Alignment of state and national river and wetland health assessment needs

September 2011

Queensland Government

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Australian Government

National Water Commission

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List of Equations

For ease of referencing, equation numbering follows that of the source document.

Equation number	Equation	Reference	Pg
1	$\text{Score}_{ij} = 1.0 - \left\| \frac{(x_{ij} - \text{Guideline}_{ij})}{(\text{WCS}_{ij} - \text{Guideline}_{ij})} \right\|$ Where: Xij is the value of the index i at a site within stream class j, Guidelineij is the corresponding 'guideline/reference' value, and WCSij is the corresponding 'worst case scenario' value.	EHMP 2003	26
2	$S' = \text{Score}_{ij} \left\| \left(1 / \sum p_{ij}\right) p_{ij} \right\|$ Where: S'is the catchment area or reach length weighted score, Scoreij is the unweighted score for index i in sample population j, pij is the catchment area or reach length for index i in sample population j.	NWC 2007a	26
3	TScore = 1- (√ (1 – A)2 + (1 - B) 2 + (1 – C) 2 + . . . + (1 – X)2 / √ n) Where: TScore is the trial score, and A, B, C,…, X are the theme scores, and n is the number of theme scores	NWC 2007a	27
10	CDI = I + LC + LU – 2 Where: CDI = Catchment Disturbance index, I = infrastructure measure, LC = land cover change, and LU = land use measure	NWC 2007a	27

Abbreviations and acronyms

ABMAP	Ambient Biological Monitoring and Assessment Program
ACTFR	Australian Centre for Tropical Freshwater Research
AECM	Aquatic Ecosystems Conceptual Models (project)
AQEIS	Aquatic Ecosystems Information System
AS/NZS 4360:2004	Australian Risk Management Standard
AusRivAS	Australian River Invertebrate Assessment System
AWR	Australian Water Resources
AWRIS	Australian Water Resources Information System
BOM	Bureau of Meteorology
C	Carbon
CO2	Carbon dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital Elevation Model
DERM	Department of Environment and Resource Management
DEWHA	Commonwealth Department of Environment, Water, Heritage and the Arts
DIBM3	Design and Implementation of Baseline Monitoring – Stage 3
DIN	Dissolved inorganic nitrogen
DIP	Dissolved inorganic phosphorus
DO	Dissolved oxygen
EC	Electrical conductivity
EHMP	Ecosystem Health Monitoring Program
EPA	Environmental Protection Agency
EPT or PET	Sensitive taxa: Ephemeroptera (mayfly), Plecoptera (stonefly), Trichoptera (caddisfly)
ESCAWRI	Executive Steering Committee for Australian Water Resources Information
FARWH	Framework for the Assessment of River and Wetland Health
FFG	Functional Feeding Groups
GBR	Great Barrier Reef
GIS	Geographic Information System
GLM	Generalised Linear Model
GPP	Gross Primary Production
GRTS	Generalised random-tessellation stratified (site selection method)

IQQM	Integrated Quantity and Quality Model
ISO 9001:2000	The International Standardisation Organisation Standard for Quality Management Systems
LEBRA	Lake Eyre Basin Rivers Assessment
LIDAR	Light Detection and Ranging
LWD	Large Woody Debris
MTSRF	Marine and Tropical Sciences Research Facility
MVG	Major Vegetation Groups
N	Nitrogen
NLWRA	National Land and Water Resources Audit
NRHP	National River Health Program
NRW	Natural Resources and Water
NRM	Natural Resource Management
NVIS	National Vegetation Information System
NWC	National Water Commission
NWI	National Water Initiative
O/E50	Ratio of observed to expected native species
O2	Oxygen
P	Phosphorus
PONSE	Percentage of native species expected – fish indicator
PPE	Personal Protective Equipment
PRAM	Pressure Risk Assessment Method
PSR	Pressure, stressor, response
QHSS	Queensland Health Forensic and Scientific Services (Queensland Government)
QLUMP	Queensland Land Use Mapping
QMS	Quality Management System
R24	Respiration over a 24 hour period
RNWS	Raising National Water Standards program
ROP	Resource Operating Plan
SEAP	Stream and Estuarine Assessment Program
SedNet	Sediment Network (a model that constructs sediment budgets for river networks)
SIGNAL	Stream Invertebrate Grade Number – Average Level
SLATS	State wide Land cover and Trees Study (DERM database)

SRA	Sustainable Rivers Audit
STP	Sewage Treatment Plant
SWAN	Surface Water Ambient Network
SWMA	Surface water management area
TOIL	Time off in lieu
WQ&M	Water quality and monitoring
WRP	Water resource plan

Executive summary

This project on aligning state and national river and wetland health assessment needs, which was conducted over three years, trialled the Framework for Assessment of River and Wetland Health (FARWH) over four different regions in Queensland: Central Queensland, South East Queensland, the Wet Tropics, and Lake Eyre Basin. These areas represent different types of ecosystems found within Queensland and northern Australia.

Within the these four regions specific surface water management areas (SWMAs) were selected for trial reporting and, where possible, the FARWH was compared against existing state-based monitoring programs with the aim of examining correlations and redundancies. The selected regions and trial SWMAs within them were chosen not only on the basis of the planned work of the state programs, but also specifically to provide a contrast between SWMAs with a significant variation in size, climate, geomorphology and other ecological attributes.

In year 1 of the project the Pioneer and Burdekin SWMAs in Central Queensland and the Moreton SWMA in South East Queensland were chosen for trialling. The FARWH was trialled against the existing Queensland Stream and Estuarine Assessment Program (SEAP) in Central Queensland and against the Ecosystem Health Monitoring Program (EHMP) in South East Queensland. In year 2 of the project the Tully SWMA in the Wet Tropics and Cooper Creek SWMA in the Lake Eyre Basin were selected. The FARWH was once again trialled against the SEAP in the Tully SWMA as part of the SEAP assessment of the Wet Tropics bioprovince.

Within the Cooper Creek SWMA in the Lake Eyre Basin no concurrent monitoring program was underway, however the Lake Eyre Basin River Assessment (LEBRA) – which is under development – was used to guide the selection of appropriate indicators. Within this report correlations and redundancies between the FARWH and those monitoring programs are examined. The aim is to recommend improvements to enable the FARWH to use statewide assessment data, or to facilitate Queensland including FARWH assessments within its current programs.

Field trials were conducted in all SWMAs using, where appropriate, a referential approach and by applying FARWH guidelines for data standardisation as outlined in NWC (2007). The guidelines recommend determining the health of aquatic ecosystems using indicators under six themes: Fringing Zone, Catchment Disturbance Index (CDI), Aquatic Biota, Water Quality and Soils, Hydrological Disturbance and Physical Form. Condition was assessed for each trial SWMA for the defined FARWH baseline year of 2004–05 using available datasets for that time period, and for the current era (when the field trials were undertaken) using a combination of indices derived from field sampling, remote sensing or modelling. Assessments were generally consistent between programs and between the baseline and current era.

In the Central and Wet Tropics field trials SEAP methods were successfully applied at the SWMA scale and supplementary sampling was done to complete a suite of FARWH themes that were then integrated to form an overall assessment. Not all themes were able to be assessed due to a lack of available data or issues associated with data confidence.

Due to the low spatial density of appropriate data, the potential to use SEAP data collected at the province scale for a FARWH assessment was limited without supplementary sampling. This was apparent for both the baseline and current era assessments. This limitation was primarily due to the state-level monitoring program's spatial scales. The pressure-stressor-response framework behind SEAP was also noted as a significant difference that hampers the compatibility of the two programs.

The South East Queensland trial proved the EHMP's ability to fulfil the Water Quality and Soils and Aquatic Biota themes for a FARWH assessment on an annual basis. The trials proved that a remote sensing/modelling-based approach could provide Fringing Zone, CDI and Hydrological Disturbance themes without using significant resources to satisfy national reporting requirements.

Within the Lake Eyre Basin trial the FARWH assessment program was successfully designed and implemented using guidance from the proposed LEBRA implementation plan, relevant literature and expert opinion. It is expected that data collected through the LEBRA in the future, supplemented with modelled or remotely sensed data available through DERM sources, would be able to satisfy the needs of a national assessment.

Obtaining a valid reference condition for many indicators was problematic in nearly all of the field trials. Where setting reference condition required data from reference sites, which was the key component for setting reference in

Queensland (partly based on the current SEAP methodology), the number of sites found to be in reference condition based on our site-specific reference criteria was below that required under our sampling protocol.

Widening the pool of reference sites to those outside the target SWMA but from similar aquatic ecosystem types worked well in the Central and particularly the Wet Tropics trials. It is recommended that further work be conducted on the setting of reference condition.

The use of remote sensing techniques is integral to enabling the collection of data across large areas. Work conducted as part of these trials has validated the accuracy of remote sensing techniques, particularly in assessing aspects of riparian vegetation cover for the Fringing Zone theme compared with a field-based assessment. Remote sensing costs are also much reduced compared with a field-based program when using existing datasets. It is felt the high costs associated with an on-ground assessment program for the other FARWH themes prevent an annual or regular short-term statewide FARWH assessment being implemented in Queensland at the SWMA level, within the current resource environment. Future investigation into the use of remote sensing techniques for other indicators under different themes is an essential step to fulfil the needs of a national reporting program. However, in the absence of seamless state-wide LIDAR coverage, remote sensing only has the capacity to provide information on a limited number of themes and indicator types over a large jurisdiction such as Queensland.

1 Background

1.1 FARWH need and development

The Australian Water Resources (AWR) 2005 project was one of several projects funded to improve knowledge of our national water resources under the Australian Government's Raising National Water Standards (RNWS) program. The project had three components: water availability, water use, and river and wetland health.

Under the river and wetland health component, the National Water Commission (NWC) funded development of a national Framework for Assessment of River and Wetland Health (FARWH), with the aim to use existing river and wetland health assessments.

The project document, A framework for comparative assessment of the ecological condition of Australian rivers and wetlands (NWC 2007a), was developed to provide methods for comparing and integrating existing river and wetland health outputs to facilitate national reporting from comparable state, territory and regional NRM assessments. The FARWH incorporates a range of river and wetland attributes indicative of key ecological processes that can be aggregated to provide an index. This information will then help managers to '…assess and develop policies, decide on investments, evaluate program and policy performance, and direct resource management…' (NWC 2007a).

The FARWH is based on the premise that ecological integrity is the fundamental measure of river and wetland health and, although the ultimate measure of that integrity is damage to biota, other components of ecosystems are just as important, and should be included in an assessment of ecosystem health. It recommends selecting indicators under six themes: Catchment Disturbance, Physical Form, Hydrological Disturbance, Water Quality and Soils, Fringing Zone, and Aquatic Biota, although the selection of specific indicators is left to the discretion of the investigator. The ecological basis of condition indicator selection should be derived from conceptual models that identify key ecological and physical drivers and pressures. Individual wetlands and reaches must be understood in terms of their physical, biological and chemical processes, and indicators should be selected to reflect the changes that may occur under different impacts.

An accompanying document, Assessment of river and wetland health: potential comparative indices (NWC 2007b), provides methods for indicators that may be used under the six themes. Many of these were developed for the National Land and Water Resources Audit I (1997–2002) and were specifically related to rivers, although more contemporary indicators developed for the Sustainable Rivers Audit, the Index of Stream Condition and other programs are also included. A referential approach will be used to assess each indicator and the resulting indices will be aggregated to generate scores that can be reported and compared at the state and/or national level.

1.2 Addressing NWI objectives

The NWC is managing implementation of the National Water Initiative (NWI), which has been signed by the Australian and all state and territory governments. It is Australia's blueprint for national water reform to improve water management across the country. The NWI's overall objective is to achieve a nationally compatible market, regulatory and planning based system of managing surface and groundwater resources for rural and urban use that optimises economic, social and environmental outcomes.

The NWI's objectives are supported by the Australian Government's $250 million RNWS program. The RNWS supports implementation of the NWI by funding projects that are improving Australia's national capacity to measure, monitor and manage our water resources.

This project, 'Alignment of state and national river and wetland health assessment needs' (aka Qld FARWH trials), is being undertaken by Queensland's Department of Environment and Resource Management (DERM). It has trialled the framework by testing it against current monitoring programs in Queensland, examining correlations and redundancies between them, and recommending improvements to facilitate the FARWH's ability to use statewide assessment data, or for the state to modify its programs. It will report to the NWC, which will then consider the framework's national applicability.

1.3 Description of FARWH trials undertaken

The project has trialled the framework over four different regions in Queensland: Central Queensland, South East Queensland, the Wet Tropics, and Lake Eyre Basin. These areas represent different types of ecosystems found within Queensland and northern Australia.

Within the trial regions, specific surface water management areas (SWMAs) were selected for study and, where possible, the FARWH was trialled against existing state-based monitoring programs (with the aim to examine the correlations and redundancies between them). The study regions and trial SWMAs within them were chosen not only on the basis of the planned work of the state programs, but also specifically to provide a contrast between SWMAs with a significant variation in size, climate, geomorphology and other ecological attributes.

As such, it is hoped the results from these trials will inform the Queensland Government, other jurisdictions and the NWC on the applicability and usefulness of the framework as a national reporting tool within the scope of Queensland's state and regional programs, and will link into future river and wetland health reporting frameworks under the Australian Water Resource Information System (AWRIS).

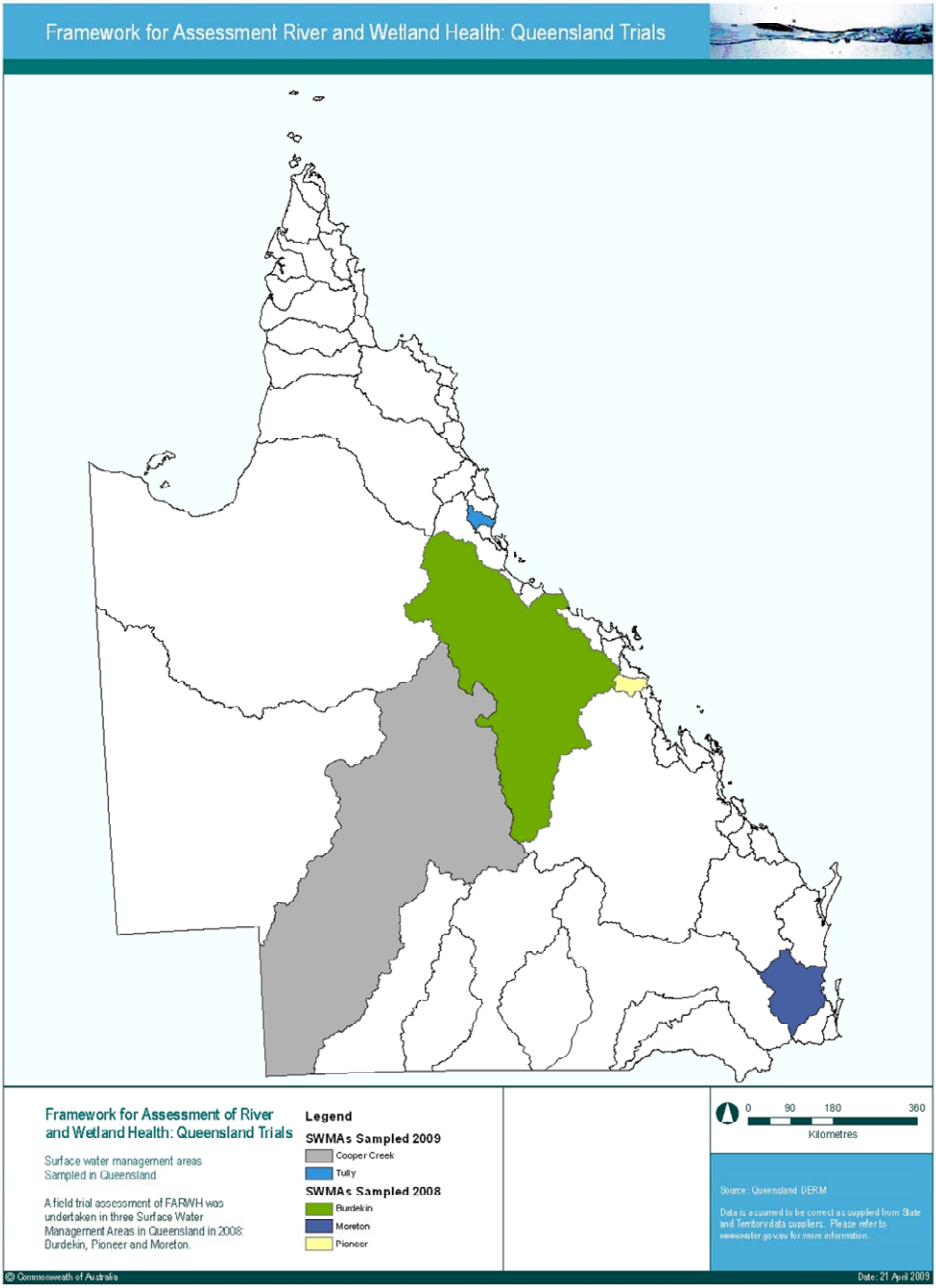

Figure 1. Surface water management areas evaluated as part of the Qld FARWH trials

2 Summary of approaches used in trials

This section provides an overview of the approaches used during the Qld FARWH trials. Specific detail on each field trial is provided in the year 1 and 2 trial reports and also in the client reports produced by CSIRO CMIS as part of this project (listed and hyperlinked in Appendix 1 of this report).

2.1 Extent and distribution of coverage of assessment

The chosen areas for study in year 1 were the Pioneer and Burdekin SWMAs in Central Queensland (Figure 2) and the Moreton SWMA in South East Queensland (Figure 3). The FARWH was trialled against the Stream and Estuarine Assessment Program (SEAP) in Central Queensland and Ecological Health Monitoring Program (EHMP) in South East Queensland. Aquatic ecosystem conditions in the three SWMAs were assessed for the baseline year of 2004–05 as specified within the schedule for this project, as well as the current era of 2008.

The chosen areas for study in the year 2 trials were the Tully SWMA in the Wet Tropics (Figure 4) and Cooper Creek SWMA in the Lake Eyre Basin (Figure 5). The FARWH was once again trialled against the SEAP in the Tully SWMA as part of the SEAP assessment of the Wet Tropics bioprovince. Within the Cooper Creek SWMA in the Lake Eyre Basin no concurrent monitoring program was underway with which to directly compare results. However the proposed Lake Eyre Basin River Assessment (LEBRA) – which is under development – was used to guide the selection of appropriate indicators. Once again assessments were made of these SWMAs for the FARWH baseline year of 2004–05 and the current era of 2009.

Where possible, as a comparison for the current era assessment, a FARWH-style assessment was also made using only data available from existing state programs – without the inclusion of any supplementary field-based data collected as part of the FARWH trials. This was conducted with the aim of assessing the potential for existing state programs to fulfill the needs of the FARWH. This was undertaken for the Pioneer, Burdekin and Tully SWMAs.

Figure 2. Burdekin and Pioneer SWMAs in Central bioprovince

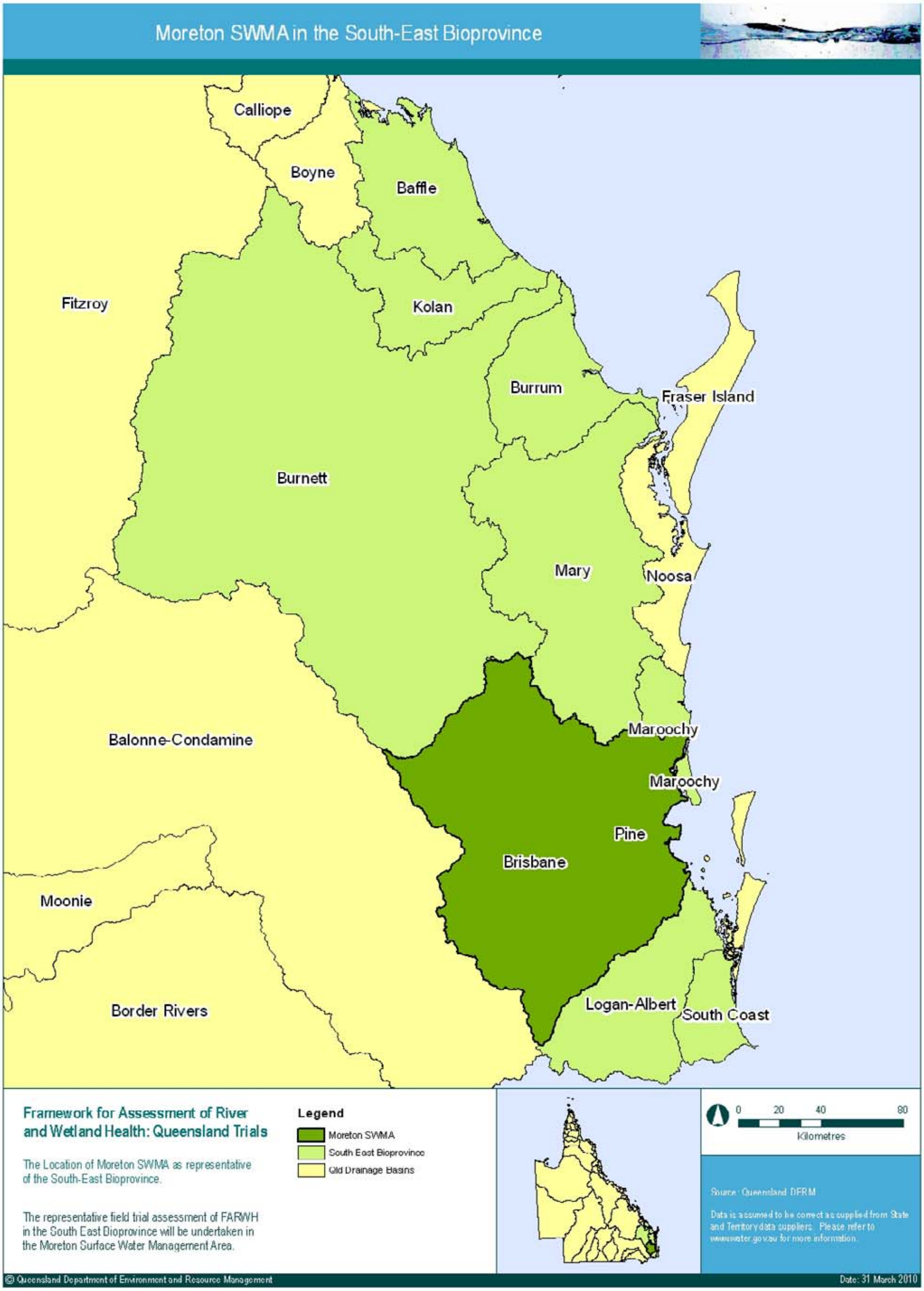

Figure 3. Moreton SWMA in South East bioprovince

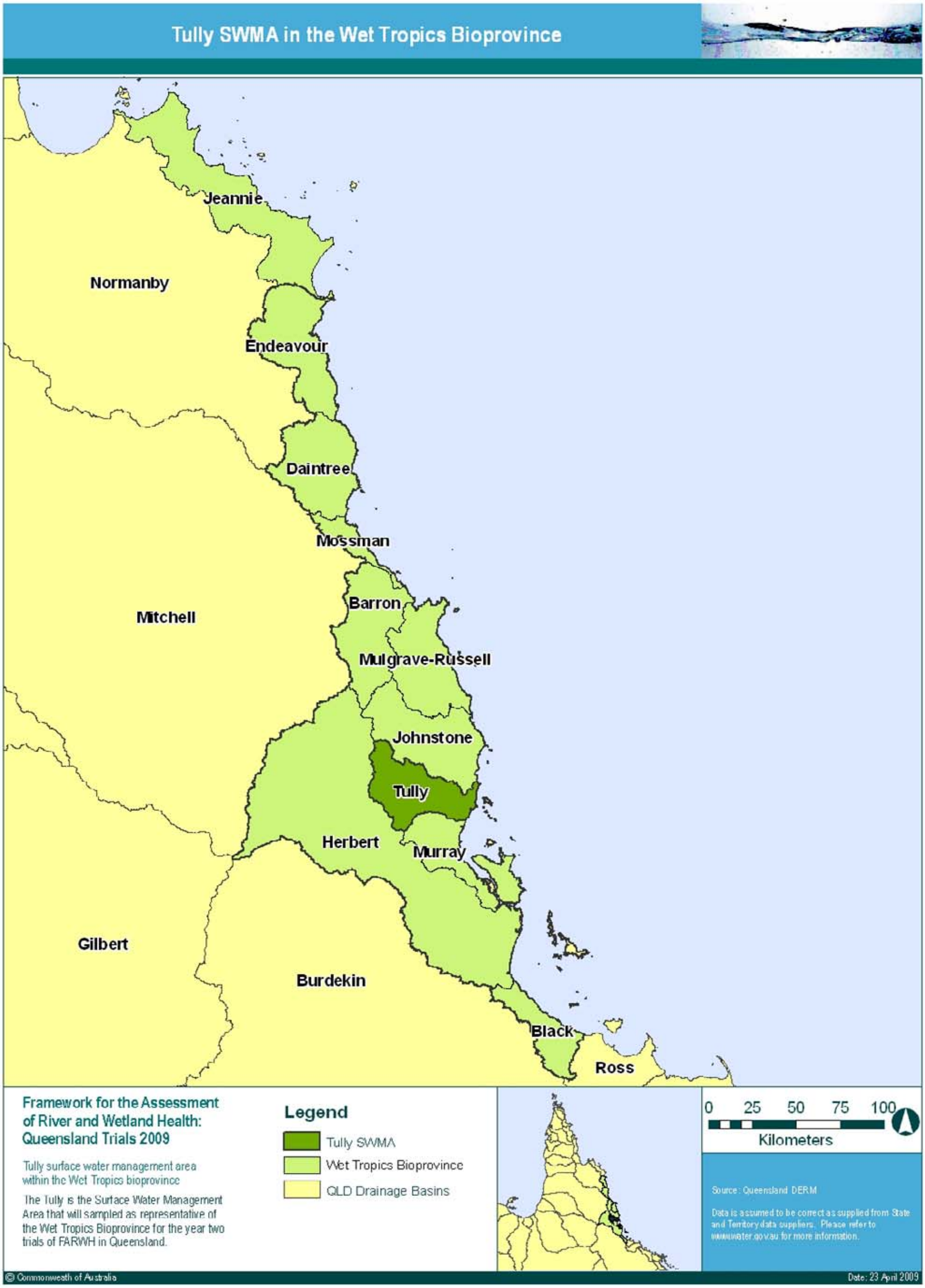

Figure 4. Tully SWMA in Wet Tropics bioprovince

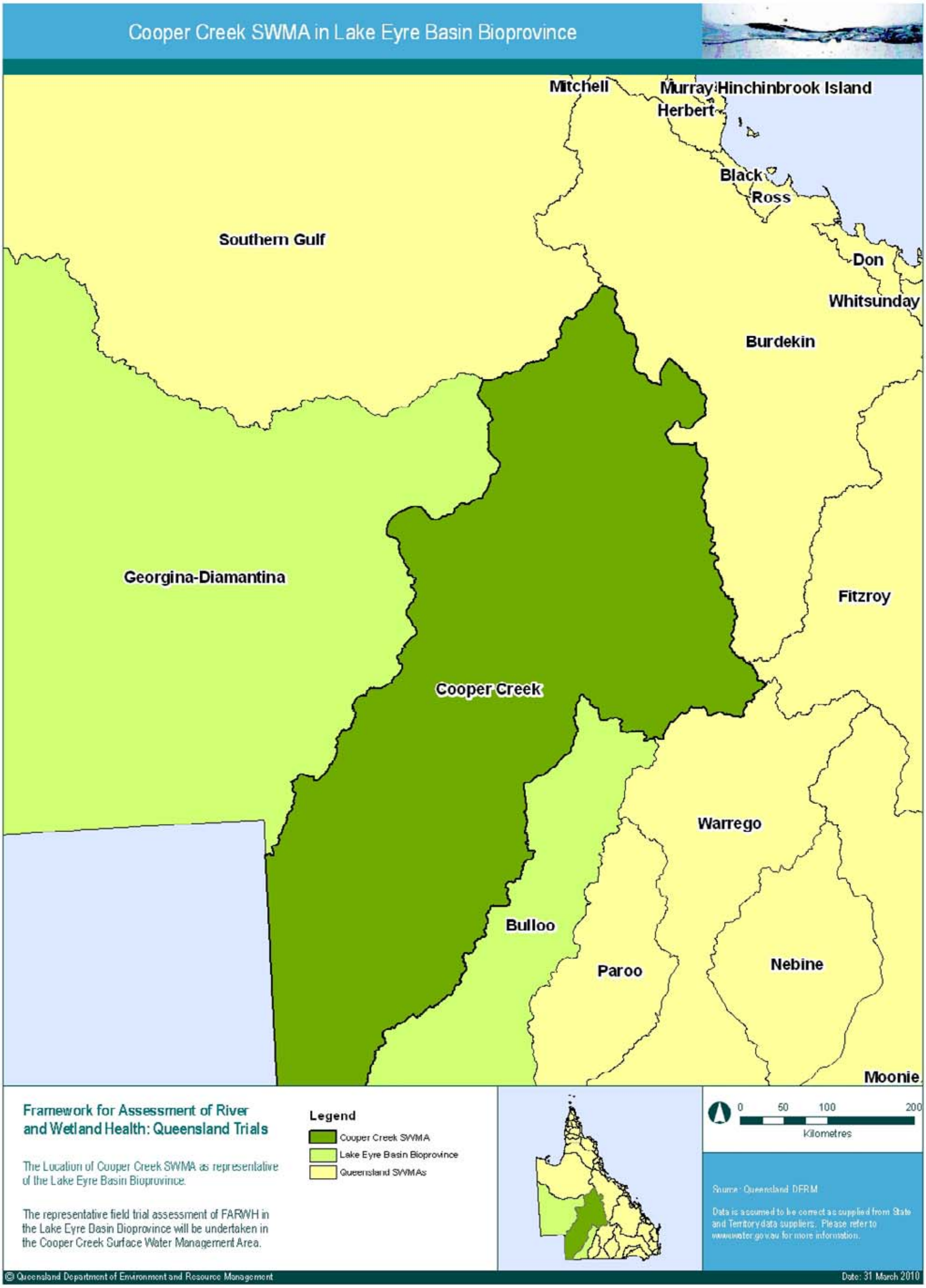

Figure 5. Cooper Creek in Lake Eyre Basin bioprovince

2.2 Sampling design

The Qld FARWH trials used a generalised random-tessellation stratified (GRTS) sampling design throughout the year 1 and 2 field trials. Primarily this was done because it was the method adopted by the SEAP and the protocols used were developed in close collaboration with statisticians from the CSIRO Computer and Mathematical Information Sciences (CMIS) and the SEAP and FARWH project teams. GRTS protocols have been used and adapted for the Qld FARWH project not only when trialling against SEAP in the Central and Wet Tropics bioprovinces, but also against the EHMP in the South East and Lake Eyre Basin trials with various adaptations to take into account the circumstances of each particular trial. CMIS has produced a series of technical sampling design reports as part of this collaboration. See Appendix 1 for hyperlinks to these reports for further technical detail and discussion on the design of each trial.

