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Fitzroy Partnership for River Health

Technical Review for the Development of an Ecosystem Health Index and Report Card for the Fitzroy Partnership for River Health

PART A: REVIEW OF ECOSYSTEM HEALTH INDICATORS FOR THE FITZROY BASIN

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EXECUTIVE SUMMARY

Background and scope

This is the first volume of a two part report that aims to provide the Fitzroy Partnership for River Health (FPRH) with a technical review that will assist them to:

(a) develop an appropriate set of ecosystem health indicators and objectives,

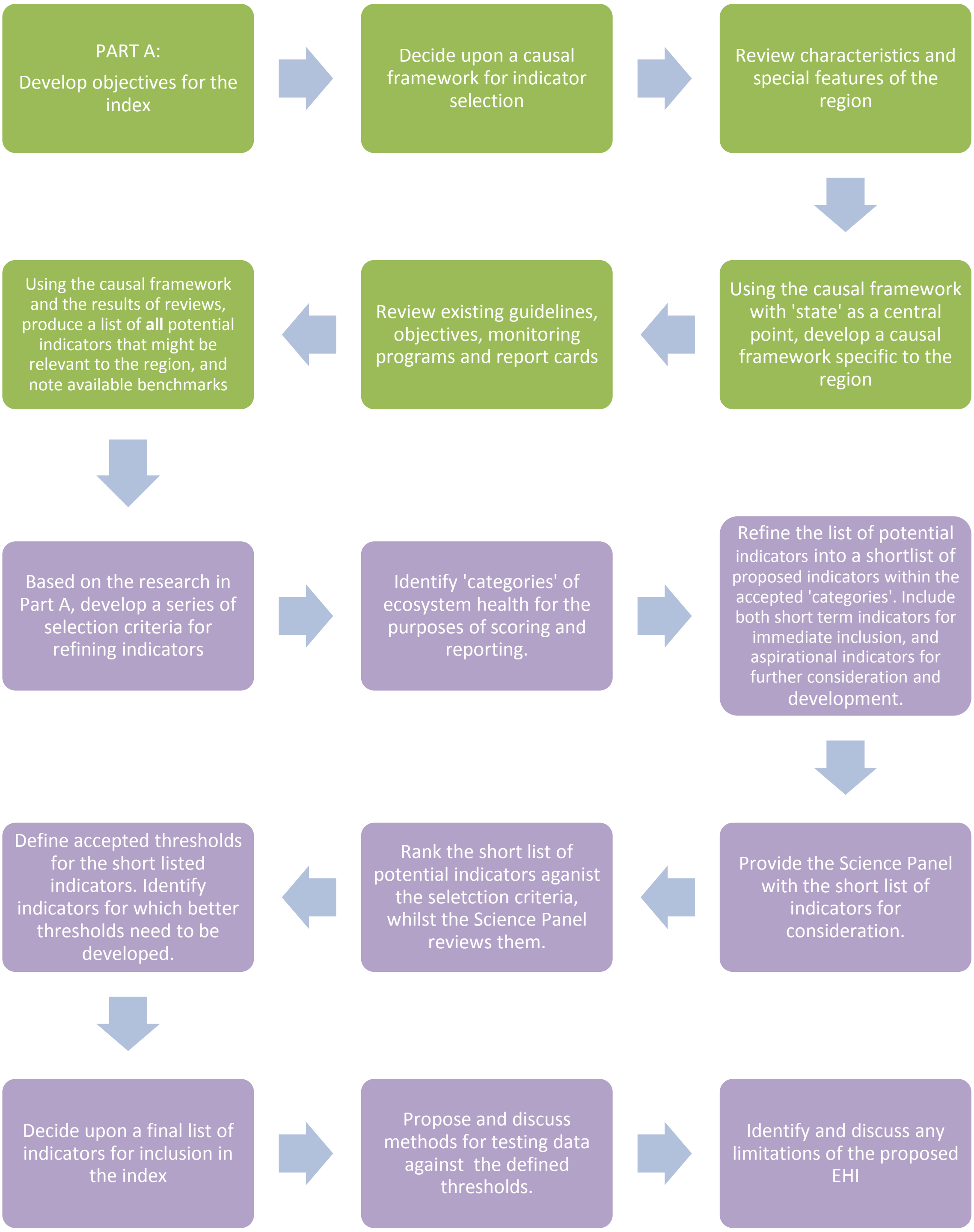
(b) develop a process to evaluate the condition of the Fitzroy system against the appropriate indicators in a simplified index system, and

(c) develop an ecosystem health report card.

This report has been prepared by CQUniversity and reviewed by members of the FPRH Science Project Team and Science Panel. It includes reviews of relevant literature, guidelines, legislation and other ecosystem health monitoring programs and ecosystem health indices. It also summarises the historical and current land uses and water quality in the Fitzroy Basin and provides the Science Panel with recommendations for objectives, a framework, potential indicators, and methods for selecting appropriate indicators for an Ecosystem Health Index and Report Card for the Fitzroy Basin.

The second volume of the report *"Part B: Analysis and interpretation of data for the Fitzroy and application to an Ecosystem Health Index and Report Card"* provides a review of FPRH monitoring data, evaluates the suitability of potential indicators against the predetermined selection criteria, provides advice on methodologies for data handling, including scoring and weighting indicators within the final index, and includes a data gap analysis to guide future improvements to the index.

A process diagram for the development of the Ecosystem Health Index and Report Card for the Fitzroy Basin is shown below.


PART A:
Develop objectives for the index
Decide upon a causal framework for indicator selection
Review characteristics and special features of the region
Using the causal framework with 'state' as a central point, develop a causal framework specific to the region
Review existing guidelines, objectives, monitoring programs and report cards
Using the causal framework and the results of reviews, produce a list of all potential indicators that might be relevant to the region, and note available benchmarks
Based on the research in Part A, develop a series of selection criteria for refining indicators
Identify 'categories' of ecosystem health for the purposes of scoring and reporting.
Refine the list of potential indicators into a shortlist of proposed indicators within the accepted 'categories'. Include both short term indicators for immediate inclusion, and aspirational indicators for further consideration and development.
Provide the Science Panel with the short list of indicators for consideration.
Rank the short list of potential indicators aganist the seletction criteria, whilst the Science Panel reviews them.
Define accepted thresholds for the short listed indicators. Identify indicators for which better thresholds need to be developed.
Decide upon a final list of indicators for inclusion in the index
Propose and discuss methods for testing data against the defined thresholds.
Identify and discuss any limitations of the proposed EHI

Purpose and framework of the Ecosystem Health Index and Report Card

The first step of the process of developing a new index is to identify specific objectives that will guide and define the index through the current development phase and continuing maintenance of the program into the future. A set of six objectives that describe the intent of the Ecosystem Health Index and associated Report Card is recommended.

RECOMMENDATION ONE.

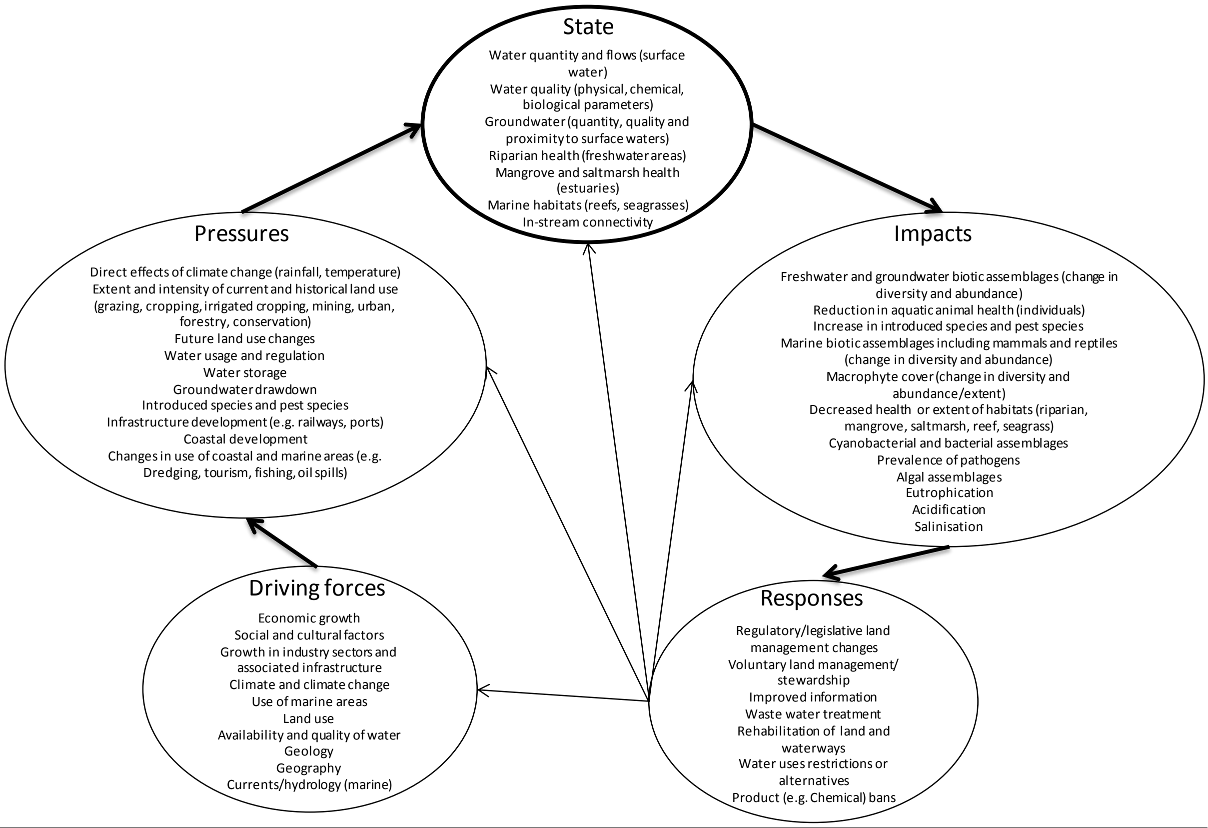
That the objectives of the Ecosystem Health Index and Report Card for the Fitzroy Basin are to:

1. document ecosystem health of waterways in the freshwater catchments, estuarine and marine environments in the Fitzroy Basin, its delta and Keppel Bay;
2. assist in identifying changes in ecosystem health over time, taking into account natural variations;
3. synthesise complex data at a regional scale into easily interpretable scores;
4. provide information on ecosystem health in the Fitzroy Basin which is accessible and interpretable by government, stakeholders and the community;
5. provide information which can be used to advise policy makers on areas of improving or declining ecosystem health, in order to drive management change; and
6. assess ecosystem health within a causal framework that helps to link management responses to current and future changes in health or functioning.

The Driving force-Pressure-State-Impact-Response (DPSIR) framework is recommended as a basis for selection of potential indicators for inclusion in the Ecosystem Health Index and Report Card for the Fitzroy Basin. By basing decisions on indicators that make up an ecosystem health index on an established causal chain framework the links between anthropogenic impacts and ecological health are more explicit, and management responses can be justifiably tailored accordingly. The DPSIR framework has been recommended as it is sufficiently detailed to allow for the full range of ecosystem characteristics, including natural variations and anthropogenic impacts in the Fitzroy Basin, while remaining simple enough to be meaningful in a relatively data-poor environment. Another useful aspect of the DPSIR framework is the conceptual separation of 'Impacts' from 'State' which allows for the recognition of sequential impacts caused by interactions between ecosystem health indicators.

RECOMMENDATION TWO.

That the Driving force-Pressure-State-Impact-Response (DPSIR) framework is used to conceptualise the causal chain of ecosystem health in the Fitzroy Basin, as a basis for deciding upon potential indicators that may be included in the index.


State
Water quantity and flows (surface water)
Water quality (physical, chemical, biological parameters)
Groundwater (quantity, quality and proximity to surface waters)
Riparian health (freshwater areas)
Mangrove and saltmarsh health (estuaries)
Marine habitats (reefs, seagrasses)
In-stream connectivity
Pressures
Direct effects of climate change (rainfall, temperature)
Extent and intensity of current and historical land use (grazing, cropping, irrigated cropping, mining, urban, forestry, conservation)
Future land use changes
Water usage and regulation
Water storage
Groundwater drawdown
Introduced species and pest species
Infrastructure development (e.g. railways, ports)
Coastal development
Changes in use of coastal and marine areas (e.g. Dredging, tourism, fishing, oil spills)
Impacts
Freshwater and groundwater biotic assemblages (change in diversity and abundance)
Reduction in aquatic animal health (individuals)
Increase in introduced species and pest species
Marine biotic assemblages including mammals and reptiles (change in diversity and abundance)
Macrophyte cover (change in diversity and abundance/extent)
Decreased health or extent of habitats (riparian, mangrove, saltmarsh, reef, seagrass)
Cyanobacterial and bacterial assemblages
Prevalence of pathogens
Algal assemblages
Eutrophication
Acidification
Salinisation
Driving forces
Economic growth
Social and cultural factors
Growth in industry sectors and associated infrastructure
Climate and climate change
Use of marine areas
Land use
Availability and quality of water
Geology
Geography
Currents/hydrology (marine)
Responses
Regulatory/legislative land management changes
Voluntary land management/ stewardship
Improved information
Waste water treatment
Rehabilitation of land and waterways
Water uses restrictions or alternatives
Product (e.g. Chemical) bans

The Fitzroy Basin

The Fitzroy Basin is the largest catchment on the east coast of Australia (142,000 km^2) and is characterised by a highly variable flow regime, ephemeral streams in its upper reaches, large tidal volumes in the estuary and periods of extensive riverine flooding. High sediment volumes and turbidity result from these characteristics.

Waterways in the catchments are heavily modified, with 28 dams and weirs across the basin playing a role in regulating flows. The size of the basin and complexity of waterways make accurate assessments of ecosystem health more challenging than in a more homogeneous system. Water quality within the basin is variable as a result of natural variations in geography, geology, climate (including droughts and flooding), soils and the somewhat unpredictable patterns of flow and runoff. Human activities and land use include extensive historical land clearing, a number of barrages and dams, and a range of land uses such as grazing, cropping, irrigated cropping, mining, urbanisation and forestry. Future land use changes with potential impacts on water quality include proposals for increasing agricultural development, more mining operations, coal terminal developments in the Fitzroy River delta and increasing coal seam gas extraction.

Water quality issues within the Fitzroy Basin can be classified into three geographic zones: freshwater, estuary and marine. Within the freshwater zone, substantial variability can be further captured by differentiating the basin into a number of sub-catchments. Classification of the basin into different zones and sub-catchments allows for more appropriate evaluation of indicators against expected conditions, addressing the variability of conditions across the region. It also allows for an environmental health index to be reported by zone and sub-catchment, improving the usefulness of the index.

RECOMMENDATION THREE.

That water quality issues within the Fitzroy Basin are classified into freshwater, estuary and marine zones, and that the freshwater zone is differentiated into a number of sub-catchments.

Water quality guidelines, ecosystem health indices and monitoring programs

The development of an Ecosystem Health Index for the Fitzroy Basin should be cognisant of current scientific knowledge and existing programs to ensure accuracy and predictability of the index, maximise acceptance and trust by the scientific community and general public, and allow for comparability and consistency with other key ecosystem health monitoring programs. The water quality guidelines, water quality objectives and ecosystem health indices available for the Fitzroy Basin as well as ecosystem health monitoring programs that are being run in the Fitzroy Basin and elsewhere are summarised in Section 6.0 of this report.

Guidelines and indices

Water quality guidelines and objectives are designed to help assess whether the water quality of a water resource is good enough for a particular purpose (such as human consumption, agriculture, or environmental values).

Relevant water quality guidelines for the Fitzroy Basin's fresh, estuarine and marine waters include the Fitzroy Basin Water Quality Objectives (WQOs – scheduled in 2011 under the Queensland Environmental Protection (Water) Policy 2009), the Queensland Water Quality Guidelines 2009, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (ANZECC Guidelines), and the Australian Government's Water Quality Guidelines for the Great Barrier Reef Marine Park 2010. Appropriate thresholds and trigger levels for many potential indicators are described in these guidelines and are recommended for use in the initial Ecosystem Health Index to set appropriate benchmarks for specific indicators in the absence of more specific benchmarks defined by conditions at reference sites. A range of other guidelines and health indexes have been identified for groundwater, habitat, fish and aquatic systems, and are reviewed in section 5 of this report.

Monitoring programs

The Fitzroy Basin catchment and its estuarine and marine ecosystems are currently monitored by a number of resource and agricultural industries, government agencies, universities, community groups, natural resource management bodies and private businesses. Although not directly relevant to the Fitzroy Basin there are also a number of ecosystem health monitoring programs in Queensland, Australia and internationally which may be of interest when deciding upon appropriate indicators to assess the health of the Fitzroy.

The South East Queensland Ecosystem Health Monitoring Program (EHMP), although much smaller in size and affected by different anthropogenic influences, shares the majority of chemical, physical and biological indicators of ecosystem health with the Fitzroy. This is a long term program that has a well-defined index system and has been critically reviewed. The structure and successful elements of the EHMP and the outcomes of the recent review process are recommended as useful starting points to consider in developing an Ecosystem Health Index and Report Card for the Fitzroy Basin.

RECOMMENDATION FOUR.

That existing guidelines, indices and successful monitoring programs at both national and international levels are taken into account when selecting indicators for inclusion in the Ecosystem Health Index and Report Card for the Fitzroy Basin.

Categories of assessment in a Fitzroy Ecosystem Health Index

An Ecosystem Health Index represents a summary of data across a range of indicators in a standardised form (index numbers) so that the indicators can be consolidated and summarised. There are several reasons why it is desirable to summarise indicators into groups or categories rather than across all available indicators. First, some indicators are more related to each other (e.g. nutrients), and it is conceptually more appropriate to group them together. Second, summarising data into indexes means that information and detail is lost in the process, but this loss can be limited by summarising into related groups first. Third, the use of categories helps in the communication of results, and can be more relevant to analysis and policy recommendation than a single condition score. Fourth, the use of categories can help to ensure that an index is designed in a systematic way, avoiding substantial gaps or overlaps in the influence of indicators. Fifth, the use of categories helps to check and adjust the weightings of different groups of indicators in the overall index.

A review of the major issues in the Fitzroy Basin and potential groupings of indicators has been conducted, with four potential categories developed for the Environmental Health Index.

RECOMMENDATION FIVE.

That the following categories are used to define indicators selected for inclusion in the Ecosystem Health Index and Report Card for the Fitzroy Basin:

1. Physical/Chemical
2. Nutrients
3. Toxicants
4. Ecology

Preliminary ecosystem health indicators for the Fitzroy

A list of potential indicators of ecosystem health for the Fitzroy Basin has been generated from a desktop review and expert knowledge, including consultation with the Science Panel (Appendix IV). This initial list is inclusive and has to be refined significantly to be suitable for an index. The process for selection of a more concise set of indicators is described in the second volume of this report

"Part B: Analysis and interpretation of data for the Fitzroy and application to an Ecosystem Health Index and Report Card".

RECOMMENDATION SIX.

That the indicators identified in Appendix IV are considered for inclusion in the Ecosystem Health Index and Report Card for the Fitzroy Basin.

