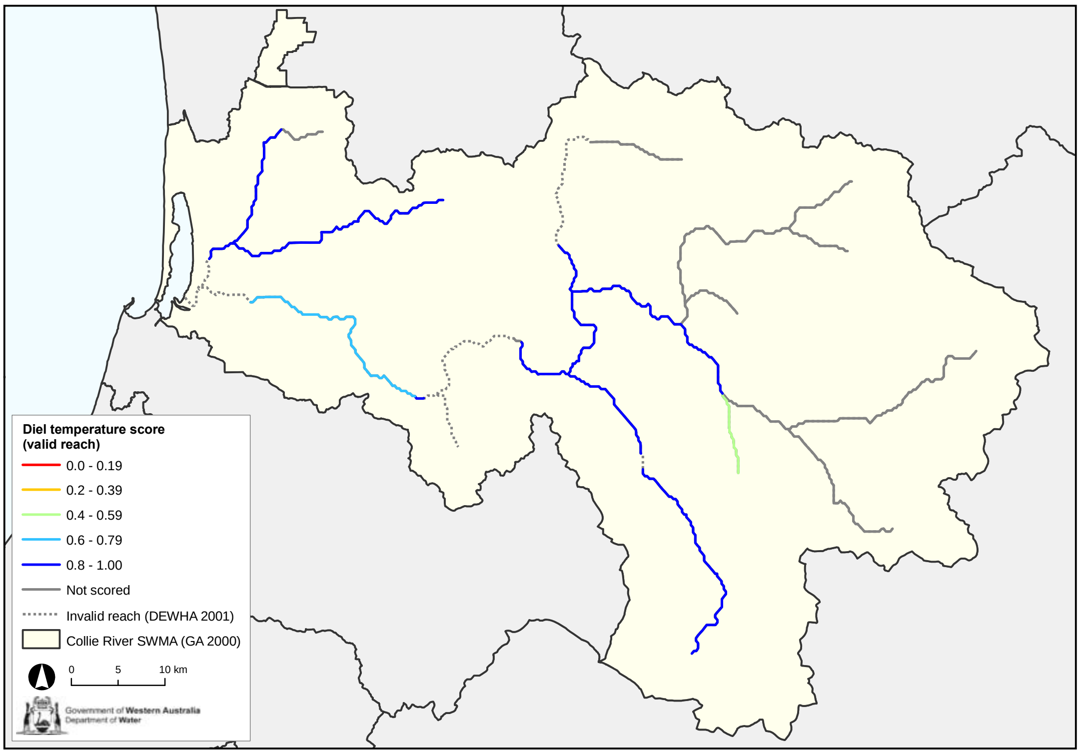

Figure 46 Diel temperature scores for the Collie SWMA

10.5 Physical form index

The overall PFI score for the Collie SWMA was 0.8 with scores for individual reaches ranging between 0.6 (slightly modified) and 1 (largely unmodified).

Figure 47 shows the overall PFI scores for each of the reaches sampled in the Collie SWMA.

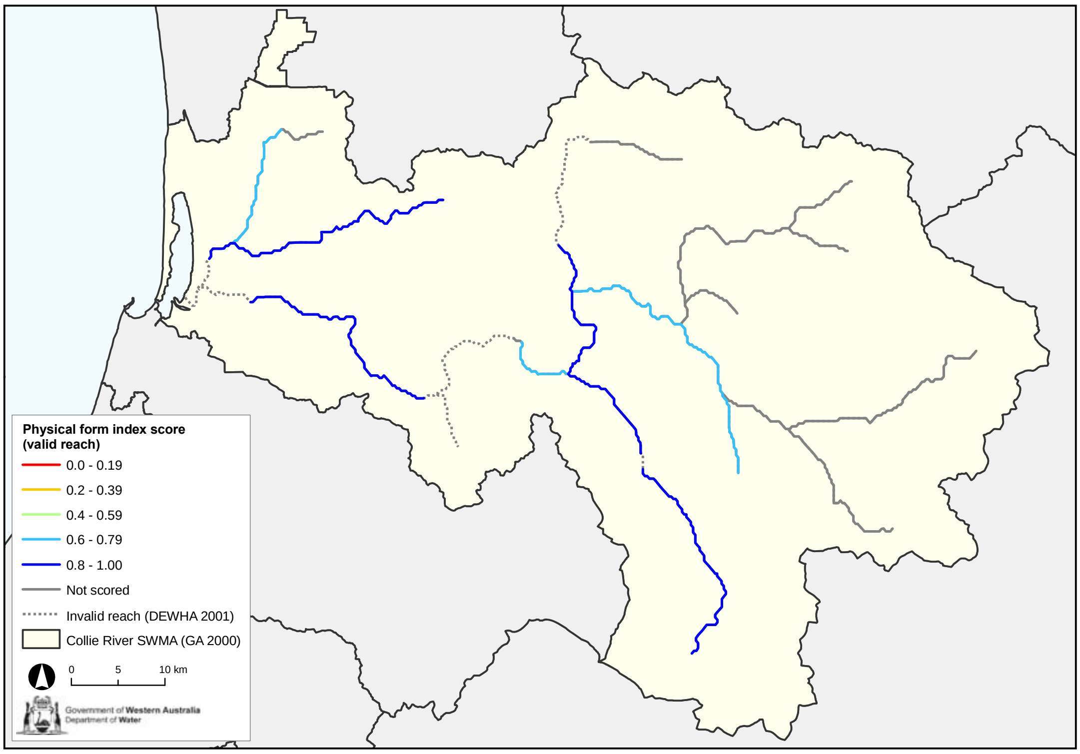

Figure 47 Overall PFI scores for the Collie SWMA

As can be seen from Figure 47, there was no obvious spatial pattern in the physical form index scores.

Channel pattern indicator

Channel pattern scored between 0.6 (slightly modified) and 1 (largely unmodified) in the reaches used to develop the overall SWMA score. As channel pattern scores were assigned using spatial data there were scores available for almost all of the reaches in the Collie SWMA, shown in Figure 48. There was only one reach, in the upper catchment of the Wellesley River, which scored zero for channel pattern.

As there was not much distinction in channel pattern scores it was decided not to assign an overall PFI score for reaches where there was not also an erosion score present.

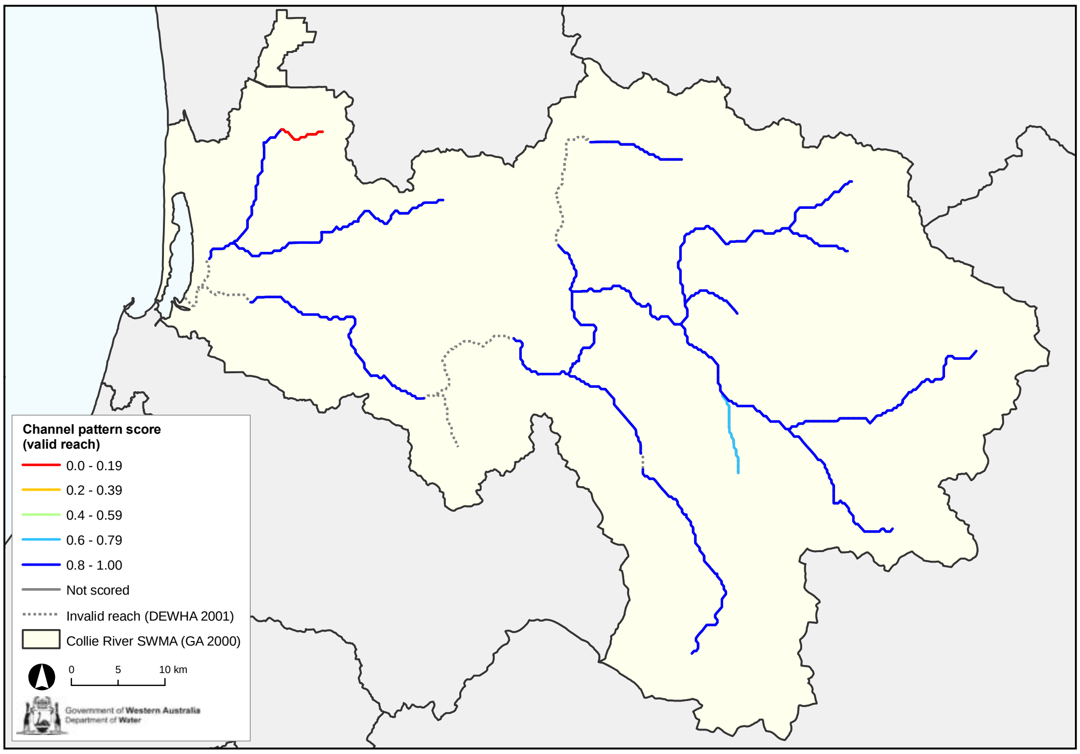

Figure 48 Channel pattern scores for the Collie SWMA

Erosion indicator

Erosion scores ranged between 0.5 (moderately modified) and 1 (largely unmodified). There was no clear spatial pattern present in the erosion scores.

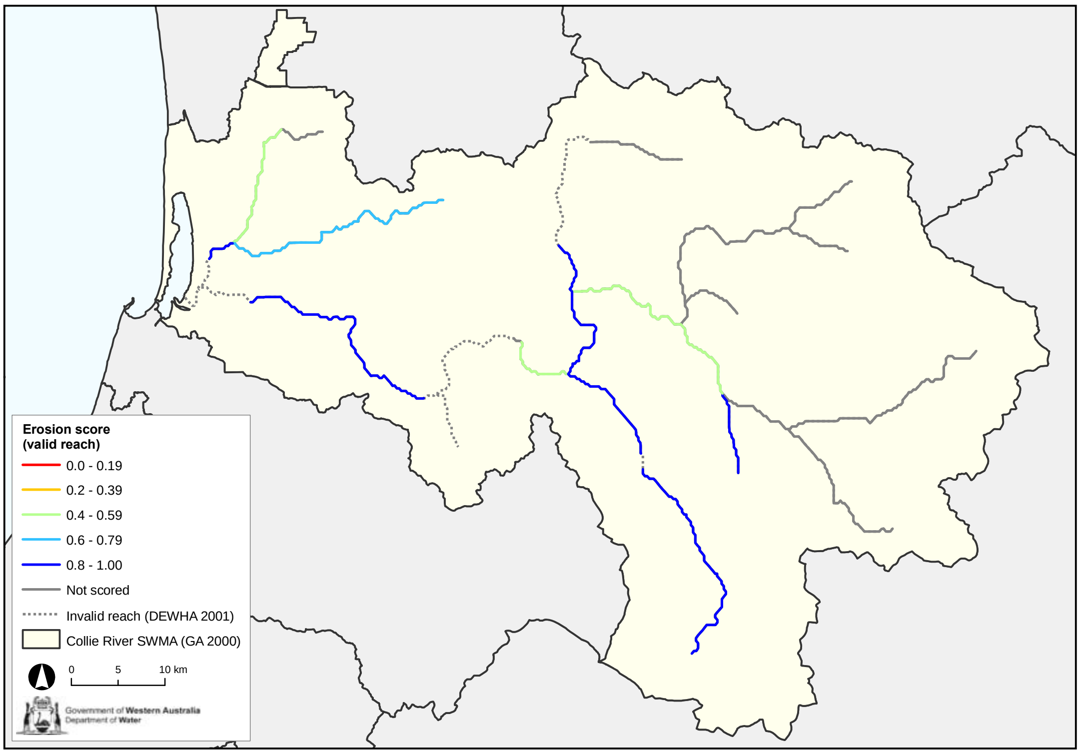

Figure 49 Erosion scores for the Collie SWMA

10.6 Fringing zone index

The overall FZI score for the Collie SWMA was 0.6, with scores for individual reaches ranging between 0 (substantially modified) and 1 (largely unmodified).