Overall GRTS is a statistically robust, spatially balanced design tool with a flexible approach allowing weighting of different stream orders, use of selective layers to identify reaches, and a subsequent random site selection process. GRTS sampling design (Stevens & Olsen 2004) is a probability-based approach with many attractive features for designing aquatic monitoring programs.

It aims to:

- yield a spatially-balanced sample (i.e. give good spatial coverage of a monitoring region, and therefore representativeness)
- enable dynamic adjustment of the sample size (which is useful if a high non-response rate is observed and additional sample sites need to be selected)
- accommodate variable inclusion probabilities to enable inclusion/exclusion of sites in the sample without compromising the statistical validity of the sample and subsequent inferences.

In preparation for selecting reaches during the first three trials, a 1:100 000 vectorised digital stream network that included Strahler stream order assignment was produced and used to define river reaches using techniques based on geomorphological principles, as were employed in the NLWRA I. Sample sites were then identified by their GPS location and randomly selected according to the GRTS design approach to remove selection bias and maximise spatial balance. However, it should be noted that the pool of available sites from which sampling sites were drawn had been filtered to exclude those sites greater than 500 m from a road. Interpretation of results needs to consider the inherent bias that results from this filtering process. Greater detail on reach identification and selection can be found within the technical reports produced by CMIS for the Qld FARWH project. All these reports can be accessed through the CSIRO website – see Appendix 1 for further information.

Following Steward (2006) and as adopted by SEAP, samples of 30 and 25 sites were drawn from test and reference populations respectively and these were numbered in sequence providing the ‘base sample’. Additional sequentially numbered sites known as the ‘oversample’ were also provided. These sites were to be accessed when base sampling sites were deemed unsuitable; for example, because they were dry, inaccessible or possibly due to health and safety concerns over sampling. The resulting test and reference site populations for the SWMAs were then targetted by field sampling in the sequentially numbered order produced by GRTS.

Methods of reach identification and selection undertaken in the Lake Eyre Basin differed to those undertaken in the other trials, primarily due to the lack of a distinct river network. Depending on the season and preceding climatic conditions, the riverine environment of Cooper Creek SWMA is made up of isolated waterholes of varying size and persistence based on the topography at a particular location. In this case mapping work undertaken by Silcock (2009) identified known waterholes throughout the catchment and classified them according to permanency based on local knowledge and mapping surveys. Only those waterholes known to have greater than 70 per cent persistency were used to form the basis for the sampling network in Cooper Creek SWMA. The GRTS methodology was then applied to this sampling frame to provide a sequentially numbered site list.

Within the Lake Eyre Basin trial the primary consideration for deciding on the sample size and site selection was the available time and resources. This decision was taken as there was deemed to be insufficient historical data across the whole SWMA to conduct a meaningful power analysis to objectively guide sample numbers. Taking indicator sampling requirements and available resources into account, a base sample of 44 sites and an oversample of the remainder of the sites in the population were selected using the GRTS methodology. This meant that all sites in the population were spatially-ordered and the first 44 of these formed the base sample and the remainder served as the oversample. Once again further details on the sampling design and site selection process can be found within the year 2 trial report and in the CMIS client report (see Appendix 1).

2.3 Indicator selection

Within the trial SWMAs in Central bioprovince, the SEAP methodology of indicator selection was applied. This included a stressor prioritisation process for the Pioneer and Burdekin SWMAs to identify the high-priority stressors (using a defined risk assessment and ranking approach) and a subsequent indicator selection process for each of those stressors. Identified indicators were then ‘fitted’ within each of the FARWH themes. SEAP indicators were also collected at all sites. This approach was fully documented within the project inception report.

Within South East Queensland the EHMP program had a suite of existing indicators covering the Water Quality and Soils and Aquatic Biota themes. Other indicators were identified following a scoping exercise based on the potential to collect or collate data under a particular theme. Once again this process was documented within the project inception report.

Within the Tully SWMA in the Wet Tropics bioprovince, the chosen SEAP indicators were used for the FARWH assessment where appropriate. SEAP’s indicators were selected on the basis of conceptual relevance, feasibility of implementation, response variability, interpretation and utility specifically in relation to the Wet Tropics bioprovince. It was decided that for this trial, the project would not redo SEAP’s indicator selection process at the SWMA level, as was done in the previous Burdekin and Pioneer trials.

This decision was driven by the desire to compare the indicator selection and sampling design process performed at differing spatial scales and under the pressure-stressor-response (PSR) framework (which following a directive (Keliher 2007) had been adopted as the overarching framework for aquatic ecosystem monitoring in Queensland) against the FARWH. Appropriate indicators that SEAP had already chosen were therefore integrated into the FARWH framework and any gaps were then supplemented with additional appropriate indicators.

Within the Lake Eyre Basin there was no concurrent monitoring program in place to explicitly guide indicator selection. Indicators were chosen based on a review of the literature relating to ecological assessment of the Lake Eyre Basin, and in consultation with ecological experts, with a view to aligning the FARWH assessment with those indicators that had been proposed under the LEBRA monitoring program. The feasibility of assessing particular indicators was considered by the project team, along with expert opinion and available resources, in assigning appropriate indicators under each FARWH theme.

For all the trial SWMAs the sub-indices assessed under each theme are listed below in Table 1.

Theme	Indicator	Description	SWMA	
			Baseline era	Current era
Aquatic Biota	PET	The number of PET (Plecoptera, Ephemeroptera, Trichoptera) families in a sample.	B, P, M, T	B, P, M, T, C
	Richness (macroinvertebrates)	The number of taxa in a sample, in most cases families but does include some subfamilies (not the total abundance of bugs).	B, P, M, T	B, P, M, T, C
	SIGNAL	The average SIGNAL score calculated for each sample (using SIGNAL 2.1iv sensitivity grades).	B, P, M, T	B, P, M, T, C
	Richness (fish)	The number of fish species identified at each assessment site.	n/a	C
	Proportion alien (fish)	The proportion of the total fish catch (number of individuals) at an assessment site made up of alien species.	M, C	M, C
	Fish O/E50	The ratio of observed to expected native species	M	M
	PONSE (fish)	Percentage of native species expected	M	M

Theme	Indicator	Description	SWMA	
			Baseline era	Current era
Water Quality and Soils	pH	Spot recording of pH	M	M
	Conductivity	Spot recording of conductivity	M	M
	Temperature	Spot recording of temperature	n/a	C
	Temperature	Daily range, maximum and minimum	M	M
	Turbidity	Spot recording of turbidity	n/a	B, P, T, C
	Dissolved oxygen	Spot recording of dissolved oxygen	M	M
	TSS	Total suspended solids mg/L (laboratory analysed water sample)	B, P	B, P,
	Ammonia nitrogen	mg/L as N (laboratory analysed water sample)	n/a	B, P,
	Nitrogen oxides	mg/L as N (laboratory analysed water sample)	B	B, P,
	Filter reactive phosphorus	mg/L as P (laboratory analysed water sample)	B	B, P,
Hydrological Disturbance	Change in flow	Recorded stream flow (compared with modelled pre-development flow)	B, P, M, C	B, P, M, C
	Duration of no flow	Duration of no-flow events (compared with modelled pre-development flow)	B, P, M, C	B, P, M, C
	Period between no flow	Period between no-flow events (compared with modelled pre-development flow)	B, P, M, C	B, P, M, C
Fringing Zone	% cover	Percentage area with FPC > 12% within 51 m buffer of water index.	B, P, M, T, C	B, P, M, T
	% exotics	The percentage of exotic species within 51 m average water mark.	n/a	C
Catchment Disturbance	Land use	The sum of the proportion of area of each land use type within a catchment weighted by its impact on aquatic ecosystems.	B, P, M (2001), T, C (1999)	n/a
	Land cover change	The proportion of land cover clearing from 1988-required era.	B, P, M, T, C	B (2007), P, M (2007), T, C
	Infrastructure	The sum of the proportion of area of each infrastructure type casement within the catchment weighted by its impact on aquatic ecosystems.	n/a 2004	B, P, M, T, C
Physical Form	Substrate heterogeneity	'Shannon Wiener' diversity index (Zar 1999).	n/a	B, P, M, T
	% pugging by pigs	The proportion of the 800 m length sampled across both banks with visual evidence of pugging by feral pigs.	n/a	C
	% pugging by cattle	The proportion of the 800 m length sampled across both banks with visual evidence of pugging by cattle stock.	n/a	C
	% bank with snags	The proportion of the 800 m length sampled across both banks and adjacent stream edge with visual evidence of snags.	n/a	C
	% bank with steps	The proportion of the 800 m length sampled across both banks with steps in the bank.	n/a	C
	% overhanging	The proportion of the 800 m length sampled	n/a	C

Theme	Indicator	Description	SWMA	
			Baseline era	Current era
	vegetation	across both banks with overhanging vegetation.		
B = Burdekin, P = Pioneer, M = Moreton, T = Tully, C = Cooper				

Table 1. Sub-indices used under each theme for all trial SWMA

2.4 Reference condition

The FARWH uses a referential framework, whereby assessments are made for each indicator against appropriate reference condition. The type of reference value is indicator specific, and may be selected from many different types; for example, using minimally disturbed or best-available reference sites, modelling, professional judgement, etc. The guiding principle is that the reference values used should be as close to natural (pre-European settlement or pre-1750) as possible (NWC 2007a).

In all of the field trials, potential reference sites (identified using the GRTS approach with road access filters) were assessed in the field using a number of criteria based on existing departmental protocols for their selection. These protocols are based on an evaluation of 11 different criteria. The reference criteria sheet along with the guidelines used to assess the individual criteria are given in Appendix 2. Sites were only considered to be in reference condition where none of the assessed criteria scored less than 4 (out of a possible 5).

For the majority of field-collected indicators, this reference site population then forms the basis for setting a spatially and temporally explicit reference range (using 20th and/or 80th percentiles) against which test site data is compared. In some cases indicators naturally had a reference value of zero and so did not require this approach, such as proportion alien fish or plant species. The methods for defining reference conditions for each sub-index vary depending on the indices and this is outlined in Table 2. From discussions after the year 1 field trials, it was decided that AusRivAS modelling would be used to set reference condition for macroinvertebrate sub-indices during the Tully SWMA field trial.

This was in addition to using the reference range approach, which so far had been adopted to provide a comparative assessment for the Aquatic Biota theme based on the varying reference condition approach. It is acknowledged that this method potentially provides a stratified and comparative approach to setting reference condition based on environmental parameters, however some AusRivAS models for Queensland are not considered sufficiently refined (Steward 2006) to provide an accurate assessment for all catchments. This was the initial basis for adopting the reference range approach during the previous trials.

In the Central and Wet Tropics trials the pool of available reference sites was widened to include those collected for SEAP from outside the trial SWMAs, but within the associated bioprovince.

This approach was endorsed by the project steering committee following discussions at the FARWH sampling design workshop held in Brisbane in November 2008. The rationale behind this decision is supported by the work of Marshall et al. (2006b) on which the bio-regionalisation of Queensland is based. Aquatic bio-provinces were determined in a bottom-up approach to regionalisation where geographical areas of Queensland sharing similar faunal assemblages were identified. Queensland was divided into nine biogeographic provinces using the natural structural patterns expressed by one ecosystem constituent (aquatic macroinvertebrates) and confirmed by another (fish). This was done at a catchment scale. This suggested that the convergent patterns of these two ecosystem constituents reflected aspects of ecosystem function at this scale.

For the South East Queensland trial in Moreton SWMA, reference condition was set using the guideline values from the EHMP program for all indicators, with the exception of the Fringing Zone. Sites were stratified into the upland, lowland, coastal and tannin-stained classifications as used by EHMP to provide a more specific reference for each identified test site. Fringing zone reference values were derived from the NVIS modelled pre-European extent.

In contrast to the other Queensland FARWH trials, no separate reference site population was defined for the trial in the Lake Eyre Basin based on statistical advice from CMIS CSIRO. Ideally we would have put in place an approach that defined a separate reference population, as was done when assessing the other SWMAs in the trials.However, it was decided it was impractical to sample two separate populations of sites, primarily due to available time and logistical difficulties.

As a result there were limited options for implementing a referential approach. Ultimately a visual assessment of the degree of reference condition according to an objective set of criteria (see Appendix 2) was recorded at all sites visited during sampling. The assessment information for the nominated reference sites based on these criteria was then summarised to form a set of reference guidelines; for example, to calculate the 20th and/or 80th percentiles of condition. The condition at all sites surveyed (including those deemed to be in reference condition) was then compared with these guidelines to assess relative condition at the test sites.

A disadvantage of this approach is the suggestion that data is being ‘double dipped’. The extent to which we are biasing the condition assessment by ‘re-using’ the data collected at the most pristine sites was evaluated as part of the CSIRO CMIS collaboration. This approach enabled more control over the reference population’s size and minimised the number of sites to be visited to achieve the minimum samples required to use such an approach. In any case, due to the limited options for implementing the referential approach, this was seen as the best-available option. The site selection and reference approach used in the Lake Eyre Basin trial is described in more detail in the CSIRO CMIS client report produced by Dobbie et al. (2010b).

2.5 Data standardisation, integration and aggregation

The methods of data analysis used for the FARWH trials, including recommended techniques for integration and aggregation, are generally those outlined in Australian Water Resources (2005). Where there were modifications applied to the recommended techniques due to the particular features of indices or SWMAs, these are documented and justified under each theme within the methods sections of the year 1 and 2 trial reports. For the convenience of referencing, equation numbering follows the original sourced documents.

2.5.1 Data standardisation and calculation of weighted index scores at the site level

Raw ‘site level’ data from the Central, Wet Tropics and Lake Eyre trials were standardised using guideline (reference) values determined from data collected at reference sites from within the respective bioprovinces. The standardisation of Moreton trial data used established EHMP guideline values developed for the stream classes of the Moreton catchment.

Worst case scenario (WSC) values were the highest or lowest observed value(s) from pooled reference and test site data across all sampling runs. All data was standardised using Equation 1. Guideline values are derived from a set of minimally disturbed reference site results identified in the DIBM3 report.

Equation 1.

$$\mathrm{Score}_{ij} = 1.0 - \left| \frac{(\mathrm{x}_{ij} - \mathrm{Guideline}_{ij})}{(\mathrm{WCS}_{ij} - \mathrm{Guideline}_{ij})} \right|$$

Where: Xij is the value of the index i at a site

within stream class j,

Guidelineij is the corresponding ‘guideline/reference’ value, and

WCSij is the corresponding ‘worst case

scenario’ value.

Catchment Disturbance, Aquatic Biota and Fringing Zone site sub-index scores were weighted according to sample reach area and the Water Quality and Physical Form sub-index scores were weighted according to sample reach length using Equation 2. The Hydrological Disturbance sub-index scores remained unweighted.

Equation 2.

$$S' = \text{Score}_{ij} \left| \left(1 / \sum p_{ij}\right) p_{ij} \right|$$

Where: S' is the catchment area or reach length weighted score,

Scoreij is the unweighted score for index i in sample population j,

pij is the catchment area or reach length for index i in sample population j.

2.5.2 Aggregation of site-level sub-index data

Site-level sub-index data is standardised and weighted using equations 1 and 2 respectively to produce site-level sub-index 'scores' (as described above). The trial sub-index score is determined by summing the weighted site scores (Figure 6).

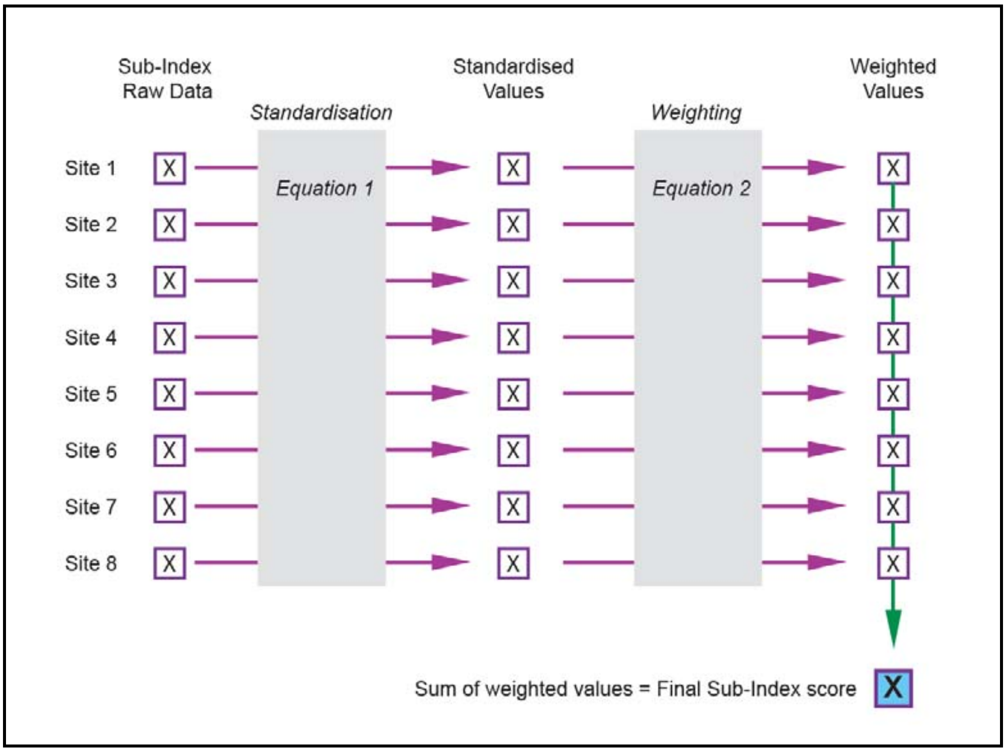

Figure 6. Site-level sub-index data is standardised and weighted to produce site-level sub-index 'scores'. The trial sub-index score is determined by summing the weighted site scores.

2.5.3 Integration of sub-index and theme scores

All FARWH theme scores were calculated by determining the standard Euclidean distance between the sub-index scores within each theme, with the exception of scores for the Catchment Disturbance Index (CDI). Theme scores for the CDI were calculated using Equation 10 as recommended by the NWC (2007a). Figure 7 illustrates the integration process in determining the FARWH theme level scores, as well as how the 'final trial scores' were calculated using the standard Euclidean distance equation (Equation 3).

Equation 3. Used for the integration of all indices except those for CDI

TScore = 1- (√ (1 – A)2 + (1 - B) 2 + (1 – C) 2 + … + (1 - X)2 / √ n)

Where: TScore is the trial score, and

A, B, C,…,X are the theme scores

and n is the number of themes

Equation 10. (Recommended by NWC) used for calculating the CDI

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

Where: CDI = Catchment Disturbance Index,

I = infrastructure measure,

LC = land cover change, and

LU = land use measure.

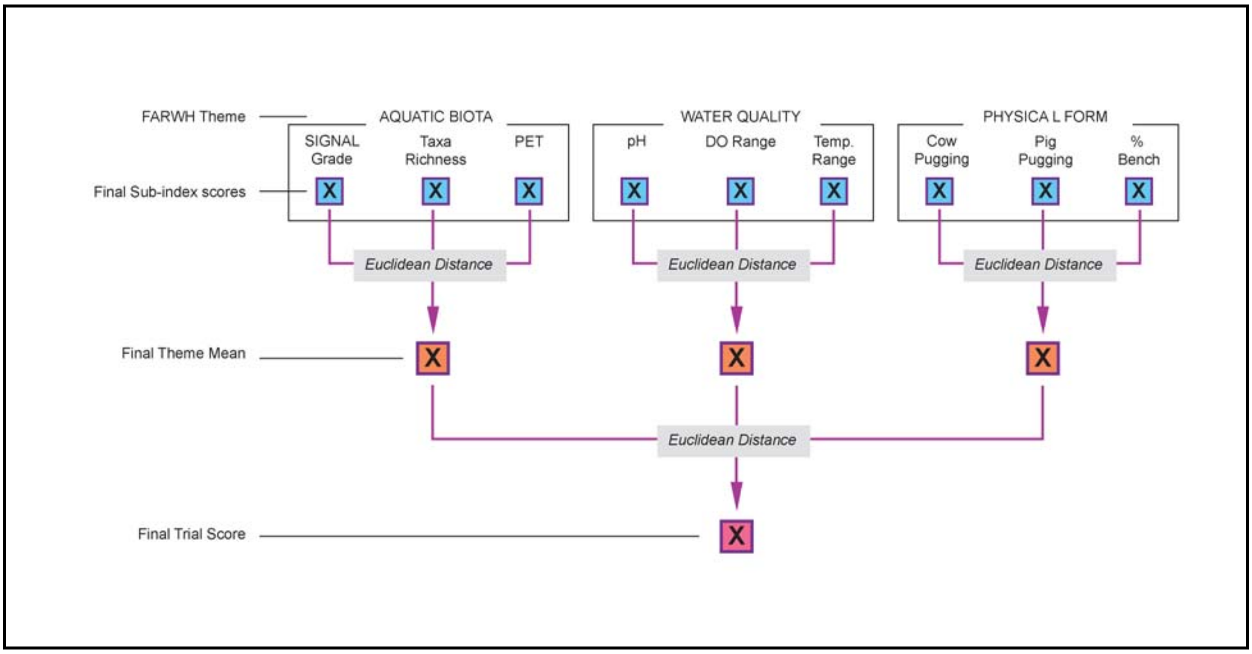

Figure 7. Illustration of the integration of sub-index scores to produce theme-level scores and integration of theme scores to produce the final trial score.

2.5.4 Discussion

Within the FARWH framework (NWC 2007b, p19) five methods for integrating sub-index and theme scores are compared. The standard Euclidean distance method was chosen for all four Queensland FARWH trials because it provided a direct measure of how different a reach is from the reference condition. The only departure from use of the standard Euclidean distance was for the CDI where the score was calculated by summing the impacts of the sub-indices. The integration method described above remained constant for all trials so that a valid comparison between trials could be made. The recommended FARWH approach where integrating themes and indicators (which represent components at different levels of ecosystem function) has the potential to create problems of bias due to measuring the same threat and equivalent response to that threat. This could bias the score for each theme, as well as the final score, towards being impacted or unimpacted with the likelihood of having a score in between less likely.

Site-level sub-index scores were weighted by reach length or area, as described by NWC (2007b) and outlined in Table 2 below and Equation 2 above, to provide a SWMA-level sub-index and theme scores. The assumption is that sampled reaches are representative of all reaches within the SWMA. However, the selection of sites for the Queensland FARWH trials (with the exception of the Moreton trial where legacy sites were used) was based on the GRTS design and sites were assigned ‘inclusion probabilities’ based on stream order and spatial distribution (Dobbie & Burridge 2010a, p8).

To ensure accessibility, the site selection process included a ‘filter’ to identify sites within 500m of a designated road. Dobbie and Burridge (2010a) note that if the sample frame is constrained, then so are the relative inferences. For example, in the linear population context (as was the case for the Central and Wet Tropics trials), if the sampling frame comprised only streams located within 500m of a documented road, then the inferences would be about the condition of road-accessible streams, and NOT all streams within the network (SWMA). Thus the assessment is likely to be an overestimate of stream condition given the known impacts of roads on streams. Making statements on the condition of the unconstrained population based on a constrained sample may lead to false conclusions–since the condition of a stream network not near a road may differ substantially from one that is near a road.

Theme	Sub-indicator	Aggregation	Integration	Reference value
Catchment Disturbance Index	Land cover change	Census	Equation 10 (from NWC)	Assumed to be zero
	Infrastructure			
	Land use type			
Fringing Zone	% cover (B, P, M & T)	Census	n/a single sub-index when used	100% cover (B, P, M) Cover of woody vegetation communities in pre-extant Regional Ecosystem Mapping (T)
	% exotics (C)	Even weightings (no stratification for GRTS)	n/a single sub-index when used	Assumed to be zero
Physical Form	Substrate heterogeneity (B, P, M, T)	Stream length	n/a single sub-index when used	Between the 20th and 80th percentile of reference site values
	% pugging by pigs (C)	Even weightings (no stratification for GRTS)	Standardised Euclidean distance	Assumed to be zero
	% pugging by cattle (C)			
	% bank with snags (C)			
	% bank with steps (C)			
	% overhanging vegetation (C)			
Water Quality and Soils	pH	Stream length	Standardised Euclidean distance	Between the 20th and 80th percentile of reference site values
	Conductivity			
	Temperature			
	Turbidity			
	Dissolved oxygen			
Aquatic Biota	PET	Stream length	Standardised Euclidean distance	Between the 20th and 80th percentile of reference site values
	Richness (bugs)			
	SIGNAL			

Table 2. Summary of sub-indices, aggregation, integration and reference used for each them

2.6 Reporting scale issues, i.e. multi-scale reporting

The FARWH document recommends that river and wetland health assessments be conducted at the scale of river reaches, and reported to the NWC at the scale of SWMAs (river basins) – enabling local needs to be met as well as aggregated to inform regional bodies, states and the national level (NWC 2007). In Queensland, the SWMAs are usually catchments, although there are some instances where they are a group of small catchments; for example, South Coast (Gold Coast). The definition of SWMAs is primarily based on the hydrological aspects of the system and correlate with the defined boundaries as set under the water resource plan for that catchment. The SWMAs defined in Queensland are shown in Figure 8 as delineated by the basin numbers and boundaries shown on that figure.

To understand aquatic ecosystem function at the whole-state-scale in Queensland, it has been necessary to categorise aquatic ecosystems into more homogeneous units. As previously described, aquatic bioprovinces were determined in a bottom-up approach to regionalisation where geographical areas of Queensland sharing similar faunal assemblages were identified. The bioprovinces were subsequently adopted as the basis for the SEAP conceptual model development. They are Central, Eastern Cape, Jardine, Lake Eyre and Bulloo, Murray-Darling, South-East, Western Cape and Gulf, Wallum, and Wet Tropics (Figure 8). The SEAP assesses these bioprovinces on a rolling basis over several years. The first bioprovince to be assessed under SEAP was Central (2008) followed by the Wet Tropics (2009). These assessments formed the basis for two of the field trials for this project.

In attempting to provide a comparative assessment of aquatic ecosystem condition between the FARWH and SEAP, the disparity in spatial scale between the two programs must be recognised. Thus it must be accepted that making a direct comparison is not simple (and possibly not justified). Comparisons were drawn between the characteristics of the two programs, as outlined in Table 19 in Section 2.8. There are several significant differences, but most fundamentally the whole program design from indicator selection, site selection and reporting are at a different spatial scale (SWMA for FARWH versus bioprovince for SEAP).

SEAP reporting at the bioprovince scale is obviously on a broader scale than that of the FARWH and, as such, is a relatively coarse tool for use in the management of aquatic ecosystems across Queensland. SEAP has been designed at that spatial scale partly due to the bioregionalisation process described above, but also as a consequence of the available resources to implement a statewide aquatic ecosystem monitoring program.

A spatial disparity also exists between the EHMP and FARWH. In contrast to SEAP, EHMP reports at the subcatchment scale for a locally focused assessment – as required by the regional councils who are partners in the program. This reporting area is different to the FARWH’s SWMA level, yet within the South East Queensland trial the defined subcatchments for EHMP reporting do form a discrete subset of the Moreton SWMA. This is represented in Figure 9. Overall this potentially makes comparison of an overall assessment much simpler than that between the SEAP and FARWH.