Selection criteria to refine the list of indicators are described below (and in Table 7.1 of this report). The selection criteria were developed based on a combination of scientific literature, expert knowledge and the criteria used for existing programs. Three of the selection criteria (e.g. insufficient data) have been flagged as "disqualifying" criteria. Due to the critical importance of these three criteria it is recommended that an indicator that scores poorly on any of the three is removed from further consideration for inclusion in the index. This should not exclude an indicator from consideration in future iterations of the index; many of the indicators that are excluded in the initial formulation of the index may be appropriate candidates for further research and monitoring projects to enable their future inclusion.

The selection process requires analysis of FPRH data and hence is included in the second volume of this report. The combination of indicators chosen to form the Ecosystem Health Index for the Fitzroy Basin must cover the full complexity of this system, or at least aim to do so as effectively as possible within current constraints and provide direction for future improvements. The balance of the number of indicators will also need to be considered to avoid issues caused by having too many indicators (costly and potentially ineffective) or too few indicators (knowledge gaps).

RECOMMENDATION SEVEN.

That the selection criteria described in Table 7.1 of this report are used to finalise the subset of indicators to include in the Ecosystem Health Index and Report Card for the Fitzroy Basin and also to identify indicators which may be useful but for which further research or monitoring will be required before future inclusion in the index.

Recommended indicator selection criteria

Data:

SC1. Reliable data currently available for the Fitzroy Basin*

SC2. Suitable interpretative algorithms are available

SC3. Errors, reliability and uncertainty in measurement are known and acceptable*

SC4. Temporal and spatial variability can be accounted for

Interpretation and communication:

SC5. Guidelines/ objectives are in place and relevant to the region*

SC6. Used in other monitoring programs (consistent with other regions, states, nations)

SC7. Scientific interpretation is straightforward and meaningful

SC8. Simple to communicate and good public understanding

Relevance:

SC9. Important to ecosystem function (will exposure cause serious environmental effects?)

SC10. Sensitive to changes in ecosystem function

SC11. Contributes to assessment of ecosystem resilience

SC12. Related to regional, state, national, international policies and management goals

Practicality and timeliness:

SC13. Feasibility and logistics to measure (monitor and analyse) are consistent with outcome benefits

SC14. Time requirements to measure (monitor and analyse) are consistent with outcome benefits

SC15. Costs to measure (monitor and analyse) are consistent with outcome benefits

SC16. Provides an early warning of ecosystem health decline

*** Critical criteria – low score means automatic disqualification of a potential indicator from the index (applies to SC1, SC3 and SC5).**

Using the ecosystem health indicators

Following finalisation of the indicators in each of the four recommended categories, a system to assess observations for each indicator needs to be established. It is recommended that observations are compared to both best case and worst case guidelines to identify if they meet, fail, or are in between the relevant guidelines. Best case guidelines are defined for this study as the relevant Water Quality Objective (WQO) and the worst case guidelines are defined as the Worst Case Scenario (WCS) values for each indicator in the relevant zone or sub-catchment.

Where possible, existing benchmarks have been identified for each of the potential indicators identified in this report. Sources include the Fitzroy Basin Water Quality Objectives, the Queensland Water Quality Guidelines, the ANZECC Guidelines, the GBRMPA Guidelines as well as existing monitoring programs including EHMP.

There are a number of issues in interpreting and setting indicators and benchmarks. These include accounting for variability in the Fitzroy Basin particularly in relation to flow, the ecological relevance of indicators and available data, understanding causality of changes in the state of the environment, predicting changes in ecosystem health, and issues related to scoring and weighting indicators within the Ecosystem Health Index. These complexities need to be considered in the development of the Ecosystem Health Index and it is recommended that they are also noted by FPRH for future improvement through further research or increased monitoring as relevant.

RECOMMENDATION EIGHT.

> Observations for selected indicators should be compared to both best case (Water Quality Objective) and worst case guidelines (Worst Case Scenario) to identify if they meet, fail, or are in between the relevant guidelines for each relevant zone or sub-catchment. There are difficulties and limitations in interpreting indicators and benchmarks, and these need to be improved over time to fully account for the unique nature of the Fitzroy Basin.

Communicating ecosystem health indicators

Report cards from other monitoring programs use a variety of approaches to communicate monitoring results. Some methods used to communicate ecosystem health indicators have been reviewed in this report. There are benefits in considering the success and applicability to the Fitzroy Basin of the various methods of reporting used in other programs, and particular benefits in selecting a similar layout to EHMP reporting. These include ease of interpretation for decision makers and others who are already familiar with the EHMP, and to allow for rapid cross-checks of ecosystem health between the two regions. While there would necessarily be differences between the two as a result of the differing pressures, state and impacts, it is recommended that a similar formatting style to EHMP is retained where possible in order to increase benefits to both programs.

RECOMMENDATION NINE.

That the designs used in other report cards is noted and successful elements from these, particularly the South East Queensland EHMP, are considered for adoption or modification to meet the needs of a Report Card for the Fitzroy Basin.

Conclusions

The development by FPRH of an Ecosystem Health Index and Report Card for the Fitzroy Basin will play a vital role in bringing together disparate monitoring program datasets, measuring ecosystem health in the waterways of the Fitzroy Basin, raising awareness about aquatic and marine ecosystem health and providing information to industry, government, other stakeholders and the community. The index and report card will be designed in a format that communicates simply and comprehensively the health of the basin to a range of stakeholders and the community. It is important that the index is based on a robust design and development methodology and provides an avenue for not just assessing but also improving ecosystem health.

This report aims to provide FPRH with the information and framework required to develop an appropriate set of ecosystem health indicators - develop a process to evaluate the condition of the Fitzroy in a simplified index system and develop an ecosystem health report card. The review provided in this report has identified an appropriate conceptual approach to, and structure of, an index system and report card, as identified in a series of recommendations. The next part will finalise the composition of the index, provide a review of available FPRH data and recommend a methodology to interpret the data so the index and report card can be finalised. Material from this next stage is included in the second volume of this report *“Part B: Analysis and interpretation of data for the Fitzroy and application to an Ecosystem Health Index and Report Card”*.

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Abbreviations

Acronym	Expansion
ABMAP	Biological Monitoring and Assessment Program
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resources Management Council of Australia and New Zealand
AUSRIVAS	Australian Rivers Assessment System
BMA	BHP Mitsubishi Alliance
BMP	Best Management Practice
BOM	Bureau of Meteorology
CQU	Central Queensland University
CRC	Cooperative Research Centre
CSG	Coal Seam Gas
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEEDI	Qld. Department of Employment, Economic Development and Innovation
DEHP	Department of Environment and Heritage Protection
DERM	Qld. Department of Environment and Resource Management
DESA	Department of Economic and Social Affairs
DNRW	Department of Natural Resources and Water
DO	Dissolved Oxygen
DPSIR	Driving force-Pressure-State-Impact-Response
DSR	Driving force-State-Response
E	Expected
EA	Environmental Authority
EC	Electrical Conductivity
EcoH	Ecosystem Health
EEA	European Environment Agency
EFAP	Environmental Flows Assessment Program
EFAP	Environmental Flows Assessment Program
EHMP	Ecosystem Health Monitoring Program
EHP	Environment and Heritage Protection
EMAP	Environmental Monitoring and Assessment Program
EMC	Event Mean Concentration
ENSO	El Nino-Southern Oscillation
EPA	Environment Protection Authority
EPP	Environment Protection Policy
EV	Environmental Value
FARWH	Framework for the Assessment of River and Wetland Health
FBA	Fitzroy Basin Association
FBP	Freshwater bio geographic provinces

FHG	Fish Habitat Guidelines
FPRH	Fitzroy Partnership for River Health
FRP	Filterable Reactive Phosphorous
GAB	Great Artesian Basin
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
GBRMPA	Great Barrier Reef Marine Park Authority
GWAN	Ground Water Ambient Network
GWDB	groundwater database
GWLN	Ground Water Level Network
GWMA	Groundwater Management Area
ISC	Index of Stream Condition
LNG	Liquidified Natural Gas
LWRRDC	Land and Water Resources Research and Development Corporation
MMP	Marine Monitoring Program
NCCR	National Coastal Condition Report
NH4	Ammonia
NOx	Nitrogen Oxide
NTU	Nephelometric Turbidity Unit
NWQMS	National Water Quality Management Strategy
O	Observed
OECD	for Economic Co-operation and Development
PCIMP	Port Curtis Integrated Monitoring Program
PDO	Pacific Decadal Oscillation
PET	Plecoptera Ephemeroptera Trichoptera
pH	a measure of acidity
PNG	Papua New Guinea
PSR	Pressure-State-Response
QLD	Queensland
QLUMP	Qld. Land Use Mapping Program
REMP	Receiving Environment Monitoring Programs
ROP	Resource Operations Plan
RRC	Rockhampton Regional Council
SEAP	Stream and Estuary Assessment Program
SEQ	South East Queensland
SIGNAL	Stream Invertebrate Grade Number Average Level
SLATS	Statewide Land cover and Trees Survey
SO4	Sulfate
SoE	State of the Environment
SWAN	Surface Water Ambient Network
SWAN	Surface Water Ambient Water Quality Network
TKN	Total Kjeldahl Nitrogen

TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TON	Total Organic Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
USA	United States of America
VM	Vegetation Management
WQG	Water Quality Guidelines
WQIP	Water Quality Improvement Plan
WQO	Water Quality Objective
WRP	Water Resource Plan

1.0 Introduction

This report aims to provide the Fitzroy Partnership for River Health (FPRH) with a technical review that will assist FPRH to (a) develop an appropriate set of ecosystem health indicators, (b) develop a process to evaluate the condition of the Fitzroy system against the appropriate indicators in a simplified index system, and (c) develop an ecosystem health report card.

The reports and information provided through this project will be used by FPRH in conjunction with advice from a Science Coordinator, Science Panel and other activities to decide upon a framework and process for developing a report card, and to produce an initial report card. This report has been prepared by CQUniversity and reviewed by members of the FPRH Science Project Team and Science Panel. The process diagram in Figure 1.1 illustrates the steps taken in developing and selecting a framework, ecological health indicators and Ecosystem Health Index for the Fitzroy Basin.

The report is presented in two volumes. This first volume of the report "*Part A: Review of Ecosystem Health Indicators for the Fitzroy System*" includes reviews of relevant literature, guidelines, legislation and other ecosystem health monitoring programs and ecosystem health indices as well as summarising the historical and current land uses and water quality in the Fitzroy Basin. That information forms the basis required to develop a framework and select indicators for an Ecosystem Health Index and Report Card for the Fitzroy Basin.

The second volume of the report *"Part B: Analysis and interpretation of data for the Fitzroy and application to an Ecosystem Health Index and Report Card"* delivers a review of the data provided by FPRH, assess the suitability of proposed indicators against a series of selection criteria and reviews the methodology for scoring and weighting of indicators within the final index. The data review includes a gap analysis and frameworks which when used in combination with the findings of Part A, will guide the practical process of identifying and selecting future indicators for inclusion in the Ecosystem Health Index for the Fitzroy Basin.

An ecosystem health index is a measure against which the condition of an ecosystem can be scored. It is designed by combining information from a variety of individual indicators. By providing a summary mechanism for assessing and communicating the health of ecosystems, it can be used to assess and communicate the effects on the environment of anthropogenic activities. In order to be more than simply a 'useful means of documenting decline or improvement', environmental monitoring and reporting should be adaptive, scientifically current, linked to clear objectives, responsive to changing values and importantly, be capable of guiding management actions and interventions (Bunn *et al.*, 2010).

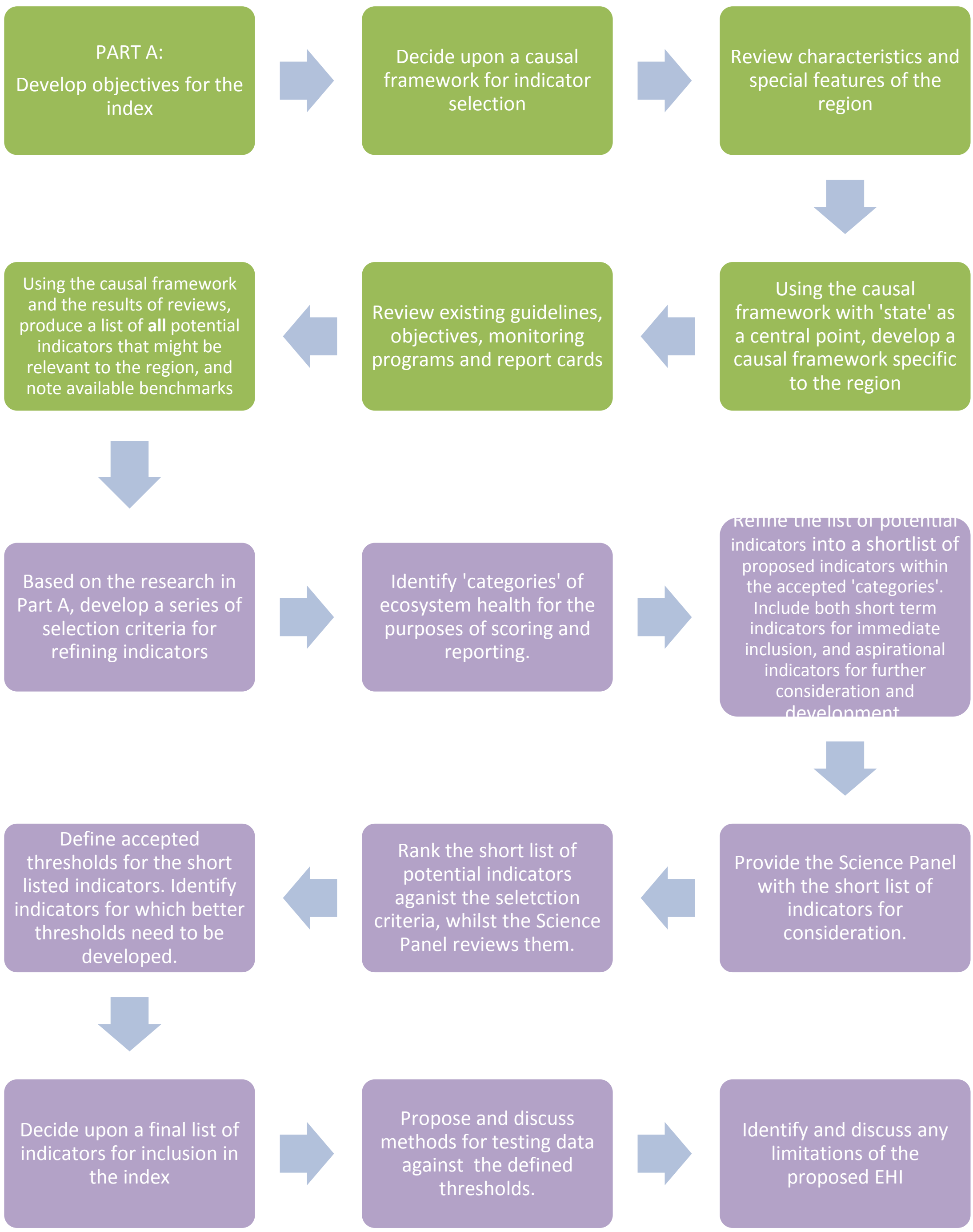

Figure 1.1: The process of developing an Ecosystem Health Index and Report Card for the Fitzroy Basin.

The scope of the FPRH includes all groundwaters, rivers, off-stream wetlands and estuaries in the Fitzroy Basin, as well as near-shore coastal and marine environments. The need for an assessment of ecosystem health is being driven by the size and ecological importance of the region on the one hand, and on the other hand the existing and future footprint of economic development , particularly through the agricultural and resource sectors. The potential for poor water quality to be generated from human activity, and for that to adversely affect water quality and uses downstream and out to the Great Barrier Reef, establish the need for this type of assessment to be performed.

The size, diversity and complexity of the Fitzroy system means that the assessment of environmental health is complex. There is large natural variety in the system, including differences stemming from geography, geology, climate (including rainfall) and soils within the basin, as well as variations in the estuary and near-marine areas. As well, there is substantial variation in the human impacts, relating in particular to different patterns of land use and resource development, as well as to the system of dams and barrages that affect natural flows through the system. These factors mean that an ecosystem health index has to be designed specifically for the Fitzroy, and for sub-regions within the basin, and not simply transferred from other location.

A number of monitoring programs already exist to assess the health of the Fitzroy system. As well, there has been substantial work to develop a range of guidelines and protection measures, as well as research to provide the knowledge to underpin these frameworks. However, this information and understanding has never been collated and condensed before into a single assessment of ecosystem health. This means that a new environmental health index for the Fitzroy system has to be established that needs to unique to the basin, and is capable of differentiating the assessments between different zones and sub-catchments in the basin.

It is important that an environmental health index is, as much as is practical, consistent with other relevant indexes to aid in communication, and builds on and synthesises available data from existing monitoring programs and other sources. Key roles of this background review are to provide suitable information about the design of an environmental health index, taking into account both the unique characteristics of the Fitzroy and the design of other relevant indexes, and to provide some guide as to the categories and parameters that might be included in an index.

The report is structured in the following way. The next sections provide some background to the measurement of environmental health and the Fitzroy Basin respectively. Section 4 outlines the purpose of a ecosystem health index and report card for the Fitzroy, and introduces a conceptual framework to underpin the index. A review of other assessment and monitoring programs in Section 5 is used to recommend the key categories (groupings) for the Fitzroy index, and a review of other indexes and available data and benchmarks in Section 6 is used to establish a list of potential indicators. Criteria to select indicators for an index are provided in Section 7, a review of methods to communicate results is provided in Section 8, and final recommendations follow in Section 9.

2.0 What is ecosystem health and why do we measure it?

2.1 What is ecosystem health

Simply, a healthy river (or healthy aquatic ecosystem) is a river in good condition (Karr, 1999). Describing the characteristics of a healthy aquatic ecosystem is more difficult (Norris and Thoms, 1999), however fundamentally a healthy aquatic ecosystem can be characterised by the presence of integrity, resilience and vigor in different components of the freshwater ecosystem (Rapport *et al.*, 1998, Karr, 1999) . Essentially, after disturbance a healthy ecosystem is able to bounce back to a similar condition to what it was before disturbance.

To be a functional concept, ecosystem health requires a predefined benchmark of what a healthy ecosystem is. This can be provided by the condition or range of conditions that are observed at sites that are considered to be in a minimally disturbed or reference condition (Norris and Thoms, 1999).

2.2 Why and how is ecosystem health measured?

Ecosystem health is measured because not only are individual components of the ecosystem important (such as water quality) but because ecosystems perform many useful functions. For example, aquatic ecosystems support a diversity of biota, absorb some wastes and toxicants, and provide water for human use and recreational enjoyment.

Considering and measuring ecosystem health is essential to the EHI because understanding of the probable causes of harm or factors that influence aquatic ecosystem health underpins the whole process. Simply, it is essential to ensure that the indicators selected have a known and measureable response to identified pressures.

Ecosystem health is not measured directly. Rather components of the ecosystem or surrogates are measured and observed in order to assess the ecosystem's integrity, resilience and vigour. This can include:

- Key structural communities (e.g. populations of fish, macroinvertebrates)
- Key structural components (e.g. critical habitat, wetlands)
- Key functional processes (e.g. nutrient cycling, sediment transport, recruitment of biota)

.