Figure 50 shows the overall FZI scores for all of the reaches in the Collie SWMA (as this index was scored using remotely sensed data there are scores available for every reach).

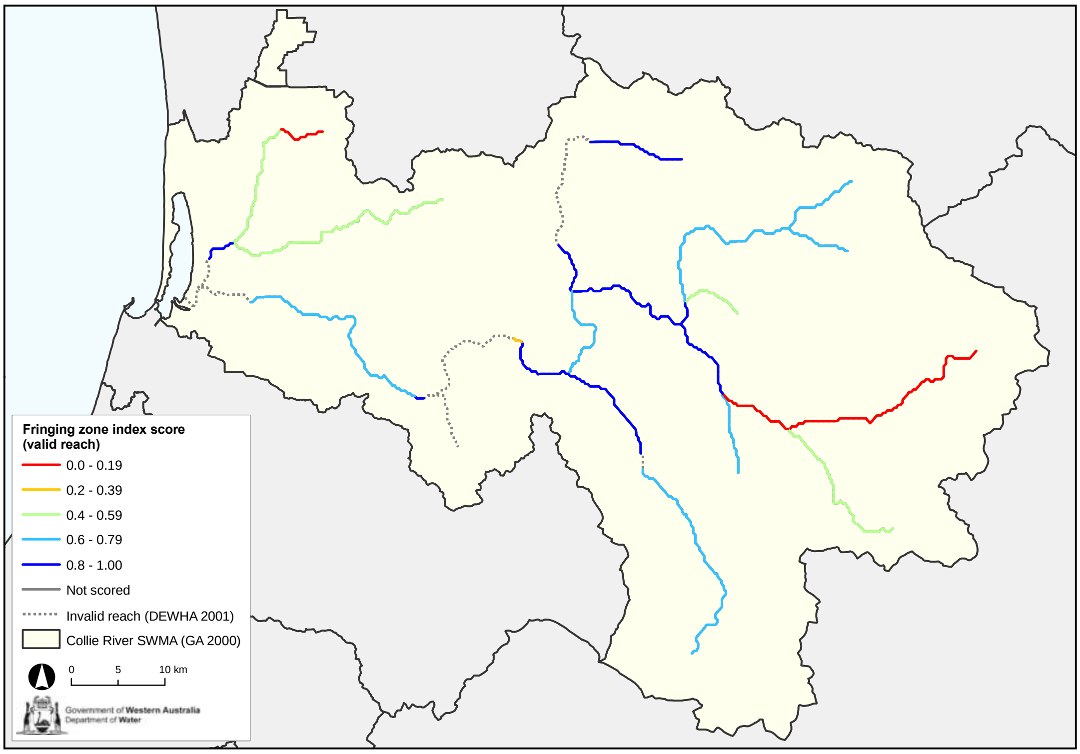

Figure 50 Overall FZI scores for the Collie SWMA

As can be seen from Figure 50, reaches located in the upper catchments of the Collie and Wellesley Rivers (at the eastern edges of these systems) tended to score worse than those near the western edge.

Longitudinal continuity indicator

Longitudinal continuity scores ranged between 0 (substantially modified) and 1 (largely unmodified). As with the overall FZI scores, those reaches lying at the eastern edge of river systems, in their upper catchments, generally scored the worst.

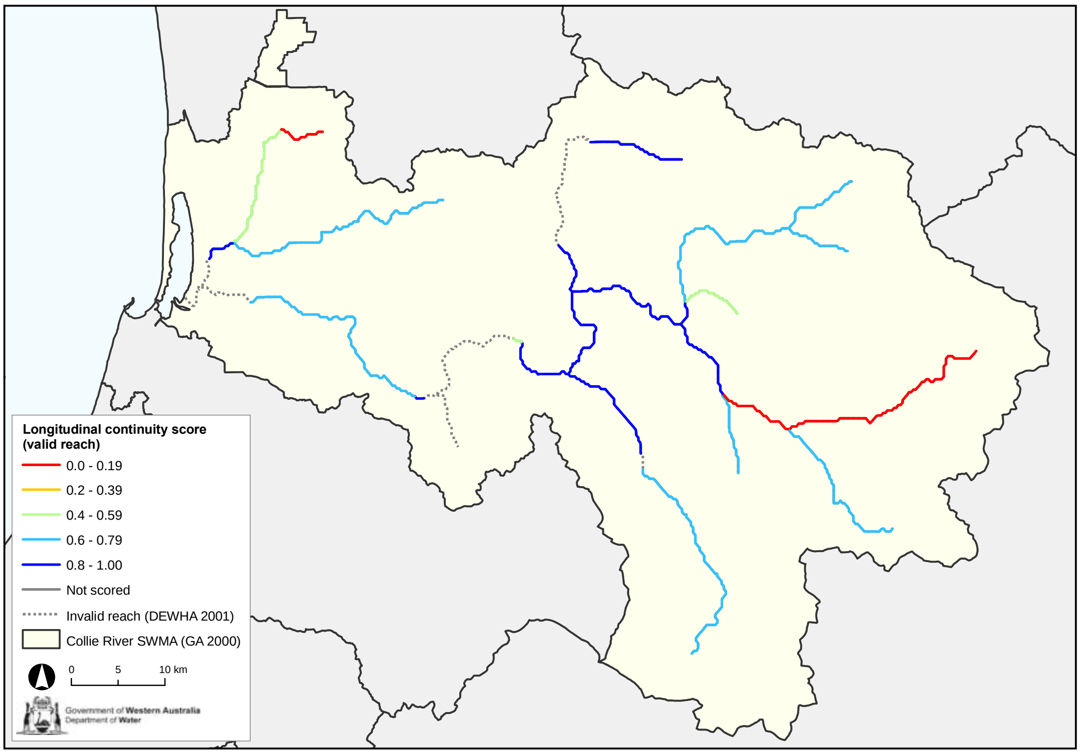

Figure 51 Longitudinal continuity scores for the Collie SWMA

Fringing zone width indicator

Fringing zone width scores ranged between 0 (substantially modified) and 1 (largely unmodified). A similar spatial pattern to the overall FZI score and the longitudinal continuity score was observed, with reaches in the upper catchments of rivers (on the eastern edge of the SWMA) generally scoring the worst.

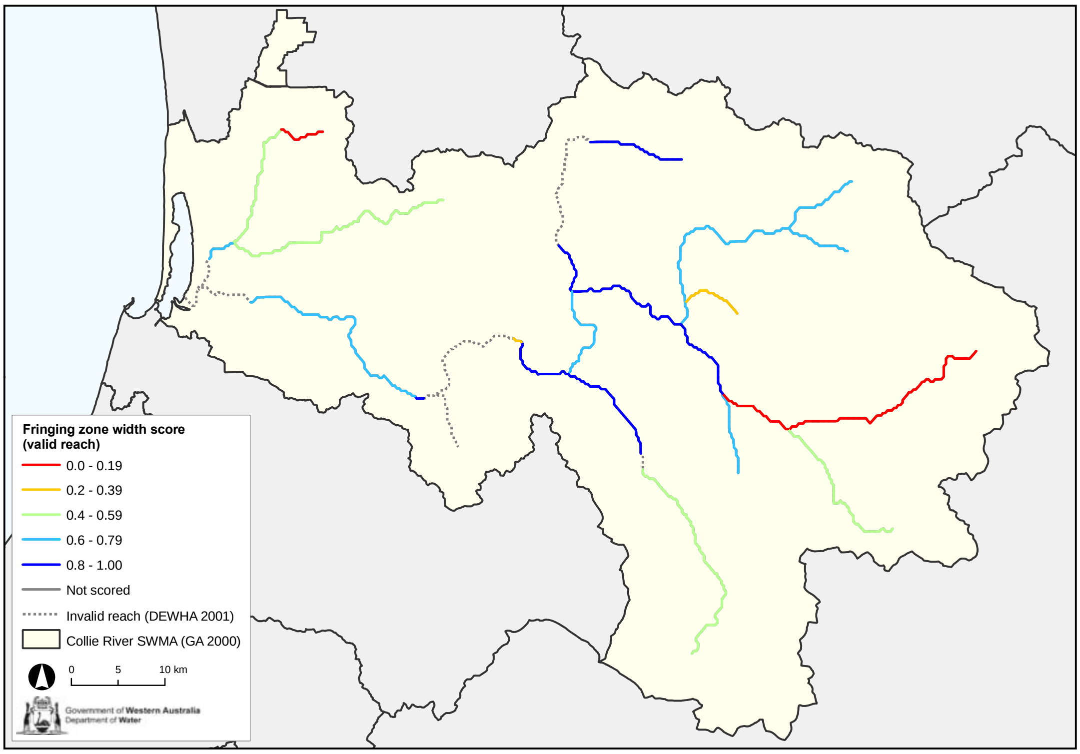

Figure 52 Fringing zone width scores for the Collie SWMA

10.7 Aquatic biota index

The overall ABI score for the Collie SWMA was 0.7 with scores for individual reaches ranging between 0.5 (moderately modified) and 0.9 (largely unmodified).

Figure 53 shows the overall ABI scores for each of the reaches sampled in the Collie SWMA.