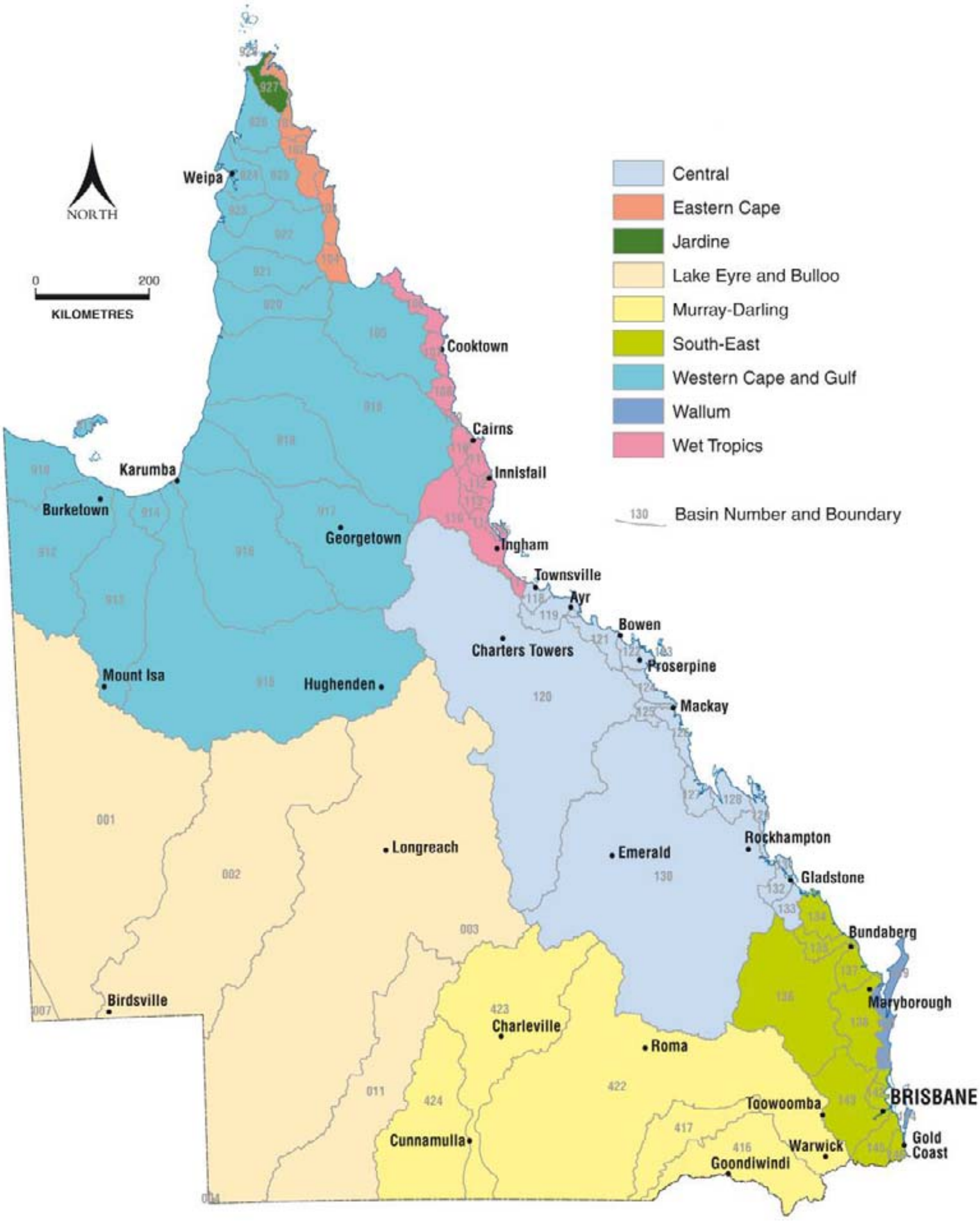

Figure 8. SEAP bioprovinces and surface water management areas (basins) in Queensland

During these trials the collection of data within field-based assessments for the FARWH has been done at the reach/site level, with data then being scaled up through weighting, aggregation and integration techniques to report at the SWMA level. This was defined by the NWC as the fundamental reporting unit for the FARWH and the assessments undertaken as part of this project have been based on this premise.

While the site-level information has not been specifically reported on within these trials, it remains as the basis for the SWMA assessments and is available for use for regional and local assessments, and management and planning purposes. The multi-scale reporting of FARWH sub-indices and themes has not been explicitly presented due to the direction received from the NWC and project steering committee on the reporting outputs from these trials. Since the inception of this project, the focus of reporting with respect to producing a single figure for an SWMA's condition may have changed and finer-scale reporting is likely to be required. Given the potential needs of state and regional bodies, there is obviously significant value to be gleaned in using and reporting on site/reach-level data. Two examples are listed below that demonstrate the potential to present and use the compiled FARWH data at a finer scale.

Example 1

During the Lake Eyre Basin trial in Cooper Creek SWMA, fish catch data used as part of the Aquatic Biota theme were presented in a map format (see Figure 10). This map represents the distribution data for a single species (Cooper Creek catfish) which is endemic to this river catchment. Data presented in this format is obviously of great value in planning the conservation and protection of such an ecological asset.

Example 2

Remotely sensed assessments undertaken as part of the Fringing Zone theme were conducted as census assessments across the trial SWMAs and, as such, provided a reach-level assessment that could potentially be used as a regional-scale management tool. As an example, the reach-level assessment for the Pioneer SWMA for overstorey foliage projective cover (the index used as the basis for the Fringing Zone theme) is shown in Figure 11.

Figure 9. Moreton SWMA relative to the EHMP subcatchments in South East Queensland

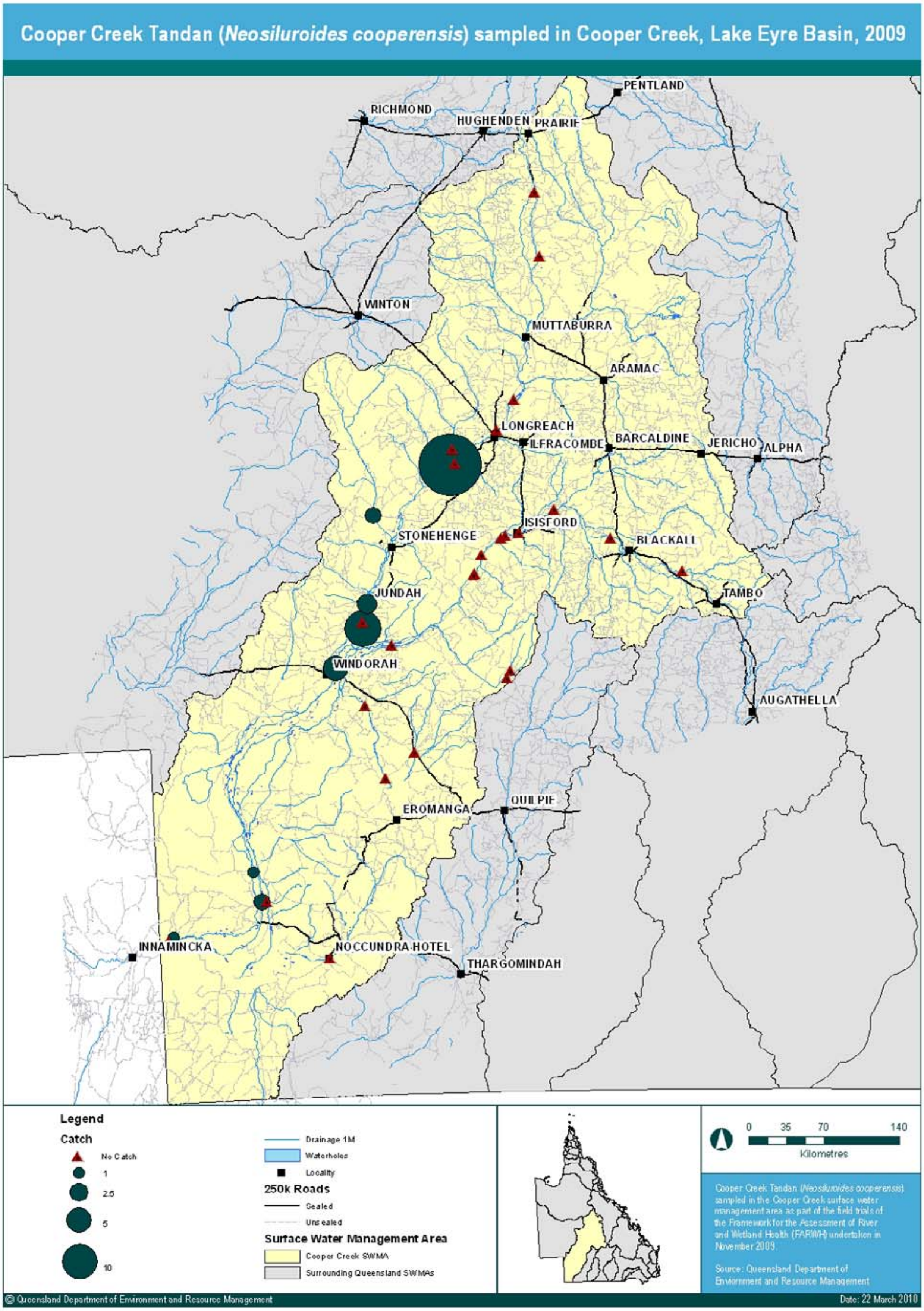

Figure 10. Distribution of Cooper Creek catfish within Cooper Creek SWMA as sampled during the FARWH trials in 2009

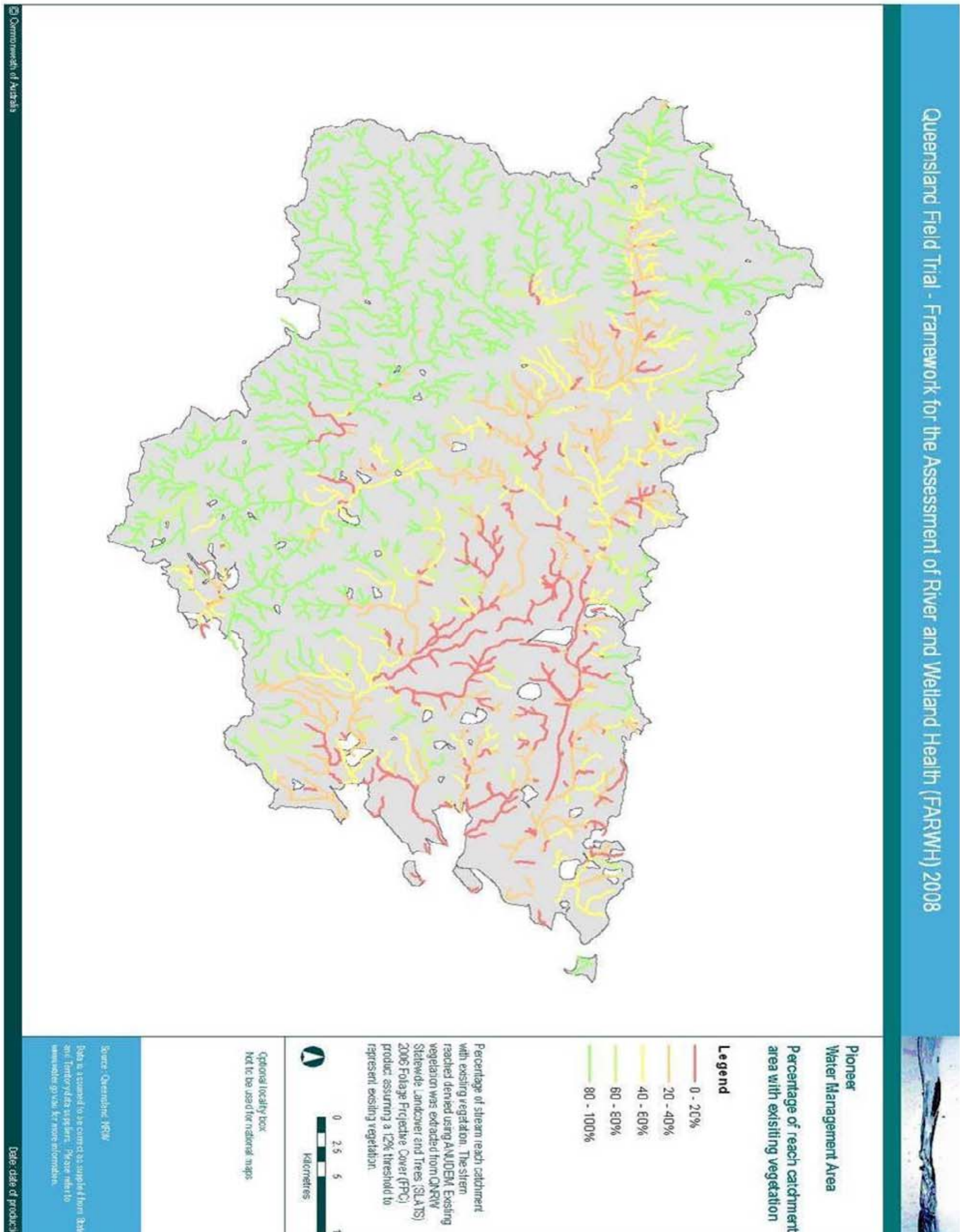

Figure 11. Map showing reach scale Fringing Zone assessment for the Pioneer SWMA undertaken as part of the year 1 trials

2.7 Data analysis

Methods for data analysis, including recommended techniques for standardisation, integration and aggregation are generally those outlined in Australian Water Resources (2005). Where the recommended techniques were modified due to particular features of indices or SWMAs, these are documented and justified in the appropriate sections of the year 1 and 2 trial reports. However, a detailed consideration of the data confidence and analysis issues encountered during the course of the trials is presented in this section.

2.7.1 Field-sampled indicators

Analysis of field-collected data was undertaken to quantify the 'confidence' associated with the resulting mean for each index. The 95 per cent confidence interval was calculated from the data on an index-by-index basis for data from each field trail. An upper and lower 95 per cent confidence interval (CI) implies there is a 95 per cent certainty that the true 'mean' value for the index lies between the calculated upper and lower CI. The 95 per cent CIs were calculated from raw data using Microsoft Excel.

To aid the interpretation of data confidence, the 95 per cent CI has been shown (in the last column in the following tables) as a proportion of the mean. This was done by calculating the 'CI to mean ratio' (CI/M). For example, if the calculated mean value of an index is 6, and the 95 per cent CI is 2, there is a 95 per cent certainty the true value of the index mean lies between 4 and 8. The CI/M ratio would be 0.33.

2.7.1.1 Central trial

For the Central field trial the FARWH field teams collected test site data and both the FARWH and SEAP teams collected reference site data. Data confidence is represented by the CI/M ratio: those ratios are presented in tables 3, 4 and 5 on an index-by-index basis with ratios being ranked from the highest to lowest.

Central trial (Burdekin) reference site data values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Water Quality	Ammonia nitrogen	0.0126	± 0.0155	16*	1.23
Water Quality	TSS	7.88	± 4.74	16*	0.60
Water Quality	Nitrogen oxides	0.0030	± 0.0018	16*	0.60
Water Quality	Filt reac phosphorus	0.0073	± 0.0027	16*	0.37
Physical Form	Substrate heterogeneity	1.00	± 0.16	41^	0.16
Aquatic Biota	PET taxa (bed)	4.11	± 0.56	37^	0.14
Aquatic Biota	PET taxa (edge)	4.11	0.39	35^	0.10
Aquatic Biota	Taxa richness (bed)	16.86	1.60	37^	0.09
Aquatic Biota	Taxa richness (edge)	23.91	1.36	35^	0.06
Aquatic Biota	SIGNAL grade (bed)	4.22	0.20	37^	0.05
Aquatic Biota	SIGNAL grade (edge)	3.72	0.10	35^	0.03

Table 3. Analysis of Burdekin catchment reference site data variability (the '*' symbol beside the sample size ('n') value indicates that data was collected by FARWH field teams only, whereas the '^' symbol beside the 'n' value indicates that FARWH data was combined with reference site data collected by the SEAP field teams).

Results displayed in Table 3 show a high CI/M ratio for the Water Quality data indices. High CI/M ratios are indicative of an insufficient sample size in relation to the variability of data. From the Water Quality index results it can be illustrated that it is theoretically possible to have a CI value that is greater than the mean value for a particular indicator. In contrast the CI/M ratios for the Aquatic Biota indices are relatively low.

Central trial (Pioneer) reference site data values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Water Quality	Nitrogen oxides	0.037	0.046	10*	1.25
Water Quality	TSS	3.80	3.70	10*	0.97
Water Quality	Filt reac phosphorus	0.007	0.003	10*	0.50
Water Quality	Ammonia nitrogen	0.007	0.003	10*	0.40
Physical Form	Substrate heterogeneity	1.00	0.16	41^	0.16
Aquatic Biota	PET taxa (bed)	4.63	0.57	38^	0.12
Aquatic Biota	PET taxa (edge)	4.27	0.46	37^	0.11
Aquatic Biota	Taxa richness (bed)	17.82	1.71	38^	0.10
Aquatic Biota	Taxa richness (edge)	23.30	1.36	37^	0.06
Aquatic Biota	SIGNAL grade (bed)	4.42	0.20	38^	0.04
Aquatic Biota	SIGNAL grade (edge)	3.81	0.11	37^	0.03

Table 4. Analysis of Pioneer catchment reference site data variability (the '*' symbol beside the sample size ('n') value indicates that data was collected by FARWH field teams only, whereas the '^' symbol beside the 'n' value indicates that FARWH data was combined with reference site data collected by the SEAP field teams)

Results displayed in Table 4 are similar to those shown in Table 3 and show high CI/M ratios for the Water Quality data indices. As with results in Table 3, the Aquatic Biota indices have the lowest CI/M ratios with the SIGNAL grade index being the least variable of the three Aquatic Biota indices.

Central trial (Burdekin) test site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Water Quality	Nitrogen oxides	0.014	0.016	21	1.13
Water Quality	Filt reac phosphorus	0.012	0.008	21	0.65
Water Quality	Ammonia nitrogen	0.004	0.002	21	0.55
Water Quality	TSS	11.24	5.83	21	0.52
Physical Form	Substrate heterogeneity	0.68	0.17	19	0.25
Aquatic Biota	PET taxa (bed)	3.24	0.70	17	0.22
Aquatic Biota	Taxa richness (bed)	12.76	1.96	17	0.15
Aquatic Biota	PET taxa (edge)	4.20	0.44	20	0.10
Aquatic Biota	Taxa richness (edge)	23.60	2.17	20	0.09
Aquatic Biota	SIGNAL grade (bed)	3.89	0.17	17	0.04
Aquatic Biota	SIGNAL grade (edge)	3.55	0.08	20	0.02

Table 5. Analysis of Burdekin catchment test site data variability. All test site data was collected by FARWH field teams

Results displayed in Table 5 follow those for the reference site data (tables 3 and 4) with the Water Quality CI/M ratios being high compared with those for the Aquatic Biota indices. In contrast to the reference site data (tables 5 and 6), Aquatic Biota and Water Quality means were calculated from similar sample sizes (n). Despite the increased sample size (from 10 to 21) for Water Quality data the CI/M ratio remained high. These results suggest that Water Quality data are highly variable compared with the data for Aquatic Biota.

Central trial (Pioneer) test site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Water Quality	Nitrogen oxides	0.280	0.184	29	0.66
Water Quality	Ammonia nitrogen	0.008	0.003	29	0.39
Water Quality	TSS	3.03	1.11	29	0.37
Water Quality	Filt reac phosphorus	0.010	0.002	29	0.23
Physical Form	Substrate heterogeneity	1.23	0.17	27	0.14
Aquatic Biota	PET taxa (edge)	4.59	0.54	30	0.12
Aquatic Biota	PET taxa (bed)	4.89	0.51	28	0.10
Aquatic Biota	Taxa richness (bed)	17.07	1.75	28	0.10
Aquatic Biota	Taxa richness (edge)	20.81	1.46	30	0.07
Aquatic Biota	SIGNAL grade (edge)	4.09	0.17	30	0.04
Aquatic Biota	SIGNAL grade (bed)	4.42	0.17	28	0.04

Table 6. Analysis results of the Pioneer catchment test site data variability. All test site data was collected by FARWH field teams

Results displayed in Table 6 are similar to those for the Burdekin test site data (Table 5) with the Water Quality data having greater variability than the Aquatic Biota data.

2.7.1.2 Moreton trial

Test site data for the Moreton field trial was collected by the FARWH and EHMP field teams. Reference site data for the Aquatic Biota and Water Quality indices was not required because test site values for those indices are compared against established EHMP guideline values for each of the four stream classes identified by EHMP.

2.7.1.2.1 Upland streams

Results displayed in Table 7 indicate the Water Quality and Aquatic Biota indices are represented through the range of data variability results. Results from the other three field trials showed the greatest data variability being associated with Water Quality indices. Data for the ‘DO range’ index had the greatest variability and data for the ‘Prop alien (fish)’ index had no variability; that is, no alien fish were caught at the three upland test sites and therefore produced a CI/M ratio of zero (see Table 7).

Moreton trial upland site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Water Quality	DO range	18.2	15.6	5	0.86
Aquatic Biota	PONSE (fish)	38.6	21.8	2	0.56
Water Quality	Temp range	3.3	1.7	5	0.52
Aquatic Biota	PET taxa	4.2	1.9	5	0.45
Water Quality	DO min	55.6	23.5	5	0.42
Water Quality	Conductivity	170.0	36.0	5	0.21
Water Quality	Temp max	21.4	3.1	5	0.15
Aquatic Biota	FishOE	0.4	0.1	2	0.14
Aquatic Biota	Taxa richness	20.4	2.8	5	0.14
Aquatic Biota	SIGNAL grade	4.6	0.5	5	0.11
Water Quality	pH	6.5	0.4	5	0.06
Aquatic Biota	Prop alien (fish)	0.0	n/a	3	0.0

Table 7. Analysis of Moreton catchment test site data variability for upland streams

2.7.1.2.2 Lowland streams

Results displayed in Table 8 indicate the Water Quality and Aquatic Biota indices are represented through the range of data variability results, as is the case with data from upland streams. The ‘Prop alien (fish)’ index produced the most variable data whereas data for the ‘pH’ index was the least variable (see Table 8).

Moreton trial lowland site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Aquatic Biota	Prop alien (fish)	17.7	12.7	20	0.72
Water Quality	Conductivity	841.0	408.9	27	0.49
Aquatic Biota	FishOE	0.4	0.1	19	0.35
Water Quality	DO range	28.8	8.8	27	0.30
Water Quality	Temp range	3.6	0.9	27	0.26
Water Quality	DO min	38.3	8.4	27	0.22
Aquatic Biota	PONSE (fish)	66.3	12.4	19	0.19
Aquatic Biota	PET taxa	3.6	0.6	27	0.18
Aquatic Biota	Taxa richness	22.1	2.0	27	0.09
Aquatic Biota	SIGNAL grade	3.7	0.2	27	0.05
Water Quality	Temp max	22.2	0.8	27	0.04
Water Quality	pH	7.1	0.2	27	0.03

Table 8. Analysis of Moreton catchment test site data variability for lowland streams

2.7.1.2.3 Coastal streams

Results displayed in Table 9 are similar to those shown in Table 7 and, as with data for lowland streams, indicate the ‘Prop alien (fish)’ index produced the most variable data. Data for the ‘pH’ index was the least variable.

Moreton trial coastal site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Aquatic Biota	Prop alien (fish)	30.0	19.3	9	0.64
Water Quality	Temp range	2.8	1.7	9	0.59
Aquatic Biota	PET taxa	1.9	0.9	9	0.47
Water Quality	Conductivity	617.1	259.3	9	0.42
Water Quality	DO range	17.1	7.0	9	0.41
Water Quality	DO min	35.0	11.5	9	0.33
Aquatic Biota	FishOE	0.6	0.2	9	0.31
Aquatic Biota	PONSE (fish)	79.4	16.2	9	0.20
Aquatic Biota	Taxa richness	18.6	3.7	9	0.20
Water Quality	Temp max	21.3	2.2	9	0.11
Aquatic Biota	SIGNAL grade	3.6	0.4	9	0.10
Water Quality	pH	6.7	0.3	9	0.05

Table 9. Analysis of Moreton catchment data variability for coastal streams

2.7.1.2.4 Tannin-stained streams

Results displayed in Table 10 show the data variability for indices from tannin-stained streams. The ‘Prop alien (fish)’ index produced the most variable data, whereas data for the ‘Temp max’ index was the least variable.

Moreton trial tannin-stained site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Aquatic Biota	Prop alien (fish)	2.1	2.4	3	1.17
Aquatic Biota	FishOE	0.4	0.4	3	1.01
Aquatic Biota	PET taxa	2.7	2.4	3	0.88
Water Quality	DO min	35.3	26.5	3	0.75
Water Quality	DO range	4.2	2.2	3	0.52
Water Quality	Temp range	0.8	0.3	3	0.42
Aquatic Biota	Taxa richness	18.7	7.5	3	0.40
Water Quality	Conductivity	148.7	26.5	3	0.18
Water Quality	pH	5.4	0.7	3	0.14
Aquatic Biota	PONSE (fish)	88.4	10.8	3	0.12
Aquatic Biota	SIGNAL grade	3.8	0.5	3	0.12
Water Quality	Temp max	20.4	0.2	3	0.01

Table 10. Analysis of Moreton data variability for tannin-stained stream

2.7.1.3 Wet Tropics trial

SEAP field teams collected reference site data for the Wet Tropics field trial. The ‘Turbidity’ index produced the most variable data, whereas data for the ‘Water temp’ index was the least variable.

Wet Tropics trial reference site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Water Quality	Turbidity	2.56	1.95	25	0.76
Water Quality	Conductivity	79.23	27.12	25	0.34
Aquatic Biota	PET taxa (edge)	4.30	0.92	23	0.21
Aquatic Biota	PET taxa (bed)	5.10	1.01	20	0.20
Aquatic Biota	Taxa richness (bed)	18.70	2.41	20	0.13
Physical Form	Substrate heterogeneity	1.60	0.20	26	0.12
Aquatic Biota	Taxa richness (edge)	18.17	2.05	23	0.11
Water Quality	DO	7.72	0.83	25	0.11
Aquatic Biota	SIGNAL grade (bed)	4.54	0.29	20	0.06
Water Quality	pH	6.73	0.36	25	0.05
Aquatic Biota	SIGNAL grade (edge)	4.41	0.19	23	0.04
Water Quality	Water temp	21.19	0.67	25	0.03

Table 11. Analysis results of Wet Tropics reference site data variability. Indices have been ranked from those with the highest CI/M ratio to those with the lowest CI/M ratio

FARWH field teams collected test site data for the Wet Tropics field trial. As with the reference site data, the ‘Turbidity’ index produced the most variable data, whereas data for the ‘Water Temp’ index was the least variable.

Wet Tropics trial test site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Water Quality	Turbidity	0.23	0.35	30	1.50
Water Quality	Conductivity	0.07	0.04	30	0.61
Aquatic Biota	PET taxa (bed)	4.15	0.89	27	0.21
Aquatic Biota	Taxa richness (bed)	12.48	2.07	27	0.17
Aquatic Biota	PET taxa (edge)	4.33	0.71	30	0.16
Physical Form	Substrate heterogeneity	1.69	0.19	29	0.11
Aquatic Biota	Taxa richness (edge)	17.73	1.39	30	0.08
Water Quality	DO	9.91	0.64	30	0.06
Aquatic Biota	SIGNAL grade (edge)	4.31	0.17	30	0.04
Aquatic Biota	SIGNAL grade (bed)	5.09	0.21	27	0.04
Water Quality	pH	6.75	0.23	30	0.03
Water Quality	Water temp	21.47	0.49	30	0.02

Table 12. Analysis results of Wet Tropics test site data variability

2.7.1.4 Lake Eyre trial

FARWH field teams collected reference and test site data for the Lake Eyre field trial. An analysis of reference site data variability was undertaken with ‘data confidence’ being represented by the CI/M ratio: those ratios are presented in tables 13 and 14 on an index-by-index basis. The ‘PcPugCow’ index produced the most variable reference site data, whereas reference site data for the ‘Prop alien (fish)’ index was the least variable because no alien fish were caught at any reference sites.

Lake Eyre trial reference site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Physical Form	PcPugCow	0.23	0.27	7	1.20
Water Quality	Conductivity	0.26	0.24	6	0.92
Physical Form	PcBench	0.32	0.29	7	0.91
Water Quality	Turbidity	451.25	394.36	4	0.87
Physical Form	Vertical depth	7.63	6.51	7	0.85
Physical Form	PcPugPig	0.03	0.03	7	0.78
Physical Form	PcSnags	0.40	0.21	7	0.52
Aquatic Biota	PET taxa (edge)	1.33	0.65	6	0.49
Aquatic Biota	Taxa richness (bed)	7.50	3.07	6	0.41
Physical Form	PcOvHang	0.65	0.21	7	0.32
Water Quality	DO	7.54	2.15	6	0.29
Aquatic Biota	Taxa richness (edge)	11.00	2.82	6	0.26
Aquatic Biota	Fish species richness	6.29	1.40	7	0.22
Water Quality	pH	9.91	1.27	6	0.13

Aquatic Biota	PET taxa (bed)	8.26	0.89	6	0.11
Aquatic Biota	SIGNAL grade (bed)	3.55	0.26	6	0.07
Water Quality	Temp	27.56	1.75	6	0.06
Aquatic Biota	SIGNAL grade (edge)	3.54	0.21	6	0.06
Aquatic Biota	Prop alien (fish)	100.00	n/a	7	n/a

Table 13. Analysis results of Lake Eyre trial reference site data variability

Lake Eyre trial test site values					
Theme	Index	Mean	95% CI	n	CI to mean ratio (CI/M)
Aquatic Biota	PET taxa (bed)	0.4	0.2	28	0.55
Physical Form	PcPugPig	0.3	0.1	24	0.54
Physical Form	PcBench	0.3	0.1	24	0.49
Aquatic Biota	PET taxa (edge)	1.1	0.4	28	0.39
Physical Form	Vertical depth	6.3	2.2	24	0.35
Physical Form	PcPugCow	0.5	0.2	24	0.34
Physical Form	PcSnags	0.4	0.1	24	0.27
Water Quality	Turbidity	482.2	120.8	26	0.25
Water Quality	Conductivity	0.3	0.1	30	0.24
Physical Form	PcOvHang	0.7	0.1	24	0.19
Aquatic Biota	Taxa richness (bed)	6.5	1.1	28	0.17
Aquatic Biota	Taxa richness (edge)	11.3	1.6	28	0.14
Water Quality	DO	7.8	0.7	32	0.09
Aquatic Biota	Species richness	8.0	0.7	24	0.09
Water Quality	pH	9.5	0.7	32	0.07
Aquatic Biota	SIGNAL grade (bed)	3.5	0.1	28	0.04
Aquatic Biota	SIGNAL grade (edge)	3.5	0.1	28	0.03
Water Quality	Temp	28.2	0.9	32	0.03
Aquatic Biota	Prop alien (fish)	99.8	0.3	24	0.00

Table 14. Analysis results of Lake Eyre trial test site data variability

2.7.1.5 Discussion

Of the 154 theme scores in the above tables, only 16 per cent (25) have the true mean within 10 per cent of the estimated mean ($p < 0.05$). The Water Quality indices assessed for the Central trial all have greater CI/M ratios than the Aquatic Biota indices. The average CI/M ratio for the Water Quality indices was 0.65, whereas the average CI/M ratio for the Aquatic Biota indices was 0.08. This trend suggests the chosen Water Quality indices display greater variability within the study area and would therefore require a larger number of sampling sites to adequately estimate mean values.