2.3 Concept Diagrams of Ecosystem Health

The health of an ecosystem can be conceptualised diagrammatically as a way of demonstrating how the whole of the ecosystem responds under natural conditions compared to when under pressure. The following diagrams demonstrate how the freshwater component of the Fitzroy might exist under healthy conditions (Figure 2.1.) compared to an impaired state (Figure 2.2.).

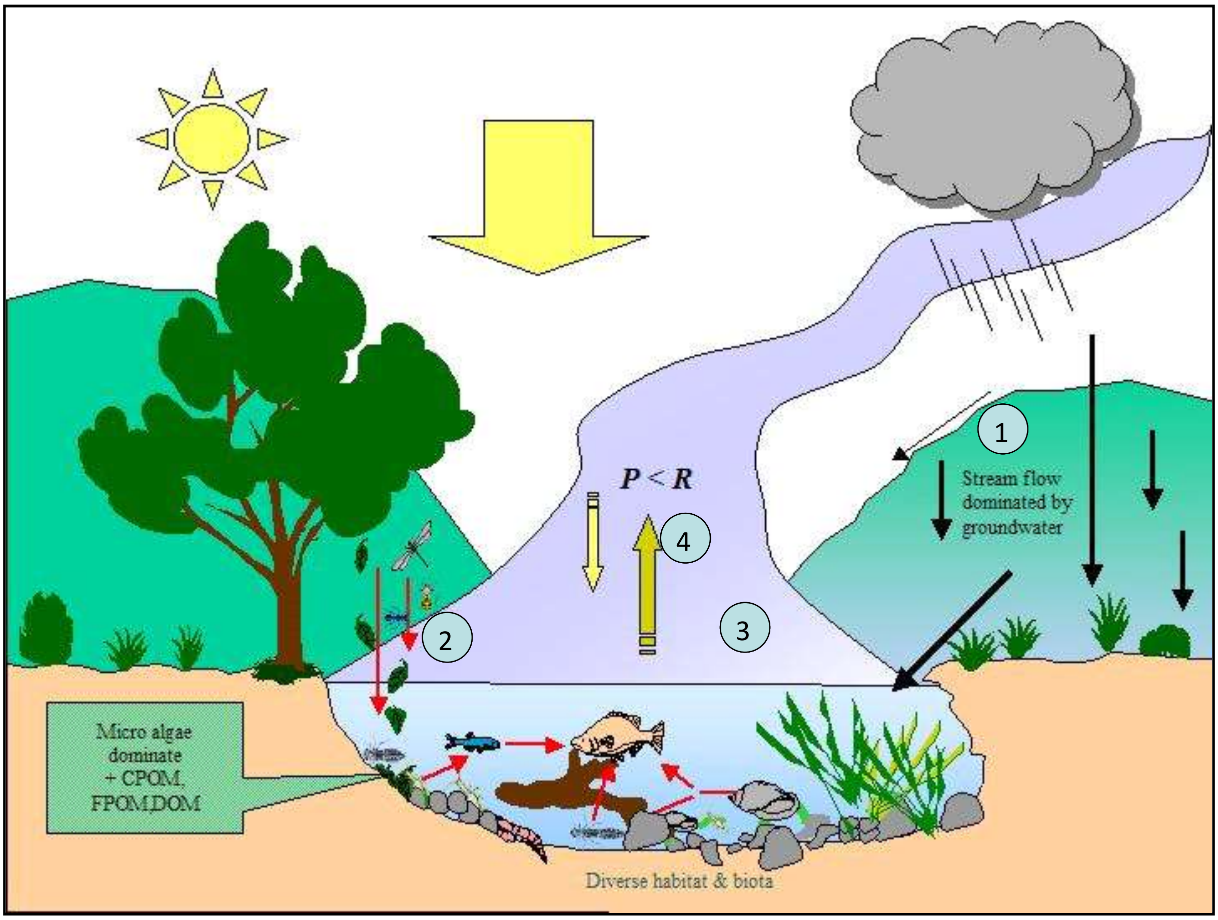

Figure 2.1: Conceptual diagram of a healthy catchment: (1) The main source of water is from groundwater discharge and natural flow; (2) The stream supports a diverse range of flora and fauna because of heterogeneous habitat; (3) Chemical characteristics are a result of the weathering of catchment geology, and soil nutrients and vegetation; (4) Productivity is driven by the breakdown of particulate organic material.

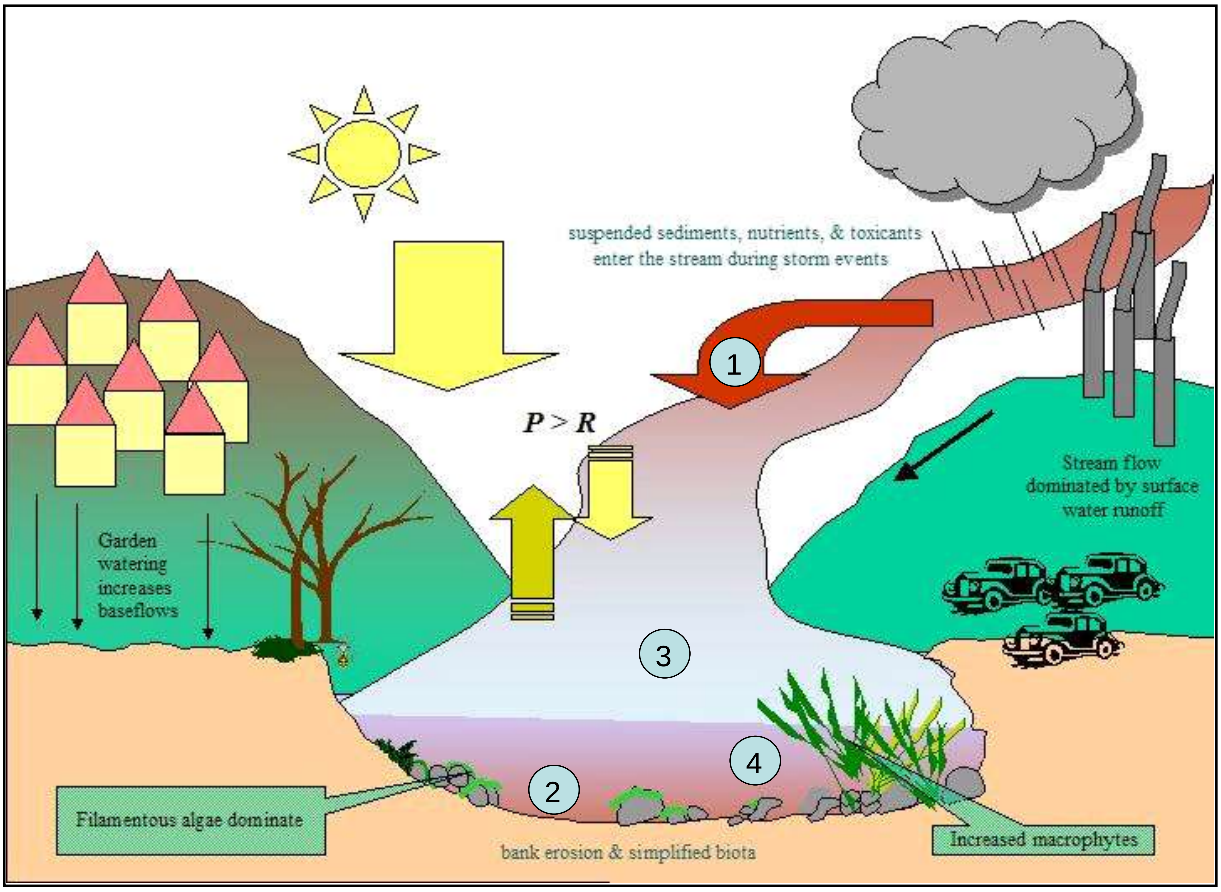

Figure 2.2: Conceptual diagram of an impacted catchment: (1) The dominant water source is from surface runoff; (2) Habitat is homogenous and flora and fauna diversity is reduced; (3) Water chemistry is a product of suspended sediments, nutrients and toxicants entering the stream during storm events and in baseflows from urban, agricultural or industrial runoff; (4) Filamentous algae are dominant, and macrophyte cover increases drives productivity.

2.4 Assessing ecosystem health using an ecosystem health index.

An ecosystem health index is a measure against which the condition of an ecosystem can be scaled. An index is created by standardising and condensing information gathered from a variety of individual indicators. It provides a summary mechanism for assessing and communicating the health of ecosystems, most usually in the presence of anthropogenic impacts.

Ecosystem health indicators are defined differently between ecosystem health programs, depending upon their applications and objectives. A useful definition is provided in the US EPA's manual *Indicator Development for Estuaries*:

> *Environmental Indicators are specific, measurable markers that help assess the condition of the environment and how it changes over time*. *Both short term changes and general trends in those markers can indicate improved or worsening environmental health.* (EPA, 2008).

Ideally, ecological indicators should quantitatively estimate the condition of ecological resources, magnitudes of stress, exposure of biological components to stress, or the amount of change in condition (EPA, 2008). Indicators are an essential element of assessment programs that allow for the tracking of ecosystem health, addressing of management questions and identification of environmental problems (Wicks *et al.*, 2010). The combined results of the indicators are used to rank or score ecosystem health. The resulting scores constitute the ecosystem health index. An index is most commonly presented as a single score or series of scores for ecosystem categories and/or particular locations within a monitoring area.

By combining an ecosystem health index with a report card communication tool it is possible to quickly and efficiently disseminate information about ecosystem health to a wide audience including government, stakeholders and the community. Ecosystem health indices and report cards play an important role in driving management change. They assist in clearly measuring, summarising and communicating changes in environmental health to policy makers to allow for evidence-based decision making at local, state and federal levels of government.

3.0 Special features of the Fitzroy Basin

With a catchment area of about 142,000 km^2 the Fitzroy Basin is the largest catchment on the east coast of Australia (Noble et al., 2005, FBA, 2008) and the second largest seaward draining catchment in Australia after the Murray-Darling (Hart, 2008). It is characterised by a highly variable flow regime with ephemeral streams in its upper reaches (Hart, 2008), large tidal volumes in the estuary, and due to its large size and fan like shape, periods of extensive riverine flooding following heavy rains (FBA, 2008). These factors contribute to high sediment volumes and turbidity, which vary in response to the tidal cycle and most prevalently in response to catchment inflows.

The Fitzroy Basin has seven major tributaries: Callide Creek, Comet River, Dawson River, Fitzroy River, Isaac River, Mackenzie River and Nogoa River; as well as numerous streams, waterholes and impoundments. The Fitzroy River collects waters from all rivers and streams of the Fitzroy Basin and delivers them to its extensive delta which flows into Keppel Bay and the Great Barrier Reef Marine Park (Figure 3.1). Flows are predominantly runoff-driven, and are highest during heavy summer rains. Winter rains may also occur in some years causing steady flows, and some flows originate from springs (e.g. upper Dawson, Nogoa Rivers and Carnarvon and Mimosa Creeks) or from alluvial reserves (Jones and Moss, 2011). The rivers of the Fitzroy Basin are heavily modified, with 28 dams and weirs across the basin designed to provide water security for agriculture, mines, industries and communities despite high seasonal variability (FBA, 2008). These dams and weirs also play a role in regulating flows. The last water storage before the Fitzroy River delta is a barrage 56 km upstream of the delta which was constructed in 1970, halving the length of the river's estuary tidal extent (Connell et al., 1981).

The Fitzroy River estuary is shallow and tide-dominated with extensive intertidal flats, intertidal salt flats and tidal sand banks (Eberhard, 2012). Its delta is a vast floodplain of channel habitats, extensive salt flats and low mud islands, with landward habitats of mangrove forests, salt marsh wetlands and coastal grass-sedge wetlands. Keppel Bay includes the 15 islands of the Keppel Bay Islands National Park and the Keppel Bay Islands National Park (Scientific) as well as Great Keppel Island outside of the National Park. The islands are surrounded by fringing reefs.

3.1 Climate and flooding of the Fitzroy system

The Fitzroy Basin lies within the dry tropics of Central Queensland and as such, the climate is highly variable. Heavy rainfall is usually restricted to the summer months, generated by tropical cyclones and monsoonal depressions, as well as isolated thermal storms in parts of the catchment (Cobon and Toombs, 2007, Packett *et al.*, 2009). The short wet seasons are normally followed by long dry seasons, and during drought years dry conditions can continue for several years. During these dry periods many of the rivers in the basin have very low flow and in areas may dry altogether (Cobon and Toombs, 2007). This characteristic of the basin makes the continuing presence of drought refugia a key survival requirement for aquatic biota. There are a range of environments within the catchment including higher-rainfall areas near the coast and semi-arid environments inland.

Figure 3.1: Map of the Fitzroy Basin and other FBA Region basins with detail of direction of water flow (Source: FBA website: http://www.fba.org.au)

Extreme droughts are more likely during El Nino periods of the El Nino-Southern Oscillation (ENSO). The influence of ENSO and the Pacific Decadal Oscillation (PDO) on annual rainfall in the Fitzroy Basin between 1885 and 2007 is clear: among 34 El Niño years, 28 have had below-median rainfall (82% probability); during 28 La Niña years, 21 years had above-median rainfall (75% probability); during 63 ENSO-Neutral years, the chance of above or below median rainfall was nearly equal; and extreme wet evens are more likely during La Niña dominant years in 'Cool' PDO phases (Zhang *et al.*, 2008).

The Fitzroy River catchment is well known to produce major flooding after heavy rain events (BOM, 2011). The first accounts of flooding of the Fitzroy River are from pre-European times when Darumbal people report that monster floods would at times be "spear deep" in the area which would later become Rockhampton's main street (Webster, 2012). The highest recorded flood in January 1918 reached 10.11 m on the Rockhampton city flood gauge (Figure 3.2). This and subsequent flood events, including a 9.3 m flood in January 1991 and the recent 9.2 m flood in December 2010/ January 2011 are described in Table 3.1 (BOM, 2011). It should be noted that high flows may occur in the Fitzroy Basin outside of flood events, as occurred during 2010/2011 (Jones and Moss, 2011).

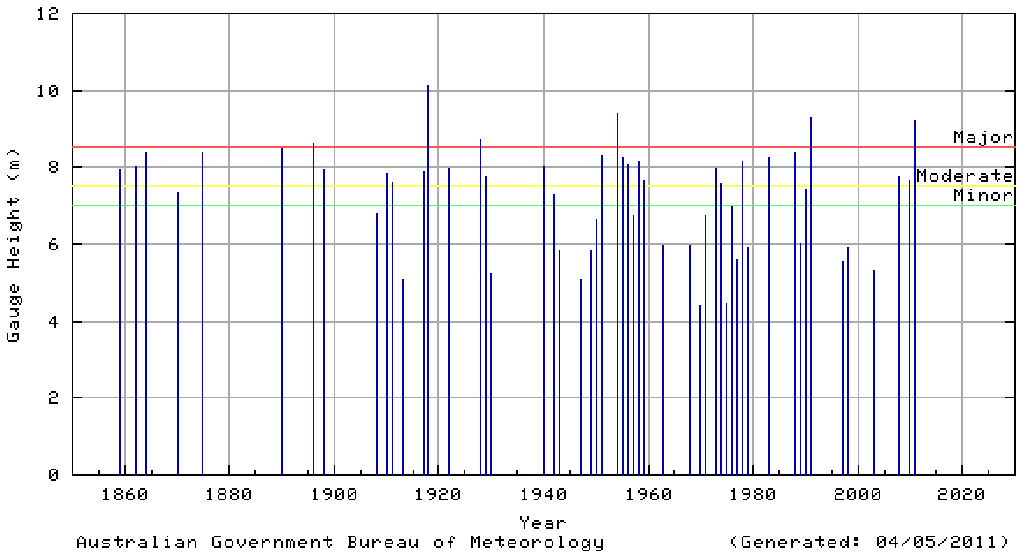

Figure 3.2: Flood records from the Fitzroy River – highest annual flood peaks (source: BOM, 2011).

Floods occur naturally and provide many beneficial functions to aquatic ecosystems, however they also have negative impacts which may be more extensive in ecosystems which have been significantly altered, making them less resilient to perturbations or disturbances. Little published information is available on the specific effects of flooding in the Fitzroy on freshwater ecosystems (Hart, 2008). However flooding has obvious impacts on these environments which have been described in other systems. Impacts include an increase in terrestrial runoff which may be high in suspended sediments and nutrients, and contaminated with substances such as pesticides, herbicides, heavy metals and ions. The physical force of floods influences aquatic plant communities, batters and sweeps small bodied animals such as macroinvertebrates and small fishes downstream. Fish and their eggs and larvae may be stranded as flood waters recede, exotic fish species may be spread to new locations by the movement of floodwaters, and the erosion of river banks causes damage to riparian zones and may impact negatively upon freshwater turtles such as the Fitzroy River turtle. When the Fitzroy floods the negative impacts extend from the affected freshwater catchment areas into the Fitzroy River estuary and surrounding marine waters (Hart, 2008).

The Fitzroy River's flood plume extends over a wide area of Keppel Bay and east across the Capricorn Bunker group. Salinity and temperature are recognised limiting factors for the growth and survival of corals (Berkelmans *et al.* 2012) and significant coral mortality has been recorded following flood events including the January 1991 flood (Taylor *et al.*, 2002) and across the GBR during the 2010/11 flood (Berkelmans *et al.* 2012). During the 1991 flood the freshwater outflow and associated sediments had a major impact on fringing reefs on the southern and western sides of the Keppel Islands, with 90% coral mortality across many of these reefs (ANZECC and ARMCANZ, 2000). Comparatively little mortality (30%) was experienced on the eastern sides of affected islands while coral communities in deeper water and offshore were also largely unaffected (Byron and O'Neill, 1992). The 2010/11 flood resulted in almost complete coral mortality on south-facing reefs in the central Keppel Islands with low mortality (< 5 %) on north-facing reefs and those further away from the Fitzroy delta (Berkelmans *et al.* 2012). Flood events may also transport high sediment loads, nutrients and contaminants such as herbicides that increase the risk of damage to marine ecosystems such as coral reefs (Kennedy *et al.*, 2012).

The 1991 flood also subjected intertidal invertebrate communities including barnacles, oysters and gastropods along the Capricorn Coast to high mortality rates, with less severe mortality on the offshore Keppel Bay islands (Coates, 1992). Short term changes to fish communities as measured by fishery-dependent studies (catch rates) were recorded following the 1991 flood. Commercial catches of estuarine species such as barramundi, bream and mullet were 30% lower than before the flood, but recouped within around three months (Byron, 1992). The fishery-dependent nature of this observation means it is confounded by fisher behaviour which may change following a significant flood event. Harvest rates are affected by the amount of floating and submerged debris associated with flood waters. While in 1988 large amounts of debris were reported in Keppel Bay, resulting in reduced catches of prawns and scallops due to net fouling, an increased harvest of these species was reported following the low-debris 1991 flood (Byron, 1992).

The above examples demonstrate the ecological importance of flood events to receiving marine waters. Flooding is a natural primary regulator of fringing reef development and succession in Keppel Bay – however anthropogenic impacts including increased sediment loads are likely to result in lower resilience and greater effects on recruitment and re-establishment on affected reefs (Byron and O'Neill, 1992).