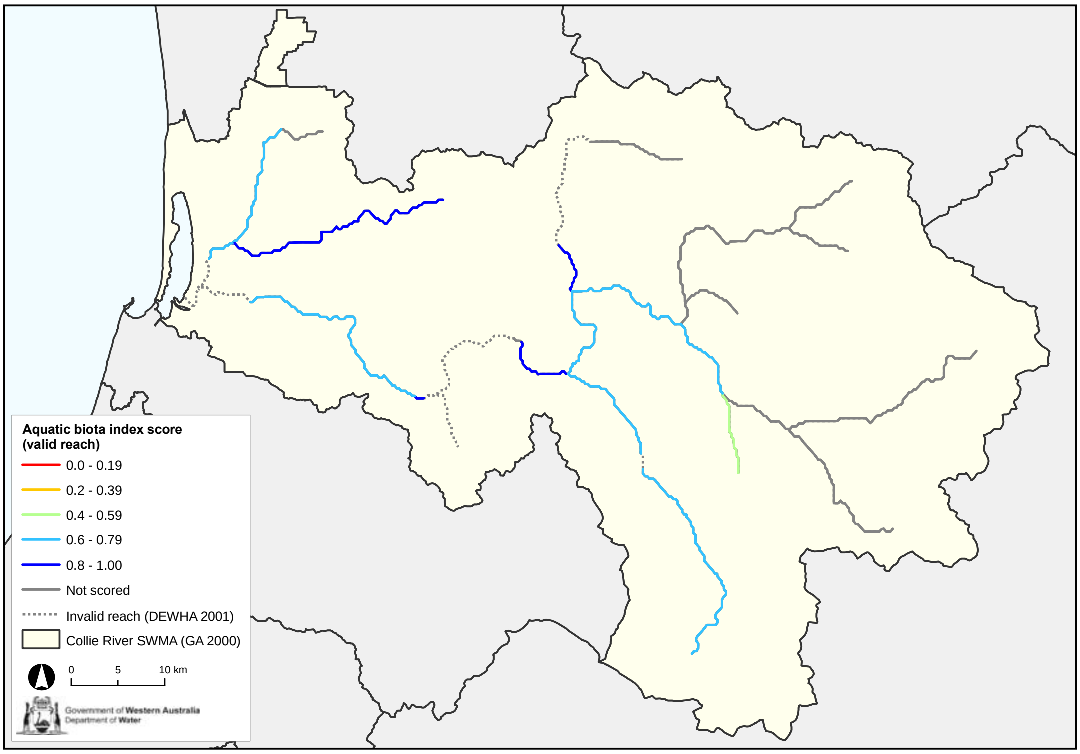

Figure 53 Overall ABI scores for the Collie SWMA

As can be seen from Figure 53, the ABI scores showed no discernible pattern.

Fish and crayfish indicator

Fish and crayfish scores ranged between 0.6 (slightly modified) and 0.9 (largely unmodified). There was no evidence of a spatial pattern in the scores.

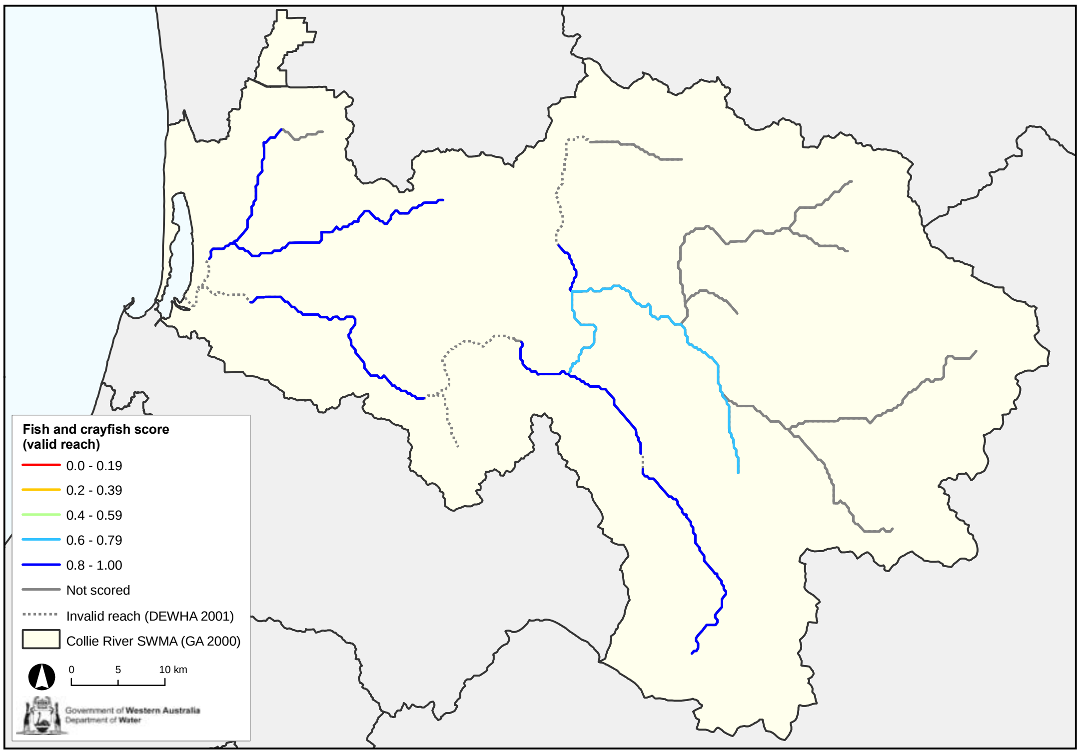

Figure 54 Fish and crayfish scores for the Collie SWMA

Macroinvertebrate indicator

Macroinvertebrate (AUSRIVAS) scores ranged between 0.4 (moderately modified) and 0.9 (largely unmodified). It was not possible to calculate AUSRIVAS scores for six of the sites sampled as they were outside the experience of the model. Of these sites, one was located on a stream which was not a recognised reach and therefore did not contribute to the overall ABI score. Two were located on reaches with more than one site sampled so it was still possible to calculate a macroinvertebrate score for these reaches, and three were located on reaches with a single sample. For these last three reaches the fish and crayfish score was used for the overall ABI score. Generally, the macroinvertebrate scores were lower than the fish and crayfish scores.

There was no obvious spatial pattern in macroinvertebrate scores.

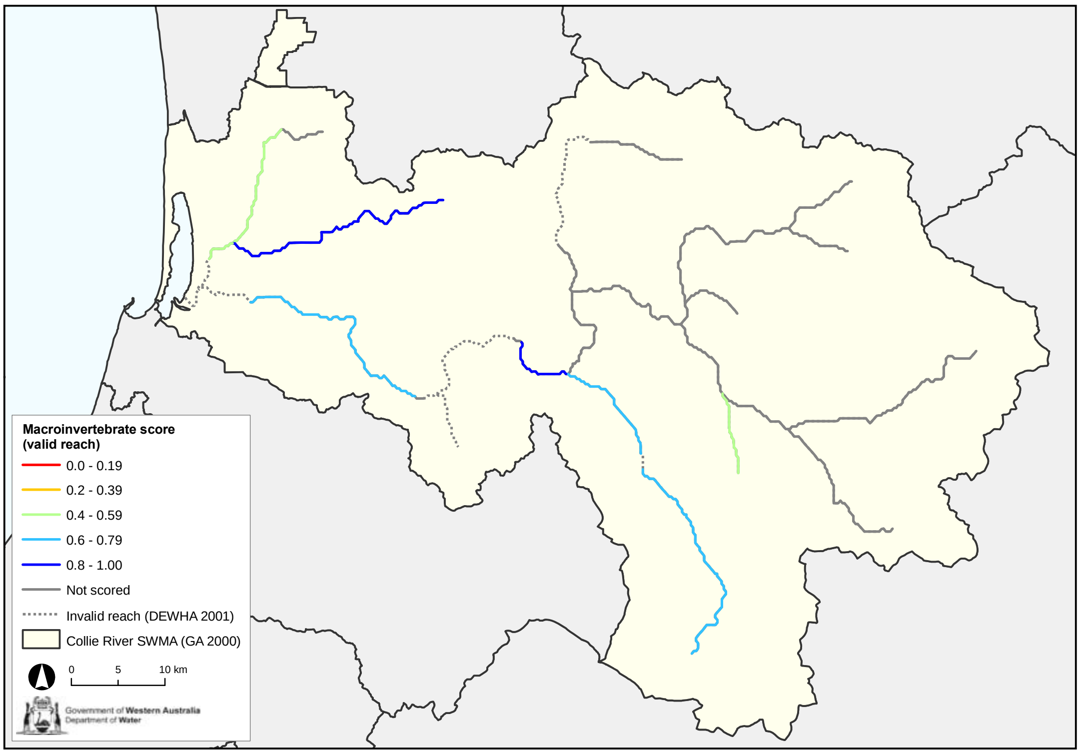

Figure 55 Macroinvertebrate scores for the Collie SWMA

11 Future directions – indicators

Power analysis

Power analysis has been conducted on those indicators which were not sampled at the whole-of-SWMA scale (that is, where there is not a value for each reach). This has been done 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.

11.1 Catchment disturbance index

All three of the indicators suggested in the inception report (van Looij & Storer 2009) were trialled and used in the overall CDI score.

Infrastructure measure performance

Infrastructure measure in round one of the trials

This indicator was assessed using spatial data. In this first round of trials the score was only calculated at the whole-of-SWMA scale. While this is appropriate to meet the needs of a FARWH assessment for the NWC it is at too broad a scale to be useful for local catchment managers.

The actual scores obtained for this indicator did not provide any differentiation between SWMAs (they all scored 1.0). This is due to the nature of development in the south-west of Western Australia where the majority of the population lives along a coastal strip, extending roughly 16 km north of Perth and 22 km south. There are other regional centres (such as Albany) but these are all much smaller than Perth. Outside these urban areas there is very little infrastructure.

Infrastructure measure in round two of the trials

While the infrastructure measure indicator did not distinguish between the three SWMAs in which it was trialled it will remain, unchanged, in the second round of trials. It is not a very useful indicator at the SWMA scale but may prove to be more so at a sub-catchment scale. Further, if calculated for a more heavily populated SWMA such as the Swan Coast, it is likely to become more valuable. Lastly, it may become a useful indicator in the future as development progresses in the south-west of Western Australia.

The feasibility of conducting the infrastructure measure at the sub-catchment scale will be investigated.

Land cover change measure performance

Land cover change measure in round one of the trials

This indicator was assessed using spatial data. In this first round of trials the score was only calculated at the whole-of-SWMA scale. While this is appropriate to meet the needs of a FARWH assessment for the NWC it is at too broad a scale to be useful for local catchment managers.

The actual scores obtained for this indicator did not provide any differentiation between SWMAs (they all scored 1.0). This is because clearing of perennial vegetation in the south-west of Western Australia was not occurring at a large scale in the SWMAs sampled. Two of them (Moore Hill and Albany Coast) are already largely cleared and the third (Collie) is not currently being actively cleared on a large scale.

Land cover change measure in round two of the trials

While the land cover change measure did not distinguish between the three SWMAs in which it was trialled it will remain, unchanged, in the second round of trials. It is not a very useful indicator at the SWMA scale but may prove to be more so at a sub-catchment scale. Further, if calculated in SWMAs where there is more active clearing of perennial vegetation it may return different scores. Lastly, it may be a useful indicator in the future if clearing occurs on a large scale.

The feasibility of conducting the infrastructure measure at the sub-catchment scale will be investigated.

Land-use measure performance

Land-use measure in round one of the trials

This indicator was assessed using spatial data. In this first round of trials the score was only calculated at the whole-of-SWMA scale. While this is appropriate to meet the needs of a FARWH assessment for the NWC it is at too broad a scale to be useful for local catchment managers.