Water Quality indices assessed during the Moreton trial produced an average CI/M ratio of 0.31 compared with an average CI/M ratio of 0.36 for the Aquatic Biota indices. The sample population size was the same for both themes. One possible explanation is that Water Quality indices used during the Moreton trial may have less inherent variability compared with those used during the Central trial. Another explanation may be that the sample population for the Moreton trial is stratified into four stream types (upland, lowland, coastal and tannin-stained) before analysis and/or that the indicators' natural variation is greater in Central bioprovince compared with South East Queensland.

Dobbie et al. (2009b) used data from the Wet Tropics trial to explore design and analysis concepts to determine sample size and data confidence. They found that for one index, PET, the sample population size had the power to detect a change to either a severely degraded system (means in range 0.0–0.166) or an almost-pristine system (means in range 0.904–1.0). For all other indices, the sample size did not give sufficient power to detect a difference between the estimated mean and a true mean of 1 (i.e. 100 per cent). However, it should be noted that little natural variability for this indicator exists within this trial area. Therefore we could conclude that this indicator may not be appropriate or may need further investigation before use in other studies.

Generally an increase in sample population size would decrease the error surrounding the mean, and result in an increased ability to detect meaningful departures from reference. Dobbie et al. (2009b) determined – as long as the sample sites account for a relatively small proportion of the sampling frame (design) – a doubling in site assessments (to 110 samples in total) could be expected to reduce the standard error by about 70 per cent for data from the Wet Tropics.

2.7.2 Remotely sensed indicators

2.7.2.1 Fringing Zone

Three aspects to consider when determining the accuracy of the Fringing Zone assessment were: accuracy of the field collection method, accuracy of each of the spatial data products used to undertake the analysis, and accuracy of the analysis method. Some components of each of these aspects differed for the alternative SWMAs assessed, as differing approaches and indices were used to assess the Fringing Zone depending on the availability of data and resources, field sampling intensity and the base sampling unit (waterholes as compared with reaches).

2.7.2.1.1 Field data collection methods

While assessment of all but one SWMA relied on spatial analysis from remotely sensed and GIS data, field data was used for assessment of the Cooper Creek SWMA and is important for validating the remotely sensed data in other SWMAs. Thus, an understanding of the field method’s accuracy is important to account for inherent error.

As the available resources to support fieldwork are always finite, all fieldwork requires a trade-off between the amount of information collected and the time and human resource input required to collect a sample. Zammit, Dobbie and Wang (2008) investigated the amount of information retained when a rapid riparian assessment method was used (e.g. that employed by FARWH) compared with a complete assessment. A complete assessment involved assessing six transects on each bank of a stream reach. Each transect was 50 m long, spaced 100 m apart, and an observation of the vegetation was made at 1 m intervals along each transect. In comparison, the rapid assessment methodology involved three transects on each bank of a stream reach, where the transects were the same length but spaced twice the distance apart (200 m), and vegetation observations were made at 3 m intervals along the transect.

The rapid method was found to retain 86 per cent of the information on the structural complexity of riparian vegetation and 84 per cent of information on the presence of exotic species that would have been collected from a complete sample: thus only 14 per cent of information is lost. The rapid method reduced the time taken to undertake the sample from five to six hours for three to four trained fieldworkers to two to three hours for two to three fieldworkers. However, these conclusions were based on a small sample of 12 sites from only one region: the Central Province in Queensland (Zammit, Dobbie & Wang 2008).

In the Tully SWMA, FARWH trialled qualitative assessments of the fringing zone. FARWH relied on SEAP quantitative assessments to validate remotely sensed imagery. Within the Wet Tropics bioprovince, SEAP collected information on vegetation cover using transects of 27m. A transect length of 27m across six transects gives a sample of 60 per site. This equates to taking just 33 per cent of the number of observations taken in the other trialled SWMAs. No analysis has been done to determine the accuracy of information collected using a transect length of 27 m for vegetation attributes.

However, as an example of how different transect length and, in turn, the number of vegetation samples could affect the accuracy of information collected – in the Burdekin SWMA CMIS looked at reducing the transect length to 25 m, taking one observation every 3m, spacing transects 200m apart (see Table 15). Clearly these results do not transfer directly from ecosystems such as Burdekin (with small changes in topographic undulation and moderate-height open-canopied vegetation) to those located in Tully (with steep inclines in stream banks where vegetation communities largely are tall with closed canopies). The comparison does, however, generally indicate the loss of information by retaining observations at 3m intervals while reducing transect length to 27m. That said, personal communication with the SEAP team indicates that extending transects is unlikely to provide greater information on riparian structure and condition, because riparian vegetation edge was contained within the 27 m transect length.

Vegetation structure	Scenario		
	Complete	8	9
	dc=1m dT=100m Dc=50m	dc=3m dT=200m Dc=50m	dc=3m dT=200m Dc=25m
Total hit	100	86.97	71.16
Trees	100	100	90.1
Shrubs	100	91.7	100
Groundcover	100	100	71.6
Vines	100	83.9	52.6
Exotics	100	84.6	52.6
Where dc is the distance between observations along a transect; dt is the distance between transects along a bank; and Dc is the length of the transect.			

Table 15. A comparison of the information retained (IR) for each structural group and exotic vegetation for the original AusRIVAS/SoR, FARWH, and 25 m transect scenarios. Adapted from Zammit et al. (2008).

2.7.2.1.2 Landsat-derived foliage projective cover product accuracy

The Statewide Landcover and Trees Study (SLATS) foliage projective cover (FPC) woody extent classification model and its resulting product has a Kappa statistic of 85.12 per cent. The Kappa statistic indicates the accuracy between estimates derived from a remote-sensing product and the reference data, adjusted for chance agreement (Congalton 1981) – as opposed to the overall accuracy statistic that is just a measure of how well something is classified as it should be.

Comparison with independent field estimates of perennial FPC acquired for a range of vegetation types over Queensland showed high agreement (R2=0.84, RMSE=8.95, N=47). Independent regional-scale comparisons with airborne Lidar and MODIS estimates of FPC found the models used to create the FPC product had predictive errors of less than 10 per cent root mean square error (RMSE) (Armston et al. 2009). More importantly, Armston et al. (2009) indicated the errors were not consistent. The bias of models depends on the density of overstorey FPC, with the bias declining at greater than ~60 per cent overstorey FPC. The product is also influenced, with biases increasing beyond 10 per cent, where there is high herbaceous or understorey FPC either typically in the plant community or where flushes in understorey coincide with imagery capture. Armston et al. (2009) concluded that the regression models used to produce overstorey FPC products derived from Landsat-5 TM or Landsat-7 ETM+ data in Queensland have an inherent assumption of senescent or absent herbaceous foliage at the time of image acquisition. Fieldwork results demonstrated that this assumption is inherently flawed (see Table 16), and may result in overestimation of vegetation cover by analysis of remotely sensed imagery.

Cover	Burdekin	Moreton	Pioneer*	Cooper Creek	Tully*
Average	76.42	93.88	68.75	0.21	88.70
Median	80.56	100.00	75.93	0.17	95.00
Min	28.70	31.48	16.67	0.01	36.67
Max	98.15	100.00	91.67	0.59	100.00
*Statistics are for cover not foliage projective cover, as only cover measurements were collected in these SWMAs.					

Table 16. The range of understorey foliage projective cover measured during sampling for three of the SWMAs sampled during the Qld FARWH field trials

2.7.2.1.3 Drainage network and water mask

For each of the first-year trials (Burdekin, Pioneer and Moreton SWMAs), the drainage network was specifically generated following the method developed for NLWRA I and described in Section 2.4 of NWC (2007b) from 100 000 contour data held by the Queensland Government. The generated stream networks were used without any error and accuracy assessment and thus had inherent topological errors. As a result, there were flow-on effects for high rates of inability to sample in-field, as well as accurate calculation of stream length and influencing catchment area during analysis. More confidence was given to the 100 000 Ordered Drainage Network and the waterhole mapping used to drive the second-year trials in the Tully and Cooper Creek SWMAs respectively. Both these networks accurately represented the presence and location of the water features as they appear in the field. In all cases the ability to calculate reach length and influencing catchment area for each stream reach was limited by the contours or DEM upon which the initial drainage network determination was performed. It is also worth noting that although the 100 000 Ordered Drainage Network provided accurate representation of stream presence and location, automatic back-propagation of the influencing catchment network by GIS proved inaccurate and inefficient and, ultimately, could only be achieved manually. The issue that remained for all networks was how accurately they represented and could be used to delineate water extent.

In all assessments where a drainage network formed the sampling framework (i.e. all SWMAs sampled except for the Cooper Creek SWMA), the drainage network lines represented the stream's centreline. This clearly leaves some disparity in matching cover in the riparian zone as measured by GIS analysis to field measurements made from watermark. An accurate estimation of typical watermark is needed to align the GIS buffer to the maximum extent of field assessment.

The SLATS water mask was explored to determine the degree to which it could represent standing water features to improve stream extent. Muir and Danaher (2008) determined that while the presence of water features was detected with a user's accuracy of 95 per cent for individual date classifications, the time-series product had a user's accuracy of only 31 per cent. This was partly a legacy of the disparity in feature surface area due to difference in capture date between Landsat and SPOT imagery, however small waterbodies and features were consistently underestimated by the comparatively coarse pixel size in Landsat.

These known limitations of the water mask time-series product correlated well with the limitations of the product demonstrated in the field trials. First, the representation is coarse, patchy and discontinuous because it is limited by the 25 m spatial resolution of the Landsat imagery on which it is based. It is a known challenge of Landsat imagery to detect linear water features such as rivers and streams, especially as the stream order, and in turn stream width, decreases. As the stream order decreases, there is an increased opportunity for the adjacent land features to dominate the response of water in the reflectance measured by the sensor. Both problems are exacerbated by the dry scene nature of the imagery used to calculate the water mask, in which water extent is most likely to be conservative and at its lowest level. Finally, the water mask was produced using imagery covering the time period 1988 until 2005, yet was ideally being used to represent imagery for the field-sampling years of 2008 and 2009.

2.7.2.1.4 Catchment Disturbance Index

As previously stated, the Catchment Disturbance Index (CDI) is calculated from SLATS statewide clearing data, Queensland land use mapping (QLUMP), and the Statewide Transport Dataset. The lineage and accuracy of each of these datasets influences the certainty associated with CDI results.

2.7.2.1.5 SLATS land cover change product

Three characteristics influence the certainty of land cover change assessments from the SLATS land cover change data product: accuracy, lineage, and spatial resolution. Following is a discussion of these characteristics in further detail.

Accuracy

Two assessments of the accuracy of the SLATS land cover change product have been conducted to date.

The initial accuracy assessment used scene overlaps of 1991–95 and 1995–97 to provide two measures of vegetation change. By analysing the discrepancies in change estimates for these overlaps, an error term of approximately 8 per cent at a 95 per cent confidence interval on the statewide clearing figures was determined (DERM 2009). Differences in path dates for the scenes forming the overlap allowed some real change to occur. Thus, the error term is likely to be conservative.

The second used independent methods rather than independent data to assess the accuracy of the land cover change analysis (Barson et al. 2000). The assessment was undertaken on the 1991–95 change data for Queensland. No significant difference in vegetation change analysis results could be detected for SLATS as opposed to the independent estimates in a high proportion of the individual subsample results at the 95 per cent confidence level. Thus no re-processing was required. Change detection methods have improved over time, so similar or better accuracy would be expected.

The science underpinning SLATS was reviewed in 2004, with an independent panel of academic, CSIRO and industry members commending the product for its quality.

Lineage

An 18-month lag period (approximately) occurs between the capture of imagery and release of the clearing data. For example, the 0708 SLATS report was released in February 2010 and the report for 0809 is expected to be ready for release by DERM in 2011. This is due to the time taken to capture and download the satellite image, provision of the imagery from the download facilities to the Remote Sensing Centre (RSC), radiometric and geometric processing, clearing algorithm application, pre-field screening, field checking, post-field editing, report compilation, ministerial sign-off and release. This discrepancy between the year being assessed and the available lineage of change data means that real changes can occur and thus the data may not represent that sampled in-field.

SLATS is driven by a process of continual revision to improve the efficiency of its processing and field-checking methods to reduce the time taken between image capture and provision to the minister for release.

Spatial resolution

Similar to the impact of sensor resolution on the delineation of linear stream reaches, the grain of imagery determines the level of change in land cover that can be detected by satellite sensors. Due to improvements in sensor technology over time, imagery from different sensors with varying resolution was used to inform land cover change assessments. The coarser the sensor's spatial resolution, the less detailed the identification of land cover change incidents (Table 17).

<table>
<tr><th rowspan="2">Reporting period</th><th rowspan="2">Landsat sensor</th><th colspan="2">Resolution</th></tr>
<tr><th>Imagery used</th><th>Statistic calculations</th></tr>
<tr><td>1988–91 (DNR&M 2004)</td><td rowspan="3">5 TM</td><td rowspan="11">30 m (resampled to 25 m)</td><td>100 m</td></tr>
<tr><td>1991–95 (DNR 1999b)</td><td rowspan="3">1 km</td></tr>
<tr><td>1995–97 (DNR 1999c)</td></tr>
<tr><td>1997–99 (DNR 2000)</td><td>5 TM & 7 ETM+</td></tr>
<tr><td>1999–2001 (DNR&M 2003a)</td><td>7 ETM+</td><td rowspan="2">100 m</td></tr>
<tr><td>2001–03 (DNR&M 2005)</td><td>5 TM & 7 ETM+</td></tr>
<tr><td>2003–04 (DNR&M 2006)</td><td rowspan="5">5 TM</td><td rowspan="5">25 m</td></tr>
<tr><td>2004–05 (DNR&W 2007)</td></tr>
<tr><td>2005–06 (DNR&W 2008b)</td></tr>
<tr><td>2006–07 (DNR&W 2008a)</td></tr>
<tr><td>2007–08 (DERM 2009)</td></tr>
</table>

Table 17. Different data used for different eras for assessing land cover change across Queensland

2.7.2.1.6 QLUMP land use

Data lineage and product accuracy influenced the certainty of land use assessments from the QLUMP land use products.

Lineage

At the time the FARWH assessments were undertaken, the maximum lineage for QLUMP land use products was 1999 for Moreton and Cooper and 2004 for Burdekin, Pioneer and Tully. While Burdekin and Pioneer are in the process of being updated to 2009, these products will not be available for use in assessments until approximately June 2011 (Simone Grounds, QLUMP project coordinator, pers. comm. 26/5/2010). Draft versions of Pine and Logan-Albert for 2006, and updates to South East Queensland catchments and the Wet Tropics have been made available since the respective trial assessments were completed. The difference in the lineage of available data products and assessment dates leaves scope for inaccuracies in the assessment due to real change.

Accuracy

The measured accuracy of the data products for the various SWMAs is detailed below:

Burdekin

Berg and Jamieson (2006) assessed the accuracy of the QLUMP land use 1999 and 2004 data product for the Burdekin catchment. The original 1999 dataset demonstrated an overall accuracy of 91 per cent. While an improved 1999 dataset has since been produced to provide a more accurate comparison with the 2004 dataset for change mapping purposes, a separate accuracy assessment has not been undertaken for the revised 1999 dataset (Witte et al. 2006).

The overall map accuracy of the 2004 land use dataset was 96.4 per cent (0.90, 0.99) and the Kappa statistic was 0.721 (0.468, 0.908) (van den Berg & Jamieson 2006). To indicate the uncertainty of the estimates, 95 per cent posterior confidence intervals are provided in the parentheses after the accuracy estimate. Users' accuracies are above 75 per cent for all but three land use categories: services, channel/aqueduct, and marsh/wetland.

Pioneer

For the Pioneer SWMA, the original version of the 1999 dataset had an overall accuracy of 0.95 (van den Berg, Grounds & Denham 2007). The accuracy of the improved 1999 land use mapping, which was used in the current study, was the same with a 95 per cent confidence interval (0.92, 0.97) and a Kappa statistic of 0.93 (0.89, 0.95). Aside from river (0.5), other minimal use (0.56), manufacturing and industrial (0.65), and other conserved area (0.77), all other land use categories had a user's accuracy of equal to or greater than 85 per cent.

Tully

QLUMP 1999 land use mapping for the Tully catchment had a total accuracy of 0.79 (0.69, 0.87) and a Kappa statistic of 0.71 (0.57, 0.82) (Witte et al. 2006). No information was available on 2004-era QLUMP land use mapping for the Tully catchment.

Cooper Creek

No specific accuracy assessment figures are available for QLUMP land use mapping over the Cooper Creek SWMA (Witte et al. 2006). Average accuracy statistics for the 1999 QLUMP land use mapping products are a likely indication of the probable accuracy of land use mapping for this catchment. The total average accuracy was 0.88 and the Kappa statistic was 0.72 (Witte et al. 2006).

2.7.3 Bands of condition

All theme and overall scores were ultimately assigned to a band of condition based on those defined within the AWR (2007) guidelines and shown below in Table 18.

It should be highlighted that these bands are an arbitrary standard and it is suggested, where available, that more ecologically relevant bands should be used. It is, however, acknowledged that the research and knowledge underpinning a more ecologically relevant cut-off is often lacking. Therefore the use of arbitrary values becomes appropriate. It is recommended that further consideration of these arbitrary cut-offs is needed.

Standardised FARWH score	Band of condition
0.8–1	Largely unmodified condition
0.6–0.8	Slightly modified condition
0.4–0.6	Moderately modified condition
0.2–0.4	Substantially modified condition
0–0.2	Severely modified condition

Table 18. Bands of condition for FARWH assessment

2.8 Alignment with jurisdiction programs

A comparison of the FARWH with the existing state-level monitoring programs that formed the basis for these trials is presented in Table 19 below. This documents the similarities and differences between the attributes of the various programs. Alignment of results between these programs is discussed in Section 4.3.

Attribute	FARWH	SEAP	EHMP
Purpose of program	National comparative reporting	Reporting to Queensland Government for management purposes	Reporting to local government for management actions
Funding	Australian Government	Queensland Government	Local governments of SE Qld, Qld Govt, CSIRO and universities of SE Qld
What ecosystems are covered	Rivers and wetlands	Rivers (estuaries as well but monitoring is not currently funded)	Rivers
Reporting scale	Surface water management areas	Bioprovinces	Subcatchments
Framework	Six themes covering general components of the aquatic ecosystem	Pressure-stressor-response (PSR) indicators are identified by expert opinion (qualitative); stressor models (threats to the ecosystem) prioritised by risk assessment; and cost/benefit criteria used to select relevant indicators (quantitative)	Indicator selection is based on a previous pilot research program that investigated indicator responses to a predetermined disturbance gradient (land use and riparian condition)
Ecological basis of indicator selection	Indicator selection using available data within the themes as collected by state-based programs	Conceptual model (natural)	Conceptual model (land clearing)
Indicator selection	Under themes of Catchment Disturbance, Physical Form, Hydrological Disturbance, Water Quality and Soils, Fringing Zone and Aquatic Biota	Generic stressors are considered by expert discussion and current data, and prioritised using a risk assessment process. Using a conceptual model these are related to pressures and ecological responses. Indicators for each PSR are selected using scored selection criteria.	Indicators selected under five indicator types: physical and chemical characteristics, nutrients, primary production (ecosystem processes), aquatic macroinvertebrates and fish
Unit of measurement: spatial	Reach (determined by change in stream character: catchment	River segment (segment of stream between major	Site on river reach (based on stream order)

Attribute	FARWH	SEAP	EHMP
	area x slope)	confluences)	
Unit of measurement: temporal	Not determined but possibly four years to align with SoE	Currently five to 10 years; possibility that priority catchments are sampled once every three to four years	Bi-annual
Assessment	Referential	Referential	Referential
Reference: detectable change	Change against natural determined by minimally disturbed sites, historical data, modelling of past conditions, and professional judgement	Change against natural determined by minimally disturbed sites, historical data, modelling of past conditions, and professional judgement	Change against fixed temporal and spatial reference
Data analysis	Range standardisation; aggregated and integrated index for each SWMA. As per NWC (2007a): depends on the indicator/theme but can include standardised Euclidean distance, worst case, arithmetic and expert rules.	Range standardised and aggregated and integrated for province – overall index and pressure/stressor and response	Range standardisation; integrated and aggregated index for each subcatchment
Weighting of data	As per NWC (2007a): depends on the indicator/theme but can include relative proportion of total reach length and relative proportion of influencing catchment area	Overall index has individual indicator data weighted by risk assessment scores from stressor prioritisation process. Standardisation uses worst case.	None: scores are averaged using several pathways to attain results for different purposes (EHMP 2007, p113). Standardisation is the same as FARWH (worst case). There is also an expert (fudge factor) weighting to get the final ABCDEF score.
Report delivery	To be confirmed	Annual report	Annual report card and technical report
Site selection	Not specified	GRTS; a probability based selection; legacy sites (long term or targeted sites) are also placed into the design	Random stratified plus extra sites depending on requests from the partners
Sample size	Guideline at least five per cent of reaches	30 test; 25 reference determined by power analysis and resource constraints	Determined by participation of local governments; number of sites determined by allocating sites to reaches and then removing redundancies
Treatment of unmeasured areas	Where possible remotely sensed or modelled data is used to provide data for those reaches not measured directly	Part of site selection design is that the selected sites are representative of the reporting area; therefore it is unnecessary to remotely sense or model missing data. This is driven by the objective that reporting does not necessarily have to encompass all reaches.	Sites were allocated to all reaches before redundant ones were removed (by local and expert opinion). Presumption is that coverage is complete and therefore it is not necessary to remotely sense or model missing data.

Table 19. A comparison of the current state-level monitoring programs and the FARWH (table reproduced from that initially presented in the project inception report prepared by Diane Conrick)

3 Results from the FARWH trials

The condition assessments for the five trial SWMAs for both the baseline (2004–05) and current era are presented in this section. Theme and overall scores were produced for each SWMA using the sub-indices specified and the weighting, aggregation and integration methods as outlined in sections 2.5 and 2.7 of this report. Specific sub-index data was presented for each theme within the year 1 and 2 trial reports and has not been reproduced here.

The SWMA baseline assessment for the year 2004–05 is based on data that was available from state-level monitoring sources only. These data were primarily from ABMAP and SWAN (the ambient monitoring programs for biological and water quality assessment respectively), as well as hydrological information from the Integrated Quantity and Quality Model (IQQM) and gauging stations within the SWMA. Fringing Zone and Catchment Disturbance indices were based on available information from the DERM Remote Sensing Centre specific to the time period.

Current era assessments were based on the field assessments conducted as part of these trials, remote sensing information and hydrological modelling (as for the baseline assessment but based on the most recently available information and outputs).

The standardised scores for each theme are presented in Table 20 (for the baseline era) and Table 21 (for the current era). Theme and overall scores are also presented in the following figures within this section. These figures show the FARWH assessment based on the band of condition as specified within AWR 2005 and shown in Table 18 (Section 2.7). All maps were produced to be consistent with the AWR 2005 format as specified within the project brief.

	Pioneer SWMA	Burdekin SWMA	Moreton SWMA	Tully SWMA	Cooper Creek SWMA
Fringing Zone	0.57	0.57	0.40	0.86	0.68
Catchment Disturbance	0.64	0.61	0.69	0.88	0.66
Aquatic Biota	1.00	0.91	0.78	0.87	0.85
Water Quality and Soils	1.00	0.94	0.77	1.00	0.45
Hydrological Disturbance	0.33	0.48	0.58	N/A	N/A
Physical Form	NA	NA	NA	N/A	N/A
Overall score	0.61	0.65	0.62	0.88	0.63

Table 20. Baseline year (2004–05) assessment for Qld FARWH trial SWMAs (0–0.2 = severely modified condition, 0.2–0.4 = substantially modified condition, 0.4–0.6 = moderately modified condition, 0.6–0.8 = slightly modified condition, 0.8–1 = largely unmodified condition)

	Pioneer SWMA	Burdekin SWMA	Moreton SWMA	Tully SWMA	Cooper Creek SWMA
Fringing Zone	0.61	0.56	0.41	0.86	0.90
Catchment Disturbance	0.62	0.56	0.66	0.82	0.47
Aquatic Biota	0.82	0.89	0.72	0.83	0.67
Water Quality and Soils	0.84	0.86	0.75	0.85	0.86
Hydrological Disturbance	0.33	0.48	0.58	N/A	N/A
Physical Form	0.96	0.86	0.97	0.90	0.70
Overall score	0.63	0.66	0.64	0.85	0.68

Table 21. Current era (2008–09) assessment for Qld FARWH trial SWMA

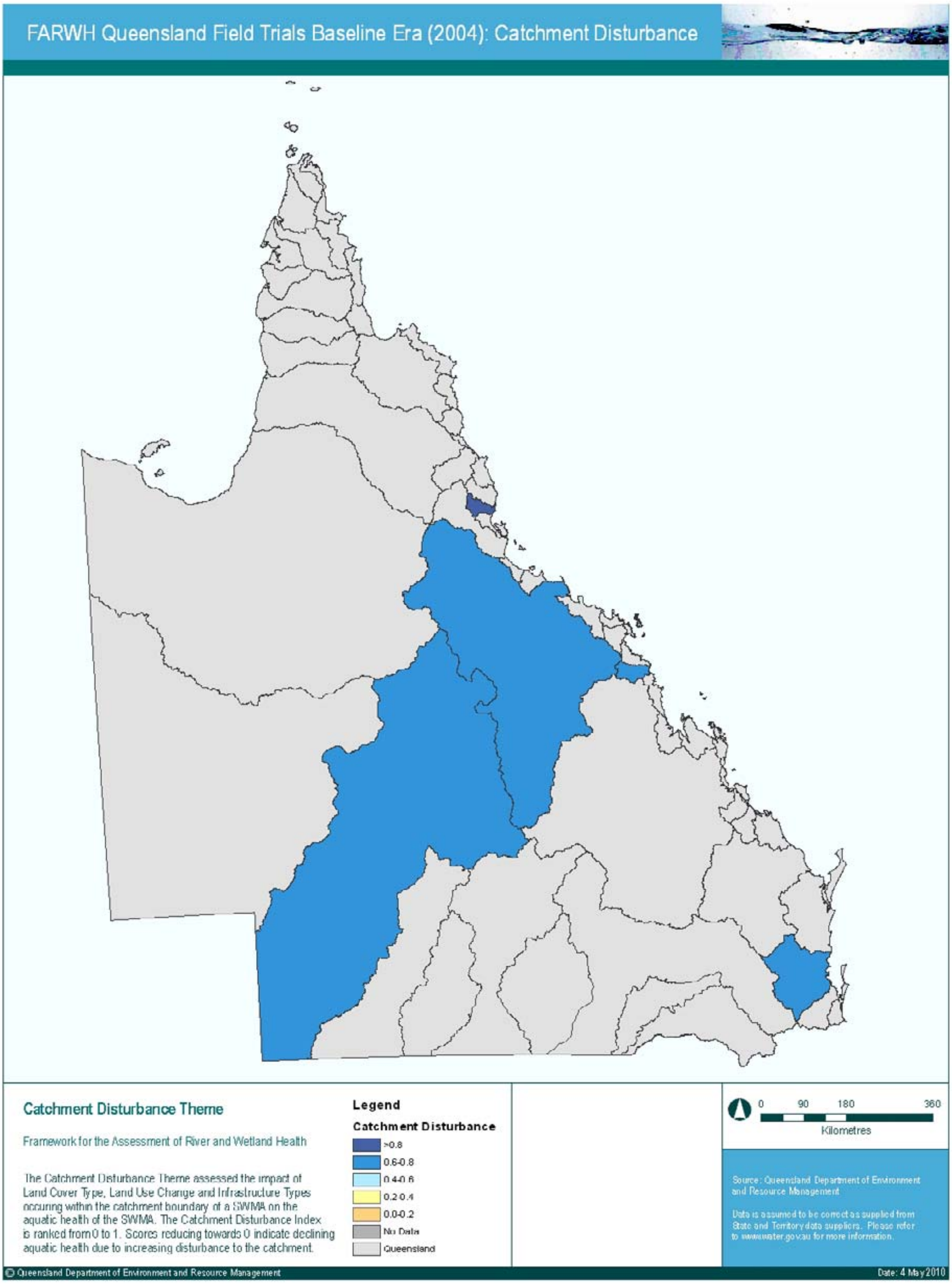

Figure 12. Aquatic Biota theme results for the 2004–05 baseline assessment of the Qld FARWH trial SWMAs (colour coded according to score)