Climate change predictions for the Fitzroy River basin range from slightly higher rainfall to much drier than the historical climate (Cobon and Toombs, 2007). Regional temperature increases and changes to potential evaporation particularly in inland catchments are projected. Such changes will undoubtedly have impacts on ecological health of the Fitzroy Basin, but to date much of the work on likely impacts of climate change that has been carried out in the region has focused on the possible impacts on grazing activities. For example Cobon and Toombs (2007) consider three possible climate change scenarios for the Nogoa catchment in 2030: a dry climate change scenario; an average climate change scenario; and a wet climate change scenario; in order to represent most of the possible ranges of change in average climate for that region and timescale and predict possible impacts on pastures and beef production. There is a need for more research into the potential impacts of climate change on natural systems in the Fitzroy Basin, including freshwater catchment, estuarine and marine environments in order to understand and potentially adapt to or mitigate some of these impacts. This will become increasingly important with the development of an Ecosystem Health Index for the Fitzroy, as climate change impacts upon the resilience of ecosystems and the variability of indicator parameters and so influences health scores.

Table 3.1: Historical flood heights for river height stations in the Fitzroy River

River height station	Jan 1918	Feb 1954	Jan/Feb 1978	May 1983	Jan 1991	Jan 2008	Feb/Mar 2010	Dec 10/ Jan 11
Waitara	-	10.67	11.90	7.35	13.60	11.10	-	-
Cardowan	-	17.37	16.38	9.95	17.10	14.80	13.40	8.00
Connors Junction	-	-	15.98	13.75	17.30	-	-	-
Emerald	-	14.12	12.97	12.00	-	15.36	9.40	16.05
Rolleston	-	-	4.23	5.50	4.60	5.15	5.87	8.54
Yakcam	-	-	23.15	20.12	13.80	20.55	15.80	23.05
Bingegang	-	-	17.23	16.0	12.35	15.80	-	17.45
Tartrus	-	17.48	16.60	14.90	18.10	16.20	11.81	16.34
Taroom	6.71	8.15	4.08	7.46	6.24	6.07	7.26	10.43
Theodore	-	13.64	11.27	13.24	7.98	-	13.45	14.70
Moura	-	-	10.46	12.09	6.60	8.00	12.23	12.66
Karamea	-	10.26	8.10	9.98	9.12	-	9.15	-
Baralaba	-	15.52	11.85	13.60	9.45	-	12.50	15.25
Newlands	-	18.16	16.28	14.63	15.29	9.05	14.70	18.55
Riverslea	31.48	28.60	23.15	22.89	27.97	21.93	15.17	27.38
Yaamba	17.32	16.59	14.75	14.97	16.65	14.25	10.73	16.55
Rockhampton	10.11	9.40	8.15	8.25	9.30	7.50	5.30	9.20

Source: Bureau of Meteorology. All heights are in metres on floodgauges.

3.2 Land use in the Fitzroy Basin

Several documents provide detailed information on land use in the Fitzroy Basin, e.g. Noble et al. (1997), Christensen and Rogers (2004), FBA (2008), Eberhard (2012), and DSITIA (2012). These sources are drawn on to provide a brief background summary of historical, current and potential future land uses in the Fitzroy Basin.

Currently, grazing dominates land use in the Fitzroy Basin at 81% while cropping covers an additional 6% of land area. Across the basin 6% of land is set aside for conservation, 5% is used for forestry, 1% is urban, 0.5% mining and 0.5% irrigation (DSITIA 2012). Agriculture is a major activity in the Fitzroy Basin, involving beef cattle, dryland cropping and irrigation as key sectors (FBA, 2008). Grazing occupies 119,320 km^2 of land (FBA, 2011) and contributes significantly to economic, social and cultural values of the region. The Fitzroy Basin supports almost one quarter of Queensland's cattle production, and around half of the cattle in Great Barrier Reef catchments (FBA, 2008). Cropping and irrigated cropping of fruits, vegetables, cereal grains and cotton also contribute to the basin's agricultural output.

Along with other land uses, the prevalence of grazing in the Fitzroy Basin has necessitated frequent localised clearing, with clearing rates increasing dramatically during the 1960s to 1980s under the Brigalow Development Scheme and associated pastoral developments (Packett et al. 2009). Land was rapidly cleared using heavy machinery, burn-offs, herbicides and blade ploughing (severing tree roots under the soil), primarily to be replaced by improved pastures for cattle production (Seabrook *et al.*, 2006, Packett et al. 2009). Issues of low ground cover within the Fitzroy Basin associated with the grazing industry relate to sediment discharges to the Great Barrier Reef, with significant interest in how to reduce those emissions (Karfs et al. 2009).

A large proportion of the Fitzroy Basin lies above the Permian coal rich Bowen Basin and mining activity is dominated by coal. In 2007/08 about 90% of Queensland's total saleable coal production was derived from Fitzroy Basin mines (DERM, 2009d). In 2011 there were 48 operating coal mines in the Bowen Basin with another 38 coal projects and advanced coal projects in varying stages of planning or preparation (DEEDI, 2012a). While coal mine leases cover only 0.5% of the basin, coal exploration leases are in place across most of the basin (Bent *et al.*, 2009) and coal mining is the Fitzroy Basin's largest asset in terms of production value (FBA, 2008). In addition to coal mining, magnesite is mined at Kunwarara, north of Rockhampton and processed in Rockhampton into calcined magnesia, deadburned magnesia and electrofused magnesia (Christensen and Rogers, 2004). Small scale gem mining (primarily sapphires) occurs west of Emerald on the Gemfields, and semi-precious chrysoprase is mined near Marlborough (Christensen and Rogers, 2004). Limestone and nickel are also mined in the basin as are small amounts of gold, and there are also quarries for sand, gravel, road building materials and railway ballast in the region (Christensen and Rogers, 2004).

Historical gold, copper and silver mining at Mount Morgan has had significant ongoing impacts on the ecology of the Dee River. The Mount Morgan Mine was operational from 1882 until 1981, and mine tailings continued to be processed until 1990. The adjacent Dee River (which flows into the Don River, the Dawson River and finally the Fitzroy River) remains heavily impacted by acid mine drainage. For 18 km downstream of the mine site it is characterised by low pH and high metal concentrations, biota have been heavily affected and fish kills occur with high flow events (Taylor *et al.*, 2002). In 2000 the Mount Morgan Mine Rehabilitation Project commenced, and aims to: reduce the contaminant load leaving the mine site and entering the Dee River; develop sustainable long-term alternatives to acid rock drainage interception and water treatment; and conserve the site's heritage values (Department of Mining and Safety, 2012).

In the near future, land use in the Fitzroy Basin appears likely to include all of the current uses with increased coal mining, coal mining-related activities and potentially coal seam methane gas extraction. Abundant reserves of coal seam gas are feeding the development of a liquefied natural gas (LNG) industry whereby natural gas reserves are converted to LNG for export. The Queensland Government considers that LNG is likely to become one of the state's major exports – a mid-range industry is expected to generate 18,000 jobs, provide over $850 million annually in royalty revenues and increase Gross State Product by over $3 billion (Queensland Government, 2012). If all current projects and proposals for LNG export are developed the state would export 50 million tonnes of LNG per annum ((DEEDI, 2012b)).

In the Fitzroy River estuary and inshore area of Keppel Bay two proposals for coal port developments are currently (January 2013) under State and Commonwealth government consideration. These include the Balaclava Island Coal Expert Terminal proposed by Xstrata Coal Queensland and the Fitzroy Terminal Project proposed by a consortium represented by the Mitchell group. Two further port expansion plans have also been identified by the Gladstone Ports Corporation. All of the projects would involve dredging of the estuary and in addition to development and construction impacts would have ongoing ramifications for the river, estuary and adjacent marine areas. A recent review of issues with the proposed developments in the Fitzroy River estuary highlighted potential impacts on wetland and estuarine ecosystem function, mangrove habitats and beach scrub ecosystems, as well as a variety of fauna (Eberhard, 2012). The two proposed port developments would represent a significant change in land use for the Fitzroy River estuary (Eberhard, 2012) and as such should be given consideration during development of an Ecosystem Health Index for the Fitzroy Basin.

3.3 Condition of the Fitzroy Basin

Much information on the current state of the Fitzroy Basin, Fitzroy River and Keppel Bay is already available in existing documents (e.g. (Christensen and Rogers, 2004, Eberhard, 2012, FBA, 2008, Noble *et al.*, 2005, Noble *et al.*, 1997). A large number of studies on the Fitzroy Estuary and Keppel Bay were also carried out as part of the Cooperative Research Centre for Coastal Zone Estuary and Waterway Management. The technical reports from these studies can be accessed at: http://www.ozcoasts.gov.au/search_data/crc_rpts.jsp.

The size of the Fitzroy Basin and the complexity of waterways are major issues for making an accurate assessment of ecosystem health. Major variations in geography, geology, climate (including rainfall), soils and historical alterations to the landscape make identifying and managing perturbations from the natural state of the environment difficult. Water quality within the Fitzroy Basin is variable as a result of these factors as well as the somewhat unpredictable patterns of flow and runoff (Jones and Moss, 2011). Geology affects the quality of runoff across the Fitzroy Basin with marked effects on water chemistry (Noble et al. 2005).

Ecosystem health in the Fitzroy Basin is also affected by human activities and land use. When considering potential indicators for the assessment of ecosystem health in the Fitzroy Basin it is necessary to understand the drivers within the system including natural influences and the scale of anthropogenic impacts.

The size of the basin and complexity of waterways make accurate assessments of ecosystem health more challenging than in a more homogeneous system. Environmental conditions within the basin are variable as a result of natural variations in geography, geology, climate (including droughts and flooding), soils and the somewhat unpredictable patterns of flow and runoff. Human activities and land use include extensive historical land clearing, a number of barrages and dams, and a range of land uses such as grazing, cropping, irrigated cropping, mining, urbanisation and forestry. Future land use changes with potential impacts on water quality include proposals for increasing agricultural development, more mining operations, coal terminal developments in the Fitzroy River delta and increasing coal seam gas extraction.

Water quality issues within the Fitzroy Basin can be classified into three geographic zones: freshwater, estuary and marine. Within the freshwater zone, substantial variability can be further captured by differentiating the basin into a number of sub-catchments. Classification of the basin into different zones and sub-catchments allows for more appropriate evaluation of indicators against expected conditions, addressing the variability of conditions across the region. It also allows for an environmental health index to be reported by zone and sub-catchment, improving the usefulness of the index.

4.0 Purpose of an Ecosystem Health Index and Report Card for the Fitzroy

4.1 Scope and objectives of an Ecosystem Health Index and Report Card for the Fitzroy

The scope of the FPRH annual report card covers the freshwater catchments of the Fitzroy Basin, the estuary and near-shore marine environment (FPRH, 2011). The report card will aim to assess and aggregate data to provide simple, aggregated results presented as indices to provide an overall score of ecosystem health. The Partnership Monitoring Program Design (Version 8.1) identifies that three main types of information will be reported: "ecological health indices for the freshwaters, estuary and marine environments, summary assessments of threats, and a stewardship index of management responses" (FPRH, 2011). FPRH intends to present the results using a variety of public communication products including the annual report card and a web-based communication tool. FPRH has also proposed the development of a web-accessible data warehouse with appropriate security levels in the longer-term.

The objectives of producing an Ecosystem Health Index and Report Card for the Fitzroy Basin are to:

1. understand ecosystem health of waterways in the freshwater catchments, estuarine and marine environments in the Fitzroy Basin, its delta and Keppel Bay;
2. identify changes in ecosystem health taking into account natural variations;
3. synthesise complex data at a regional scale into easily interpretable scores;
4. provide information on ecosystem health in the Fitzroy Basin which is accessible and interpretable by government, stakeholders and the community;
5. provide information which can be used to advise policy makers on areas of declining ecosystem health, in order to drive management change; and
6. assess ecosystem health within a causal framework that helps to link management responses to current and future changes in condition.

This report deals only with the technical aspects of measuring and communicating ecosystem health and not with any management actions that may result. Threats, management responses and stewardship are being addressed and reported on by the FPRH through a separate process. The focus of the report card is to assess the current condition (or State) of the relevant ecosystems in the Fitzroy, with comparisons over time used to identify changes in condition.

4.2 Framework underpinning an Ecosystem Health Index

Ideally, an assessment of ecosystem health should be set within a contextual framework that links ecological systems with pressures and changes in a systematic way. Not all ecosystem health indices are based on a formal framework; in some cases the indicators that form the basis of an index may be chosen by expert consensus or by other informal processes, such as using historical practices as a basis for selection. However, the use of an established framework for selection increases transparency, promotes public confidence, and clarifies the interpretation and validation of information provided by indicators (Niemeijer and de Groot, 2008).

Some commonly used causal chain frameworks for selecting indicators are the Pressure-State-Response (PSR) framework, the Pressure-State-Response/Effects framework, the Driving force-State-Response (DSR) framework, the Driving force-Pressure-State-Impact-Response (DPSIR) framework and the enhanced Driving force-Pressure-State-Impact-Response framework (a causal network rather than causal chain framework). These conceptual frameworks help to “focus and clarify what to measure, what to expect from measurement and what kinds of indicators to use” (DESA, 2007), as well as making linkages and management responses more explicit. Details on these frameworks are provided in Appendix I.

Each causal chain/network framework has advantages and disadvantages and could be used for the required purpose. Given the large size of the Fitzroy Basin, the complexity of interacting pressures and most importantly the limited data currently available on which to base indicator selection, a causal chain rather than causal network approach to developing an index is recommended as the most appropriate at this time[1]. It is noted that a Pressure-Stressor-Response framework was used in the FPRH Monitoring Program Design (v8.1) (FPRH, 2011) and also by the Queensland Government in the Queensland Integrated Waterways Monitoring Framework. Pressures, Stressors and Responses were identified in that document for each of the three monitoring programs it describes (Catchment, Estuary and Marine, Threats and Management Response) (DERM, 2010).

While commonly used, the PSR causal chain framework and similar DSR framework are constrained by their simplicity. Instead, the more comprehensive DPSIR approach is proposed as a suitable conceptual framework. This framework describes the relationship between society in the environment by extending the Organisation for Economic Co-operation and Development’s (OECD) PSR framework. The DPSIR framework (Figures 4.1 and 4.2) was adopted by the EEA in the late 1990s, and is the basis of most indicator sets that are currently used by national and international bodies (EEA, 1999) and for Australian State of the Environment reporting (SoE, 2011).

[1] An alternative causal network method would require a thorough understanding of the ecosystem and all of its characteristics and interactions. Until further research in the Fitzroy Basin can adequately satisfy existing knowledge gaps a causal chain approach is more suitable for meaningful application.

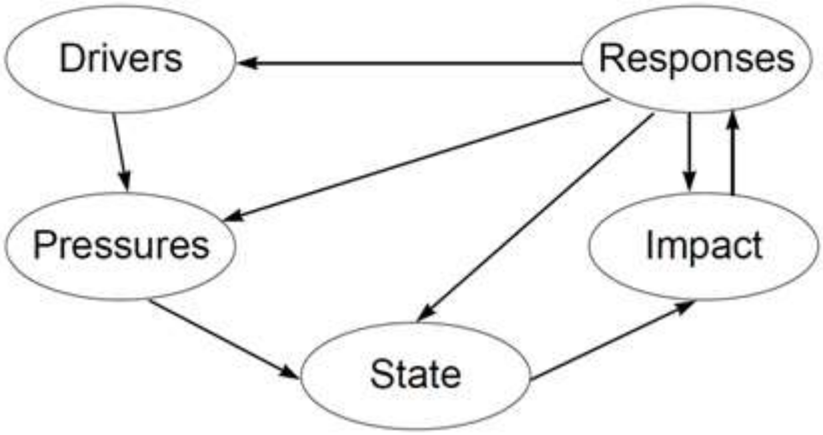

Figure 4-1: The DPSIR framework (source: EEA, 1999)

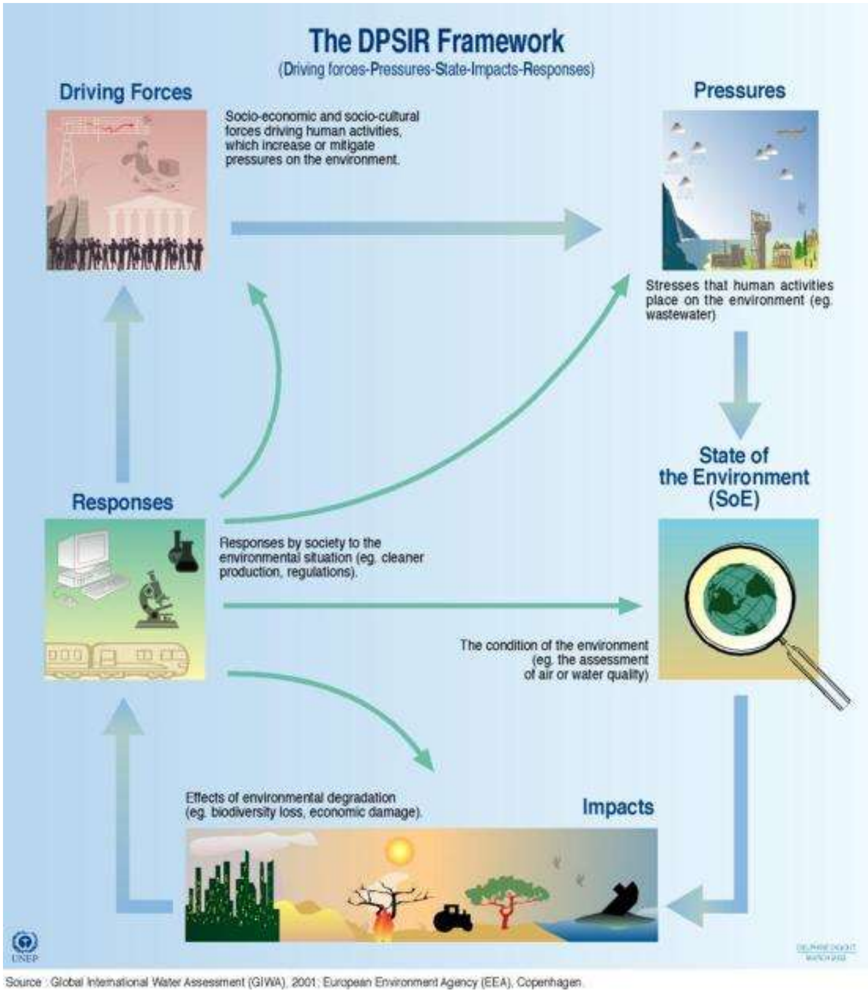

Figure 4.2: The DPSIR framework for State of Environment Reporting (Delphine Digout, UNEP/GRID-Adrenal. http://www.grida.no/graphicslib/detail/dpsir-framework-for-state-of-environment-reporting_379f#**)**

4.3 Applying the DPSIR framework to the Fitzroy Basin

The DPSIR framework has been applied to ecosystem health in the Fitzroy Basin using 'State' as the central point for defining indicators (Figure 4.3). The direction of the thick arrows indicates the flow from driving forces through to responses, and responses may influence indicators at any level as illustrated by the thin arrows. Indicators are necessarily broad for inclusion in the DPSIR framework, and are elaborated upon further in the second volume of this report. Some indicators may equally be described by more than one of the five DPSIR categories. For simplicity, duplication of indicators has been reduced within the framework diagram by describing indicators as broadly as possible.