This indicator showed greater differentiation between the assessed SWMAs than the other two indicators that make up the CDI. It classed the Collie SWMA as being in better condition than the Albany Coast and Moore Hill SWMA which reflects the land-use in those catchments.

Land-use measure in round two of the trials

The land-use measure will remain, unchanged, in the second round of trials.

The feasibility of conducting the land-use measure at the sub-catchment scale will be investigated.

11.2 Hydrological change index

As mentioned, work has not commenced on this index as yet. The intent is to try and calculate all the indicators suggested by the flow stress ranking, namely:

- low flow index
- high flow index
- proportion of zero flow index
- monthly variation index and
- seasonal period index.

Once this index has been developed a retrospective analysis of the SWMAs assessed in this round of the trials will be conducted (the Albany Coast, Moore Hill and Collie SWMAs).

11.3 Water quality index

All of the indicators suggested in the inception report (van Looij & Storer 2009) were trialled and used in the overall score. The ability of the indicators to detect change did not vary significantly.

Total nitrogen indicator performance

Total nitrogen indicator in round one of the trials

The number of samples collected overall and within each SWMA was found to be able to detect between a 15% and 19% change in the mean over time, as can be seen in Table 14, and Figure 56.

Table 14 Power analysis results for total nitrogen indicator

SWMA	Number of reaches in SWMA	Number of samples to detect 10 % Δ in mean	Number of samples to detect 20 % Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Combined	123	111	29	52	15
Albany	101	80	21	24	19
Collie	22	32	9	12	17
Moore	90	53	14	16	19

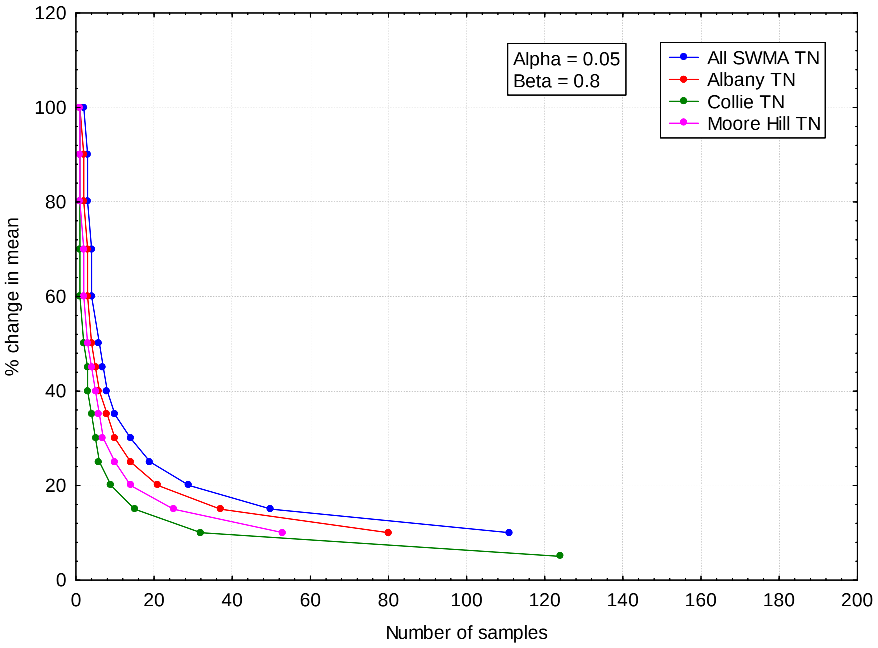

Figure 56 Power analysis results for total nitrogen indicator

Total nitrogen indicator in round two of the trials

Work will shortly commence on trialling the SedNet model in the south-west of Western Australia. If SedNet is found to be effective then the modelled results will be used for future assessments. This will allow a total nitrogen score to be determined for every reach in a SWMA.

The second round of field trials will continue to collect water quality samples, including total nitrogen. This data will be used to help calibrate and validate SedNet and, if the model is found to be unsuitable for use in the south-west of Western Australia, to allow scoring of total nitrogen to continue. In the second round of sampling a total of 30 reaches will be sampled in each SWMA. This number of reaches is achievable both in terms of staff time conducting field work and analysis costs and should allow for an 80% chance of detecting a 20% change in mean over time. Where there are less than 30 reaches present in a SWMA all available reaches will be sampled (remembering that some reaches will almost certainly be dry).

The current categories and methods used for scoring TN will be used again for scoring data from the second round of trials.

Total phosphorus indicator performance

Total phosphorus indicator in round one of the trials

The number of samples collected overall and within each SWMA was found to be able to detect between a 14% and 29% change in the mean over time, as can be seen in Table 15, and Figure 57.

Table 15 Power analysis results for total phosphorus indicator.

SWMA	Number of reaches in SWMA	Number of samples to detect 10 % Δ in mean	Number of samples to detect 20 % Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Combined	123	74	20	52	14
Albany	101	47	13	24	15
Collie	22	42	12	12	20
Moore	90	119	31	16	29

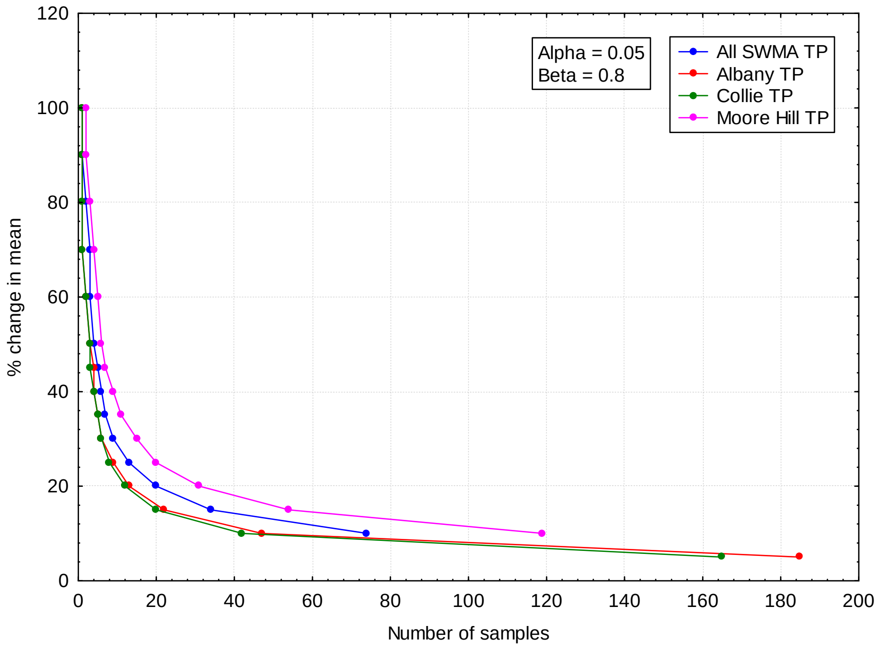

Figure 57 Power analysis results for total phosphorus indicator

Total phosphorus indicator in round two of the trials

Work will shortly commence on trialling the SedNet model in the south-west of Western Australia. If SedNet is found to be effective then the modelled results will be used for future assessments. This will allow a total phosphorus score to be determined for every reach in a SWMA.

The second round of field trials will continue to collect water quality samples, including total phosphorus. This data will be used to help calibrate and validate SedNet and, if the model is found to be unsuitable for use in the south-west of Western Australia, to allow scoring of total phosphorus to continue. In the second round of sampling a total of 30 reaches will be sampled in each SWMA. This number of reaches is achievable both in terms of staff time conducting field work and analysis costs and should allow for an 80% chance of detecting a 20% change in mean over time. Where there are less than 30 reaches present in a SWMA all available reaches will be sampled (remembering that some reaches will almost certainly be dry).

The current categories and methods used for scoring TP will be used again for scoring data from the second round of trials.

Turbidity indicator performance

Turbidity indicator in round one of the trials

The number of samples collected overall and within each SWMA was found to be able to detect between a 13% and 20% change in the mean over time, as can be seen in Table 16, and Figure 58.

Table 16 Power analysis results for turbidity indicator

SWMA	Number of reaches in SWMA	Number of samples to detect 10 % Δ in mean	Number of samples to detect 20 % Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Combined	123	79	21	52	13
Albany	101	95	25	24	20
Collie	22	23	7	12	15
Moore	90	63	17	16	20

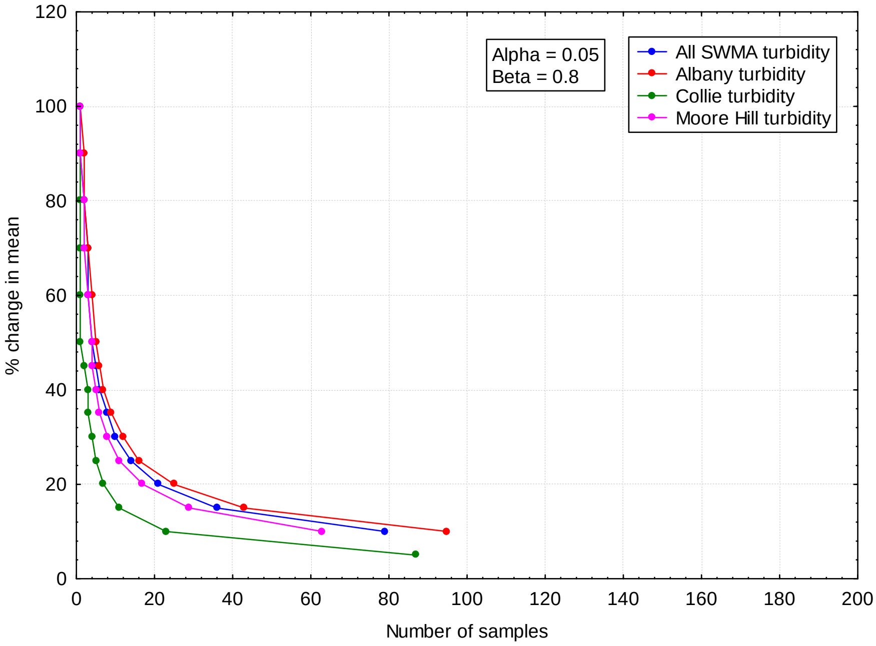

Figure 58 Power analysis results for turbidity indicator

Turbidity indicator in round two of the trials

As it is not possible to measure turbidity concentrations using the SedNet model, turbidity data will continue to be collected in the field in the second round of field trials. This data will be used for scoring and may, in the future, be useful for constructing a model for determining turbidity levels (although this will be outside the scope of the current project). In the second round of sampling a total of 30 reaches will be sampled in each SWMA. This number of reaches is achievable both in terms of staff time conducting field work and analysis costs and should allow for an 80% chance of detecting a 20% change in mean over time. Where there are less than 30 reaches present in a SWMA all available reaches will be sampled (remembering that some reaches will almost certainly be dry).