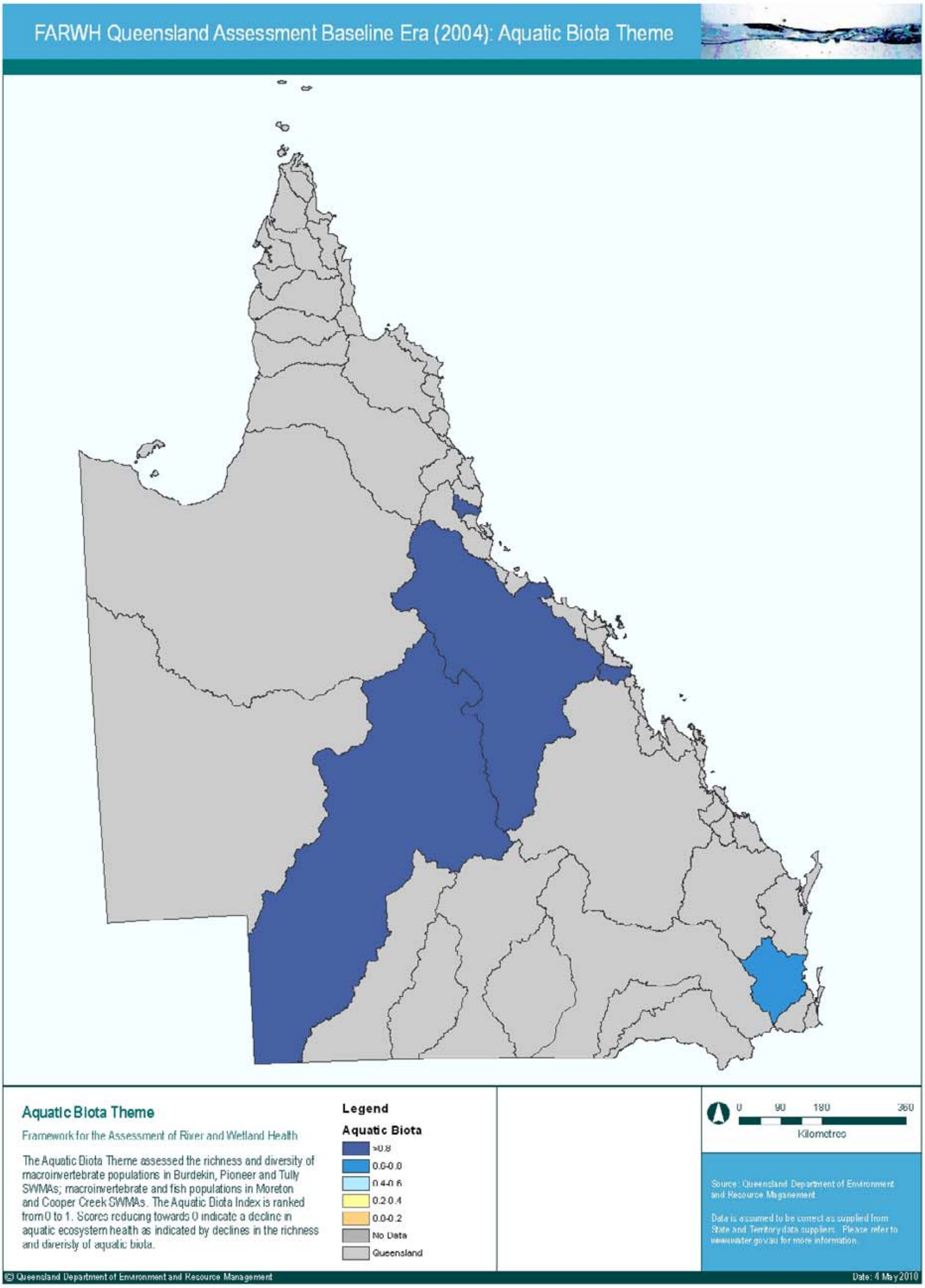

Figure 13. Catchment Disturbance theme results for the 2004–05 baseline assessment of the Qld FARWH trial SWMAs (colour coded according to score)

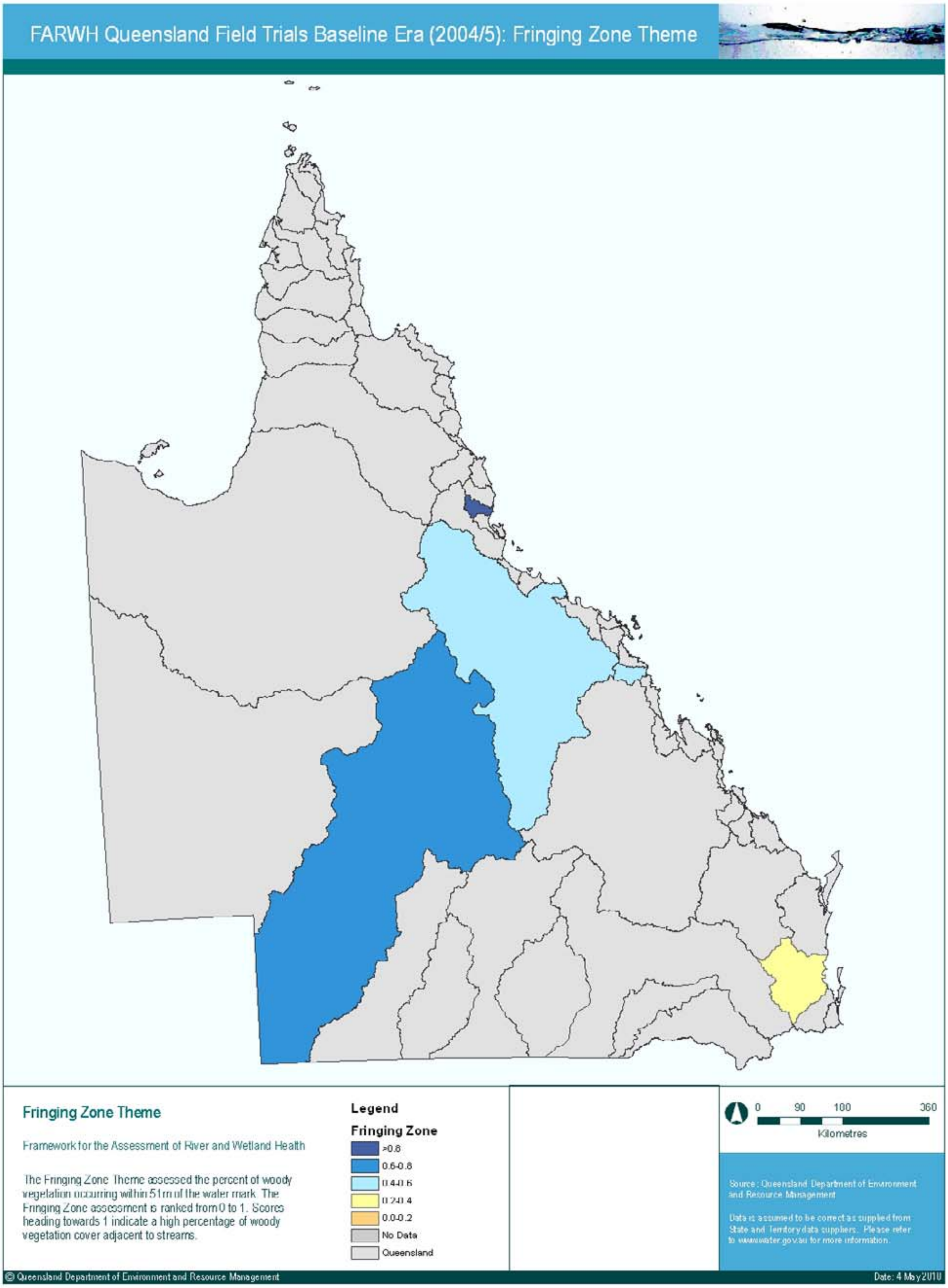

Figure 14. Fringing Zone theme results for the 2004–05 baseline assessment of the Qld FARWH trial SWMAs (colour coded according to score)

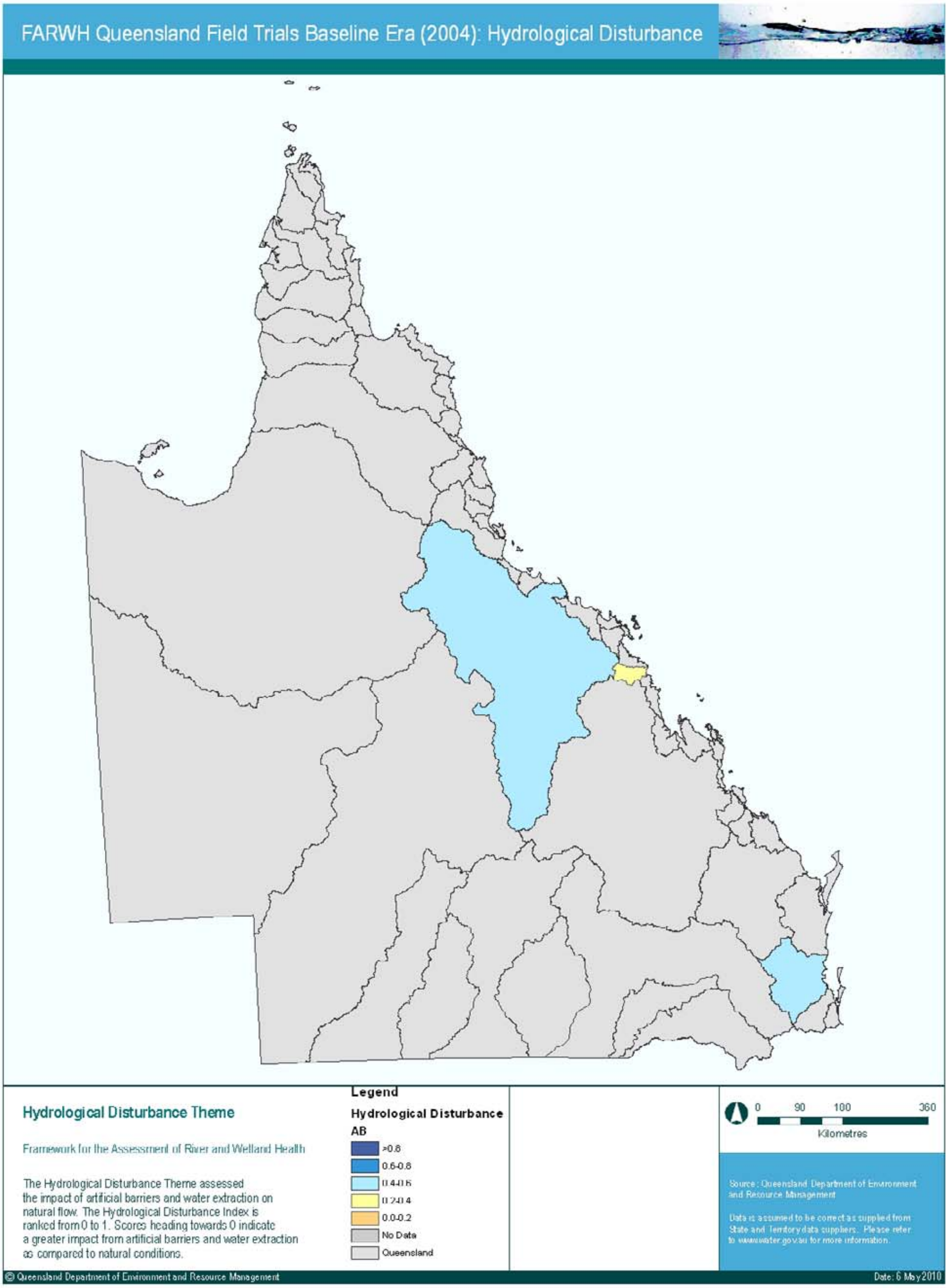

Figure 15. Hydrological Disturbance theme results for the 2004–05 baseline assessment of the Qld FARWH trial SWMAs (colour coded according to score)

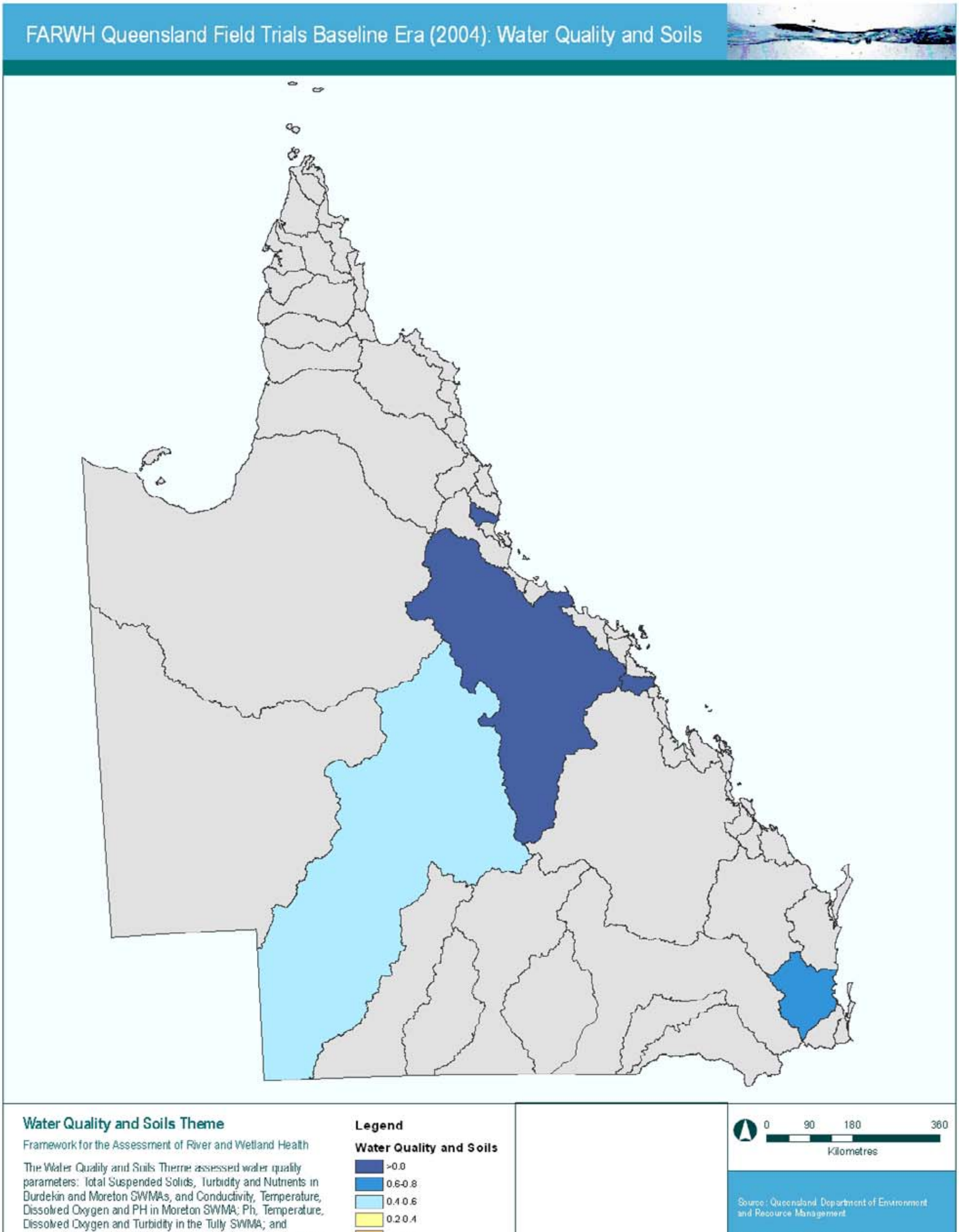

Figure 16. Water Quality and Soils theme results for the 2004–05 baseline assessment of the Qld FARWH trial SWMAs (colour coded according to score)

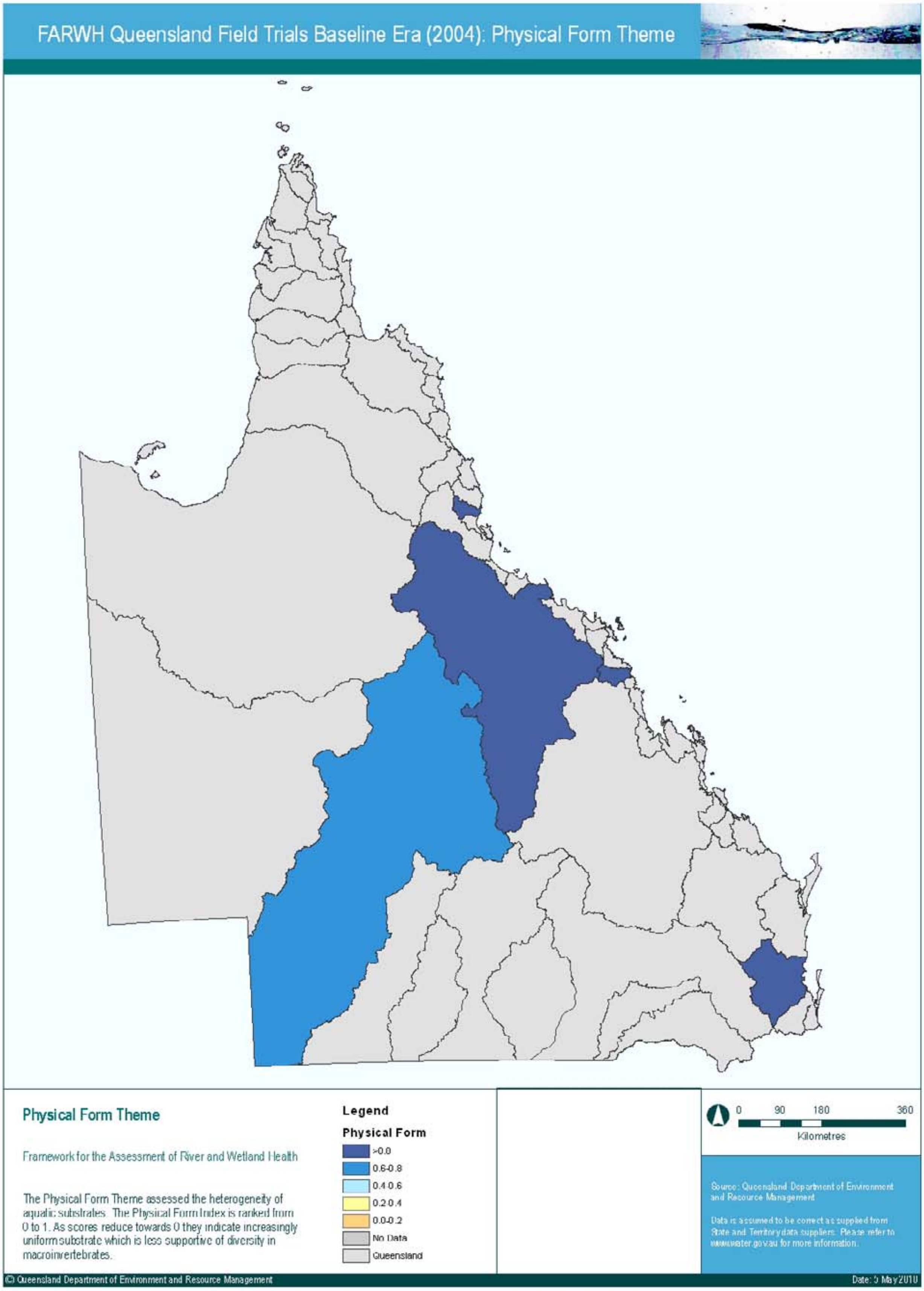

Figure 17. Physical Form theme results for the 2004–05 baseline assessment of the Qld FARWH trial SWMAs (colour coded according to score)

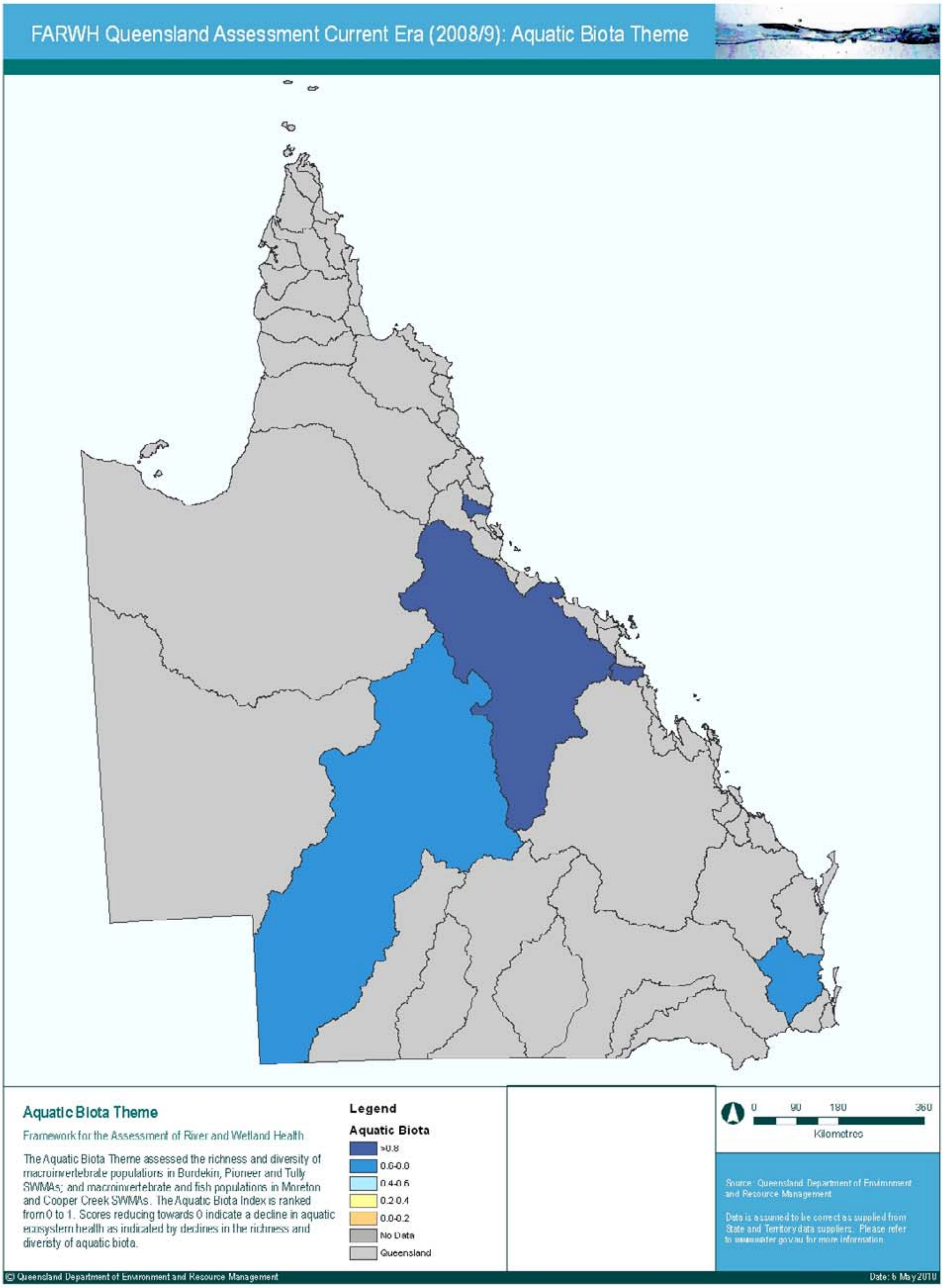

Figure 18. Aquatic Biota theme results for the 2008–09 assessment of the Qld FARWH trial SWMAs (colour coded according to score)

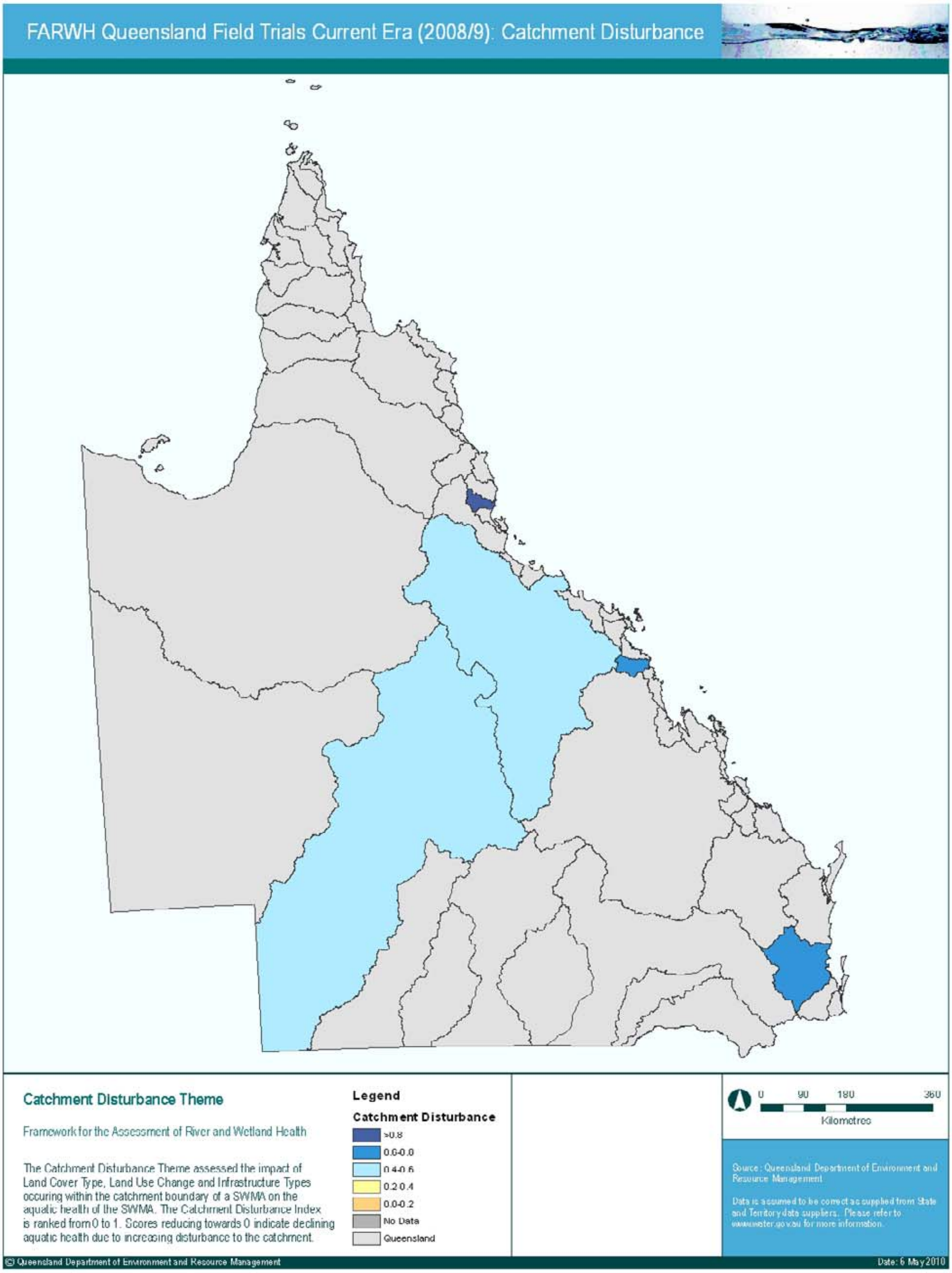

Figure 19. Catchment Disturbance theme results for the 2008–09 assessment of the Qld FARWH trial SWMAs (colour coded according to score)