Driving Forces in the Fitzroy Basin, as in many developed areas, are largely economic and social with environmental influences such as weather/climate and land and water availability. Major driving forces for current land uses are included; many of these affect all or most land uses sectors in the Fitzroy Basin and some driving forces influence and interact with others.

Pressures in the Fitzroy Basin include mostly anthropogenic activities and events that have occurred in the past or are currently occurring. They include emissions, physical and biological agents, land use and resource use. Some major pressures include the direct effects of climate change, extent and intensity of land uses, flows, introduced and pest species and development activities.

State indicators include descriptions of the quantity and quality of the environment, for example through physical, chemical and biological phenomena. These may result from natural or anthropogenic impacts, and include water quantity and quality, habitats, in-stream connectivity and groundwater indicators.

Impact indicators are caused by changes in the state of the environment. Impacts typically interact significantly and one impact may directly or indirectly result in the manifestation of another. Impacts of particular note in the Fitzroy Basin include changes to biotic communities and individual health of aquatic animals, changes in extent or health of habitat areas and prevalence of pathogens and cyanobacteria.

Responses by government and society attempt to prevent, compensate, ameliorate or adapt to changes in the state of the environment. Society may respond to changes in the state of the environment in various ways. Some responses may include regulatory or legislative changes, voluntary/stewardship measures, improved information and rehabilitation activities. Responses may in some situations also be or cause driving forces or pressures. For example reducing grazing or mining activities in sensitive ecological areas may displace these activities to other habitats, causing a pressure on that habitat which then results in a change to its state and impacts on localised ecosystems.

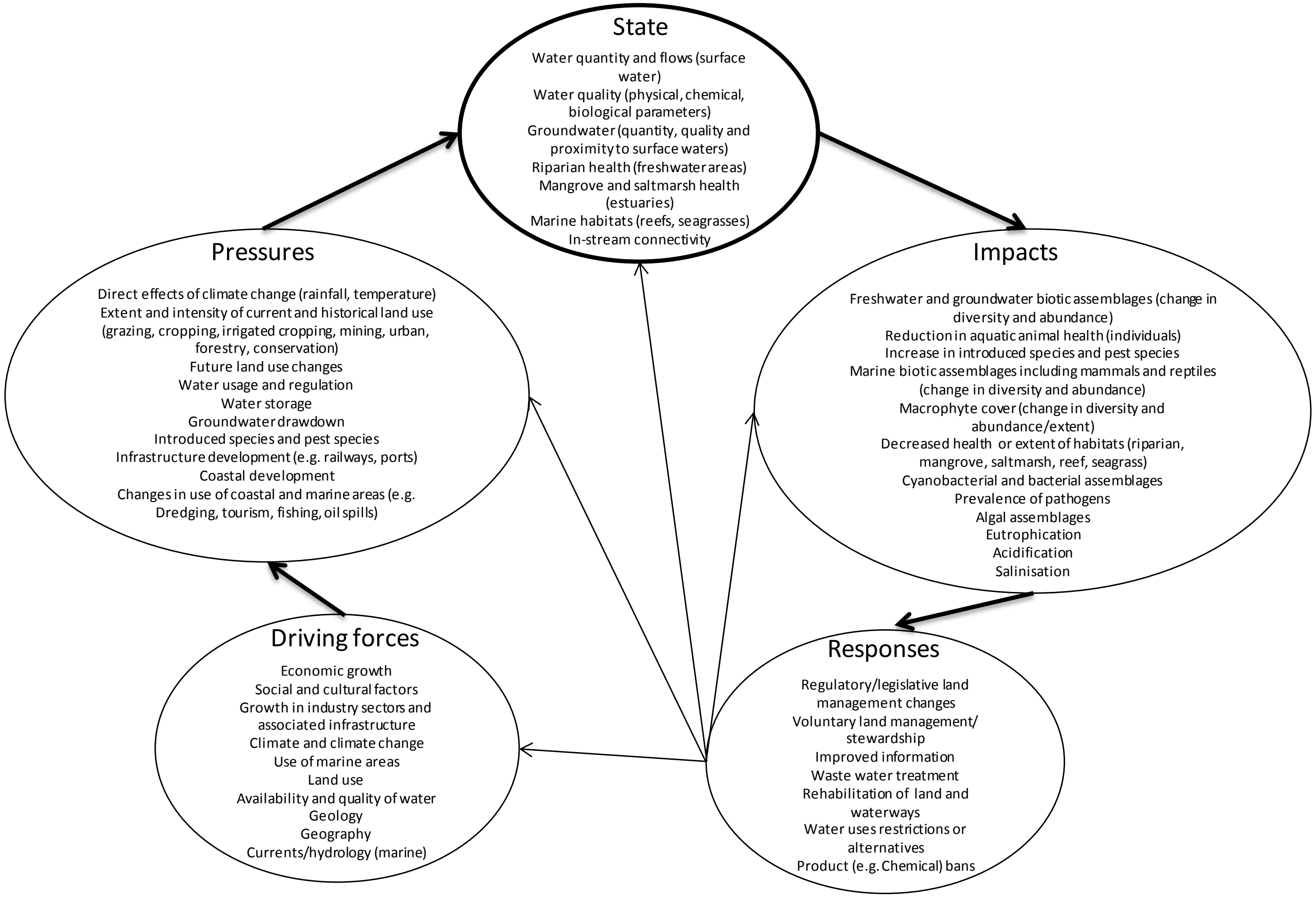

Figure 4.3: DPSIR framework for ecosystem health in the Fitzroy Basin. Thick arrows indicate the flow from driving forces through to responses, and responses may influence indicators at any level as illustrated by thin arrows.

5.0 Review of Water Quality Guidelines, Ecosystem Health Indices and Monitoring Programs

This section provides a brief summary of some of the ecosystem health monitoring programs that are being run in the Fitzroy Basin and elsewhere. The aim of this section is to provide information about the type of parameters that is considered important to collect in monitoring programs, so that the key categories can be defined for use in an Ecosystem Health Index for the Fitzroy Basin.

The Fitzroy Basin and its estuarine and marine ecosystems are currently monitored by a number of resource and agricultural industries, government agencies, universities, community groups, natural resource management bodies and private businesses. Additionally there are a number of ecosystem health monitoring programs in Queensland, Australia and internationally which may be useful to consider when deciding upon appropriate indicators to assess the ecological health of the Fitzroy. A number of these programs, the parameters they monitor and any notable outcomes or limitations are reviewed below.

There are also a range of legislative and other regulatory mechanisms that are relevant to ecosystem health and species protection in the Fitzroy. For convenience, these are summarised in Appendix II.

5.1. Fitzroy Freshwater Catchment Programs

- Environmental Flows Assessment Program (EFAP)

The Environmental Flows Assessment Program (known as 'EFAP' since 2007) commenced in 2005. EFAP assesses the performance of Water Resource Plans (WRP) and Resource Operations Plans across Queensland, including the Fitzroy Basin.

The purpose of EFAP is to identify whether critical ecosystem water requirements are being met and whether ecological outcomes within WRPs are probable based on current flow management practices. EFAP can be used to determine risks to ecological assets and to build on scientific knowledge that shapes water management practices (DERM, 2009a).

Queensland Department of Environment and Heritage Protection (EHP) oversees EFAP, and a number of research organisations and government groups have collaborated in the past. Due to the program's objectives being hypothesis-based, the indicators that are measured and the frequency of monitoring are variable. Results of EFAP monitoring can be found in EFAP summary reports, Queensland water resource plan annual reports, and some scientific papers.

- Groundwater Ambient Network

The Ground Water Ambient Network (GWAN) consists of 367 bores across Queensland including the Fitzroy Basin. Annual and some continuous water quality measurements are taken from these and used by the Queensland Government to assess and manage sustainable ecological outcomes. The parameters measured are: conductivity, pH at degrees C, temperature, total hardness, temporary hardness, alkalinity, residual alkalinity, silica, total dissolved ions, total dissolved solids, true colour and turbidity. Ratios determined are: pH sat, saturation index, mole ratio, sodium absorption ratio, figure of merit ratio, as well as sodium, potassium, calcium and magnesium cations. Calculated results include: hydrogen, bicarbonate, carbonate and hydroxide as well as chloride, fluoride, nitrate and sulphate anions. Other dissolved elements measured as part of GWAN are: iron, manganese, zinc, aluminium, boron and copper (DERM, 2012a).

GWAN data is used to assess the condition and trend of groundwater quality, including the monitoring of saltwater intrusion and suitability of water for town or irrigation purposes. GWAN results are reported as part of the State of the Environment Reports and are commonly used as baseline data for mining, development and coal seam gas operations (DERM, 2012a) .

- Ground Water Level Network

The Ground Water Level Network (GLN) consists of 5772 bores across Queensland, including the Fitzroy basin. The water levels of bores may be measured, monthly, bi-monthly or quarterly depending requirements. 95 of the GLN bores are constantly monitored and many of these have the capacity to produce near-real-time data through the use of a web server and remote telemetry. The objectives of the GLN are to assist water resource planning and to assist the Great Artesian Basin Sustainability Initiative. Queensland Government groundwater level records date back to 1800 (DEHP, 2012).

- Stream Gauging Station Network

The Queensland Government uses 400 stream gauging stations across Queensland, including the Fitzroy Basin, to measure river height and stream flow. In addition to those measurements, some sites within the Stream Gauging Station Network also take continuous in-situ water quality readings such as temperature and conductivity. This data is used to monitor water quantity, condition and to some extent the trend of water quality. The stream gauging network can aid management decisions such as water harvesting. It is used to model catchment hydrology and support flood warnings via the Bureau of Meteorology.

Further information on Queensland Government water resource monitoring can be found at: *http://watermonitoring.derm.qld.gov.au/host.htm*

- Ambient Biological Monitoring and Assessment Program

Following on from the 1994 National Monitoring River Health Initiative program and the 1997 First National Assessment of River Health program; from 2001 - 2008 the Department of Natural Resources and Water ran an Ambient Biological Monitoring and Assessment Program (ABMAP). This was a broad scale program that used aquatic macroinvertebrate indicators to assess the ecological condition of Queensland waterways and to identify possible high-risk areas. The ABMAP did not place emphasis on determining the underlying cause of observed effects.

The macroinvertebrate indicators that were used were: taxa richness, PET taxa richness, SIGNAL index, percentage of sensitive taxa, percentage of tolerant taxa. Some water quality variables such as pH, DO, temperature, EC, turbidity, alkalinity, nutrients and ions were measured by ABMP. These variables were not used indicators of ecosystem health; rather, they were measured to assist other projects such as the SWAN program (see below), and also to aid interpretation of the macroinvertebrate results (DNRW, 2008).

- Surface Water Ambient Water Quality Network

The Surface Water Ambient Water Quality Network (SWAN) monitors some of the physical and chemical parameters of surface freshwater quality. It was first implemented in 1991 in the Condamine Balonne region before being expanded Queensland-wide. The program has been redefined several times, but since 2010, in keeping with the implementation of a new state-wide program (see SEAP below), the main objective has been to '... provide information for planning purposes by regularly measuring and keeping publically available records of the volume and quality of water in Queensland', as defined in Part 3 of the Queensland *Water Act 2000* (DERM, 2012b).

Presently there are 416 surface water gauging stations across Queensland. After a review in 2009, these stations were given a primary, secondary, tertiary or 'not required rating' in relation to their importance within the network. There are now 196 SWAN sites and approximately 40 of these are within the Fitzroy Basin. Water samples may be collected from these stations to test for major ions and total and speciated nutrients. In-situ readings taken at these sites may include: conductivity, temperature, pH, turbidity, DO and total alkalinity. Additionally, time series results (from loggers left permanently at these sites) may include: river height, conductivity, temperature, pH and turbidity (although turbidity is not actually included in the SWAN time series monitoring itself). In 2011 a SWAN condition assessment was produced for the Central Province (see Figure 8.3). Four key indicators (conductivity, total nitrogen, total phosphorus and turbidity) were assessed at sites within the province and given a colour code of green – healthy or slightly impacted; yellow – uncertain; red – impacted and in need of management action. Trend analysis of the Central Province during the period from 1998 -2008 was also conducted.

- Stream and Estuary Assessment Program

The Stream and Estuary Assessment Program (SEAP) is a Queensland-wide integrated monitoring and assessment program that was designed to combine and improve existing monitoring methodology. Through SEAP, the Queensland Government draws upon national initiatives such as the Monitoring River Health Initiative and the National River Health Program. It also brings together Queensland-based programs such as SWAN and the former ABMAP.

The objectives of SEAP are to report on the condition of provincial aquatic ecosystems (including any trends over time), and to identify the risks to these ecosystems. This is in turn intended to aid government natural resource management decisions. SEAP analysis utilises a cause and effect framework. Through SEAP it is hoped that further understanding of aquatic ecosystem processes will be gained (Negus *et al.*, 2011a).

Because SEAP monitors two distinct geographical and functioning ecosystem types (estuarine and riverine), total integration of the assessment methodology is not possible. However, a simplified general pressure-stressor-ecosystem response model is used to identify ecologically important indicators within these systems (Negus *et al.*, 2011b).

Sampling is conducted in nine freshwater biogeographic provinces (FBP) across Queensland: Central, Eastern Cape, Jardine, Lake Eyre and Bulloo, Murray-Darling, South-East, Western Cape and Gulf, Wallum and Wet Tropics (DEHP, 2012). The structural patterns of aquatic macroinvertabrates and fish are known to reflect patterns in ecosystem function, and they were used to define these biogeographic provinces (Water Planning Ecology, 2011).

The Central FBP is largely formed by the Burdekin and Fitzroy drainage basins to the west. Coastal drainage basins to the east include the Ross, Haughton, Don, Proserpine, O'Connell, Pioneer, Plane, Styx, Shoalwater, Waterpark, Curtis Island, Calliope, and Boyne (DEHP, 2012). One FBP is monitored per year and the indicators monitored vary according to the province.

As mentioned previously, a Central Province SWAN water quality assessment was made for the 2004-2008 period. The Central Province was also subjected to a SEAP assessment for the same period. The results of the two assessments differed, and as such SEAP has been redefined to include additional data from other notable monitoring programs. This allows the inclusion of additional sites within a province through increased sample numbers of the individual parameters (Water Planning Ecology, 2011).

- Other freshwater catchment monitoring in the Fitzroy Basin

The water quality of authorised mine-affected water releases in to the rivers of the Fitzroy basin, as well as accidental discharges during high rainfall or flood events, are monitored and reported to the Queensland Government. Publicly available updates of this monitoring can be found on the Fitzroy River website (http://www.fitzroyriver.qld.gov.au/waterquality/water-releases.html).

Regular water quality monitoring within the Fitzroy Basin also occurs to determine compliance of environmental licences and to meet developmental approval conditions set out by Environmental Authorities (for example the Receiving Environment Monitoring Programs (REMP)). This monitoring typically includes the measurement of physical and chemical parameters of water quality and to a lesser extent the measurement of biological indicators, such as macroinvertabrates, algae and fish.

Some companies known to conduct private monitoring programs include: Stanwell power plant, Yancoal, Xstrata, Rio Tinto, Peabody, Jellinbah, BMA, Anglo American, Sojitz, Santos, Vale, Wesfarmers, RRC, CHRC, Idemitsu, Origin, IsaacPlains Coal, New Hope Coal and Sunwater.

The Dee River, which is part of the Dawson River Catchment within the Fitzroy Basin has historical metal mining pollution issues and as such has been monitored by the FBA, Queensland Government departments and CQUniversity (see section 4.3).

- Fitzroy Priority Neighbourhood Catchments Water Quality Monitoring Program

Since 2005 monitoring of total nitrogen, total phosphorus, suspended solids, salinity, turbidity and pH has been undertaken by landholders contracted to take samples from strategic locations within the Fitzroy Basin neighbourhood catchment. Results of this monitoring provide a basis for FBA to: review water quality requirements; refine water quality models used to set water quality targets; collect baseline water quality data at a neighbourhood catchment scale (300-2000 km^2); and to involve landholders and stakeholders to bring about management change at the neighbourhood catchment scale (DEHP, 2012).

5.2 Fitzroy Estuarine and Marine Programs

- Central Queensland Ambient Estuary Program

Ten estuaries and inshore coastal areas from Tin Can Inlet to the Fitzroy Estuary are monitored monthly by the Queensland Government for conductivity, temperature, dissolved oxygen concentration, turbidity, clarity, pH, nutrients and chlorophyll-a concentration. This monitoring began in 1993 and is subject to ongoing review. The program provides information on indicator trends and site conditions that may then be used for State of the Environment reporting; as baseline data for EIS or licensing requirements; or as reference data for Water Quality Guidelines (WQG) (DEHP, 2012).

- Reef Water Quality Protection Plan (Reef Plan), Paddock to Reef Integrated Monitoring, Modelling and Reporting Program and the Reef Rescue Marine Monitoring Program

Reef Plan is the major water quality program relevant to marine waters in the Fitzroy. It is designed to improve water quality in the Great Barrier Reef by improving land management practices in reef catchments, including the Fitzroy Region. Reef Plan, a joint initiative of the Australian and Queensland Governments was first introduced in 2003, and was renewed in 2009. The two primary goals of Reef Plan are to halt and reverse the decline in water quality entering the reef by 2013, and to ensure that by 2020 the quality of water entering the Reef from adjacent catchments has no detrimental impact on the health and resilience of the reef.

A marine monitoring program was set up as part of Reef Plan, however, since 2008 it has fallen under the ‘Caring for our country’ government initiative and is now known as the Reef Rescue Marine Monitoring Program (MMP). The MMP has two main components: Inshore biological modelling which monitors inshore coral reef, intertidal seagrasses and light interactions; and water quality monitoring which deals with inshore marine, flood plume and some river water quality monitoring, as well as remote sensing of Great Barrier Reef water quality.

The physical and chemical parameters that are routinely monitored by the MMP and for which guideline trigger values have been derived are: water clarity (Secchi depth), chlorophyll-a (as a proxy for dissolved inorganic nitrogen), suspended solids, particulate nitrogen, particulate phosphorus, sedimentation, temperature, several pesticides and one biocide (Johnson, 2011).

Biological monitoring of the inshore GBR includes the determination of coral reef community status, through measurement of coral cover, macroalgae cover, juvenile hard coral density and settlement of coral spat. Seagrass environment status is determined through light availability (seagrass tissue C:N ratio), nutrient status (seagrass tissue N:P and C:P ratios, and epiphyte abundance). Seagrass community status (abundance and reproduction) is also monitored (Johnson, 2011).

The output of the MMP is a report card, excerpts of which are shown in Figures 8.10 to 8.13.

5.3 Other Ecosystem Monitoring Programs

In addition to those programs covered in the Fitzroy Monitoring sections of this review (5.3.1 and 5.3.2), there are some other Queensland, national and international programs that maybe relevant to the Fitzroy Basin. Further detail of these can be found in Appendix III. Four Queensland programs of particular relevance to the Fitzroy are the Mackay Whitsunday Integrated Monitoring Program, PCIMP, the South East Queensland EHMP, and the Queensland trials of the Framework Assessment for River and Wetland Health. As such, these are described below, rather than appended.