The current categories and methods used for scoring turbidity will be used again for scoring data from the second round of trials.

Salinity indicator performance

Salinity indicator in round one of the trials

Because the data used for the salinity indicator was modelled and, as such, provided scores for the majority of reaches in each SWMA, no power analysis has been conducted on these scores. The same modelled dataset will be used for scoring in the second round of field trials.

Salinity indicator in round two of the trials

For the second round of field trials the same modelled salinity dataset will be used for scoring.

If the modelled dataset used for scoring is not updated in the future, it may be necessary to either update the modelling results (which is outside the scope of the current project and not yet necessary), or investigate the use of field collected salinity data for scoring. To facilitate both of these options specific conductivity and salinity (in mg/L) will be measured using in-situ probes at each sampling site visited.

The current categories and methods used for scoring salinity will be used again for scoring data from the second round of trials.

Diel dissolved oxygen indicator performance

Diel dissolved oxygen indicator in round one of the trials

The number of samples collected overall and within each SWMA was found to be able to detect between an 11% and 34% change in the mean over time, as can be seen in Table 17, and Figure 59.

Table 17 Power analysis results for diel dissolved oxygen indicator

SWMA	Number of reaches in SWMA	Number of samples to detect 10 % Δ in mean	Number of samples to detect 20 % Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Combined	123	69	18	52	13
Albany	101	27	8	23	11
Collie	22	125	32	12	34
Moore	90	70	19	16	23

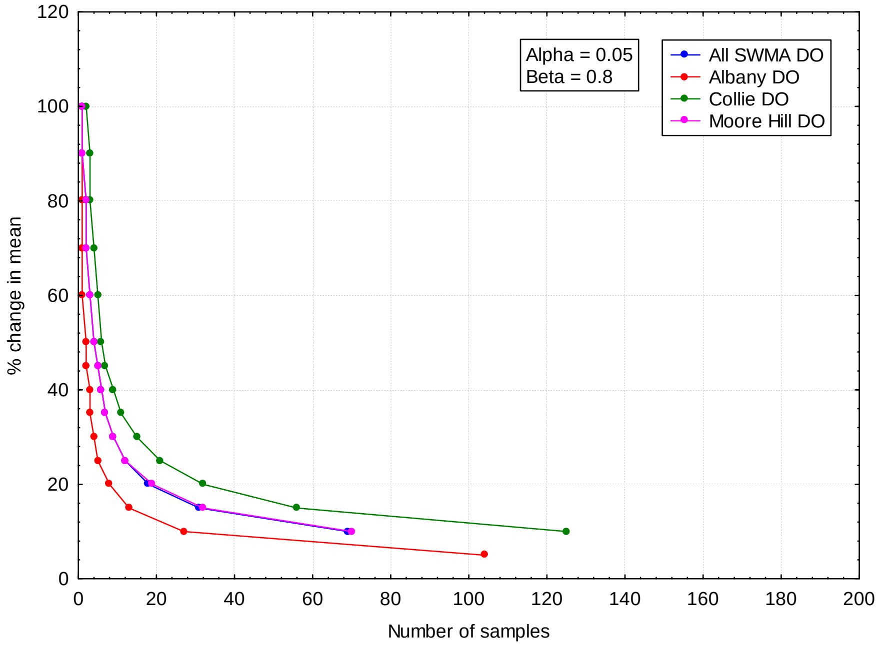

Figure 59 Power analysis results for diel dissolved oxygen indicator

Diel dissolved oxygen indicator in round two of the trials

As there is currently no model available which will model diel dissolved oxygen concentrations, this data will continue to be collected in the field in the second round of field trials. In the second round of sampling a total of 30 reaches will be sampled in each SWMA. This number of reaches is achievable in terms of staff time conducting field work and should allow for an 80% chance of detecting a 15% change in mean over time. Where there are less than 30 reaches present in a SWMA all available reaches will be sampled (remembering that some reaches will almost certainly be dry).

The current categories and methods used for scoring diel dissolved oxygen will be used again for scoring data from the second round of trials.

Diel temperature indicator performance

Diel temperature indicator in round one of the trials

The number of samples collected overall and within each SWMA was found to be able to detect between an 18% and 33% change in the mean over time, as can be seen in Table 18, and Figure 60.

Table 18 Power analysis results for diel temperature indicator

SWMA	Number of reaches in SWMA	Number of samples to detect 10 % Δ in mean	Number of samples to detect 20 % Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Combined	123	140	36	51	18
Albany	101	165	42	23	29
Collie	22	79	21	12	25
Moore	90	160	41	16	33

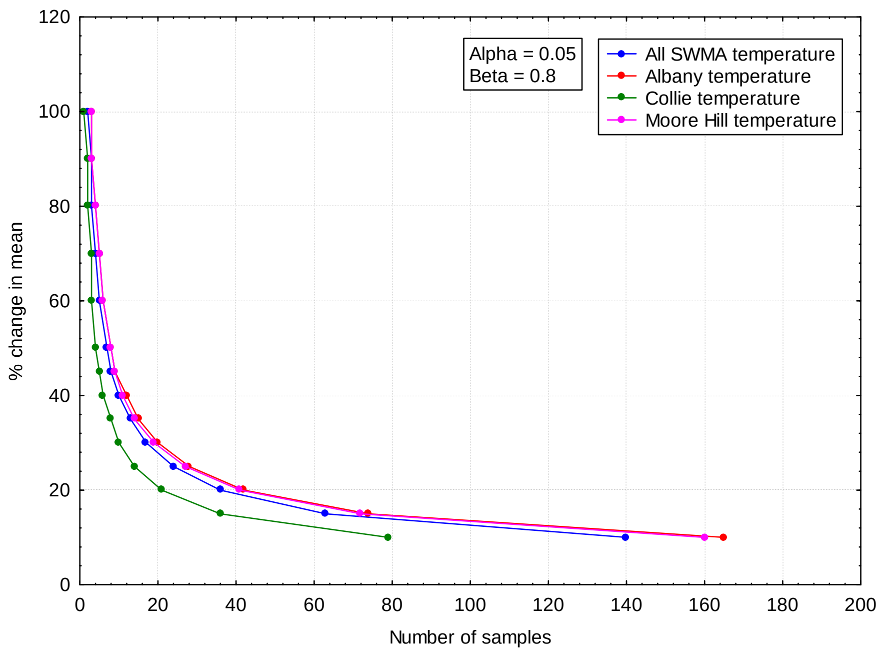

Figure 60 Power analysis results for diel temperature indicator

Diel temperature indicator in round two of the trials

As there is currently no model available which will model diel temperature, this data will continue to be collected in the field in the second round of field trials. In the second round of sampling a total of 30 reaches will be sampled in each SWMA. This number of reaches is achievable in terms of staff time conducting field work and should allow for an 80% chance of detecting a 23% change in mean over time. Where there are less than 30 reaches present in a SWMA all available reaches will be sampled (remembering that some reaches will almost certainly be dry).

While the current scoring methodology for diel temperature range could certainly do with refinement it is unlikely that there will be sufficient work done by other researchers prior to the end of this project to allow this to occur. As such, data will continue to be collected which will allow the indicator to be refined in the future as a larger dataset becomes available.

11.4 Physical form index

Not all of the indicators suggested in the inception report (van Looij & Storer 2009) were trialled and used in the overall score. Of the original indicators, channel pattern was the only one which has been used in the final score. With the exception of farm dams, this is because work on the remaining indicators is either still in progress or about to commence. Farm dams were determined as not possible to score at this stage due to their inadequate mapping in the south-west of Western Australia and they are not further discussed here.

Channel pattern indicator performance

Channel pattern indicator in round one of the trials

Power analysis was not conducted on the channel pattern indicator as scores were available for almost all reaches in the SWMAs. Whilst this indicator generally returned high scores, this is indicative of what is actually present as only small portions of the river reaches have been channelised in the SWMAs sampled. Visual inspection of the Hydrography Linear dataset suggests that the majority of channelisation occurs on minor rather than major waterways and hence do not coincide with the reaches defined for this round of trials (250K-reach).

Channel pattern indicator in round two of the trials

Whilst channelisation of the reach network was not prevalent in the SWMAs sampled it still has the potential to cause significant impacts on the physical form of rivers (and on the aquatic biota) and is a valuable indicator to retain in the south-west Western Australia FARWH. This will allow any future channelisation of reaches to be detected within the SWMAs sampled and also may be found to be more prevalent in other SWMAs in the south-west of Western Australia.

The current scoring methodology for channel pattern will be retained for the second round of field trials.

Artificial barriers to fish migration indicator performance

Artificial barriers to fish migration indicator in round one of the trials

This indicator was not used during the first round of trials as the dataset with which to calculate this indicator is not yet complete. This dataset is being compiled by a different project, and will be ready in time for the second round of trials.

Artificial barriers to fish migration indicator in round two of the trials

Scoring for this indicator has not yet been developed but is likely to involve assessing the severity of each fish barrier and assigning a score to each reach based on this severity (for example a barrier which allows no fish passage at all will be assigned a very low score). All reaches above an identified barrier will be assigned the score of that barrier (as the barriers impact will continue upstream of the reach in which it is located).

Once scoring protocols have been developed a retrospective analysis of the SWMAs included in this first round of trials will be conducted.

Sedimentation indicator performance

Sedimentation indicator in round one of the trials

Work is about to commence on evaluating the use of the SedNet model in the south-west of Western Australia. As modelled results were not available for this round of trials, field observations on the severity of bank erosion at each sampling site were used instead.

The number of samples collected overall and within each SWMA was found to be able to detect between a 23% and 62% change in the mean over time, as can be seen in Table 19, and Figure 61. Clearly, a detection of 63% change is not particularly useful when conducting an assessment.