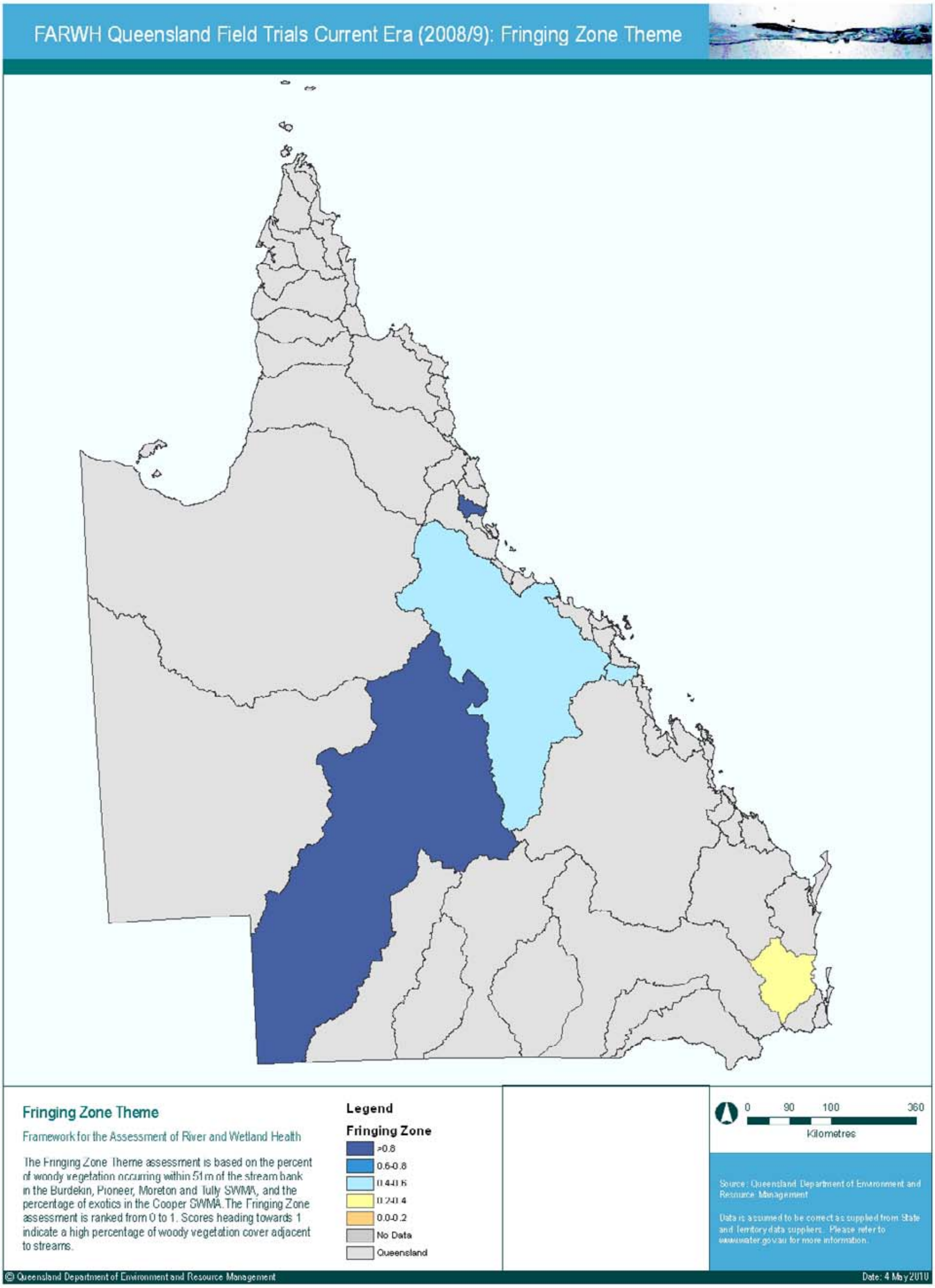

Figure 20. Fringing Zone theme results for the 2008–09 assessment of the Qld FARWH trial SWMAs (colour coded according to score)

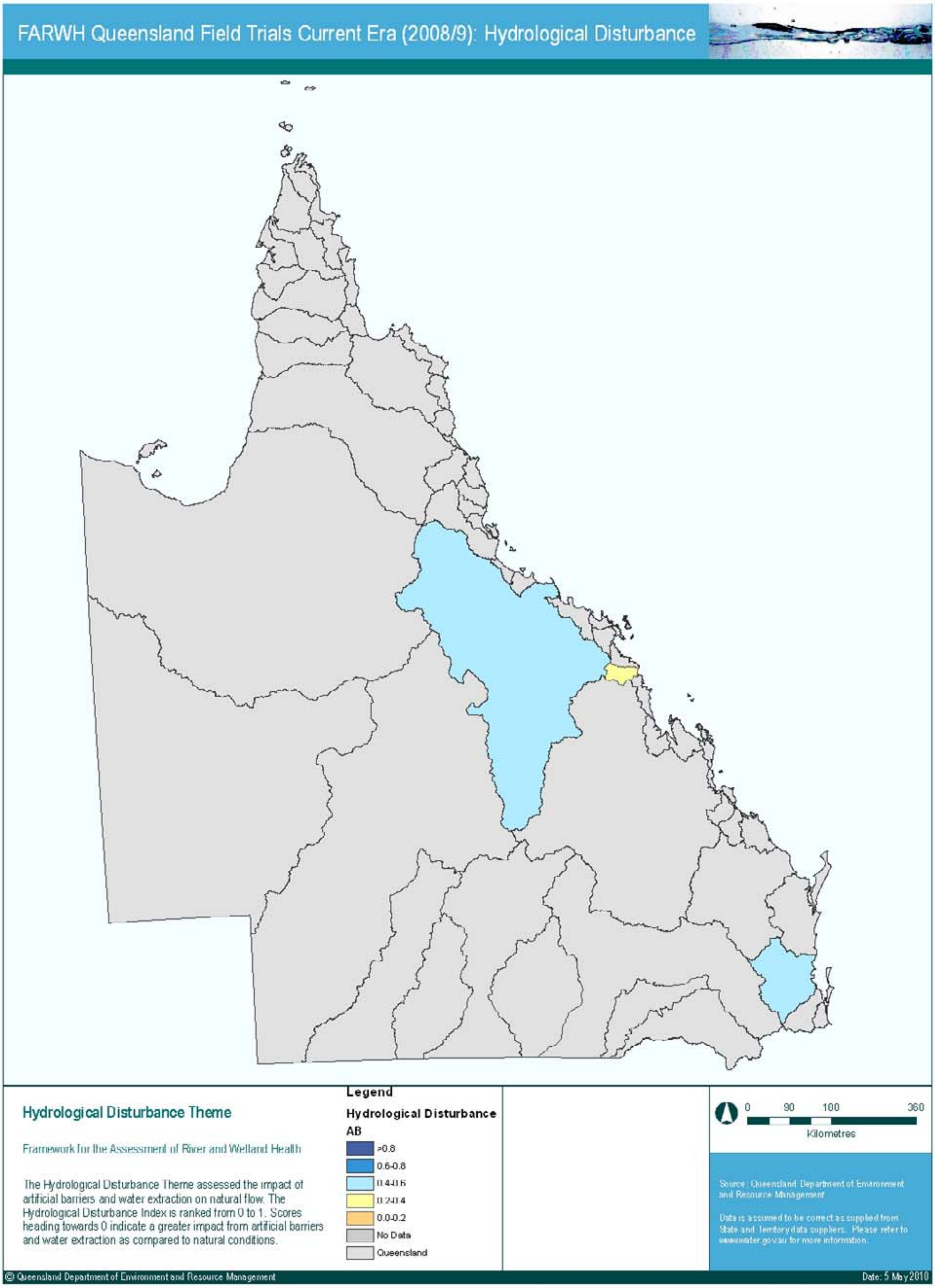

Figure 21. Hydrological Disturbance theme results for the 2008–09 assessment of the Qld FARWH trial SWMAs (colour coded according to score)

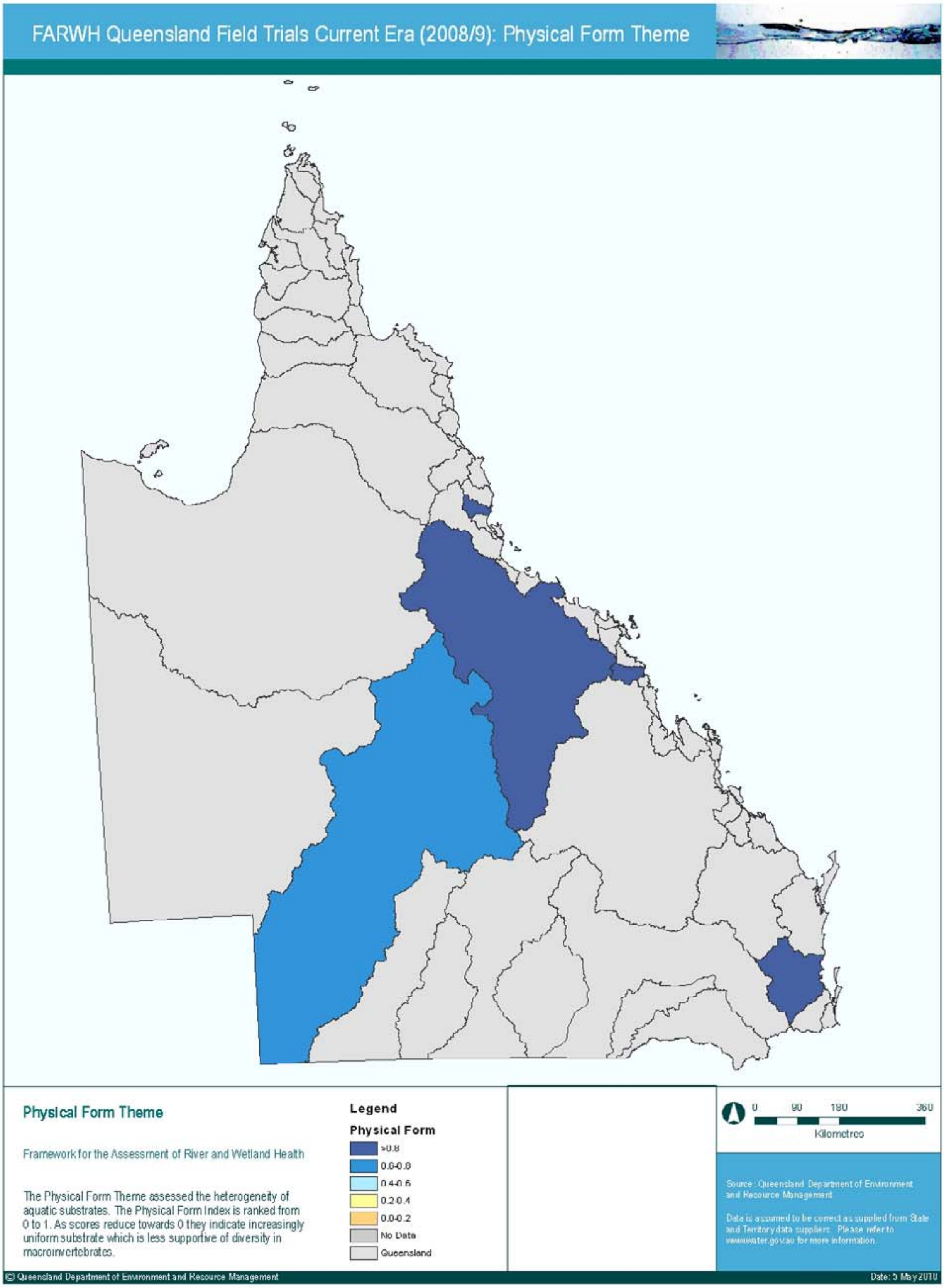

Figure 22. Physical Form theme results for the 2008–09 assessment of the Qld FARWH trial SWMAs (colour coded according to score)

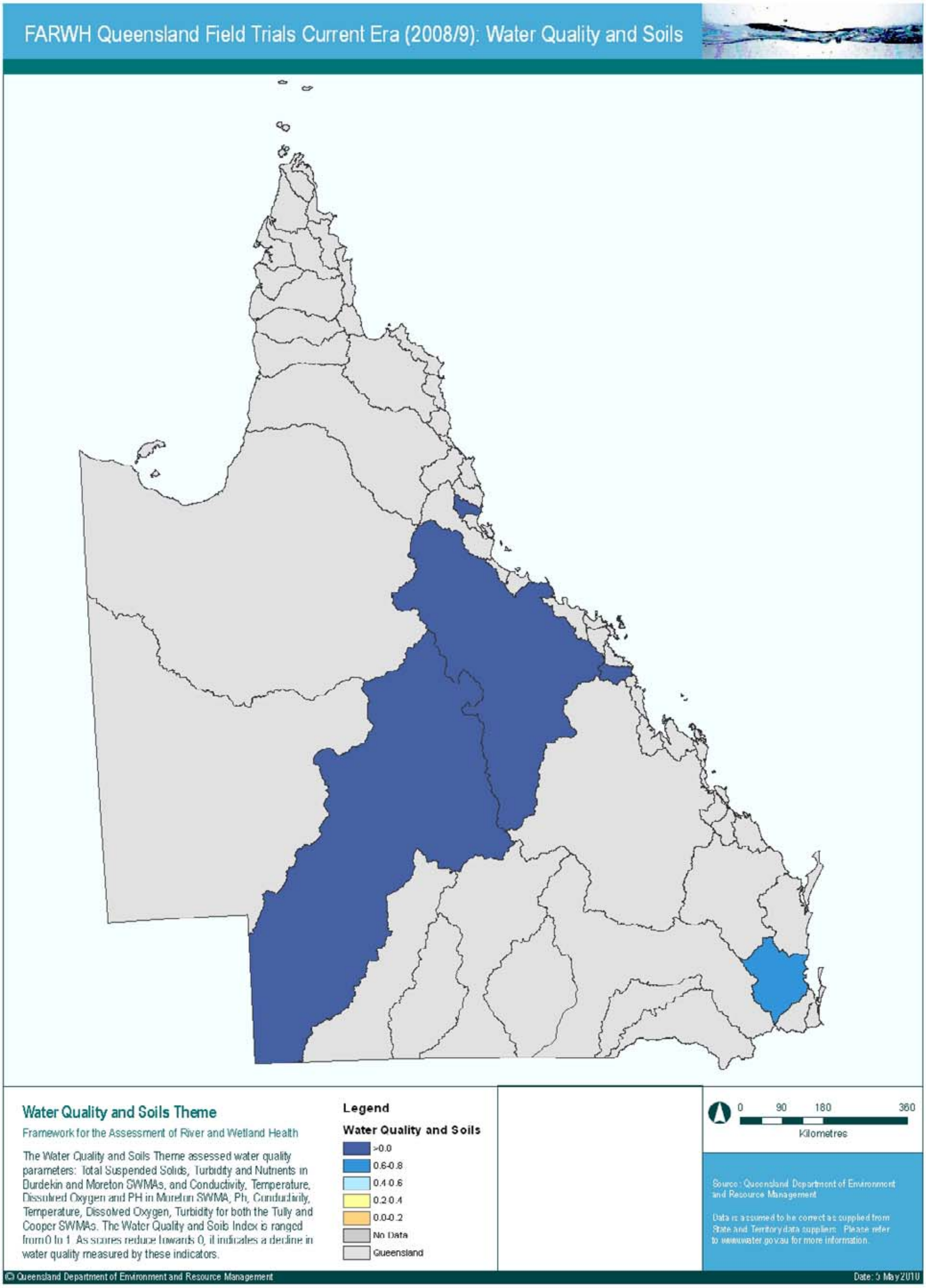

Figure 23. Water Quality and Soils theme results for the 2008–09 assessment of the Qld FARWH trial SWMAs (colour coded according to score)

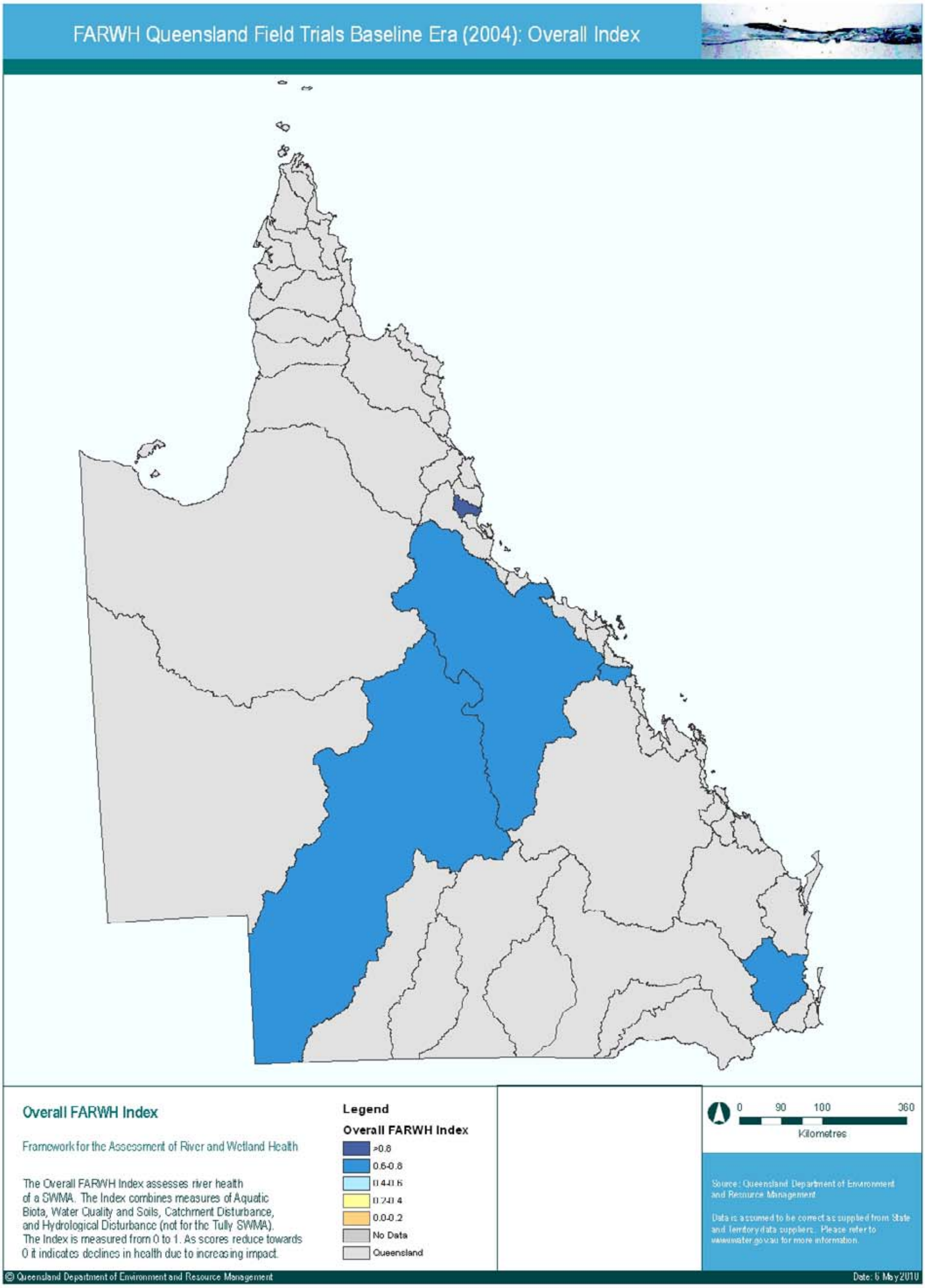

Figure 24. Overall results for the 2004–05 baseline assessment of the Qld FARWH trial SWMAs (colour coded according to score)

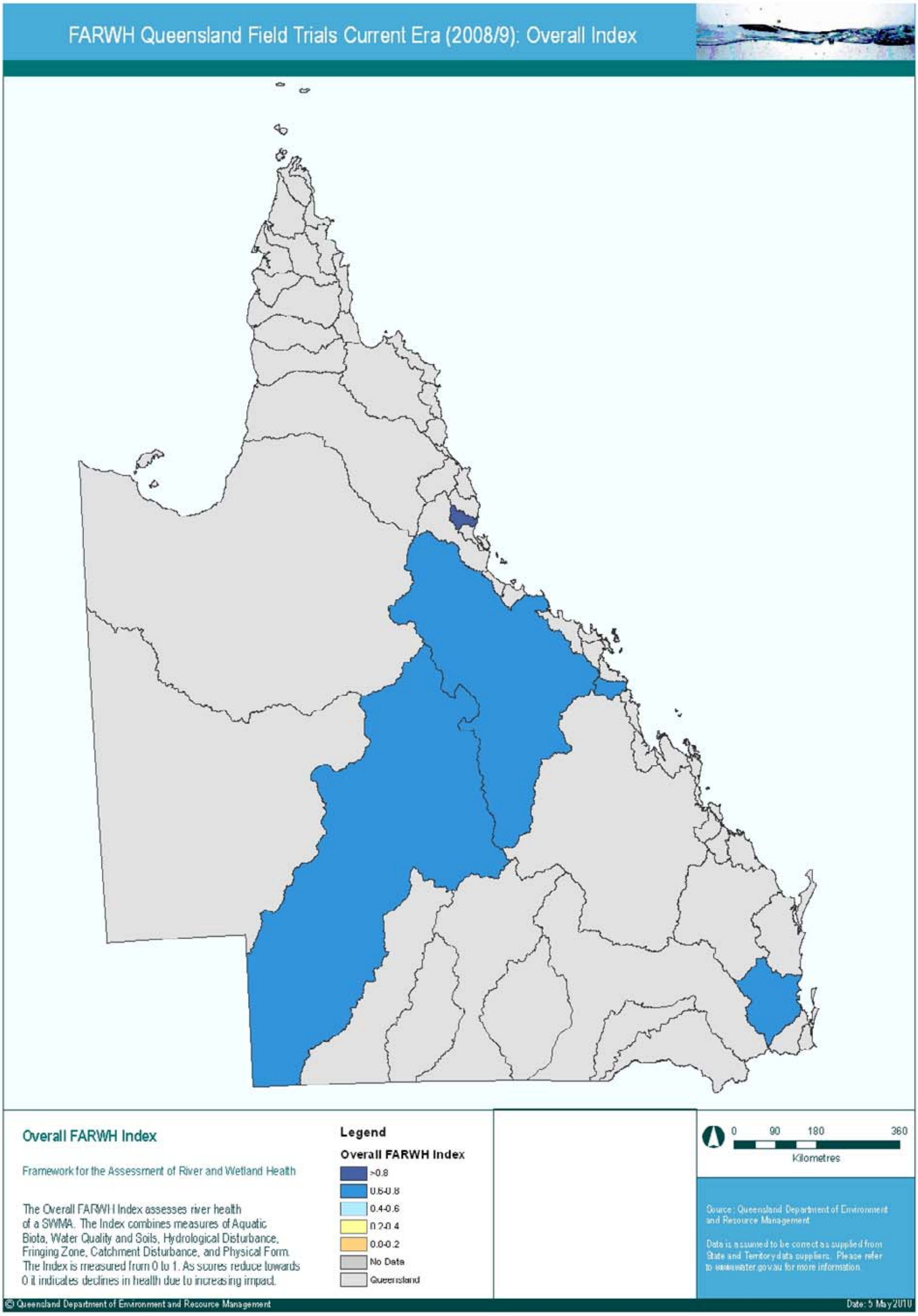

Figure 25. Overall results for the 2008–09 assessment of the Qld FARWH trial SWMAs (colour coded according to score)

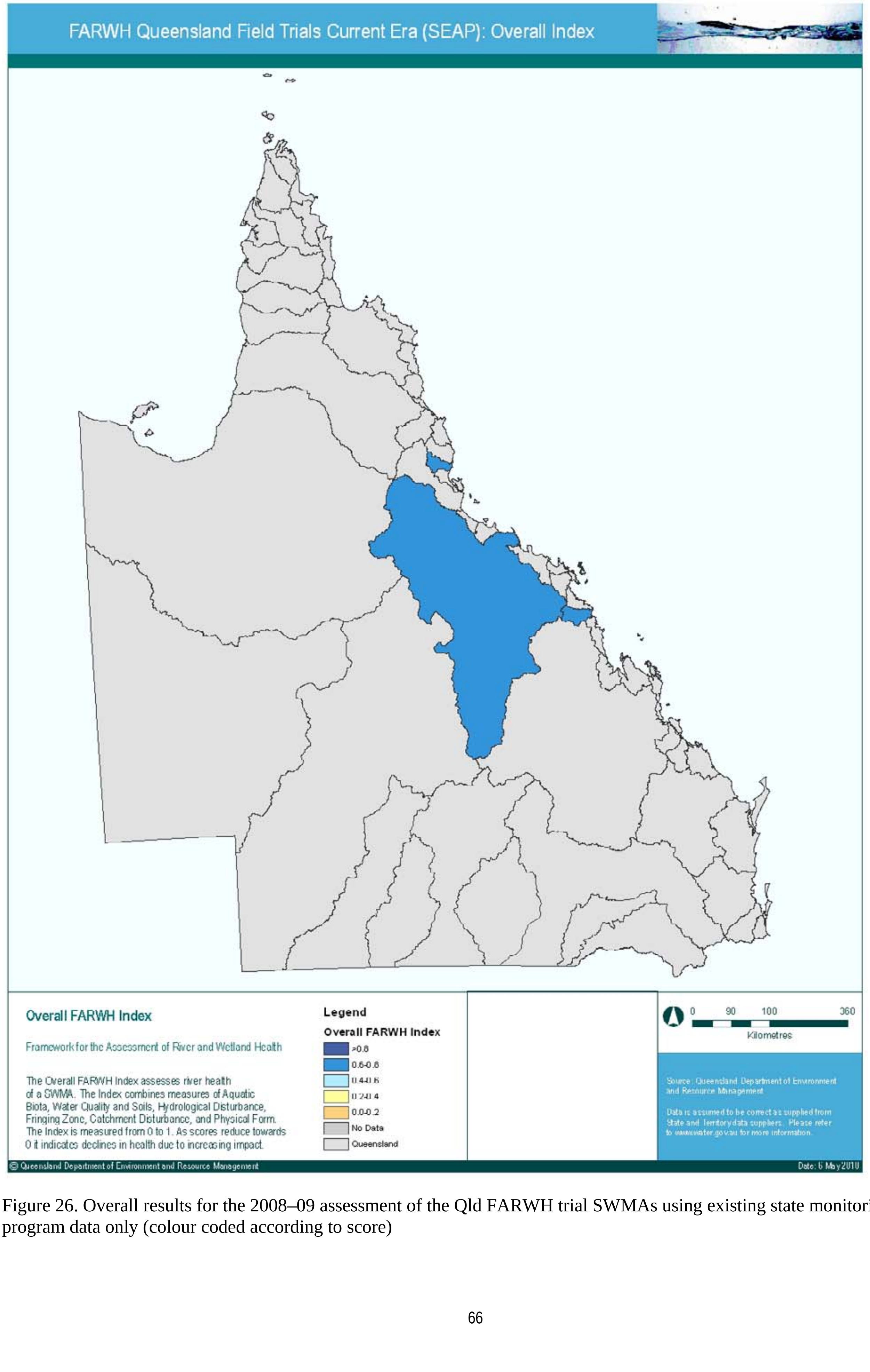

Figure 26. Overall results for the 2008–09 assessment of the Qld FARWH trial SWMAs using existing state monitoring program data only (colour coded according to score)

4 Discussion of results

4.1 Performance of FARWH

Based on the condition assessments presented in Section 3, there is a perception that in some cases the assessment of condition for the trial SWMAs does not accurately reflect the fieldwork observations. Due to the small sample sizes and the inherent variability in datasets, in some cases we have low confidence in the data. This was especially the case for water quality data where the single samples collected at each site did not represent the temporal variability inherent in water quality parameters. However this was also true for some other indices, for instance the Lake Eyre trial where hydrological modelling from IQQM was not used due to data confidence issues. Issues with data confidence were presented in Section 2.7 and, based on these findings, we suggest that a possible weighting approach for future reporting could be based on a measure of data confidence. Further research and development is needed before adoption for operational reporting.

An issue when using integration techniques, such as those of averaging or standardised Euclidean distance, is the tendency for data to be ‘smoothed’ – meaning that the detail provided in the sub-indices is lost. This issue has been raised at various forums including the FARWH National Technical Steering Committee since the findings of the year 1 and 2 trials became clear. It has been broadly accepted that the issue of data ‘smoothing’ makes the individual theme scores a more useful assessment tool than the integrated overall score.

4.2 Sensitivity of indices

4.2.1 Sensitivity analysis

A sensitivity analysis of the trial data was performed using a ‘jack-knife’ approach whereby one data component at a time was removed from the calculation. This analysis was performed on two levels – to test the contribution of sub-indices to each theme score and also to examine the contribution of each theme score to the overall trial assessment. A summary of results from the analysis are presented here on a trial-by-trial basis. The aim of the sensitivity analysis was to determine which sub-indices/themes had the greatest impact on aquatic ecosystem health and should be the focus of management or further study.

Changes to mean scores have been ranked from the greatest to smallest absolute change. An increase in the theme or trial mean is indicated by positive values and green type, whereas a reduction is indicated by negative values and red type.

4.2.1.1 Central trial

Table 22 shows the results of the Central trial’s sub-index-level data sensitivity analysis. The last column displays the change to the theme mean after the sub-index listed in the first column is removed.

The mean values for the Physical Form and Fringing Zone themes were determined using a single sub-index (‘substrate heterogeneity’ and ‘percentage cover’ respectively) and therefore an analysis of sensitivity for those sub-indices is not applicable.

Index	Theme	Theme mean (before index removal)	Theme mean (after index removal)	Change to theme mean
Land use	Catchment Disturbance	0.59	0.91	0.33
Land cover change	Catchment Disturbance	0.59	0.64	0.05
Duration of no flow	Hydrological Disturbance	0.40	0.37	-0.04
Infrastructure	Catchment Disturbance	0.59	0.62	0.03
Change in flow	Hydrological Disturbance	0.40	0.43	0.03

Turbidity	Water Quality and Soils	0.84	0.86	0.01
Filt Ph	Water Quality and Soils	0.84	0.85	0.01
Nit oxide	Water Quality and Soils	0.84	0.83	-0.01
Amm nit	Water Quality and Soils	0.84	0.83	-0.01
PET	Aquatic Biota	0.86	0.85	-0.01
SIGNAL	Aquatic Biota	0.86	0.86	0.01
Period between no flow	Hydrological Disturbance	0.40	0.41	0.01
Taxa richness	Aquatic Biota	0.86	0.86	0.00
TSS	Water Quality and Soils	0.84	0.84	0.00
% woody cover	Fringing Zone	0.59	n/a	n/a
Substrate heterogeneity	Physical Form	0.91	n/a	n/a

Table 22. Results of the Central trial's sub-index-level data sensitivity analysis

Table 23 shows the results of theme-level data sensitivity analysis for the Central trial. The last column displays the change to the trial mean after the theme listed in the first column was removed.