- Mackay Whitsunday Healthy Waterways Integrated Monitoring Program

In 2002, as result of the first *Healthy Waterways Forum,* the Mackay Whitsunday Healthy Waterways Integrated Monitoring Program was established. Under this initiative the Queensland Government, through funding from Reef Catchments Mackay Whitsundays Incorporated, ran three monitoring sub programs, the results of which were used to determine water quality targets and objectives for the 2008 Mackay Whitsunday Water Quality Improvement Plan (WQIP). The sub programs were:

  - The community ambient volunteer network

Trained community volunteers measured in-situ water temperature, pH, dissolved oxygen, conductivity, filterable reactive phosphorus and water clarity. Monitoring of 40 sites was performed monthly, usually at the same time of day each time, and within watercourses of varying size and surrounding land use (DERM, 2009b, DNRW, 2008). Median, minimum, maximum, 20^{th} and 80^{th} percentile calculations were performed on the data; then comparisons to guidelines, upstream and downstream sites, and known land uses were made (DNRW, 2008). Results were used to assist development of the Mackay-Whitsunday WQIP (DERM, 2009b).

  - Regional baseline water quality

Between July 2006 and June 2008, the Department of Natural Resources and Water conducted monthly monitoring of 13 reference sites within the Mackay-Whitsunday region. A number of in-situ parameters were measured and additional sediment, nutrient and herbicide samples were taken and for laboratory analysis (DNRW, 2008).

The program objectives were to develop ambient water quality guidelines for fresh water in the Mackay Whitsunday region and to provide input into the WQIP (DERM, 2009b).

- Regional flood plume and event monitoring

This project was designed to determine the water quality within end of catchment sites by measuring sediment, nutrient and herbicide concentrations. Correlations between land use and water quality were examined. The major land uses of the region include sugar cane farming, grazing, forestry and urban development.

The program also monitored flood plumes and resultant sediment, nutrient and herbicide discharge into the near-coastal Great Barrier Reef Lagoon. The monitoring data was used to establish the Mackay-Whitsunday WQIP (DERM, 2009b).

- Port Curtis Integrated Monitoring Program (PCIMP)

PCIMP is designed to assess marine water quality, ecosystems and trends within the Port Curtis region. This program is intended to raise public awareness and understanding of local water quality management issues, and to inform stakeholders of suitable management practices, if required.

PCIMP, a consortium of 17 industry, government, research and stakeholder members, has been in operation since 2001 and monitoring is ongoing. More than 170 sites spanning from the Narrows to Colosseum Inlet and Seal Rocks are assessed. Intertidal sites and seagrass meadows are also part of the Port Curtis monitoring program.

PCIMP is currently under review. However the physical and chemical water quality parameters analysed through PCIMP up until 2011 included: pH, dissolved oxygen, temperature, specific electrical conductivity, turbidity, light attenuation (Kd or euphotic depth), total suspended solids, nutrients (ammonia, total N, TKN, nitrate, nitrite, phosphorus, orthophosphate), metals (17 total, 10 DGT-liable, 17 oyster accumulation). Biological indicators within water column included: chlorophyll-a, macroalgal abundance and diversity on settlement nets. Intertidal sediment, mangroves, intertidal invertebrates and seagrasses were also monitored as part of PCIMP.

PCIMP historically conducted water quality assessments annually and intertidal monitoring every three years (last conducted in 2009). Seagrass meadows throughout Port Curtis and Rodds Bay are annually monitored by divers and through aerial surveys. Additional PCIMP seagrass monitoring is undertaken continually on three specific meadows (DEHP, 2012).

The results of the monitoring program are presented as the Port Curtis Ecosystem Health Report Card (EcoCard). The latest EcoCard pertains to July 2008 – November 2010 monitoring.

- Ecosystem Health Monitoring Program

Through *Healthy Waterways,* the Queensland Government, universities and CSIRO, manage the South East Queensland (SEQ) Ecosystem Health Monitoring Program (EHMP). The EHMP measures particular biological, physical and chemical indicators that allow an assessment of ambient ecosystem health and the response of aquatic ecosystems to human activities and natural processes to be made. Smith and Storey (2001) identified five key categories of healthy freshwater systems in SEQ, those being: 1) Physical and Chemical, 2) Nutrient Cycling, 3) Ecosystem Processes, 4) Aquatic Macroinvertebrates and 5) Fish.

The EHMP covers 19 major catchments, 18 river estuaries and Moreton Bay. This includes 135 freshwater sites that are monitored biannually in spring and autumn and 254 estuarine and marine sites that have monthly monitoring (Healthy Waterways, 2012).

Results of the program are standardised to provide a single score for both seasons and all indicators within a catchment (Bunn *et al.*, 2010). This analysis is conveyed to the public in the form of a report card, where catchments are awarded scores ranging from A-F depending on their similarity to ecosystem health guidelines or worst case scenarios.

The methodology of these summary scores is quite detailed and involves transforming the value of each index for each site into a score that is standardised for natural and spatial variation across streams with different physical conditions. It also accounts for differences in the scale of measurement across indices (EHMP). The calculation of scores also involves comparison to ecosystem health guidelines and worst case scenarios.

The EHMP can be sub-divided into Freshwater, Estuarine and Marine and Event Based monitoring. The Freshwater program began in 2002 and is ongoing. The parameters monitored included diel temperature, diel dissolved oxygen concentration, conductivity and pH. Nutrient cycling, ecosystem processes (e.g. benthic respiration and production), aquatic macroinvertebrates and fish are also monitored (DEHP, 2012).

The Estuarine and Marine program began in 2001 and is ongoing. The indicators monitored for water quality include: turbidity, conductivity, temperature, clarity, dissolved oxygen, pH, nitrogen, phosphorus and chlorophyll-a. Sewage plume is mapped annually through this program using N15 uptake in macroalage. Other biological indicators that are monitored (on smaller subsets of the 254 marine sites) include: *Lyngbya* (variable monitoring), coral (5 sites, annually), seagrass (18 sites, depth –biannually; distribution -triennially) and riparian habitat (biennially) (DEHP, 2012).

Event Based Monitoring started in June 2006 and is ongoing subject to annual renewals. The event based monitoring has additional objectives to the Freshwater and Estuarine and Marine programs, as it is mainly undertaken during storm events and is designed to monitor non-urban diffuse pollution. There are 29 end of catchment gauging stations within the program that are intended to gather data over 30 years, and ten mini gauging stations in small catchments or single land use areas. Continuous loggers measure stream height. Monthly water quality sampling occurs during baseflow; monitoring during high flow events occurs as required. The indicators monitored at each site differ, but may include: discharge, total nitrogen, total phosphorus, oxidised nitrogen, total dissolved nitrogen, ammonium nitrogen, dissolved organic nitrogen, total dissolved phosphorus, dissolved organic phosphorus, filterable reactive phosphorus and suspended sediment and particle size analysis. This data may then be used for third party catchment modelling and other cross-organisational partnership activities (DEHP, 2012).

The EHMP was recently reviewed (Fisk, 2010)and the following areas for improvement were identified:

- A lack of emphasis on sub-catchment ecosystem health changes
- 10 year old sampling and monitoring processes
- Potentially unaccounted climate and rainfall influences on annual report card grades
- Inability to attribute 'cause and effect' / management actions
- Infrequent pattern and trend analysis and interpretation of data
- A perceived lack of integration with local monitoring activities
- A failure to address human health risk issues

Overall, Fisk (2010) found that: 'A range of additional monitoring components are needed in order to separate out the effects of anthropogenic drivers and pressures, the effect of climate variability such as rainfall and drought on waterway health and developing and sharing monitoring information that assesses the effectiveness of management actions'.

Since 2010 the results of all three EHMP programs, along with models, management actions, South East Queensland (SEQ) water results, Bureau of Meteorology data, and other land use and database information has been combined through one web portal *Health-e-waterways*. This portal displays EHMP results by location and provides further detail on their annual score. A bar-chart overview of how the five categories (or indicators as they refer to them), compare to the previous year is given. Ecosystem health 'EcoH' plots that show the five categories as segments of a pentagon individually graded by colour (relative to their indexed score) are provided. The individual box and whisker plots of each parameter within the five categories are also provided on the portal.

- Framework for the Assessment of River and Wetland Health

As part of the Australian Government *Raising National Water Standards* 2005 program, the Framework for the Assessment of River and Wetland Health (FARWH) was developed. This framework was designed to allow the national comparison of state and territory river and wetland health.

The FARWH set-up drew upon established monitoring programs, including the Queensland Wetlands Program, the Sustainable Rivers Audit, the Victorian Index of Stream Condition, the Victorian Index of Wetland Condition and the Tasmanian Conservation of Freshwater Ecosystem Values Framework (Norris *et al.*, 2007a)**.**

Whilst implementing the FARWH, investigators select indicators from six groups, those being: Catchment Disturbance, Physical Form, Hydrological Disturbance, Water Quality and Soils, Fringing Zone and Aquatic Biota (Norris *et al.*, 2007a)**.** In 2005 the National Water Commission prepared a document called *Potential comparative indices* (Norris *et al.*, 2007b) which details examples of parameter selection and reasoning. This document draws upon methodologies from existing monitoring program such as SEAP and the Assessment of River Condition (National Land and Water Resources Audit). The selected indicators are then indexed as a measure of overall ecosystem health.

Queensland FARWH trials: two basins within the Central Queensland Province have undergone a trial FARWH assessment; these are the Burdekin and Pioneer basins. First, the 2004-2005 baseline condition of these basins was determined, and then the condition of the current year (2008) was determined and compared to baseline. The SEAP stressor ranking approach was used to identify appropriate indicators for the trial. However, this was not found to be entirely compatible with all six FARWH themes and data confidence issues precluded some themes altogether. Some supplementary sampling was also necessary due to spatial scale of SEAP (Senior *et al.*, 2011).

Compatibility of the EHMP program in South East Queensland to the FARWH has also been investigated. The use of remote sensing and modelling in the EHMP, was highlighted as a more cost-effective way of meeting the Fringing Zone, CDI and Hydrological Disturbances components of the FARWH (Senior *et al.*, 2011).

Overall, the biggest difficulty implementing the framework in Queensland was the ability to find enough sites within a monitoring area that met FARWH reference site conditions. This was overcome by allowing similar ecosystems outside of an area to be used reference sites. Indicators in test sites were then compared to corresponding reference levels (Senior *et al.*, 2011).

5.4 Categories for the Fitzroy Environmental Health Index

The objectives of the ecosystem health monitoring programs that were reviewed included: determination of surface and groundwater flows (both quantity and extent); measurement of water quality (including variability and trends); correlation of results with land use; determination of end of catchment loads; investigation of urban run-off; sustainability of particular species; infrastructure planning; measurement of cyanobacteria (presence, causes and impacts); identification of the extent of vegetated wetlands; determination of rehabilitation success; management plan performance tracking; quantification of sediment and nutrient run off; measurement of response to disturbances; specific targets (e.g. salinity targets); overall condition of ecological resources (including contaminant impacts); community education and involvement; compliance monitoring; baseline data determination; provision of modelling data; protection of natural habitats, drinking water or species; assistance with policy making and guideline determination; increasing scientific understanding; water use suitability; risk identification; determination of habitat conditions (including riparian, coral reefs and seagrasses); and measurement of diffuse pollution.

The monitoring programs that were reviewed took a variety of approaches to meet their objectives. The specific indicators monitored depended on the objectives. The number of individual parameters that have been used as indicators of ecosystem health is quite extensive; many of these indicators are listed as potential indicators in the second volume of this report.

In some instances multiple parameters may be categorised by a particular group of ecosystem health indicators, for example: catchment disturbance, nutrients, aquatic biota, fringing zone, habitat or toxicants. Often programs measured individual indicators; alternatively, the programs collated a suite of these indictors into a particular index, in an index method approach.

Often programs ranked results against water quality objectives or environmental guidelines (benchmark approach). Other programs identified suitable background sites and used them as references against which to compare monitoring site conditions. Another method of analysis was to use long term monitoring results and identify how monitoring data compared to trends over time. Other types of assessment included the use of predictive functions (models). Often ecosystems were scored as a result of the monitoring and sometimes the output was conveyed to the public in the form of a report card (see section 6.0 for examples).

The frequency of which the monitoring and reporting took place ranged from continual to daily, weekly, monthly, bi-monthly, seasonally or yearly. Some monitoring programs were specifically event based and only took place for example, after a flood or in response to an algal bloom.

Those programs that were of most relevance to the Fitzroy were discussed in sections 5.3.1, 5.3.2 and 5.3.3, examples of other successful monitoring programs can be found in Appendix III. Overall the Queensland Government's SWAN and GWAN monitoring programs are useful for their long term Fitzroy Basin results (for example, flow, drought, salinity trends). The SEAP is useful for its framework approach and successful application to the Queensland Central Province, although it may lack in data confidence as it only requires a minimum of five results per parameter.

The Strickland River system monitoring in Papua New Guinea could be of importance to the determination of an Ecosystem Health Index for the Fitzroy as it has been monitoring mining-based contaminants such as metals since 1990, and has devised a method of incorporating this type of data into an index and report card. Similarly, the USA's EMAP which has also been operational since 1990, uses biological monitoring to measure contaminants such as metals and pesticides.

Programs such as the Central Queensland Ambient Estuary program provide good long term physical and chemical data for the Fitzroy Estuary and could possibly be enhanced by the inclusion of benthic invertebrates monitoring or the use of an index of estuarine benthic conditions.

In addition to physical and chemical parameters, PCIMP included biological monitoring of mangroves and seagrasses; the Reef Rescue MMP also monitors seagrass and it has an extensive coral reef community status component.

The EHMP based in South East Queensland, although affected by different anthropogenic influences, shares the majority of physical and biological indicators of ecosystem health with the Fitzroy. This is a long term program that has a well-defined index system and has been critically reviewed. The EHMP and the outcomes of the recent review process are useful starting points to create an Ecosystem Health Index for the Fitzroy Basin, one that uses the validated indexing methodology but includes extra categories of ecosystem health to ensure relevant sub-basin anthropogenic effects are covered. The intended development of a stewardship index through the FPRH may also overcome some of the limitations of the EHMP identified by Fisk (2010).

At a minimum, the following categories should be used to group indicators selected for inclusion in the Ecosystem health Index and Report Card for the Fitzroy Basin:

1. Physical/Chemical
2. Nutrients
3. Toxicants
4. Ecology*

- Note that breaking the 4th group (ecology) into four separate categories (as below) was considered. However, on discussion with the Science Panel, it was agreed that this put more weighting on these components than on the other three categories, and at least for this version of the report card these categories be treated as individual indicators within an overarching category (ecology).
    - Ecosystem processes;
    - Habitat;
    - Invertebrates; and
    - Fish,

The EHMP uses a benchmark approach whereby the catchments, estuary and bay are awarded scores depending on their similarity to ecosystem health guidelines. This approach could also be appropriate for the Fitzroy Basin.

6.0 Review of Existing Water Quality Guidelines and Ecosystem Health Indices

This section provides a brief summary of the water quality guidelines available for the Fitzroy Basin. The aim of this section is to provide background information relevant to selecting potential indicators and acceptable thresholds/trigger values for use in an Ecosystem Health Index for the Fitzroy Basin.

6.1Water quality guidelines and objectives

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ, 2000), often referred to as the ANZECC Guidelines, are a key component of the Australian National Water Quality Management Strategy (NWQMS) – a joint strategy of the Australian and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resources Management Council of Australia and New Zealand (ARMCANZ). They provide, amongst other provisions, "water quality guidelines proposed to protect and manage the environmental values supported by the water resources". The main objective of the ANZECC Guidelines is to "provide an authoritative guide for setting water quality objectives required to sustain current or likely future environmental values for natural and semi-natural water resources in Australia and New Zealand". They provide a set of tools for the assessment and management of water quality according to designated environmental values. NWQMS has also developed the Australian Guidelines for Water Quality Monitoring and Reporting and Guidelines for Groundwater Protection in Australia (ARMCANZ and ANZECC, 1995).

The primary legislative instrument protecting water quality in Queensland is the Environment Protection (Water) Policy 2009 (EPP Water). The purpose of the EPP (Water) is to achieve the object of the Queensland *Environmental Protection Act 1994* in relation to Queensland waters[2]. The object of the Act is to "protect Queensland's environment while allowing for development that improves the total quality of life, both now and in the future, in a way that maintains the ecological processes on which life depends".

The Queensland Water Quality Guidelines 2009, under the EPP (Water), inform the setting of water quality objectives (WQOs) for Queensland waters. They provide guideline values tailored to Queensland regions and water types and provide a process and framework for deriving and applying locally specific guidelines for waters in Queensland (DERM, 2009c). Under these auspices, environmental values (EVs), which include drinking water, recreation, aquatic ecosystems, livestock watering and water for irrigation and cultural heritage, are identified for local Queensland waters, and water quality guidelines and objectives are then developed to enhance or protect the EVs of these waters.

[2] Queensland *Environmental Protection (Water) Policy 2009* Explanatory Notes for SL 2009 No. 178 made under the *Environmental Protection Act 1994*.

The Australian Government Great Barrier Reef Marine Park Authority has developed Water Quality Guidelines for the Great Barrier Reef Marine Park 2010. The GBRMP Guidelines describe "concentrations and trigger values for sediment, nutrients and pesticides that have been established as necessary for the protection and maintenance of marine species and ecosystem health of the Great Barrier Reef" (GBRMPA, 2009). The trigger values are used for various functions including supporting target setting for quality of water leaving catchments, prompting management actions when triggers are exceeded, encouraging strategies that minimise contaminant release, identifying research into the impacts of contaminants, and assessing the cumulative impacts at local and regional levels.

6.1.1 Freshwaters

For freshwaters in the Fitzroy Basin, WQOs for the Fitzroy Basin, the Queensland Water Quality Guidelines 2009 and the ANZECC Guidelines apply in this preferential order, as per the EPP (Water) 2009.

Physical and chemical indicators:

The most locally relevant guidelines for the assessment of physical and chemical water quality parameters in the Fitzroy Basin are the WQOs set down in Schedule 1 of the EPP (Water). These objectives include specific values for the individual catchments: the Comet, Callide, Upper and Lower Dawson, Lower Fitzroy,Upper and Lower Isaac, Mackenzie, Theresa Creek and Upper and Lower Nogoa, and have been in place since 2011. Environmental values and WQOs for these catchments involve those for lowland freshwater riverine systems, groundwater, fish species in the main river trunks, and the Fitzroy estuary.

Sub-regional WQGs were developed to support the derivation of the WQOs to protect aquatic ecosystems within the Fitzroy Basin. These were more locally relevant and deemed necessary since two zones of the ANZECC guidelines related to the Fitzroy Basin, i.e. guidelines that serve either the whole of northern Australia or most of southern Australia applied to the Fitzroy. Additionally, the the regional guidelines in the QWQGs are not entirely suited to the Fitzroy Basin with its large and diverse catchment that is supposedlyunique in water quality characteristics (Noble et al. 1997).

Data of reference locations (unmodified or less impacted sites within the Fitzroy Basin) were used to derive the sub-regional water quality guidelines, which are the basis for the WQOs to protect the aquatic ecosystems of the Fitzroy Basin (Jones and Moss, 2011).