Table 19 Power analysis results for erosion indicator

SWMA	Number of reaches in SWMA	Number of samples to detect 10 % Δ in mean	Number of samples to detect 20 % Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Combined	123	268	68	52	23
Albany	101	196	50	24	29
Collie	22	105	27	12	31
Moore	90	588	148	16	62

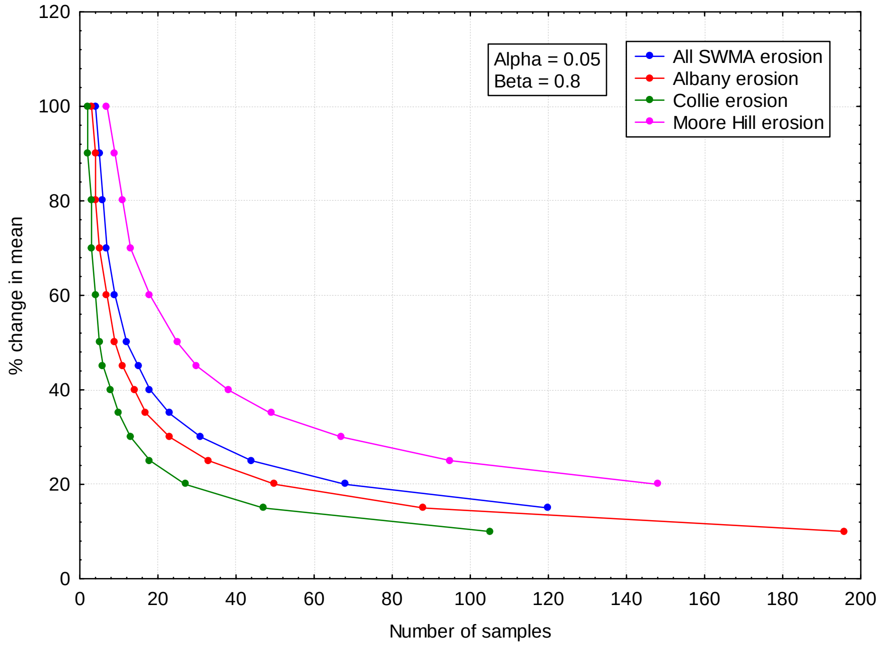

Figure 61 Power analysis results for erosion indicator

Sedimentation indicator in round two of the trials

Work will shortly commence on trialling the SedNet model in the south-west of Western Australia. If SedNet is found to be effective then the modelled results will be used for future assessments. This will allow a sedimentation score to be determined for every reach in a SWMA.

Field observations will continue to be recorded in the second round of field trials as they provide good interpretive data for management, even if not suitable in themselves for scoring. Due to the high number of samples required per SWMA to allow a meaningful change in the mean to be detected over time for the erosion indicator, this indicator will not be used for calculating scores in the second round of trials.

11.5 Fringing zone index

Both of the indicators suggested in the inception report (van Looij & Storer 2009) were trialled and used in the overall FZI score.

Longitudinal continuity indicator performance

Longitudinal continuity indicator in round one of the trials

As this indicator was assessed using spatial data it was possible to calculate scores for every reach in the SWMAs included in these trials. Therefore no power analysis was conducted on the scores. This indicator proved to be both easy to assess and showed a good degree of variation.

Longitudinal continuity indicator in round two of the trials

The longitudinal continuity indicator will remain, unchanged in the second round of trials.

Fringing zone width indicator performance

Fringing zone width indicator in round one of the trials

As this indicator was assessed using spatial data it was possible to calculate scores for every reach in the SWMAs included in these trials. Therefore no power analysis was conducted on the scores. This indicator proved to be both easy to assess and showed a good degree of variation.

Fringing zone width indicator in round two of the trials

The fringing zone width indicator will remain, unchanged in the second round of trials.

11.6 Aquatic biota index

Not all of the indicators suggested in the inception report (van Looij & Storer 2009) were trialled and used in the overall score. A fish and crayfish indicator was developed and used in the final scoring. A number of macroinvertebrate indicators were tested but only one, the AUSRIVAS score was found to be both possible to calculate as well as returning a range of scores. The SIGNAL, number of taxa, functional feeding groups, presence of indicator species and EPT indicators were all examined and discarded and are not discussed further here.

Fish and crayfish indicator performance

Fish and crayfish indicator in round one of the trials

The number of samples collected overall and within each SWMA was found to be able to detect between a 12% and 31% change in the mean over time, as can be seen in Table 20 and Figure 62.

Table 20 Power analysis results for fish and crayfish indicator

SWMA	Number of reaches in SWMA	Number of samples to detect 10 % Δ in mean	Number of samples to detect 20 % Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Combined	123	145	37	51	17
Albany	101	230	59	23	31
Collie	22	22	6	12	12
Moore	90	131	34	16	30

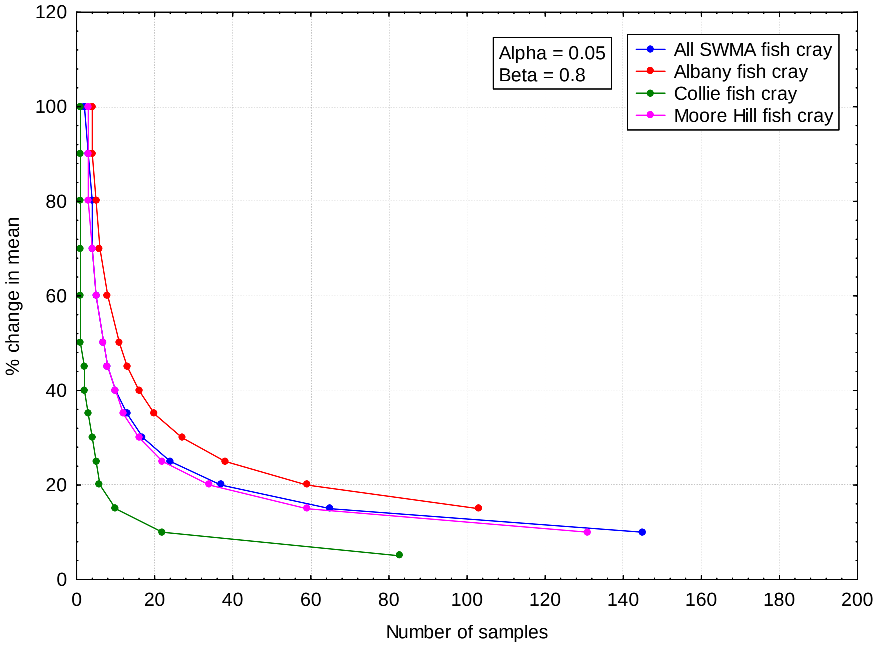

Figure 62 Power analysis results for fish and crayfish indicator

Fish and crayfish indicator in round two of the trials

The second round of field trials will continue to collect fish and crayfish samples, as was done in the first round. In the first round of field trials two fyke nets (one upstream of the sampled reach and one downstream) as well as 10 large box traps and 10 small box traps were deployed, half of the traps were baited with cat food and half with chicken pellets. The fyke nets were found to capture all fish species present at most sites (at much greater abundance than the box traps) and are therefore considered sufficient for the second round of field trials for fish. There were a number of occasions where crayfish species were caught in the box traps but not the fyke nets so trapping will also continue in the second round of trials.

During the first round of trials traps baited with both chicken pellets and dry cat food were deployed (equal numbers of both at each site). Cat food was found to be a less effective bait as it floats once waterlogged and sits against the top of the trap. There were numerous occasions where field staff observed crayfish sitting on top of traps baited with cat food, consuming the bait through the trap, and no crayfish in the actual trap. Therefore for the second round of trials only chicken pellets will be used as bait. To remain consistent with the first round of trials five large traps and five small traps will be deployed at each site (as this is the number that were deployed with chicken pellets at each site in the first round of trials).

While the power analysis has shown that ideally approximately 40 reaches (to detect a 20% change in mean) should be sampled for fish and crayfish per SWMA this number is simply not feasible in terms of staff time in the field. Therefore, 30 reaches will be sampled per SWMA, where there are less than 30 reaches present, all available reaches will be sampled (remembering that some reaches will almost certainly be dry). Power analysis will be re-done after the second round of field trials when there will be a larger dataset available with which to do it. This should give a better indication as to the number of sites required to ensure reasonable power to detect a change in the mean.

Further work will also be conducted on the fish and crayfish indicator. Some of these tasks will be outside the scope of the current FARWH project but are identified here as future required work:

- Distribution maps will be developed for the whole of the south-west and included in the final project report.
- As fish species not encountered in the first round of field trials, such as *Geotia australis* (pouched lamprey), are encountered, their inclusion as rare or common species will be determined on a case-by-case basis.
- Identification of rare species for the OE metric within the expectedness indicator was made on limited data. As more data becomes available regarding these species this metric will be refined. This will include examining the percentage change of capture of each species. This work is outside the scope of the current FARWH project.
- There were a number of sites where *Gambusia holbrooki* (mosquito fish) were observed but not collected. This is the most widespread of the exotic species in the south-west so their non-capture is problematic. Further work needs to be carried out regarding the probability of trapping this species. This is outside the scope of the current FARWH project.
- Determining the pre-European distribution of three crayfish species (*Cherax preissii, C. glaber* and *C. crassimanus*) proved to be difficult due to a paucity of literature and historical data. For this reason they do not contribute to the fish and crayfish score. As the amount of data regarding these species increases it may be possible to construct useful distribution maps which will allow their inclusion in the expectedness indicator, perhaps as a rare species.

- Currently all exotic species have the same weight applied to them for scoring. Future work may be able to determine different weightings for different species, dependent on their impact on river health and their residence time in systems. This work is outside the scope of the current FARWH project.

Macroinvertebrate (AUSRIVAS) indicator performance

Macroinvertebrate (AUSRIVAS) indicator in round one of the trials

The number of samples collected overall and within each SWMA was found to be able to detect between an 18% and 40% change in the mean over time, as can be seen in Table 21, and Figure 63.

Table 21 Power analysis results for macroinvertebrates (AUSRIVAS) indicator

SWMA	Number of reaches in SWMA	Number of samples to detect 10 % Δ in mean	Number of samples to detect 20 % Δ in mean	Number of samples collected	Actual % Δ in mean able to be detected
Combined	123	112	29	36	18
Albany	101	108	28	13	30
Collie	22	109	28	8	40
Moore	90	109	28	15	29

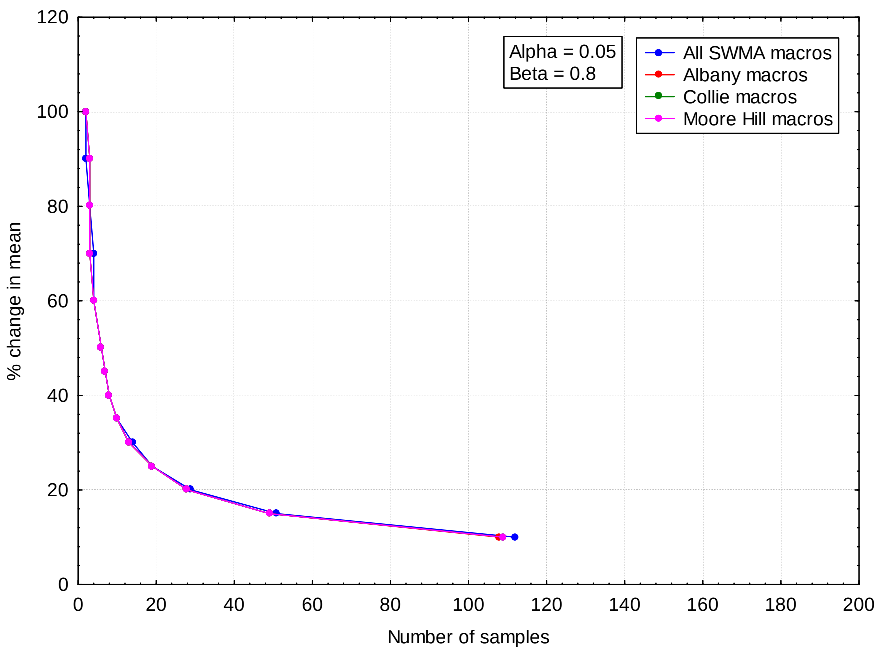

Figure 63 Power analysis results for macroinvertebrate (AUSRIVAS) indicator

Macroinvertebrate (AUSRIVAS) indicator in round two of the trials

The second round of field trials will continue to collect macroinvertebrate samples, using the same methodology as the first round. Thirty reaches will be sampled in each SWMA which will allow the detection of a 20% change in the mean over time. This number is feasible both in terms of field staff time and identification costs. Where there are less than 30 reaches present in a SWMA all available reaches will be sampled (remembering that some reaches will almost certainly be dry). Further, it is not possible to determine if a particular site will be outside the experience of the model (and therefore not possible to calculate an AUSRIVAS score) until after field work has been conducted. This is because one of the predictor variables in the current spring channel model (log maximum velocity) is a field measured variable. So, it may be possible that sites will be sampled but subsequently found not to be suitable for running through the AUSRIVAS models (as was found in this first round of trials).