Theme	Trial mean (before theme removal)	Trial mean (after theme removal)	Change to trial mean
Hydrological Disturbance	0.65	0.72	0.07
Physical Form	0.65	0.61	-0.03
Aquatic Biota	0.65	0.62	-0.03
Water Quality and Soils	0.65	0.62	-0.03
Fringing Zone	0.65	0.66	0.01
Catchment Disturbance	0.65	0.66	0.01

Table 23. Results of the Central trial's theme-level data sensitivity analysis

4.2.1.2 Moreton trial

The table below shows the results of the Moreton trial's sub-index-level data sensitivity analysis. Theme mean values for the Physical Form and Fringing Zone themes were determined using a single sub-index ('substrate heterogeneity' and '% woody cover' respectively) and therefore an analysis of sensitivity for those sub-indices is not applicable.

Index	Theme	Theme mean (before index removal)	Theme mean (after index removal)	Change to theme mean
Land use	Catchment Disturbance	0.66	0.94	0.28
Temp	Water Quality and Soils	0.70	0.78	0.07
Fish OE	Aquatic Biota	0.69	0.75	0.06
Period between no flow	Hydrological Disturbance	0.57	0.62	0.05
Change in flow	Hydrological Disturbance	0.57	0.52	-0.05
pH	Water Quality and Soils	0.70	0.66	-0.05
Land cover change	Catchment Disturbance	0.66	0.70	0.04
Taxa richness	Aquatic Biota	0.69	0.67	-0.03

Infrastructure	Catchment Disturbance	0.66	0.68	0.03
Prop alien	Aquatic Biota	0.69	0.67	-0.02
DO	Water Quality and Soils	0.70	0.69	-0.02
SIGNAL	Aquatic Biota	0.69	0.69	-0.01
Duration of no flow	Hydrological Disturbance	0.57	0.57	0.00
PET	Aquatic Biota	0.69	0.69	0.00
Conductivity	Water Quality and Soils	0.70	0.70	0.00
PONSE	Aquatic Biota	0.69	0.69	0.00
% woody cover	Fringing Zone	0.41	n/a	n/a
Substrate heterogeneity	Physical Form	0.97	n/a	n/a

Table 24. Results of the Moreton trial's sub-index-level data sensitivity analysis

The table below shows the results of the Moreton trial's theme-level data sensitivity analysis. The second column displays the change to the trial mean after the sub-index listed in the first column was removed. Changes to the trial mean have been ranked from the greatest absolute change to the smallest absolute change.

Theme	Trial mean (before theme removal)	Trial mean (after theme removal)	Change to trial mean
Physical Form	0.97	0.59	-0.38
Fringing Zone	0.41	0.69	0.28
Water Quality and Soils	0.70	0.61	-0.09
Aquatic Biota	0.69	0.61	-0.08
Hydrological Disturbance	0.57	0.64	0.07
Catchment Disturbance	0.66	0.62	-0.04

Table 25. Results of the Moreton trial's theme-level data sensitivity analysis

4.2.1.3 Wet Tropics

The table below shows the results of the Wet Tropics trial's sub-index-level data sensitivity analysis. The last column displays the change to the theme mean after the sub-index listed in the first column was removed. The Fringing Zone theme value was determined using a single sub-index ('% woody cover') and therefore an analysis of sensitivity for that sub-index is not applicable.

Index	Theme	Theme mean (before index removal)	Theme mean (after index removal)	Change to theme mean
DO	Water Quality and Soils	0.85	0.98	0.13
Land use	Catchment Disturbance	0.82	0.94	0.12
Infrastructure	Catchment Disturbance	0.82	0.87	0.06
Taxa richness	Aquatic Biota	0.83	0.87	0.03
SIGNAL	Aquatic Biota	0.83	0.80	-0.03
Turbidity	Water Quality and Soils	0.85	0.83	-0.02
Temp	Water Quality and Soils	0.85	0.83	-0.02
Conductivity	Water Quality and Soils	0.85	0.83	-0.02

Land cover change	Catchment Disturbance	0.82	0.83	0.01
PET	Aquatic Biota	0.83	0.83	0.00
pH	Aquatic Biota	0.83	0.83	0.00
% woody cover	Fringing Zone	0.85	n/a	n/a
Substrate heterogeneity	Physical Form	0.90	n/a	n/a

Table 26. Results of the Wet Tropics trial's sub-index-level data sensitivity analysis

Theme	Trial mean (before theme removal)	Trial mean (after theme removal)	Change to trial mean
Physical Form	0.85	0.84	-0.01
Catchment Disturbance	0.85	0.86	0.01
Aquatic Biota	0.85	0.85	0.00
Water Quality and Soils	0.85	0.85	0.00
Fringing Zone	0.85	0.85	0.00

Table 27. Results of the Wet Tropics trial's theme-level data sensitivity analysis

4.2.1.4 Lake Eyre trial

Table 28 shows the results of the Lake Eyre trial's sub-index-level data sensitivity analysis. The last column displays the change to the theme mean after the sub-index listed in the first column was removed. The Fringing Zone theme value was determined using a single sub-index ('% exotics') and therefore an analysis of sensitivity for that sub-index is not applicable.

Index	Theme	Theme mean (before index removal)	Theme mean (after index removal)	Change to theme mean
Land use	Catchment Disturbance	0.47	0.79	0.32
Infrastructure	Catchment Disturbance	0.47	0.66	0.19
PET	Aquatic Biota	0.67	0.77	0.10
PcSnags	Physical Form	0.70	0.76	0.05
Proportion alien (species)	Aquatic Biota	0.67	0.63	-0.04
PcPugCow	Physical Form	0.70	0.74	0.03
PcBench	Physical Form	0.70	0.67	-0.03
PcOvHang	Physical Form	0.70	0.67	-0.03
Taxa richness (fish)	Aquatic Biota	0.67	0.64	-0.03
Land cover change	Catchment Disturbance	0.47	0.50	0.03
SIGNAL	Aquatic Biota	0.67	0.64	-0.02
PcPugPig	Physical Form	0.70	0.69	-0.02
Turbidity	Water Quality and Soils	0.86	0.87	0.01
pH	Water Quality and Soils	0.86	0.85	-0.01
Taxa richness (macroinvertebrates)	Aquatic Biota	0.67	0.67	0.01
Temp	Water Quality and Soils	0.86	0.87	0.01
DO	Water Quality and Soils	0.86	0.86	0.00

Conductivity	Water Quality and Soils	0.86	0.86	0.00
% exotics	Fringing Zone	0.71	n/a	n/a

Table 28. Results of the Lake Eyre trial's sub-index level data sensitivity analysis

The table below shows the results of the Lake Eyre trial's theme-level data sensitivity analysis. The second column displays the change to the trial mean after the sub-index listed in the first column was removed.

Theme	Trial mean (before theme removal)	Trial mean (after theme removal)	Change to trial mean
Catchment Disturbance	0.62	0.66	0.04
Water Quality and Soils	0.62	0.59	-0.03
Fringing Zone	0.62	0.61	-0.02
Physical Form	0.62	0.61	-0.01
Aquatic Biota	0.62	0.61	-0.01

Table 29. Results of the Lake Eyre trial's theme-level data sensitivity analysis

4.2.2 Discussion

The calculations used to determine index sensitivity were the same between themes, except for Catchment Disturbance. Mean scores for the other themes were calculated using the standard Euclidean distance formula, whereas the mean score for Catchment Disturbance used Equation 10 – as recommended by the NWC (2007). Equation 10 accounts for the cumulative effect of the impacts from the Catchment Disturbance indices. The calculated theme mean is therefore lower than it would otherwise be if the standard Euclidean distance formula were used. As a result, index scores associated with the Catchment Disturbance theme appear to have greater influence at the theme mean level than do the indices from other themes. The Central trial's sensitivity analysis was recalculated using the standard Euclidean distance and the results are shown in Table 30.

Index	Theme	Change to theme mean	
		Equation 10	Std. Euclidean distance
Land use	Catchment Disturbance	0.33	0.15
Infrastructure	Catchment Disturbance	0.03	0.04
Land cover change	Catchment Disturbance	0.05	0.04

Table 30. Sensitivity analysis for the Central trial recalculated using the standard Euclidean distance (rather than Equation 10)

The table below shows the ranked absolute change to theme scores from all trials resulting from the sensitivity analysis. The Catchment Disturbance theme is the most influenced by the removal of indices, whereas the Water Quality and Soils theme is influenced the least. The Fringing Zone theme has only one index, thus an analysis of sensitivity for that theme is not applicable.

Index level	
Theme	Mean absolute change
Catchment Disturbance	0.12
Physical Form	0.03
Hydrological Disturbance	0.03

Aquatic Biota	0.02
Water Quality and Soils	0.02
Fringing Zone	n/a

Table 31. Average change to theme means resulting from the removal of indices. Results are averaged across all four trials.

The table below shows the ranked absolute change to the final trial scores from all trials. The Catchment Disturbance theme had the greatest influence on final trial scores, whereas the Water Quality and Soils theme had the least influence.

Theme level	
Theme	Mean absolute change
Catchment Disturbance	0.10
Physical Form	0.09
Hydrological Disturbance	0.06
Fringing Zone	0.06
Aquatic Biota	0.04
Water Quality and Soils	0.04

Table 32. Average change to final trial scores resulting from the removal of theme scores. Results are averaged across all four trials.

Aside from differences in sub-index and theme 'sensitivity' that can be attributed to using different methods of integration (Euclidean distance compared with Equation 10), sensitivity differences vary within and between each trial. The trial with the least variation in sensitivity (as indicated by a change in the theme mean score) is Moreton. One likely explanation is that variation resulting from the range of values within each sub-index has been reduced by stratifying sites into four stream classes (each with potentially different reference values) before standardising.

4.3 Alignment with other programs

4.3.1 Central and Wet Tropics trials – SEAP comparison

One of the problems found during the trials has been how the SEAP and FARWH programs have aligned. Many of these problems arose due to the fact that initially SEAP was still being developed and this meant the FARWH project timeline processes (e.g. site selection, fieldwork and data analysis and reporting) were not able to be synchronised. Also the fundamental differences in spatial scale and use of the PSR framework for project design and reporting hampered the process when trying to make a direct comparison of assessments between the two programs.

SEAP reporting is consistent with the PSR framework on which the program is based (P. Negus, pers. comm.). Scores (standardised between 0–1) are produced for stressors, pressures and responses within each conceptual model that indicator selection was based on. Summary scores are also produced for PSRs across the relevant bioprovince, however no overall score combining these elements is assigned to avoid a bias in reporting (which would be the equivalent of the overall FARWH score albeit at the bioprovince scale). SEAP scores are then attributed to bands of condition for reporting purposes, but these bands are not consistent with those used for the FARWH assessment.

Broadly, the overall condition assessment of the riverine ecosystems in the Central bioprovince as being 'slightly disturbed' is comparable to the overall SWMA score for the Pioneer and Burdekin SWMAs found during the year 1 trials. While the SEAP assessment obviously takes into account the condition of all the other catchments contained within the bioprovince at a coarse level, the assessment of condition is attributable to the trial SWMAs. Even considering the differences in indicators, methods of data handling, integration and reporting, this assessment appear consistent.

Macroinvertebrate data from ABMAP (the previous state-level monitoring program before SEAP was developed) (Steward 2007) stated that Central bioprovince was assessed as being in a similar condition to that of the reference sites. This would appear to be consistent with the FARWH 2008 Aquatic Biota index for both Burdekin and Pioneer SWMAs, which assessed them both as being in 'largely unmodified' condition. While ABMAP did not assess other components of ecosystem condition, human pressures were noted in the provinces but did not appear to be great enough to cause significant differences to the aquatic ecosystems at the present time (ABMAP 2007). The lower condition assessment provided from FARWH themes such as Catchment Disturbance and Fringing Zone within the Burdekin and Pioneer SWMAs indicates that human impacts are a key factor influencing aquatic ecosystem health in those trial areas.

In the Wet Tropics, both the 2009 and 2004–05 FARWH assessments report the Tully SWMA as being in 'largely unmodified 'condition. These results provide a consistent assessment of aquatic ecosystem condition across the SWMA, suggesting no change in condition between the baseline year and the current time period. All themes from the current and baseline assessment were in the upper banding, suggesting that every component is in 'largely unmodified' condition. Based only on data available from current (2009) DERM sources (primarily SEAP), the Tully SWMA's condition was classified as 'slightly modified'. However the difference in the overall assessment score was not very large and the primary reason was a lower result for the Fringing Zone (0.65), based on the SEAP field-collected data within the Tully SWMA. This result and the others based just on SEAP data were calculated on a very small sample size and therefore should be treated with some caution when making judgements on the SWMA's condition.

Before the current SEAP assessment the most recent aquatic ecosystem health assessment overlapping the Tully SWMA was ABMAP in 2003–04. Once again there is a spatial disparity in reporting between FARWH and ABMAP as with SEAP. Based on macroinvertebrate data, however, ABMAP (Prior 2004) stated that Wet Tropics bioprovince was assessed as being in 'moderate to good' condition with most macroinvertebrate communities being similar to those found in the reference sites. This would appear to be consistent with the FARWH 2009 Aquatic Biota index for the Tully SWMA, which was assessed as being in 'largely unmodified' condition. The baseline assessment for the Tully SWMA in 2004–05 was consistent with the ABMAP result, as this was based on the same data. While ABMAP did not assess other components of ecosystem condition, human pressures were noted in the bioprovince including intensive cropping (sugar cane and bananas), urbanisation and light cattle grazing. From part of the FARWH assessment within the Tully SWMA (based on compiled reference criteria scores presented in the year 2 trials report) a variety of pressures appear to have been recognised. Those most consistently recorded were impacts from agriculture and forestry, riparian and valley flat vegetation clearing and the presence of weeds in the riparian zone. In contrast to the ABMAP findings, grazing pressure and upstream urbanisation were scarcely noted. SEAP stressor prioritisation work in 2008 identified feral pigs and invasive weeds as a significant risk to aquatic ecosystem health at the bioprovince scale.

The State of the Rivers assessment was conducted in the Tully and Murray catchment in 1998. This methodology provided condition assessments based on a snapshot approach considering physical stream habitat components, reach environs and aspects of the riparian and aquatic vegetation. All Tully subcatchments were reported on and they varied considerably in their classification, particularly between the upper and lower parts of the catchment. Results were then combined into an overall assessment whereby across the whole catchment, 31 per cent of the stream length was in poor condition, 39 per cent in moderate condition and 30 per cent in good condition. Subjectively comparing these results to those of the FARWH for the Fringing Zone and Physical Form themes (considered to be those most closely aligned with the State of the Rivers methodology) for 2009 assessment – 0.86 and 0.90 respectively – there appears to be a higher classification based on the FARWH assessments.

The impression gained from the collated reference criteria data for the Tully SWMA, where only 10 per cent of the test sites visited were in reference condition, does not seem to fit with the FARWH's overall assessment of the SWMA being in 'largely unmodified' condition. Similarly this assessment does not seem to fit with the description given for the bands of condition within AWR 2005, and it would appear the SWMA's condition has possibly been overestimated.

4.3.2 South East Queensland – EHMP comparison

The reporting area is different, with EHMP providing assessments for subcatchments compared with the SWMA level for FARWH; however, the defined subcatchments for EHMP reporting do form a discrete subset of the Moreton SWMA. EHMP uses report card grades (A–F) to classify the subcatchments into bands of condition that correspond with the bands of condition for a FARWH assessment. This makes the comparison of an overall assessment much simpler than that between the SEAP and FARWH. It must be noted that the EHMP assessment is based on only two of the FARWH theme indices – Water Quality and Soils and Aquatic Biota. The report card grades for the subcatchments making up the Moreton SWMA area, as given within the 2008 EHMP report, are listed below.

Catchment	**Grade**	**Assessed condition**
Bremer	F	Very poor condition
Caboolture	C+	Fair condition
Lockyer	F	Very poor condition
Lower Brisbane	F	Very poor condition
Oxley	D	Poor condition
Pine	D+	Poor condition
Pumicestone	B+	Very good condition
Stanley	B-	Good condition
Upper Brisbane	D-	Poor condition

The FARWH assessment within South East Queensland described the Moreton SWMA as being in 'slightly modified' condition, which indicates better condition than that determined by EHMP.

4.3.3 Lake Eyre Basin

The 2009 FARWH assessment reports the Cooper Creek SWMA as being in 'slightly modified' condition. These results suggest an improvement in aquatic ecosystem condition across the SWMA from that found in the baseline year 2004–05 when the SWMA was assessed as being in 'moderately modified' condition. While the assessments classify the SWMA as being in a different band of condition, the improvement is only marginal based on the difference between the actual overall score (0.59 – 0.64).

The theme scores from both the current and baseline assessments were much more variable than those found in the Tully SWMA trial. During the 2009 assessment the Catchment Disturbance and Hydrological Disturbance indices were significantly lower than the other indices. Both these indices were based on either modelled or remotely sensed data and, based on experience from previous trials, might be expected to provide a better assessment due to the census nature of the measurement. There were, however, a number of issues that may have affected these results. Catchment Disturbance data for Cooper Creek appeared to be affected primarily by a low value for the land use sub-index. Looking more deeply at the cause (see methods in Appendix 3), more than 95 per cent of the SWMA was classed as grazing land. This result which would seem legitimate but the weighting applied to that land use category (0.33) – the same as applied to grazing in the other field trials – may be considered to be too high, although this should be clarified. Due to the nature of the environment in Cooper Creek SWMA, the intensity of the cattle production is lower than in other trial areas and possibly a readjustment to the applied weighting should be considered. This would have a profound impact on the land use sub-index and potentially on the Catchment Disturbance Index for this SWMA.

There are few condition assessments covering the whole of the Cooper Creek catchment with which to compare the results. One notable exception was the State of the Rivers assessment conducted for Cooper Creek and all of its subcatchments in 1994. While this study is obviously significantly dated, it does provide an assessment of condition based on riparian vegetation and aspects of the physical habitat that relate specifically to the FARWH Fringing Zone and Physical Form themes across the entire Cooper Creek SWMA as under investigation in this trial.

From survey work conducted as part of State of the Rivers, the Cooper Creek catchment's overall condition was assessed as such: 'the streams of the catchment were in moderate to good condition'. This would seem to fit with the overall FARWH assessment of the catchment being in 'slightly disturbed' condition and also with the individual scores for the Fringing Zone and Physical Form themes. This report also discussed the evident pressures on the catchment, with the primary issues being 'clearing of vegetation adjacent to streams and the unrestricted access of stock to the stream banks and beds'. This description of the pressures would appear to agree with the observed pressures as noted in the collation of the reference criteria scores for all the sites sampled across the SWMA (see Appendix 7 in the year 2 trials report). Grazing pressure was the most common impact noted, with clearing of riparian and adjacent vegetation and the presence of weeds in the riparian zone also being significant.

It was previously assumed the Cooper Creek SWMA was relatively undisturbed as compared with the other SWMAs in Queensland. The field trials and subsequent analysis conducted during the Qld FARWH field trials have demonstrated the disturbance to Cooper Creek is possibly greater than previously assumed. For example, analysis of the QLUMP land cover change dataset demonstrated that 96 per cent of the catchment is under rangeland grazing in relatively natural environments (Witte et al. 2006). Despite most of the land being in this state, grazing has had a significant impact on aquatic ecosystem health – which has been well documented in the literature (Kennard et al. 2006; Fleischner 2002). As noted in the trials report and earlier in Section 2.7, the land use data available for Cooper Creek (on which the analysis was performed) is only available for 1999, and the spatial statistics were calculated based on a spatial resolution of mostly 1 km (DERM 2009). Both these factors may contribute to discrepancies between the land use as measured in 1999 and representation of the current land use within the catchment. In addition to land use type, clearing in the Cooper Creek SWMA was higher in total area compared with that measured in the other SWMAs sampled (see Table 33).

SWMA	Total area cleared (m2)	Proportion of catchment cleared
Tully	19870000	1.18
Cooper	9453135000	3.88
Burdekin	142427150	0.11
Pioneer	63573125	4.05
Moreton	867724375	5.56

Table 33. Land clearing in the Cooper Creek SWMA as compared with the other SWMAs assessed during the Qld FARWH field trials

5 Outcomes of the FARWH trials

5.1 Capacity building, training and improving scientific knowledge

The Qld FARWH trials have contributed to capacity building and training of state-based aquatic ecosystem health monitoring across the following facets of practice and knowledge:

5.1.1 Riparian assessment by remote methods

A riparian assessment method developed by Muir (2008) for the extraction of riparian cover measurements from foliage projective cover (FPC) products derived from Landsat imagery has been tested in five novel SWMAs: Burdekin, Pioneer, Moreton, Tully and Cooper. An ArcGIS add-on tool has been developed to execute the method on a given SWMA that has the necessary data: waterhole/stream network; FPC product from the Remote Sensing Centre (RSC) or similar; waterbodies product from the RSC or similar; and the relevant specified buffer distance.

To improve the correlation between information collected from the SEAP rapid riparian sampling methodology (WPE) and estimates of FPC extracted from SLATS Landsat imagery, a new riparian sampling method has been developed. When the new field sampling methodology was executed in the Moreton SWMA, correlation increased from an R2 of 0.79 to an R2 of 0.82 for the relationship between field-measured cover and Landsat-derived FPR. The method has been drafted as an addendum to the rapid riparian assessment methodology: it is now available for use where riparian field sampling results are required to support riparian cover assessment from spatial data products derived from remote sensing.

5.1.2 Fieldwork OH&S skills

To develop staff capacity to undertake fieldwork in line with current occupational health and safety (OH&S) requirements, training initiatives as outlined in Table 34 were undertaken.

Course	Date	For trial SWMA	Run by
Crocodile awareness training	12/4/2008 16/3/2009	Burdekin/Pioneer Tully	Charlie Manolis, Wildlife Management International, Sanderson, Darwin NT 0813
4WD training	6/4/09, 27/10/09	Tully Cooper Creek	Advanced Defensive and 4WD Centre Australia, Mt Cotton Training Centre
Swiftwater first responder	30–31/03/09	Tully	Rescue Training Group, 49 Halls Flat Road, Alexandra VIC 3714
Wilderness first aid	28–30/10/09	Cooper Creek	Equip Wilderness First Aid Institute, 18 King Edward St, Ulverstone TAS 7315
Manual handling training	20/02/2009	All	Kassie Heath, Lifestyle Therapies, 209 Manly Road, Manly QLD 4179

Table 34. Fieldwork training for the Qld FARWH trials

These training programs typically included SEAP staff in addition to the FARWH working group, thus extending the skills of a broader sample of aquatic ecologists from Water Planning Ecology. In preparation for the Cooper Creek field sampling, staff were sourced from a broader range of subdepartments, and these staff were also trained in the above skills.

Following on from fieldwork OH&S skills training, and based on the experience of the preparation and execution of field sampling and consequent post-field work annual review, the following work practice field protocols were revised and improved:

WQMWP012_Fieldwork work practice

WQMTP005_WQM project risk assessment for fieldwork

WQMWP021_Crocodile awareness for fieldwork

WQMWP023_Fieldwork emergency response procedure

5.1.3 Fieldwork operator standardisation

To ensure consistent methods for field sampling of each indicator across the different field operators, the following in-house training was undertaken between experienced and new staff in line with Aquatic Ecosystems Information System (AQEIS) standardised methods. For example, Joanna Blessing from the SEAP team provided riparian sampling training to core FARWH staff in April 2008. In turn, after adjustment to methods to extend canopy cover measurements to FPC measurements, Cate Simpson provided training to new FARWH team members Ryan Woods and Sarah Rogers and core FARWH team members in October 2008. Similarly when sampling of Cooper Creek SWMA began in November 2009, at the first field site core FARWH team members provided training to staff recruited for that sampling round.

5.1.4 Obtaining landowner contact information

A standardised method for sourcing landowner contact information has been developed including: GIS analysis to extract the lot and plan details from the Digital Cadastral Database (DCDB), determining owners from lot and plan information, verifying owners, and sourcing contact details for the property owners. The method was initially developed during the Central field sample round; used to direct landholder information letters for the Tully sampling round; and again both to direct information letters and make verbal contact for arranging access for the Cooper Creek sampling round.

5.1.5 GRTS sampling framework

A two-day workshop was held for FARWH and SEAP team members from 24 to 25 February 2010 by Professor Don Stevens. The workshop’s primary purpose was to develop the capacity of team members to design and implement large-scale environmental surveys using a GRTS approach (Stevens & Olsen 2004) in the R programming language. In addition, the workshop provided an introduction to programming in the R language, including instruction in reading map data into R. The workshop also expanded knowledge on sampling theory and survey design, and gave practical examples of the benefits and disadvantages of common sample designs.

5.1.6 Physical Form field sampling method

In all but the Cooper Creek SWMA, the SEAP method for assessing substrate heterogeneity was used as the indicator of Physical Form for the FARWH assessment. In the waterways encountered in the Cooper Creek SWMA, the typically high suspended sediment load prevents the use of such methods (as they are based on the visual inspection of submerged substrates), while the natural lack of substrate heterogeneity means this was not an appropriate indicator. Instead, in consultation with scientific experts, a novel method was developed and tested for the Cooper Creek SWMA. This method involved assessment of physical form on bank and stream-edge characteristics including: proportion of stream edge with pugging by cattle, proportion of stream edge with pugging by pigs, percentage of overhanging vegetation, proportion of stream edge with snags, and proportion of bank with benches.

5.2 Resource condition knowledge

The work conducted during these trials has contributed significantly to the body of knowledge on the condition of the riverine aquatic ecosystems across all of the trial SWMAs. This was especially true in Cooper Creek SWMA where the lack of baseline information and available data for some aspects of the ecosystem were very pronounced.

Within the wider Lake Eyre Basin the data amassed during these trials will be used to help inform the upcoming programs:

- SEAP Lake Eyre Basin bioprovince assessment (June-August 2011)
- Lake Eyre Basin High Conservation Value Aquatic Ecosystem (HCVAE) pilot project (to be conducted in conjunction with SEAP sampling across Cooper Creek)

- The Lake Eyre Basin Rivers Assessment – the proposed long-term monitoring program was implemented in July 2011 and findings from the FARWH trials are to be used to inform decisions about the on-ground implementation of the program.

5.3 Costs

A significant outcome of the Queensland FARWH trials has been the analysis of the costs involved in implementing a field-based assessment program at the SWMA scale.

From the Lake Eyre Basin trial in particular, it is evident the resources required to complete an on-ground FARWH style assessment across large and remote SWMAs would be extensive. The significant logistical, environmental and workplace health and safety challenges encountered while working in such a remote location, under extreme conditions and over such a large area, significantly added to the budgeted costs. This has serious implications for the potential to rollout the FARWH across similar SWMAs in Queensland if a field-based assessment is to be conducted.

A summary of the costs associated with fieldwork are shown in Table 35 on the next page. These figures include all aspects associated with the fieldwork such as staff costs (including overtime/time off in lieu), travel allowances, accommodation, vehicle hire maintenance and repair, fuel, equipment purchase and pre-trip training. These figures are based on a post-trip analysis of the true costs rather than what was budgeted. Not included in these figures are sample analysis, data handling and reporting–which are also potentially significant when considering the means to provide data for a national assessment program such as the FARWH.

Region sampled	Central	South East	Wet Tropics	Lake Eyre Basin
SWMAs sampled	Burdekin and Pioneer	Moreton	Tully	Cooper Creek
Staff salaries (base)	32 436.00	26 214.00	8 390.00	49 415.00
Staff salaries (overtime)	12 484.00	-	2 991.00	87 701.00
Staff salaries (toil)	42 191.00	10 904.00	2 046.00	1 582.00
Staff travel allowance	18 561.00	5 755.00	3 543.00	30 324.00
Salary costs (other LSL/Qsuper etc.)	6 877.00	5 557.00	1 785.00	10 879.00
Vehicles (lease costs)	23 729.00	23 729.00	8 814.00	8 814.00
Vehicles (hire costs)	1 736.00	-	-	13 690.00
Fuel costs	400.00	217.00	-	5 072.00
Vehicle modification/repair/maintenance	530.00	316.00	-	6 145.00
Trailer (purchase cost)	-	-	-	4 379.00
Trailer (hire cost)	-	-	-	900.00
Accommodation	10 313.00	6 121.00	3 600.00	10 954.00
Air fares	2 275.00	-	2 140.00	4 890.00
Travel other (e.g. taxi etc.)	1 300.00	150.00	300.00	1 297.00
TMS costs	400.00	-	108.00	290.00
Training costs	1 233.00	-	2 260.00	8 504.00
Uniform and PPE	1 244.00	813.00	436.00	3 507.00
Equipment purchase	2 496.00	1 021.00	100.00	9 386.00
Consumable items (including camp gear)	2 239.00	850.00	145.00	10 907.00
Telephone/satellite phone hire and call charges	700.00	150.00	90.00	3 504.00
Other equipment repair/maintenance	-	1 240.00	1 845.00	500.00
Total cost	$ 161 144.00	$83 037.00	$ 38 593.00	$ 272 640.00

Table 35. Fieldwork costs for Qld FARWH trial

In Section 8 of this report the cost implications of implementing FARWH within Queensland based on these figures are explored further.

6 Identification of key scientific knowledge gaps

6.1 Hydrological modelling

IQQM data was unavailable for some areas of the state (e.g. most of the Wet Tropics) during these trials. In other cases, it was noted the modelled data was based on sparse gauging station distribution and, in general, gauged data from smaller tributaries was lacking. Poor rainfall records in some areas of the state also hampered the potential accuracy of some IQQM models.