Jones and Moss (2011) report that current land use activities in the Fitzroy Basin suggested that the appropriate water quality indicators for freshwaters would include dissolved oxygen (DO), turbidity, total suspended solids (TSS), pH, electrical conductivity (EC), sulfate, nutrients (total nitrogen – TN, nitrogen oxides, ammonia, total phosphorus – TP, filterable reactive phosphorus), chlorophyll *a*, metals and pesticides. Upper and lower percentiles were used to calculate guideline values for these indicators. For every reference site, percentiles were calculated for each indicator, and where two or more reference sites were available within a catchment the values were averaged. The 80th percentile was used as the upper guideline variable for most variables except EC, for which the 75th percentile was used to maintain consistency with the Queensland Water Quality Guidelines 2009.

For some indicators there were insufficient data to derive guidelines. These include TSS, EC, TN and TP for some flow conditions in some catchments, and dissolved nutrients in all catchments. For the same reason it was not possible to derive guidelines of any flow condition for metals, pesticides, DO and chlorophyll *a at the regional level*, and hence the Queensland Water Quality Guidelines 2009 and ANZECC Guidelines are used as default guidelines. A lower default value of 6.5 was set for pH, as used in the ANZECC Guidelines for South-east Australia, and the upper pH value was set at 8.5 to reflect local conditions (reference site 80th percentile was generally between 8.0 and 8.5) (Jones and Moss, 2011).

Toxicants in sediments:

Safe levels of toxicants in sediments are provided by the ANZECC Guidelines for the following toxicants: metals (antimony, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc), metalloids (arsenic), organometallics (tributyltin), and organics (acenaphthene, acenaphthalene, anthracene, flourene, naphthalene, phenanthrene, low molecular weight PAHs, benzo(a)anthracene, benzo(a)pyrene, bibenzo(a,h)anthracene, chrysene, fluoranthene, pyrene, high molecular weight PAHs, Total PAHs, total DDT, p.p'-DDE, o.p'- + p.p'-DDD, chlordane, dieldrin, endrin, lindane, total PCBs).

While guideline values are not available for ammonia or nutrients in sediments, these may pose a threat to benthic communities and the ANZECC Guidelines therefore recommend testing of ammonia in pore waters for comparison against water quality guidelines. Regionally specific toxicant guidelines for sediments are not currently available.

Biological indicators:

Biological assessment detects departures from the reference condition, including such effects as changes to species richness, community composition, community structure, abundance and distribution of species determined to be of high conservation value or important to the functioning of the ecosystem, and to physical, biological and chemical changes to ecosystem processes (ANZECC and ARMCANZ, 2000). While physical and chemical indicators tend to provide limited (snapshot) information, the main advantage of biological indicators is that they integrate over time, combine the impacts of multiple stressors and directly relate to the health of an ecosystem (Wicks *et al.*, 2010).

Macroinvertebrates

The WQOs for the Fitzroy set down in Schedule 1 of the EPP (Water) include objectives for macroinvertebrate communities in freshwaters, which include composite (all bed habitats) and edge habitat (along the stream bed) values for each of the following: taxa richness, PET taxa richness, SIGNAL index and % tolerant taxa. The values (20th and 80th percentiles) are identical for each catchment in the Fitzroy and are derived from the Queensland Water Quality Guidelines for the Central Coast for moderately disturbed waters. Median values at a sampling site are to be compared against the 20th and 80th percentile values provided by the WQOs.

Taxa richness is the number of all macroinvertebrate taxa that are collected in a sample and is a commonly used index. Particularly low or high taxa richness can indicate deterioration of habitat condition. PET taxa richness records the number of families from three orders of aquatic insects: Plecoptera (stoneflies), Ephemeroptera (mayflies) and Trichoptera (caddisflies). The SIGNAL index is the stream invertebrate grade number – average level, an indicator developed for Australian water quality monitoring. It is calculated by averaging the sensitivity grades of macroinvertebrate families sampled. High SIGNAL scores indicate high numbers of sensitive taxa and demonstrate a higher likelihood of low salinity, turbidity and nutrients, and high dissolved oxygen levels (DERM, 2009c).

The ANZECC Guidelines recommend the application of AUSRIVAS predictive models (which use observed/expected ratios – O/E Families and O/E SIGNAL) for assessment of macroinvertebrate assemblages; although at present the applicability of these models to the Fitzroy region are uncertain (C Sellens 2012, pers. comm.).

Fish assemblages

The WQOs for the Fitzroy set down in Schedule 1 of EPP (Water) describe values for native fish species observed/expected (O/E) ratio. Expected native species should be found to be present in > 50 % of sampling events in main river trunks/channels. A ratio of one or above indicates the expected number of fish has been identified in a sample.

Species richness of fishes can be used as an indicator of ecosystem health, and when species richness is close to the expected richness the sampling site is considered in good condition. O/E is one of several approaches to comparing species richness. O/E objectives and exotic fish records for the Fitzroy catchments are based on state government sampling events conducted across the Basin from 1994 to 2009 and on Berghuis and Long's (1999) study of fishes of the Fitzroy catchment (Platten, 2011). Because migratory barriers such as dams and weirs may have affected the distribution of several fish species their presence or absence may be misleading and they have been excluded from the guidelines for most catchments. Exotic species and stocked species have also been excluded from the O/E guidelines in relevant catchments.

Fish taxa included in the lists of expected taxa in Fitzroy catchments include: *Melanotaenia splendida, Nematolosa erebi, Glossamia aprion, Craterocephalus stercusmuscarum, Leiopotherapon unicolour, Macquaria ambigua oriens, Oxyeleotris lineolatus, Strongylura krefftii, Amniataba percoides, Hypseleotris klunzingeri, Hypseleotris* sp., *Neosilurus hyrtlii, Scleropages leichardti, Scortum hillii, Ambassis agassizii, Tandanus tandanus, Pseudomugil signifier, Arius graeffei, Anguilla reinhardtii, Lates calcarifer, Megalops cyprinoides* and *Mugil cephalus.* These species were recorded in main channels and in Fitzroy River floodplain waterholes. A number of other fish species have been recorded in the Fitzroy, but were found in less than 50% of samples (Platten, 2011).

The WQOs also includes an objective for no increase in the number of exotic species present in a main channel relative to the current number of exotic species identified. The native species and exotic species expected are different for each catchment in the Fitzroy. As exotic species may impact the natural ecology of waterways their presence is considered a departure from normal conditions (Platten, 2011). Exotic fish species that have been encountered in some Fitzroy catchments include: *Carassius auratus, Gambusia holbrooki, Poecilia reticulata* and *Hephaestus fuliginosus* (a species that is native to Queensland but introduced to the Fitzroy).

Habitat:

Habitat is a crucial factor influencing ecosystem health and as such guidelines and objectives are in place for some critical habitat measures in catchment (freshwater) areas.

Riparian zones and vegetation management

Riparian zones perform a variety of crucial ecosystem functions including stabilising banks against erosion, reducing sediment input to streams, modifying water quality by filtering pollutants including nutrients, controlling aquatic plant growth, maintaining in-stream habitat, serving as part of aquatic food webs, and providing terrestrial habitat and wildlife corridors (Karssies and Prosser, 1999).

In Queensland, vegetation management relating to waterways is determined by codes under the *Vegetation Management Act 1999* (VM codes) and by some schemes under the *Sustainable Planning Act 2009* (DERM WQOs 2011). VM codes include performance requirements for waterways and wetlands that aim to maintain water quality, bank stability and aquatic and terrestrial habitat, and include vegetation clearing controls; and planning schemes under the *Sustainable Planning Act 2009* may specify riparian buffers (DERM WQOs 2011).The VM codes cover riparian protection provisions including the extent of the riparian buffer to be preserved (DERM, 2009c). The relevant code for the Fitzroy Basin is the “Regional Vegetation Management Code for the Brigalow Belt and New England Tableland Bioregions”.

Technical guidelines for riparian areas are provided in the Queensland Water Quality Guidelines 2009. Riparian functions of ecological processes, habitat and bed and bank stability are provided for within a number of water types including upland freshwater, lowland freshwater, tannin stained and coastal freshwaters, estuarine waters and coastal foreshores. Within upland freshwaters, guidelines for perennial, ephemeral and gully waters are described (DERM, 2009c). Guidelines include, for example: maintaining or restoring vegetation for canopy shade; eradicating weeds and maintaining or restoring in-stream large woody debris, native trees, shrubs and groundcover, and tree roots to provide stable undercut banks; maintaining or restoring bed or bank vegetation to minimise erosion; and managing cattle access to banks.

Reference to riparian protection is also made in the Fitzroy WQOs, besides reference to the relevant management and planning Acts. WQOs are listed, for example, to maintain existing riparian areas, achieve effectively unmodified riparian areas, or protect or restore riparian areas.

The Riparian Land Management Technical Guidelines published by the Land and Water Resources Research and Development Corporation (LWRRDC, 1999) provides management objectives and guidelines for riparian zones. Attention is given to controlling nuisance aquatic plants, managing snags and large woody debris, controlling stream erosion, using buffers to reduce sediment and nutrient delivery to streams, managing and rehabilitating riparian vegetation, managing riparian land for terrestrial wildlife, and managing stock in the riparian zone.

The Guidelines for Stabilising Streambanks with Riparian Vegetation (Abernethy and Rutherfurd, 1999) were developed by LWRRDC to provide assistance in establishing riparian plantations to stabilise riverbanks and retard erosion rates to more natural levels. They provides generalised rules for determining the structure and width of vegetated riparian zones for the purposes of controlling bank erosion, as opposed to other uses of riparian zones such as habitat retention or intercepting nutrients and sediment in runoff. The Guidelines are primarily aimed at regions where water extraction occurs. They also provide criteria to assess existing riparian condition:

(1) Reach assessment: (a) historical channel change (bed degradation/aggradation, stability of channel planform), (b) stream hydrology (flood size, occurrence and effects), (c) channel hydraulics (channel obstructions or bars that concentrate flow), and (d) channel form (bank shape, width and depth, incidence of erosion, size and shape of failures, undercutting or evidence of scour, seepage through bankface).

(2) Bank assessment: (a) rate of bank retreat, (b) bank geometry, (c) signs of bank slumping, (d) bank material, (e) desiccation cracks, (f) wind thrown trees, (g) seepage through the bank face, and (h) stock tracks.

(3) Vegetation assessment: (a) structure, (b) species, (c) density, and (d) location.

The Guidelines for Riparian Filter Strips for Queensland Irrigators (Karssies and Prosser, 1999) were commissioned by the (then) Queensland Department of Natural Resources for use within broader guidelines for land and water management, to evaluate applications for water extraction licences for irrigation. They are intended for application to new irrigation developments as well as for renewal or expansion of existing water extraction entitlements, and provide a set of design procedures to be used for designing riparian filter strips to trap sediments and nutrients eroding from agricultural land (Karssies and Prosser, 1999). Indicative soil losses and design filter widths for bio-geographical regions of Queensland, including the Brigalow, are provided for various rainfall erosivity, soil erodibility, slope and land cover conditions. The Guidelines also describe a procedure for assessing existing riparian zones as filter strips by considering vegetation structure, filter location and filter width (Karssies and Prosser, 1999).

Fish Habitat Guidelines

A series of Fish Habitat Guidelines (FHGs) have been developed by the Queensland Government, beginning in 1998. The FHGs cover a variety of issues relevant to fish habitat management in freshwaters, estuaries and coastal marine waters. They are designed to help direct planning and management and are not mandatory. Those FHGs relevant to freshwaters include:

- Fish passage in streams: Fisheries guidelines for design of stream crossings (FHG 001) is currently under review and not available.
- In the Fisheries Guidelines for Fish Habitat Buffer Zones (FHG 003), minimum recommended buffer zones (disturbance free areas) for freshwater areas are 50 m setbacks incorporating natural vegetation and other buffer elements (Bavins *et al.*, 2000). This is a generic buffer width which is considered as a starting point from which negotiations on specific site requirements can be made. FHG 003 provides technical background for the generic buffer zone width and information on which to base site-specific buffer zone refinements when assessing development proposals. It describes buffer widths required for various buffer functions including: sediment removal and erosion control; excess nutrient and metal removal; maintaining bank stability; moderating stormwater runoff and water temperature; protecting fish habitat diversity and species distribution; protection from pesticide spray drift; and mosquito/midge control (Bavins *et al.*, 2000).
- The Fisheries Guidelines for Fish-Friendly Structures (FHG 006) aims to "encourage consideration of, and provide guidance for, the planning, design, construction and operation of aquatic infrastructure so that it is fish-friendly". The guidelines should help to minimise impacts of aquatic infrastructure developments on fish and fish habitats and encourage opportunities for the enhancement of structures as fish habitat (Derbyshire, 2006).
- The Fisheries Guidelines for Conducting and Inventory of Instream Structures in Coastal Queensland (FHG 007) provides a standardised and consistent approach to conducting instream structure inventory projects in declared fish habitat areas. Instructions include how to undertake an inventory project and how to identify and prioritise instream structures for management responses. Relevant instream structures include causeways, floodgates, jetties, revetments, boat ramps and moorings (Lawrence *et al.*, 2010).

<u>Groundwater:</u>

The WQOs for the Fitzroy set down in Schedule 1 relate to groundwater as well as surface waters. Specific objectives for groundwater are applied according to 44 discrete water chemistry zones across the Fitzroy Basin (Raymond and McNeil, 2011). Objectives have been derived for electrical conductivity, hardness (calcium carbonate), pH (as calcium carbonate), alkalinity, calcium, magnesium, sodium, chloride, sulfate, bicarbonate, nitrate, silica, fluoride, iron, manganese, zinc, copper, sodium adsorption ratio, residual alkali hazard and redox (oxidation/reduction) potential

(DERM WQOs 2011 – all Sub-basins). Within each chemistry zone objectives are provided for both shallow (<30 m) and deep (>30 m) depths; however for some combinations of parameters and chemical zones there was insufficient data to derive objectives.

As water quality parameters have been monitored for groundwater and maintained in the EHP groundwater database (GWDB) for around 60 years, a large amount of data were available on which to base objectives. In addition to the parameters mentioned above, water quality data also typically include colour (hazen), total dissolved ions, total dissolved solids, dissolved oxygen, temperature and water level (Raymond and McNeil, 2011).

Groundwater is not specifically addressed in the Queensland Water Quality Guidelines 2009. In 1995 NWMQS produced the Guidelines for Groundwater Protection in Australia (ARMCANZ and ANZECC, 1995) with the goal that all Australian states, territories and the Commonwealth "have a beneficial use classification in place for all significant aquifers by the end of the decade". The national guidelines provide a framework for management arrangements to protect Australia's groundwater resource from contamination and list potential groundwater contaminants and sources, but do not aim to provide specific guidelines for water quality parameters. The Groundwater Guidelines recommend the ANZECC Guidelines as a useful starting point for setting water quality criteria for groundwater (ARMCANZ and ANZECC, 1995). The ANZECC Guidelines recommend that surface water guidelines also apply to the quality of groundwater, and that underground aquatic systems are afforded the highest level of protection. Part of the reason for this recommendation is for the protection of underground aquatic fauna (stygofauna) about which little is currently known, and which have a high conservation value (ANZECC and ARMCANZ, 2000).

6.1.2 Estuaries

For estuaries in the Fitzroy Basin, the WQOs for the Fitzroy Basin, the Queensland Water Quality Guidelines 2009 and the ANZECC Guidelines apply, in this preferential order, as per the EPP (Water) 2009.

Physical and chemical indicators:

The Fitzroy WQOs specify objectives for physical and chemical indicators in the estuarine reaches of waterways of the Fitzroy River. Separate WQOs have been established for upper estuary and mid estuary waters (tidal canals, constructed estuaries, marinas and boat harbours) for the following: ammonia N, oxidised N, organic N, total nitrogen, filterable reactive phosphorus, total phosphorus, chlorophyll a, dissolved oxygen, turbidity, Secchi depth and pH. WQOs have also been developed for the same indicators in enclosed coastal/lower estuary waters, with the exceptions of turbidity and Secchi depth (DERM WQOs 2011 – Fitzroy River Sub-basin).

Local turbidity and Secchi depth water quality guidelines were derived for baseflow conditions in the mid to lower (20 km to 45 km from the mouth) and upper reaches (45 km to 60 km from the mouth) of the Fitzroy River estuary (Moss, 2011). As above, it is not possible to derive guidelines for the lower estuary (0 km to 20 km from the mouth). Similarly, during high flow conditions turbidity is highly variable and consistent guidelines could not be derived for such conditions (Moss, 2011).

The ANZECC Guidelines provide trigger levels of toxicants in saline waters including metals, non-metallic inorganics, anilines, aromatic hydrocarbons, phenols and xylenols, miscellaneous industrial chemicals, agricultural chemicals (organochlorine pesticides, organophosphorus pesticides), and generic groups of chemicals (oil spill dispersants). Trigger levels have been determined for a limited number of metals in marine waters, including cadmium, chromium (CrIII), chromium (CrVI), cobalt, copper, lead, mercury (inorganic), nickel, silver, tributyltin, vanadium and zinc.

Toxicants in sediments:

Safe levels of toxicants in sediments are provided by the ANZECC Guidelines and are identical to those for freshwaters. Sediment quality guidelines are provided for the following toxicants: metals (antimony, cadmium, chromium, copper, lead, mercury, nickel, silver, zinc), metalloids (arsenic), organometallics (tributyltin), and organics (acenaphthene, acenaphthalene, anthracene, flourene, naphthalene, phenanthrene, low molecular weight PAHs, benzo(a)anthracene, benzo(a)pyrene, bibenzo(a,h)anthracene, chrysene, fluoranthene, pyrene, high molecular weight PAHs, Total PAHs, total DDT, p.p'-DDE, o.p'- + p.p'-DDD, chlordane, dieldrin, endrin, lindane, and total PCBs).

As described for freshwaters, guideline values are not available for ammonia or other nutrients in sediments, however as these may pose a threat to benthic communities the ANZECC Guidelines recommend testing of ammonia in pore waters for comparison against water quality guidelines.

Biological indicators:

Fish assemblages

The floodplain wetlands habitat of the Fitzroy River Sub-basin is seasonally estuarine and as such both freshwater and marine species are listed in the O/E species list for this area. Species expected to be present in the floodplain wetlands and associated main river trunks and channels include: *Nematolosa erebi, Anguilla reinhardtii, Craterocephalus stercusmuscarum, Leiopotherapon unicolour, Melanotaenia splendida, Lates calcarifer, Megalops cyprinoides, Hypseleotris klunzingeri* and *Mugil cephalus*. Exotic species which have been recorded to date are *Poecilia reticulata* and *Carassius auratus*.

Metals in biota

By measuring metals in biota it is possible to gain information on the biological uptake of metals, and potentially entrance of metals into food webs, which is not available solely from measuring metal levels in waters or sediments (DERM, 2009c). Reference ranges for oysters (*Saccostrea glomerata*) and mussels (*Trichomya hirsuta*) have been developed using data collected from sites in Moreton Bay and are listed in the Queensland Water Quality Guidelines 2009. The data are to be compared with the median of several samples from a test site, rather than a single sample, and each sample should itself contain at least five individual shellfish of the given species (DERM, 2009c).