To try and refine the AUSRIVAS model for the south-west of Western Australia, the possibility of constructing a new spring channel model which will use a lower level of taxonomic resolution (genus) for the orders Odonata, Plecoptera and Trichoptera will be investigated. If this model is found to be suitable then it will be used for future FARWH scoring. Work is continuing on the construction of this model.

The use of alternative indicators, such as EPT, will not be further investigated within this project. As the biology of macroinvertebrates in the south-west of Western Australia becomes better understood it may be feasible to revisit these (and other) potential indicators into the future.

11.7 Aggregation to overall SWMA score

For this round of trials the Standardised Euclidean distance, components unweighted, has been used to aggregate the individual index scores to the overall SWMA score, as per NWC 2007a. There is a second aggregation technique recommended in this document which is the Standardised Euclidean distance with inverse weighted rankings. Both methods will be trialled after the second round of field trials, both for those SWMAs sampled in the second round and those that were sampled in this first round. The final aggregation method for the south-west Western Australia FARWH will be recommended at that stage.

12 Round two sampling

12.1 SWMA selection

Five SWMAs have been identified as potential candidates for the second round of field trials. These are Denmark River, Shannon River, Busselton Coast, Preston River and Harvey River. Depending on how long field sampling in the first four SWMAs takes, the Murray River may be substituted for the Harvey River. Table 22 summarises the area and number of reaches for each of these SWMAs.

Table 22 Background information on round two SWMA candidates

SWMA	SWMA area (km^2)	Number of reaches*	Total length of reaches (km)	Shortest reach (km)	Longest reach (km)	Average reach length (km)
Denmark River	2617	21	220.26	0.26	46.49	10.49
Shannon River	3295	12	233.48	3.34	55.94	19.46
Busselton Coast	3057	18	223.99	1.14	48.94	12.44
Preston River	1135	3	117.57	24.35	59.52	39.19
Harvey River	2001	18	160.07	0.27	21.95	8.89
Murray River (Western Australia)	9941	62	942.83	0.59	53.46	15.21

* Note: these reaches have not yet been verified so the final number and lengths may vary from those shown in this table, though not significantly as the first round of trials showed.

The locations of these SWMAs can be seen in the study area map, Figure 1, in Section 1.

12.2 Reach selection

As there were generally no clear, overlying spatial patterns observed in the field collected indicator scores in the first round, there is no obvious reason to stratify sampling in any way. Therefore a completely random selection strategy will be used for selecting reaches in which to sample for the second round of trials where necessary. As there is a high probability that some reaches will be dry a larger number of reaches than required will be selected. As most of the SWMAs proposed for the second round of field trials have less than 30 reaches, all reaches which are flowing will be sampled. If time allows for the sampling of the Murray River SWMA rather than the Harvey River SWMA then a random reach selection technique will be used.

Site locations on the reaches will be determined largely by access with the proviso that they are not located immediately downstream of roads or other potential point sources of contamination. Further, where reaches are found to have dried into a series of pools these will not be sampled. This is because the ecology and processes occurring in these pools will differ from flowing waters, therefore the scoring methods developed will not be relevant to these systems.

Appendices

Discussion paper

SWMA scale assessments

The current assessment scale recommended by the NWC is the SWMA scale. In this first round of field trials three SWMAs were assessed and all returned a final FARWH score in the ‘slightly modified’ category (two SWMAs scored 0.6 and one scored 0.7). Given the size of the SWMAs encountered in the south-west of Western Australia it is unrealistic to expect a single score to adequately represent each one. Further, from a natural resource management perspective conducting assessments at the SWMA scale is meaningless as the threats and issues, and consequently management actions, will vary across the reporting scale. For a FARWH style assessment to be meaningful it needs to be conducted at a finer scale than the SWMA scale. Ideally, assessments should be reported at a range of scales, from the site to the catchment scale, to increase the relevance of any data outputs to a wide range of stakeholders.

An issue that has not been addressed in this first round of trials but which will need to be dealt with prior to conducting the 2005 assessment is SWMAs which lie across the boundary of the study area. This project aims to develop a river health assessment tool for the south-west of Western Australia. The study area is defined as all NRM regions with the exception of Rangelands. There are seven SWMAs which cross the boundary into the Rangelands NRM region. These are; Wooramel River, Murchison River, Greenough River, Yarra Yarra Lakes, Ninghan, Esperance Coast and Salt Lake. The following list shows the project teams recommendations on which to include and exclude from the study area:

- *Wooramel River – exclude*. Only a very small portion of the Wooramel River SWMA lies within the study area. This portion does not have any reaches as defined in the ARC reach dataset within it.
- *Murchison River – exclude*. While there are recognised reaches of the Murchison River within the study area there is only a very small portion of the SWMA within the study area, with the majority situated in the Rangelands NRM region.
- *Greenough River – include*. The majority of the Greenough River SWMA lies within the study area boundary. Therefore this SWMA should be included within the study area and a retrospective 2005 analysis performed.
- *Yarra Yarra Lakes – exclude*. Just over half of the SWMA lies in the Rangelands NRM region. Further, all the reaches defined in the ARC reach dataset lie within the Rangelands region with no reaches present in the study area.
- *Ninghan – exclude*. Roughly half of the SWMA lies in the Rangelands NRM region. Further, all the reaches defined in the ARC reach dataset lie within the Rangelands region with no reaches present in the study area.

- *Esperance Coast – include*. Only a very small portion of this SWMA lies outside the study area. Therefore this SWMA should be included within the study area and a retrospective 2005 analysis performed.
- *Salt Lake – exclude*. Only a minute portion of this SWMA lies within the study area and there are no recognised reaches within this area.

In this first round of the south-west Western Australia FARWH trials aggregation of index scores to the overall SWMA score has been performed using Euclidean distance with unweighted components. The feasibility of using an inverse weighting coupled with Euclidean distance will be investigated after the second round of trials to determine the most appropriate aggregation technique.

Reach definition

The ARC reach dataset has been used for this round of trials. Problems were identified with a number of reaches in the three SWMAs studied including;

- reaches being identified where there is actually a chain of wetlands
- reaches being identified in large dams (e.g. the Wellington Dam in the Collie SWMA)
- reaches being identified where none exists. Generally in this situation a reach has been inserted connecting two river systems which are not actually connected.

Therefore there is a clear need to validate the reaches prior to using them for assessment.

Another issue that was identified with the reaches is that they often do not lie on the actual streamline. This is an artefact of the methodology used in their development but does have implications for scoring certain indicators such as fringing zone width, longitudinal continuity and channel pattern. As there has often been vegetation left along river channels in areas that have otherwise been completely cleared using the ARC reaches will underestimate the amount of fringing vegetation remaining. For the purpose of this round of trials this difficulty has been addressed by reconstructing the reaches from the NATMAP 250K dataset which more closely aligns with the actual location of waterways. It is recommended that this approach be taken for all future assessments to reduce the amount of error associated with scoring. Of the indicators trialled in the first round assessment this only needs to be carried out for the fringing zone width, longitudinal continuity and channel pattern indicators. A final list of indicators to which this applies will be compiled and included in the final report.

Indicators

Catchment disturbance index

In this round of trials the CDI and its component indicators were all assessed at the whole-of-SWMA scale.

Infrastructure measure

While the infrastructure measure showed no differentiation between the three SWMAs assessed (all three returned a score of 1) it will be retained in the second round of trials in its current form. There are two reasons for this; firstly the three SWMAs assessed in this round of trials had limited infrastructure present, therefore returning high scores (this will be true of most SWMAs in the south-west of Western Australia). However, if the level of infrastructure increases into the future (or if SWMAs with more infrastructure such as Swan Coast are assessed) then this indicator may start returning more useful scores at the SWMA scale. The second reason for retaining this indicator is that when calculated and reported at the sub-catchment scale there is likely to be more distinction between scores so it will be useful at this scale. Therefore, this indicator will be retained in its current form but will be assessed at the sub-catchment scale.

Land cover change measure

As with the infrastructure measure, the land cover change measure returned identical scores for all SWMAs assessed (a score of 1). This indicator will be retained in its current form for the second round of trials. It is likely that there will be greater differentiation between scores when they are calculated at the sub-catchment level (the overall SWMA scores will remain the same but the individual sub-catchment scores are likely to vary). Therefore it will be a useful assessment tool at the sub-catchment scale. Further, if large scale clearing were to occur in a SWMA then this indicator will become very useful.

Land-use measure

The land-use measure showed the greatest differentiation between SWMAs of the three indicators that make up the CDI. It will remain, unchanged, in the second round of trials but will be calculated at the sub-catchment scale as this scale is more relevant to local managers.

Water quality and soils index

Generally the WQI performed well in the first round of trials.

Total nitrogen

In the first round of trials spot measurements of TN were used for scoring. This limited the number of reaches that could be assigned TN scores, as many reaches were not sampled. Further, there are potential issues associated with spot measurements; it is possible that a particular concentration returned will be unusually high, or low, for a site. At an SWMA scale assessment this will often not be a problem as the effect of any outliers will be ameliorated by the remaining scores. In the second round of trials the scoring methodology will be retained however the SedNet model will be trialled to see if it is appropriate for use in the south-west of Western Australia. If it is found to be useful then modelled TN concentrations will be used for scoring.

Total phosphorus

In the first round of trials spot measurements of TP were used for scoring. This limited the number of reaches that could be assigned TP scores as many reaches were not sampled. Further, there are potential issues associated with spot measurements, it is possible that a particular concentration returned will be unusually high, or low, for a site. At an SWMA scale assessment this will often not be a problem as the effect of any outliers will be ameliorated by the remaining scores. In the second round of trials the scoring methodology will be retained however the SedNet model will be trialled to see if it is appropriate for use in the south-west of Western Australia. If it is found to be useful then modelled TP concentrations will be used for scoring.