This was a particular problem when we attempted to use the model for the Lake Eyre Basin trial. The Hydrological Disturbance theme for this trial was to be determined using stream-gauge flow data and pre-disturbance flow modelled data from the IQQM. After analysis of available data it was decided the Hydrological Disturbance theme should not be analysed as part of this assessment, due to some inconsistencies in flow records and the sparse nature of the gauging station network in this region. State of the basin 2008: rivers assessment (LEBSAP 2008) indicated only a low level of flood and flow modification existed in all rivers of the basin and this was mainly due to minor alterations for stock and domestic use.

It is recommended that future work investigate the potential for using the Flow Stress Ranking (FSR) as a tool for assessing hydrological disturbance in Queensland rivers. FSR was used in the FARWH trials in other jurisdictions and thus its use would enable consistent reporting within a national framework. In the future it is expected that the hydrological component of the proposed Lake Eyre Basin River Assessment will also consider the issues encountered during the FARWH Lake Eyre Basin trial. Also, within the DERM Wetlands Group a draft tool is being developed that may yield information relevant to assessing hydrological disturbance. This may be a valuable future avenue of investigation.

6.2 Setting reference condition

Consistent and confident setting of reference condition is seen as a key issue for the success of the trials in Queensland and also in other jurisdictions. It is acknowledged that the overall approach used in these trials (as akin to the SEAP methodology using reference ranges from collated reference site data) has limitations. It does, however, provide a reference which is temporally consistent with the test site data to take account of seasonal variability. It is also acknowledged that alternative methods for setting reference such as the development and application of appropriate and robust models and/or the use of expert opinion also have their place.

With regard to outcomes from the Qld FARWH trials, it was recommended that reference sites from outside the SWMA but within the surrounding bioprovince be used to supplement the number of reference sites. This approach was successfully implemented and partly overcame the difficulties encountered in some of the trials. Regardless, insufficient numbers and/or lack of representativeness failed to encapsulate the natural variability inherent in the SWMAs assessed.

Further work in this area is recommended, particularly research and development for appropriate modelling techniques to set more accurate reference condition.

6.3 Scoping of alternative remote assessments

The current trials used available spatial information to assess two of six indicators by remote sensing and GIS analysis. Within one of these themes, the Fringing Zone, spatial analysis provided assessment of only one sub-index: percentage cover of riparian vegetation.

A number of novel methods for assessing other indicators of aquatic ecosystem health are being researched, such as:

- Riparian condition (Johansen et al. 2007; Johansen & Phinn 2006)
- Proportion of weeds building on work from Stewart et al. (2008) on mapping lantana, and Muir and Speller (2010) mapping prickly acacia and rubber vine

- Alluvial gully erosion (Knight et al. 2007; Eustace 2007)
- Turbidity, light penetration and/or depth (Ward pers. comm. 6/5/2010).

However, a number of factors have prevented the adoption of these methods for operational monitoring purposes including, but not limited to:

- the methods have not yet been made available to the scientific community through publication
- the methods are not yet developed to an operational standard
- the methods are not yet cost-effective for operational purposes, due to either cost feasibility of imagery acquisition (especially for coverage over a state such as Queensland) or processing complexity and costs
- the methods are not currently being used to produce an operational product by RSC (remembering that the purpose of the Queensland field trials was to use data from state-based programs to undertake the FARWH assessment rather than undertaking spatial science research and development).

The only exception is the novel Catchment Disturbance Index by Stein, Stein and Nix (2001). While this method was available at the start of the FARWH trials, the method following NWC (2007b) was used during the Queensland field trials.

A comparative assessment of Catchment Disturbance sub-indices is recommended to ascertain the most relevant method for quantifying catchment-scale impacts on aquatic ecosystem health.

Continued development of the operational monitoring of additional indicators should be a key priority to improve the efficiency of aquatic ecosystem health assessments.

7 Synthesis of key findings and recommendations

- The integration of theme scores to provide an overall SWMA assessment is seen as flawed due to the tendency for data to be ‘smoothed’. This occurs when statistical techniques such as standardised Euclidean distance or averaging are applied, with a resulting loss of detail and accuracy of the assessment. It is recommended that theme-based SWMA assessments be the coarsest FARWH reporting tool.
- The disparity in spatial reporting and design scales between the FARWH and key state-level reporting programs such as SEAP and SWAN means a significant lack of data is currently available to conduct a robust condition assessment of aquatic ecosystem condition – at the SWMA level – without significant supplementary resource input including field-based assessment. This was proven through both the baseline and current era assessments undertaken using only existing state-level data.
- It is felt the high costs associated with an on-ground assessment program would prevent implementation of a statewide FARWH assessment in Queensland, at the SWMA level, within the current resource environment.
- Obtaining the required data from internal and external sources proved to be a problem in some cases and relied on locating the right people with the right knowledge, skills, willingness and available time with which to provide data. The issue of how much time and resources are required to implement data gathering should not be underestimated.
- When working over large and remote areas, as in Cooper Creek and Burdekin SWMAs, both spatial and temporal sampling issues were noted:
  - Spatially it was difficult to sample enough sites (both test and reference) to obtain sufficient statistical power. This has led to a lack confidence in certain indicators, particularly those under the Water Quality and Soils theme. Recommendations from statistical work conducted by CSIRO CMIS suggested a large increase in sample numbers would be required to pick up ecologically meaningful changes in these types of indicators. It was also noted that any increased sampling effort would be best attributed to increasing numbers of both test and reference sites together, as opposed to one or the other.
  - High levels of natural temporal variability in geographic areas such as the Cooper Creek or Burdekin SWMAs provide a barrier to meaningful condition assessments based on the snapshot approach (with sampling conducted in a single year). The boom and bust nature of the ecosystem, particularly in the Lake Eyre Basin, cannot be adequately assessed without long-term monitoring data. The proposed Lake Eyre Basin River Assessment program due to start in July 2011 may in part address this issue for this area of the state and potentially provide a source of data that could feed into a national assessment framework.
- Obtaining a valid reference condition for many indicators was problematic in nearly all of the field trials. Where setting reference condition required data from reference sites, which was the key component for setting reference in Queensland (partly based on the current SEAP methodology), the number of sites found to be in reference condition based on our site-specific reference criteria was below that required under our sampling protocol. Widening the pool of reference sites to those outside the target SWMA but from similar aquatic ecosystem types worked well in both the Central and particularly Wet Tropics trials. It is recommended that further work be conducted into the setting of reference condition. At present, a project investigating the potential to model reference condition is planned to take place through DERM in the coming financial year.
- The use of remote sensing techniques is seen as a key component in enabling the collection of data across large areas. Work conducted as part of these trials has validated the accuracy of remote sensing techniques, particularly in assessing aspects of riparian vegetation for the Fringing Zone theme compared with a field-based assessment. Remote sensing costs are also much reduced compared with a field-based program when using existing datasets. Future investigation into the use of remote sensing techniques for other indicators

under different themes is suggested as an essential step to potentially fulfilling the needs of a national reporting program over a large jurisdiction such as Queensland.

- For pressure type indicators such as the Catchment Disturbance sub-indices, a risk-assessment-type exercise is suggested to set disturbance weightings specific to the area being assessed. Across all these trials a consistent approach was adopted in the categorisation and weightings of land use and infrastructure types for the Catchment Disturbance Index. In some cases, particularly in the Lake Eyre Basin, it was felt a more specific consideration of the influencing pressures was required to accurately reflect the magnitude of pressures acting on the SWMA.
- Exploration and development of different options for the presentation and reporting of data are suggested. As has been trialled within some of the other jurisdictions undertaking FARWH trials, the use of different presentation devices such as pie charts detailing theme and sub-index data is seen as a better method of communicating results compared with a single SWMA score. The reporting of reach/site-level data using techniques such as those given in Section 2.6 is also recommended.
- To address statistical issues when reporting at different spatial scales and/or using different sample sizes, it is suggested that different power/confidence levels are used for analysis at different spatial scales and/or sample sizes. Risk assessment could be used to establish the power/confidence level that reflects the priorities of each catchment within each province. The SEAP program lends itself to such an approach and could be a future path for investigation for the SEAP team, with a view to improving alignment with a national reporting scheme such as the FARWH.
- It is recommended that more research be undertaken into identifying more ecologically relevant bands of condition, to improve on the use of arbitrary bands.

8 Taking key recommendations forward and next steps

As stated previously, further development of remote sensing techniques to improve accuracy and harness the potential for effective assessment of other indicators is seen as a key area for future work. Remotely sensed data has the potential to span jurisdictional boundaries and be applied consistently to enable a truly comparable national assessment to be made.

A modified FARWH assessment should ensure consistency in data layers, weighting, aggregation and integration techniques for at least some themes. Pressure-type indicators such as the Catchment Disturbance Index (CDI), and possibly the Fringing Zone and Hydrological Disturbance themes, could be standardised to provide an assessment that all jurisdictions could put in place without requiring a large resource input. As an example, nationally consistent datasets are currently available to produce a seamless CDI across all jurisdictions. This relies on spatially and temporally consistent datasets and clear national protocols for the setting of disturbance weightings. By using a risk-assessment-type exercise to set disturbance weightings specific to the area being assessed (as suggested in Section 7 of this report), a truly comparable and ecologically defensible CDI should result. This issue has been discussed by the FARWH National Technical Steering Committee.

More costly field-based assessments can then be targetted at either the SWMA or subcatchment scale depending on a risk-based ranking and state and local reporting needs.

8.1 Projected costs of implementing the FARWH in Queensland

Based on figures from these trials (as presented in Section 5.5) estimated costs are about $110 000 per SWMA on average to provide a field-based assessment fulfilling the needs of the FARWH. This is purely field-based costs and does not include staff costs for data analysis and or reporting. This component has been omitted because under a national reporting framework the potential exists for that work to be conducted at the national level. If this were not the case then costs would be significantly higher.

There are 54 SWMAs in Queensland. If all SWMAs were to be assessed then this equates to an estimated cost of $5 940 000.

Although the accuracy of these figures cannot be guaranteed when scaled up to the state level, the field trials were nevertheless designed to sample a cross-section of SWMAs in terms of their location, scale and logistical considerations for assessing aquatic ecosystem condition. Based on these facts it is felt these figures do represent a fair estimate of the fieldwork costs involved.

Rounding figures up, approximately AU$6 million would be required to implement a FARWH assessment, including field-based components, across all SWMAs in Queensland. As noted previously, these costings do not account for data analysis and/or reporting. The frequency of assessment would obviously have a major impact on projected costs. If the assessment were conducted on a rolling basis over different time scales then the annual costs would be:

Frequency of assessment	Annual fieldwork costs
Annual	$6 000 000
Five year	$1 200 000
Nine year (in line with current SEAP monitoring)	$666 000

Table 36. Estimated annual costs for a FARWH assessment based on different sampling frequencie

At present the annual budget of all these options far outweigh the available resources currently used by SEAP to implement a statewide assessment at the bioprovince scale.

8.1.1 Spatial data product costings

To date spatial data products provided by the Remote Sensing Centre (RSC) including the FPC product, the water mask, SLATS land cover clearing statistics and the QLUMP land use products have been provided 'in-kind' to Water Planning Ecology for use within the FARWH assessments. The current Landsat sensors on which these products are based are decommissioned, and RSC must source imagery from alternative sensors. Alternative imagery is unlikely to be provided at an equivalent (minimal) cost to Landsat imagery, which is currently sourced through Australian Centre for Remote Sensing (ACRES) or free through the United States Geological Survey (USGS) (due to the declining performance of the Landsat sensors). Therefore, the current 'in-kind' contribution of processed image products from RSC cannot be assumed as a continuing agreement to any broadscale aquatic ecosystem condition assessments. A contingency for increased imagery costs would be to account for a proportional costing of the products used in the field trials and incorporate this into estimates for implementing the FARWH in Queensland.

8.2 Integrated Waterways Monitoring Framework project

Drivers and integration opportunities for DERM water quality, water quantity and ecosystem health monitoring, assessment and reporting programs are being reviewed as part of the Integrated Waterways Monitoring Framework project. In addition, a review of the EHMP is in its final stages.

The Queensland Government has identified the need to improve the coordination and comprehensiveness of waterway monitoring programs to better understand the state's water quality and aquatic ecosystem health. The Integrated Waterways Monitoring Framework is being developed with the intention of improving and assimilating key aspects of waterway monitoring such as indicator selection, sampling methods, data access and storage, data interpretation and reporting. The framework is also designed to investigate the prioritisation of regions for waterway monitoring based on management and policy drivers (DERM 2010).

While this review is currently waiting on approval, based on the work conducted the following recommendations have been made:

- SEAP reporting is to be refined with reporting requirements at both catchment and province scales. Reporting on catchments will be undertaken using variable confidence (and therefore sample sizes) and will be determined using a statewide risk assessment.
- Partial integration of monitoring and reporting between DERM and regional Natural Resource Management groups is to be implemented.
- The frequency of SEAP reporting is to be adjusted. Priority regions will be reported on more regularly to fit with the four-yearly State of the Environment reporting requirements and low-risk regions reported on less frequently. Statewide pressure assessments will initially be done more frequently (e.g. yearly) until an assessment of the variability in likely changes and data acquisition is accounted for.

Changes to monitoring frequency, scale, data interpretation and reporting could have significant implications for the ability of state-level programs to feed into a national reporting framework and should be considered carefully at both the state and national level to maximise opportunities for data usage.

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Appendix 1—CSIRO CMIS

Since the beginning of the project there has been an ongoing collaboration on various aspects of sampling design and data analysis as part of the QLD FARWH trials with the CSIRO Computing and Mathematical Information Sciences (CMIS) unit. Staff from CMIS have been involved in the sampling design process for all of the field trials and have provided guidance on subsequent data analysis and other aspects of the project. Technical detail and discussion on many aspects of the work conducted over the course of the project are contained in the seven CMIS client reports (listed below) produced as part of the contract between DERM and CSIRO CMIS. These reports have been referred to in the text of this document and are available for viewing at the CSIRO website.

CSIRO CMIS client report 08/110

Framework for Assessing River and Wetland Health: design of field trial in Queensland's Central Province.

CSIRO CMIS client report 08/122

Integrating indicators for assessing aquatic ecosystem condition of a large-scale stream network

CSIRO CMIS client report 08/123

Framework for Assessing River and Wetland Health: design of field trial in Queensland's Moreton SWMA

CSIRO CMIS client report EP10991

Framework for Assessing River and Wetland Health: spatial design of field trial in Queensland's Tully SWMA and a tutorial on design-based analysis

CSIRO CMIS Water for a Healthy Country report EP10052

Framework for Assessing River and Wetland Health: spatial design of field trial in Queensland's Cooper Creek SWMA

CSIRO CMIS Water for a Healthy Country report EP10844

Framework for Assessing River and Wetland Health: general data analysis recommendations for all trial SWMAs and specific recommendations for analysis of the Cooper Creek SWMA data.

CSIRO CMIS Water for a Healthy Country report EP102114

Framework for Assessing River and Wetland Health: exploration of design and analysis concepts using data from the Tully SWMA trial to demonstrate key recommendations.

Appendix 2—Reference criteria field sheet and guidelines

Site reference criteria sheet page 1 of 2

Reference Condition Selection Criteria

Version 5 September 2008

Project Name:__________ Project Code:__________ Date: __________ Assessors:__________

GS Number:__________ Site Name:__________ Run Number: __________

(If the impacts are unknown, seek further information before scoring; more than one person must complete this form)

Photos taken: __________

Enter score (1-5)

Possible Impacts	5 (No Impact)	4 (Minor Impact)	3 (Moderate Impact)	2 (Major Impact)	1 (Extreme Impact)	Desktop	Bugs	Rip'n Veg	Fish
1. Agriculture and forestry*	No impact	Present but level of impact is barely discernible	Evident, however, not severe and/or widespread	Obvious impact to stream, moderate and/or widespread	Severe and widespread, impact obvious				
2. Grazing Intensity	No impact	Present but level of impact is barely discernible	Impacts evident, however, not severe and/or widespread	Obvious impact to stream, moderate and/or widespread	Severe and widespread, impact obvious				
3. Sand/gravel extraction*	No evidence or prior knowledge of extraction	Small scale historical extraction	No current extraction; large historical extraction	Current small scale/localised extraction	Current and widespread extraction				
4. Upstream urban areas*	No impacts from urbanisation	Possible impacts caused from urbanisation	Definite impacts caused from urbanisation	High impacts caused from urbanisation	Extreme impacts caused from urbanisation				
5. Point source pollution*	Nil point source pollution	Low volumes of point source pollution discharged	Low to moderate volumes of point source pollution discharged	Moderate to high volumes of point source pollution discharged	High to extreme volumes of point source pollution discharged				
6. Barriers –impact on biota*	No artificial barriers in basin which will affect the site	Few small upstream barriers; not within impoundment	Many small barriers; site not within impoundment	Multiple small barriers; Large barriers upstream; within small impoundment	Large barriers upstream; within large impoundment				
7. Flow regime alteration*	Seasonal flow regime natural	Seasonal flow regime not obviously altered	Flow regime altered	Flow regime obviously altered	Flow regime highly modified				
8. Riparian and valley flat vegetation@	Streamside vegetation unaltered	Vegetation slightly modified	Obvious modification	Highly modified vegetation	Severe modification				
9. Weed species in riparian Zone@	Weed species absent or insignificant	Few introduced species present; disturbance is minor	Some introduced species present ; disturbance is moderate	High percentage of introduced species; disturbance is high	Vegetation dominated by introduced species; extreme disturbance				
10. Bankside erosion / deposition@	No evidence of erosion beyond natural	Slightly more than natural levels of erosion	Moderate levels of unnatural erosion	High levels of erosion	Extreme erosion				
11. Instream habitat alteration@	Instream habitats of natural appearance and diversity	Barely discernible impacts	Moderate modifications to instream habitats	Highly modified modifications to instream habitats	Severe modification of instream habitats				
					Total				

Enter Y or N

	Desktop	Bugs	Rip'n Veg	Fish
Site suitable for survey of indicator?				

*: the level of impact will generally decrease as the distance from the source of impact increases.
@: some of these variables will vary between and within catchments; compare with what should be expected (i.e. natural)
In all cases assessments should be made with respect to the indicator being considered

Site reference criteria sheet page 2 of 2

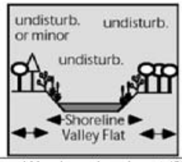
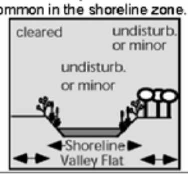
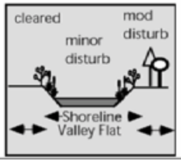
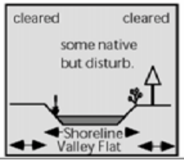
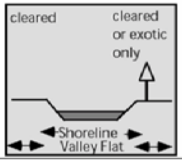
Provide as much information as possible, such as:

- Identifying desk based resources used in assessment.
- Justification of alteration of scores from desk based assessment based on field observations.
- Details of type and source of impacts including approximate distances from those sources.
- Specific comments relating to assessments for each indicator
- Ability to conduct specific indicator survey based on water availability, site access, H&S considerations, etc.

	Comments
SC1	
SC2	
SC3	
SC4	
SC5	
SC6	
SC7	
SC8	
SC9	
SC10	
SC11	
Suitable for indicator?	

Provide sketch map showing site access details and other relevant information

Site reference criteria sheet guide

Possible impacts and examples	5 (No Impact)	4 (Minor Impact)	3 (Moderate Impact)	2 (Major Impact)	1 (Extreme Impact)
7. Impacts from impoundments, abstractions or water releases affecting flow regime.	• No flow alteration due to abstraction, impoundments or water releases • Or "No knowledge" of any such effects	• Some abstraction from large stream • Base flow stopped or decreased	• Occasional releases supplement base flow • Abstraction high relative to stream size decreasing or stopping flow • Low abstraction during low/no flow periods • Base flow stopped	• Frequent releases supplement base flows • Large abstraction from a permanent small stream obviously reducing/stopping flow and water level • Moderate abstraction during low/no flow periods • Base or medium flow stopped or reduced	• Seasonality of flow regime reversed by dams/weirs stopping flood flows and frequently/continuously • Releasing supplemental base flows, site severely affected by abstraction or regulation • Large abstraction during low/no flow periods
8. Impacts from upstream and/or adjacent streamside vegetation alteration	**Valley Flat Vegetation** - Native vegetation present on BOTH sides of the river with a virtually intact canopy **Shoreline Vegetation** - Native vegetation on BOTH sides of the river is generally in good condition. Any disturbance is minor. 	**Valley Flat Vegetation** - Agricultural land and/or cleared on ONE side; native vegetation on the other in reasonably undisturbed state **Shoreline Vegetation** - Native vegetation on BOTH sides with canopy intact or with native species widespread and common in the shoreline zone. 	**Valley Flat Vegetation** - Agricultural landand/or cleared on ONE side; native vegetation on the other clearly disturbed **Shoreline Vegetation** - Bank vegetation moderately disturbed though native species remain. 	**Valley Flat Vegetation** - Agriculture and/or cleared land BOTH sides. **Shoreline Vegetation** – Native vegetation present, but it is modified BOTH sides. 	**Valley Flat Vegetation** - Agriculture and/or cleared land BOTH sides. **Shoreline Vegetation** - Absent or severely reduced. Vegetation present is extremely disturbed 
9. Weed species in riparian Zone	• Weed species absent (0%)	• Weed species (<20%) • Disturbances from presence of weeds is minor	• Obvious presence of exotic species (20-40%)	• High percentage of exotic species in riparian zone (40-60%)	• Riparian zone dominated by exotic vegetation (>60%)
10. Bankside erosion and deposition	• Riparian zone and stream banks in natural condition • No unnatural erosion	• Riparian zone and stream banks with barely discernable erosion impacts • Infrequent, small areas (<20%) of unnatural erosion	• Riparian zone and stream banks with erosion impacts • Moderate sized areas (20-40%) of unnatural erosion	• Riparian zone and stream banks with obvious erosion impacts • Extensive areas (40-60%) of unnatural erosion	• Riparian zone and stream banks with severe erosion impacts • Majority (>60%) of area unnaturally eroded
11. Impacts from instream habitat alteration	• Diverse number of naturally occurring instream habitats in natural condition • (e.g. some macrophyte growth, little algal growth, abundant coarse woody debris) • No evidence of stream bed aggregation or degradation (NOTE: Degraded symptoms include: Bed shallowing or deepening; bed erosion; steepening/undercutting banks; exposure of bridge bases; headcut or nick point; steep/mobile riffles)	• Partial loss of some habitats and alteration to condition • (e.g. increased macrophyte growth, algal growth, some loss of woody debris) • If present then only slight degradation or aggregation • Exhibits few of the degraded symptoms	• Limited loss of some instream habitats (from drying, drowning, silting, scouring etc) and alteration to conditions • Moderate algal and/or macrophyte growth, may extensively cover some areas of reach • Some coarse woody debris removal • Exhibits more than a few symptoms • Moderate degradation	• Widespread loss of instream habitats (from drying, drowning, silting, scouring etc) and alteration to conditions • Extensive algal and/or macrophyte growth, smothering areas of reach • Coarse woody debris removed • Exhibits more than a few symptoms • Moderate to severe degradation	• Dominated by only 1 habitat (due to drying, drowning, filling or scouring) conditions highly modified • Extensive macrophyte and algal growth chokes whole reach • No woody debris • Substrate smothered with deep layer of rotting vegetation (such as in Para grass choked streams) • Exhibits many of the degradation symptoms listed • Severe degradation s

Appendix 3 — Summary of sub-indices and data handling techniques for each FARWH theme within the trial SWMAs

FARWH theme	SWMA	Method	Sub indices	Aggregation technique and weighting	Integration technique	Reference approach	Confidence
WQ & soils	Moreton	Field collection	Conductivity, Temperature, DO, ph, Turbidity,	Length weighted average.	Standard Euclidean Distance	Sites classified into upland, lowland, coastal or Wallum. Predetermined EHMP reference and worst case scenario values per stream class.	Reference: Test sites $n = 35$
	Pioneer and Burdekin	Field collected and laboratory analysed	Above indicators + Alkalinity			Test data compared to 20th or 80th percentiles of sampled reference range. Worst case values set from minimum or maximum values in each index from pooled ref and test data	Sites classified into upland (U) or lowland (L): Reference sites; L $n = 7$, U $n = 16$ Burdekin test sites; L $n = 2$, U $n = 20$ Pioneer test sites; L $n = 30$, No U sites.
	Tully	Field collected with hand held probe. Titration (for Alkalinity).					Reference sites; (from SEAP sites across, Wet Tropics Bioprovience) Tully test sites;
	Cooper	Field collected using Hariba probe. Titration (for Alkalinity).		Unweighted average.			Reference sites; $n=7$ Test sites; $n = 33$

FARWH theme	SWMA	Method	Sub indices	Aggregation technique and weighting	Integration technique	Reference approach	Confidence
Hydrological Disturbance	Pioneer and Burdekin	IQQM modelled no flow spells compared to gauged flow data from gauging station nodes within SWMA.	Annual flow Number of annual no flow periods Duration of no flow periods	Unweighted mean of all node scores.	Standardised Euclidean distance.	Reference values produced from IQQM model.	No. of nodes used in calculation: Burdekin: $n = 6$; Pioneer: $n = 13$ Moreton: $n = 44$ Cooper Creek: $n = 3$
	Moreton						
	Cooper		Above indicators + Number of no flow days				
	Tully	Unable to provide assessment of hydrological disturbance in the Tully SWMA due to lack of IQQM model within SWMA.					

FARWH theme	SWMA	Method	Sub indices	Aggregation technique and weighting	Integration technique	Reference approach	Confidence
Fringing Zone	Pioneer and Burdekin	GIS analysis validated with field survey data.	Percentage woody vegetation (percent upper and middle overstorey cover) within 51m of streams	N/A - Census	N/A - Census	Census measurement from SLATS FPC product as compared to measurement from the National Vegetation Information system Pre-1750 vegetation theme (v3.1)(e06) (Burdekin, Pioneer and Moreton) or the pre-European extent Regional Ecosystem mapping produced by the Queensland Herbarium (v???)(e???).	Slats FPC: 25m^2 raster e88-07: Burdekin, Pioneer and Moreton e88-09: Tully NVIS: 1:100000, 100m^2 raster RE: 1:100000, 25m^2 raster
	Moreton						
	Tully						
	Cooper	Field Sampling	Percentage Exotics in all strata	Waterhole index aggregated to SWMA by unweighted average of all waterhole scores.	Integrated to SWMA index score by Standardised Euclidean distance approach.	Test data compared to 20th or 80th percentiles of defined sampled reference range. Worst case values set from minimum or maximum values in each index from pooled ref and test data. 0 values used as reference for percentage exotics sub-indices.	Reference sites; $n=7$ Test sites; $n = 33$

FARWH theme	SWMA	Method	Sub indices	Aggregation technique and weighting	Integration technique	Reference approach	Confidence
Catchment Disturbance	Pioneer and Burdekin	GIS analysis of data products derived from remotely sensed imagery.	Catchment Landuse Infrastructure Land Use Change	N/A -Census	Impacts summed and components unweighted. (As per Equation 10 from NLWRA 1)	Census measurement for current and baseline era derived from Queensland Land Use Mapping Program (e99-04), DERM State Transport Dataset (e09), and SLATS Land Cover Change (e88-07).	QLUMP: 1:50000, user's accuracy 80% min (e04: Burdekin, Pioneer, Tully; e99 Cooper Creek) DERM STD: 10-50m, 1:25000 SLATS Land Cover Change: 25m^2 raster (e88-07 Pioneer, Burdekin, Moreton; e88-09 Tully, Cooper Creek)
	Tully						
	Cooper Creek						
	Moreton					As above with BRS Land Use of Australia (e01-02) in place of incomplete QLUMP coverage.	

FARWH theme	Method	SWMA	Sub indices	Aggregation technique and weighting	Integration technique	Reference approach	Confidence
Physical Form	Collected field data on substrate composition collected at macro-invertebrate sampling sites.	Pioneer and Burdekin	Substrate Heterogeneity	Length weighted average of all reach scores.	No integration required due to only one index value.	Test data compared to 20th percentile of sampled reference range. Worst case values set at 0 (relates to only one substrate type recorded at a site)	Pooled reference sites $n = 41$ Burdekin test sites $n = 27$. ANOVA (test vs. ref sites) $p = 0.22$ Pioneer test sites $n = 19$. ANOVA (test vs. ref sites) $p = 0.08$
		Moreton					Sites: Reference $n = 5$; Test $n = 30$ ANOVA results (test vs. reference) $p = 0.18$
		Tully				Test data compared to 20th or 80th percentiles of sampled reference range. Worst case values set from minimum or maximum values in each index from pooled ref and test data.	Pooled reference sites $n =$ (SEAP reference sites collected from the Wet Tropics Bioprovince) Burdekin test sites $n = 27$. ANOVA (test vs. ref sites) $p = 0.22$
	Physical habitat assessment field data collected longitudinally between transects in conjunction with the riparian vegetation survey.	Cooper	% of benches % of overhang vegetation % of snags % pugging (pigs) % pugging (cattle)	Unweighted average of all waterhole scores.	Integrated to SWMA index score by Standardised Euclidean distance approach.	Test data compared to 20th or 80th percentiles of sampled reference range. Worst case values set from minimum or maximum values in each index from pooled ref and test data.	Reference sites $n = 7$ Test sites $n = 33$.