Turbidity

The turbidity indicator was assessed using spot measurements of turbidity in the first round of trials. This limited the number of reaches that could be assigned a turbidity score as many reaches were not sampled. As there are currently no modelling approaches suitable for turbidity measurement the turbidity indicator data collection and scoring will remain, unchanged in the second round of trials.

Electrical conductivity (salinity)

In the first round of trials the salinity indicator was assessed using modelled data. As long as this data remains relatively current it will continue to be used. If FARWH style assessments continue after the life of the current project it will become necessary to re-model salinity concentrations. For the second round of trials the salinity indicator data collection and scoring will remain, unchanged.

Diel dissolved oxygen

Diel dissolved oxygen was measured in the field for the first round of trials. As there are no appropriate models that can be used to determine diel dissolved oxygen concentrations, field based data collection will continue in the future. The diel dissolved oxygen indicator data collection and scoring will remain, unchanged in the second round of trials.

Diel temperature

In the first round of trials diel temperature readings were taken in the field for scoring. As there are no appropriate models for determining diel temperature levels, field based data will continue to be used in the future. Whilst the scoring of this indicator is currently coarse, the continued collection of data will allow a more robust scoring methodology to be constructed in the future. This will be outside the scope of the current project. The current scoring method will therefore be used in the second round of trials.

Physical form index

The PFI did not perform very well in the first round of trials. This was due to the indicators scored and it is hoped that this will improve as more indicators are scored in the second round of trials.

Channel pattern

Channel pattern was scored using the Hydrography linear dataset. Generally areas that have been channelised lie outside the reaches and are therefore not detected by this indicator. This is a limitation of the coarse-scale of reach definition rather than the actual indicator. The same dataset and scoring methods will be used in the second round of trials.

Artificial barriers to fish migration

This indicator was not scored in the first round of trials as the database with which it will be scored is not yet complete. The database is being developed as part of another project and will be available for use in September 2009. At this time a scoring method will be developed and a retrospective assessment done for the SWMAs included in the first round of trials.

Presence of farm dams

Due to a lack of suitable data on farm dam locations and dimensions this indicator was not developed. It will be removed from future south-west Western Australia FARWH trials.

Sedimentation

In the first round of trials this indicator was scored using field based observations on bank erosion. This method was not very powerful, in that a large number of sites need to be assessed to provide a reasonable confidence in the overall SWMA score. This indicator is not useful in its current form. During the second round of trials SedNet will be assessed to determine its usefulness in the south-west of Western Australia. If it is found to be useful then a scoring method will be constructed based on the sedimentation information it provides.

Fringing zone index

In this round of trials the FZI and its components were all assessed using remotely sensed data. It therefore provided scores for all reaches present in each SWMA.

Longitudinal continuity

This indicator was assessed using remotely sensed data and was found to perform well. The only limitation to this indicator was the need to reconstruct the reaches from the NATMAP 250K dataset. This was done because of the disparity between the spatial location of the ARC reaches and the actual waterways which was going to cause an underestimation of the longitudinal continuity score. While transcribing the reaches is a time consuming process it should not need to be repeated once a

SWMA has been done. The longitudinal continuity indicator will remain, unchanged for the second round of trials.

Fringing zone width

This indicator was assessed using remotely sensed data and was found to perform well. The only limitation to this indicator is the need to reconstruct the reaches from the NATMAP 250K dataset. This was done because of the disparity between the spatial location of the ARC reaches and the actual waterways which was going to cause an underestimation of the fringing zone width score. While transcribing the reaches is a time consuming process it should not need to be repeated once a SWMA has been done. The fringing zone indicator will remain, unchanged for the second round of trials.

Aquatic biota index

The ABI generally worked well in the first round of trials. It was assessed using field collected data so scores were only available for those reaches that were visited during the field trials.

Fish and crayfish

The fish and crayfish indicator was scored using field collected data. In the first round of field trials two fyke nets and 20 box traps (10 large and 10 small) were deployed at each site. The traps were baited with both cat food and chicken pellets (half of each). The cat food was found to be a less effective bait than the chicken pellets because of its propensity to float once waterlogged allowing crayfish to access the bait from outside the trap and reducing trapping efficiency. For the second round of field trials only chicken pellets will be used as bait and the same number of traps deployed (so five large and five small).

There were a few issues with scoring, predominantly associated with trying to define pre-European distribution for species as there is limited historical data and published information available and the biology of many south-west species is poorly understood. Hence the distribution maps that will be presented in the final report will be considered the best available and will need updating as more information regarding the biology of fish and crayfish species becomes available. Other recommendations have been made regarding future refinements of the fish and crayfish indicator score, these can be found in Section 11.6 but are not repeated here as they are outside the scope of the current project.

The number of samples required to be 80% sure of detecting a 20% change in mean was quite high (37 when looking at the combined SWMA data). Collecting this number of samples within each SWMA is not feasible due to time constraints. For this reason 30 samples will be collected per SWMA and the power analysis re-run after the second round of field trials when a larger dataset will be available with which to compute it.

Macroinvertebrates

The macroinvertebrate indicator was assessed using field collected data and the existing spring channel AUSRIVAS model. A number of the sites sampled were outside the experience of the model and so it was not possible to calculate a macroinvertebrate score for those sites. Work has begun on developing a spring channel AUSRIVAS model for the south-west of Western Australia which will use the current level of taxonomic resolution for all taxa except Odonata, Plecopteran, and Trichopterans which will all be identified to genus. It is hoped that by identifying these generally sensitive groups to a lower level of taxonomic resolution a more robust model will be developed. If this model proves to be useful then it will be used for the second round of trials.

Summary of recommendations

- Assessments at the SWMA are too broad. It is recommended that assessments be reported at a range of scales, from the site to the catchment scale. This will ensure that the outputs of the FARWH will be relevant to a wide range of stakeholders.
- The list below shows which of For The seven SWMAs which lie partially within the study area and partially within the Rangelands NRM region include/exclude them as follows:
    - Wooramel River – exclude
    - Murchison River – exclude
    - Greenough River – include
    - Yarra Yarra Lakes – exclude
    - Ninghan – exclude
    - Esperance Coast – include
    - Salt Lake – exclude.
- After the second round of trials, investigate applying an inverse weighting to index scores when aggregating to the overall SWMA score.
- Prior to conducting any assessment the ARC reaches need to be validated.
- Prior to assessing the fringing zone width, longitudinal continuity and channel pattern indicators the validated ARC reaches need to be reconstructed from the NATMAP 250k dataset. This layer should then be used for the assessment.
- Retain the infrastructure indicator in its current form but assess it at the sub-catchment scale.
- Retain the land cover change indicator in its current form but assess it at the sub-catchment scale.
- Retain the land-use indicator in its current form but assess it at the sub-catchment scale.
- Retain the current method of scoring the total nitrogen indicator, but assess the usefulness of SedNet for determining TN concentration in the south-west of Western Australia. If SedNet is found to be useful then use modelled concentrations for scoring.

- Continue to collect TN samples, to assist with model validation.
- Retain the current method of scoring the total phosphorus indicator, but assess the usefulness of SedNet for determining TP concentration in the south-west of Western Australia. If SedNet is found to be useful then use modelled concentrations for scoring.
- Continue to collect TP samples, to assist with model validation.
- Continue to collect diel temperature data and use the existing scoring method. As more data becomes available in the future, re-assess the scoring method used.
- Retain the channel pattern indicator in its current form.
- Develop the artificial barriers to fish migration indicator once the fish barrier dataset becomes available in September Conduct a retrospective assessment for the three SWMAs assessed in the first round of trials.
- Investigate the applicability of SedNet for assessing sedimentation to the south-west of Western Australia. If it is found to be useful then develop a scoring method around the outputs of the model for the sedimentation indicator.
- Retain the longitudinal continuity indicator, unchanged, for the second round of trials. To do so will require reconstruction of reaches from the NATMAP 250K dataset.
- Retain the fringing zone indicator, unchanged, for the second round of trials. To do so will require the reconstruction of reaches from the NATMAP 250K dataset.
- Retain the fish and crayfish scoring method, unchanged, for the second round of trials. Modify the field sampling so that two fyke nets and five large and five small box traps are deployed at each site using chicken pellets as bait for the traps. Re-run the power analysis after the second round of trials when a larger dataset will be available.
- Retain the macroinvertebrate data collection and scoring method for the second round of field trials. Continue to develop the new south-west Western Australia AUSRIVAS model using genus level identification for Odonata, Trichoptera and Plecopterans and, if this is found to be more useful than the current model, use this for calculating the AUSRIVAS scores in the second round of trials.

Shortened forms

ABI	aquatic biota index
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
CDI	catchment disturbance index
DEC	Department of Environment and Conservation
DO	dissolved oxygen
EPT	orders Ephemeroptera, Plecoptera and Trichoptera.
FARWH	Framework for the assessment of river and wetland health
Flex	presence of exotics in absence of natives
FZI	fringing zone index
HCI	hydrological change index
NATMAP 250K	National Topographic Map Series 1:250 000 Scale
NLWRA I	National Land and Water Resource Audit mark I
NRM	natural resource management
OE	observed to expected ratio
OP	observed to predicted ratio
P_{Ab}	proportion native abundance
PFI	physical form index
P_{Sp}	proportion native species
RHAS	River Health Assessment Scheme
SWMAs	surface water management areas
TN	total nitrogen
TP	total phosphorus
WIN	Department of Water's water information network
WQI	water quality index

Disclaimer

The maps in this publication were produced by the Department of Water with the intent that they be used in this report only. While the Department of Water 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 of Water acknowledges the following datasets and their custodians in the analysis of data and the production of the maps:

Dataset name	Custodian	Metadata year
Australia – Assessment of River Condition (Reach) 2001	DEWHA	2008
Australian Coastline, WRC	DOW	2006
Australian Surface Water Management Areas (ASWMA) 2000	GA	2000
CALM Operational Graphic Trails	DEC	2005
Farm Dams	DOW	2008
Hydrography Linear	DOW	2006
Hydrography Points	DOW	2006
Hydrography, Linear (Hierarchy)	DOW	2007
Hydrography, Linear (Hierarchy)	DOW	2007
Land Monitor Vegetation Change Products: Lm50_south_VegMask_2003_mga Lm50_nwest_VegMask_2003_mga And equivalents to 2007	Landgate	2008
Land Use in Western Australia, Version 5	DAFWA	2001
Natural Resource Management (NRM) Region Boundaries	DEWHA	2006
Railways – WA State	Landgate	2000
Rivers from National Topographic Map Series 1:250 000 Scale (NATMAP 250K)	GA	1997

Dataset name	Custodian	Metadata year
Road Centrelines DLI	Landgate	2008
WA Petroleum Pipelines	DMP	2005
Western Australia Towns	Landgate	2001

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):

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