Habitat:

Fish Habitat Guidelines

Several of the Queensland Government's FHGs series as described above for freshwaters are relevant to estuaries and coastal marine areas, including:

- Restoration of fish habitats: Fisheries guidelines for marine areas (FHG 002), which provides methods useful during the planning stages of restoration process. A stepwise approach to restoring and rehabilitating disturbed or degraded marine wetland areas for fisheries purposes is described (Hopkins *et al.*, 1998).
- The Fisheries Guidelines for Mangrove Nurseries: construction, propogation and planting (FHG 004) provide technical information on design, construction and establishment of mangrove nurseries, techniques for propagating mangroves and for planting out of nursery-reared mangroves (Clarke and Johns, 2002).
- The Fisheries Guidelines for Fish-Friendly Structures (FHG 006) is described above (section 5.1.1).
- The Fisheries Guidelines for Conducting and Inventory of Instream Structures in Coastal Queensland (FHG 007) is described above (section 5.1.1).

6.1.3 Marine waters

For marine waters in the Fitzroy Basin delta and Keppel Bay, the ANZECC Guidelines, Queensland Water Quality Guidelines 2009 and the Great Barrier Reef Marine Park Authority's (GBRMPA) Water Quality Guidelines for the Great Barrier Reef Marine Park 2010 apply. Where parameters are not presented in the GBRMPA Water Quality Guidelines the default is to apply the Queensland Water Quality Guidelines, and these default to the ANZECC Guidelines (GBRMPA, 2009). The GBRMPA Water Quality Guidelines provide trigger levels for water quality contaminants that trigger management actions if they are reached.

Physical and chemical indicators:

Nutrient guideline trigger values for coastal water bodies within the GBRMP were derived from the Queensland Water Quality Guidelines 2006, and regional guidelines are available for the Central Coast as well as other regions (GBRMPA, 2009). To derive trigger values for open coastal, midshelf and offshore areas more than ten years of sediment and nutrient data was analysed, including Secchi depth, chlorophyll, suspended solids, particulate, dissolved and total nitrogen, and particulate, dissolved and total phosphorus (GBRMPA, 2009). The trigger values were then derived by modelling relationships between the condition of reef biota and the parameter; or by analysing the spatial distribution of water quality in Cape York waters (as a reference site).

The GBRMPA Water Quality Guidelines define guidelines trigger values at various levels of reliability for water clarity (Secchi depth), chlorophyll *a*, suspended solids, particulate nitrogen, particulate phosphorus, sedimentation, temperature, several pesticides (diuron, atrazine, ametryn, simazine, hexazinone, 2,4-D, tebuthiuron, chlorpyrifos/oxon, endosulfan, 2-Methylethyl mercuric chloride and diazinon) and one biocide (tributyltin); for enclosed coastal, open coastal, midshelf and offshore water bodies.

Trigger levels of some additional toxicants in marine waters are provided by the ANZECC Guidelines, including metals, non-metallic inorganics, anilines, aromatic hydrocarbons, phenols and xylenols, miscellaneous industrial chemicals, agricultural chemicals (organochlorine pesticides, organophosphorus pesticides), and generic groups of chemicals (oil spill dispersants).

Trigger levels have been determined for a limited number of metals in marine waters, including cadmium, chromium (CrIII), chromium (CrVI), cobalt, copper, lead, mercury (inorganic), nickel, silver, tributyltin, vanadium and zinc (ANZECC and ARMCANZ, 2000).

The Queensland Water Quality Guidelines 2009 also provide regional guideline values for physical and chemical indicators in the Central Coast region. Many of these are necessarily identical to the GBRMPA Water Quality Guidelines, however additional parameters listed include: ammonia N, oxidised N, organic N (enclosed coastal waters only), filterable reactive phosphorus, turbidity (NTU), pH and DO. Temperature guidelines need to be defined for particular areas using the 80^{th} and 20^{th} percentiles of ecosystem temperature distribution (DERM, 2009c).

<u>Biological indicators:</u>

No guidelines relevant to the Fitzroy Basin provide advice on using biotic indices as part of an ecosystem assessment of marine waters. However reference material is provided in the Queensland Water Quality Guidelines 2009 relating to measuring metals in biota.

Metals in biota

As described for estuaries in section 5.1.2 above, by measuring metals in biota it is possible to gain information on the biological uptake of metals, and potentially entrance of metals into food webs, which is not available solely from measuring metal levels in waters or sediments (DERM, 2009c). Reference ranges for oysters (*Saccostrea glomerata*) and mussels (*Trichomya hirsuta*) have been developed using data collected from sites in Moreton Bay and are listed in the Queensland Water Quality Guidelines 2009. The data are to be compared with the median of several samples from a test site, rather than a single sample, and each sample should itself contain at least five individual shellfish of the given species (DERM, 2009c).

6.2 Aquatic Ecosystem Health Indices

Environmental degradation affects aquatic ecosystems, and for well over 100 years, the response of individual organisms to specific pollution or degradation has been measured, and used to develop biotic indices. In more recent years community response, ecosystem, and landscape response have been integrated to provide a holistic assessment (Bain *et al.*, 2000). Indices for aquatic ecosystem health can quantify catchment and hydrological condition, habitat and ecological condition.

Aquatic ecosystem health indices provide a ranking of ecosystem condition based on a range of physical, chemical and biological variables (e.g. temperature, dissolved oxygen, salinity, conductivity, pH, faecal coliform bacteria, turbidity, nitrates, phosphorus, and metal concentrations in water, sediment and biota). For each of the factors measured, water quality standards are applied to determine whether values provide ecosystem protection. Scores are generally averaged over a period of time (such as a year) to provide a final ranking for a waterway.

Ecosystem health indices are commonly used in catchment health monitoring programs. They are extensively used in watershed management in the United States (Bain *et al.*, 2000), and are a critical component of catchment monitoring and assessment programs in Australia. For example, a biotic index and an environmental index were derived for the whole of Australia assessment *Australia River Condition* program in 2001 (Norris *et al.*, 2007a). This assessment included different indices including a biotic index based on AUSRIVAS assessments, hydrological disturbance index based on pre-European flow, a habitat index, nutrient load index, and a sediment and nutrient index. This approach has also been used for the assessment of the Murray-Darling Basin (Norris *et al.*, 2001) and to develop a state-wide index for Tasmania (NRM, 2009).

Other local programs that use a range of indices to measure ecological condition of waterways include the Port Curtis Integrated Monitoring Program, the Reef Water Quality Protection Plan, and the South East Queensland Ecological Health Monitoring Program.

6.2.1 Biotic Indices

<u>Community taxonomic structure:</u>

The use of taxonomic structure is an intuitive and direct measure of ecosystem condition. The more sensitive taxa that are present, the better the condition; and the more tolerant taxa that are present, the poorer the condition of the aquatic ecosystem. For example, the PET index is the total number of taxa in the insect orders Plecoptera (stoneflies), Ephemeroptera (mayflies), and Trichoptera (caddisflies). These are taxa that are universally indicative of good ecological condition.

Note that in the Fitzroy catchment, Plecoptera are rare since they are typically found in riffle habitat, and in upland streams and these habitats are uncommon in the Fitzroy. Because of this, PET scores from many streams in the Fitzroy are naturally low (C. Sellens 2012, pers. comm.).

<u>Community biotic structure:</u>

Numerical values can be applied to individual taxa at the species, genus or family level, and the community biotic structure can be measured by averaging or scoring the pollution sensitive grades of taxa present in a sample. The identification of both impact and non-impact conditions are required to establish disturbance tolerance scores. However, because individual taxa are not equally responsive to all types of disturbances including response to specific pollutants, or different land use impacts (Chessman and McEvoy, 1998) index scores reflect an average response to a range of disturbances (Chessman, 1995) and this may reduce the sensitivity of the index to specific impacts.

Examples of community biotic structure include the Biological Monitoring Working Party (BMWP) index developed in the United Kingdom (Armitage *et al.*, 1983), and the Australian Stream Invertebrate Grade Number Average Level (SIGNAL) index (Chessman, 1995) (incorporated into AUSRIVAS reference condition approach predictive modelling (Simpson and Norris, 2000)). It is noted that SIGNAL scores for ephemeral streams (such as those in the Fitzroy) may be naturally low and give a similar assessment as perennial streams affected by river regulation.

Other examples of community biotic structure used outside of Australia include the Hilsenhoff Index (Hilsenhoff, 1977, Plafkin *et al.*, 1989), and the use of fish in a similar index (see Bain *et al.*, 2000).

<u>Community function and structure:</u>

The index of biotic integrity was developed in the United States (Karr, 1981) and includes many measures of community structure including taxonomic composition, tolerance ratings and trophic structure. Criteria for quality determination require comparison to a set of metrics determined from minimally disturbed references sites.

At present there is not a similar index available for use in the Fitzroy catchment, however the potential for this type of measure is being investigated at CQUniversity.

<u>Predictive Modelling:</u>

In AUSRIVAS, an assessment of ecological condition is determined by comparing the community at a test site to the community expected to be present in the absence of human disturbance. In the predictive model, sites are grouped together based on similarities of taxonomic composition, and then environmental attributes of the taxonomic groups are compared to identify a subset of explanatory (predictor) variables. A measure of site degradation is obtained by observing the taxa at a site (O), comparing this to the taxa expected (E), to be at the site and expressing the deviation as a ratio (O/E). The expected number of taxa (E) is the sum of the probabilities of the number of taxa predicted to occur at a site (Simpson and Norris, 2000).

The assessment of site condition requires the model to incorporate reference sites and reference site conditions that are similar to the conditions that would have been found at the test site naturally. The Queensland AUSRIVAS models do not include many sites from central Queensland, and cannot always be used to assess sites from the Fitzroy catchment.

Multi-metric ecosystem structure:

In Australia the integration of different indices to allow for the calculation of stream condition began in 1999 with the development of the Index of Stream Condition (ISC) (Ladson *et al.*, 1999). The ISC provides scores for five components of stream condition: (i) hydrology (based on change in volume and seasonality of flow from natural conditions); (ii) physical form (based on bank stability, bed erosion or aggradation, influence of artificial barriers, and abundance and origin of coarse woody debris); (iii) streamside zone (based on types of plants; spatial extent, width, and intactness of riparian vegetation; regeneration of overstorey species, and condition of wetlands and billabongs); (iv) water quality (based on an assessment of phosphorus, turbidity, electrical conductivity and pH); and (v) aquatic life (based on number of families of macroinvertebrates).

6.2.2 Implications for use in the Fitzroy Basin

A number of simple biotic indices for macroinvertebrates and fish are already established for the Fitzroy Basin, and guideline ranges are indicated in the Water Quality Objectives for each sub-catchment. These have been derived from a limited number of reference sites, and account for the naturally low number of sensitive taxa.

The development of more complex indices that incorporate functional or structural biotic data or physical attributes (such as bank condition, or riparian condition) will be dependent on the availability of historical data or on the collection of additional data, and should be considered at a future point.

7.0 Selection of potential indicators for the Fitzroy system

An ecosystem health index is based on a series of individual indicators which focus on measuring specific parameters of interest. Parameters can relate directly to the state of an ecosystem of interest, as well as to drivers and pressures that influence that state, and to impacts and responses resulting from the state. A discussion paper from the United Nations Department of Economic and Social Affairs (DESA) on merging the ecosystem approach with the conventional PSR/DPSIR frameworks suggests in the context of ecosystem health it is helpful to consider state as the central point for indicator selection (Weber, 2010). As such, it is important to understand the state of the Fitzroy Basin and the pressures and driving forces that change environmental state (section 3.0 of this report). When considering indicators for inclusion in the Ecosystem Health Index for the Fitzroy Basin, attention may be placed on how potential indicators affect the state, or can be used as a measure of the state, of the Fitzroy Basin.

An ecosystem health index is typically formed of a group of related parameters that together explain the condition of the ecosystem of interest. For more complex ecosystems, a series of indices may be used in combination to provide a comprehensive assessment.

7.1 Criteria for selecting indicators

Potential indicators for an Ecosystem Health Index for the Fitzroy Basin have been identified based on the review of relevant water quality guidelines, other monitoring programs (including EHMP), a review of the scientific literature, and expert knowledge. The DPSIR framework of causality with state as a central focus was used to identify potential indicators that may by relevant to the Fitzroy (see section 3.2).

The list of potential indicators is provided in Appendix IV, which also includes water quality benchmarks for indicators where they exist.

The potential indicators identified through this process are then assessed against a set of selection criteria which were developed using a combination of scientific literature, expert knowledge and the criteria used for existing programs.

There are two steps to using selection criteria to determine indicators: firstly the selection criteria need to be predefined, and secondly the indicators need to be assessed against the criteria (Wicks et al. 2010). It is within the scope of this volume of the report to identify and describe the criteria for selecting suitable indicators for an Ecosystem Health Index (Table 7.1). However as the selection criteria includes an appraisal of whether or not reliable data from the Fitzroy Basin are available for each indicator, evaluation of each indicator against the selection criteria will be completed in the second volume of this report: *“Part B: Analysis and interpretation of data for the Fitzroy and application to a Report Card approach”*.

As a final step in the indicator selection process, the combination of indicators chosen to form the Ecosystem Health Index for the Fitzroy Basin must cover the full complexity of this system, or at least aim to do so as effectively as possible within current constraints and provide direction for future improvements. The balance of indicators selected will also need to be considered in terms of the total number of indicators – too many indicators would be costly and potentially ineffective at while too few indicators may result in knowledge gaps (Wicks et al., 2010).

Table 7.1 Recommended indicator selection criteria

Data:

SC17. Reliable data currently available for the Fitzroy Basin*

SC18. Suitable interpretative algorithms are available

SC19. Errors, reliability and uncertainty in measurement are known and acceptable*

SC20. Temporal and spatial variability can be accounted for

Interpretation and communication:

SC21. Guidelines/ objectives are in place and relevant to the region*

SC22. Used in other monitoring programs (consistent with other regions, states, nations)

SC23. Scientific interpretation is straightforward and meaningful

SC24. Simple to communicate and good public understanding

Relevance:

SC25. Important to ecosystem function (will exposure cause serious environmental effects?)

SC26. Sensitive to changes in ecosystem function

SC27. Contributes to assessment of ecosystem resilience

SC28. Related to regional, state, national, international policies and management goals

Practicality and timeliness:

SC29. Feasibility and logistics to measure (monitor and analyse) are consistent with outcome benefits

SC30. Time requirements to measure (monitor and analyse) are consistent with outcome benefits

SC31. Costs to measure (monitor and analyse) are consistent with outcome benefits

SC32. Provides an early warning of ecosystem health decline

*** Critical criteria – low score means automatic disqualification of a potential indicator from the index (applies to SC1, SC3 and SC5).**

7.2 Using the ecosystem health indicators

Following finalisation of the indicators in each of the four recommended categories, indicator benchmark or trigger values will be identified to set the benchmarks for ecosystem health. These benchmarks can be for both best attainable values (Best Case Scenario) and worst attainable values (Worst Case Scenario).

7.2.1 Benchmarks for best case scenarios

Defining the benchmarks for ecosystem health is critical to the assessment of the system. There are several ways of defining benchmark values for each parameter of interest. These include:

- values from reference (natural) sites;
- values from water quality guidelines;
- transferred values from other systems (e.g. benchmarks used in other ecosystem health indices such as EHMP);
- values set by using analysis of data from the ecosystem;
- expert opinion; and
- predictive functions where values are related to levels of other relevant variables.

Ideally, the benchmark should be set using regionally relevant reference sites, and the range of values for each indicator determined from multiple sampling times in order to capture the natural variability. This is particularly important in the Fitzroy system where there are considerable differences in flow between the wet and dry seasons, and natural differences for variables in the different sub-catchments. Regionally specific water quality thresholds such as the water quality objectives for the Fitzroy are based on data from reference sites and can also provide relevant benchmarks. Regional and national guidelines may provide more general benchmarks.

Where possible, existing benchmarks were identified for each of the potential indicators identified in this report. Sources include the Fitzroy Basin Water Quality Objectives, the Queensland Water Quality Guidelines, the ANZECC Guidelines, the GBRMPA Guidelines as well as existing monitoring programs including EHMP. These are provided in Appendix IV

There are a number of difficulties with interpreting indicators and benchmarks. These include accounting for variability in the Fitzroy Basin particularly in relation to flow, the ecological relevance of indicators and available data, understanding causality of changes in the state of the environment, predicting changes in ecosystem health, and issues related to scoring and weighting indicators within the Ecosystem Health Index. These complexities need to be considered in the development of the Ecosystem Health Index and it is recommended that they are also noted by FPRH for future improvement through further research or increased monitoring as relevant.

Methods for calculating an ecological health index using benchmarks are discussed in the report *"Part B: Analysis and interpretation of data for the Fitzroy and application to an Ecosystem Health Index and Report Card".*

7.2.2 Benchmarks for worst case scenarios

In many assessment methods it is also important to know when an observation fails, or when it indicates that a system is in an unacceptable condition. To assess this, threshold values are needed to establish the point at which a system can be classified as failing.Similar to best case scenarios, there are several ways of defining worst case benchmark values for each parameter of interest. These include:

- values from water quality guidelines;
- transferred values from other systems (e.g. benchmarks used in other ecosystem health indices such as EHMP);
- values set by using analysis of data from the ecosystem;
- expert opinion; and
- predictive functions where values are related to levels of other relevant variables.

There is more limited data about worst case scenarios than best case scenarios, so it is not always possible to set each from the same source. Worst case scenarios need to be adjusted reflect regional and sub-regional variations in the same way that best case scenarios should be.

8.0 Communicating Ecosystem Health Indicators

Summarised monitoring results are often communicated to the public, stakeholders and decision makers through a report card. A variety of approaches are used to communicate indicators in different ecosystem health report cards – all aim to integrate divergent data into scores that can easily be communicated to the public (Williams *et al.*, 2010). The graphical presentation of indicator scores is important for successful communication of ecosystem health assessment findings. It is important that report cards are easy to interpret while providing enough meaningful information to the reader. To gain a full or more in-depth understanding of the indicators used in report cards it is usually necessary to refer to an associated methods section or technical report.

The following section of this report reviews some examples of report cards and discusses different approaches to communicating ecosystem health indicators. Because there are so many ways of graphically displaying ecosystem health indices, only those that may potentially be adapted to a report card for the Fitzroy Basin have been included. The reviewed report cards include: the Queensland Government's Stream and Estuary Assessment Program (SEAP), the Queensland Government's Ambient Surface Water Quality program (SWAN), the South East Queensland Ecosystem Health Monitoring Program (EHMP), Reef Rescue Marine Monitoring Program (MMP), Mackay Whitsunday Region Water Quality Improvement Plan, the Port Curtis Integrated Monitoring Program (PCIMP), Gippsland Lakes Intensive Water Quality Monitoring Program, Chesapeake Bay Total Maximum Daily Load program (TMDL) (USA), Waikato River Water Quality Monitoring Program (New Zealand), Gui River health assessment (China), the United States Environmental Protection Agency National Coastal Condition Report (NCCR) (USA), and the Strickland River Report Card (PNG).

A common way of relaying the result of ecosystem health assessments is by giving a letter score (e.g. A+ to F). The EHMP, PCIMP, Chesapeake Bay, Gippsland and Waikato River reports all use this method. This is a quick and easy way to communicate the overall ecosystem health score of the waterway in question. However, if more information about particular indicator scores (e.g. macroinvertebrate diversity) is needed, it is necessary to refer to the detailed technical report. The Chesapeake Bay TMDL report card improves on score detail by also using a colour guide to indicate ecosystem health (Figure 8.1).

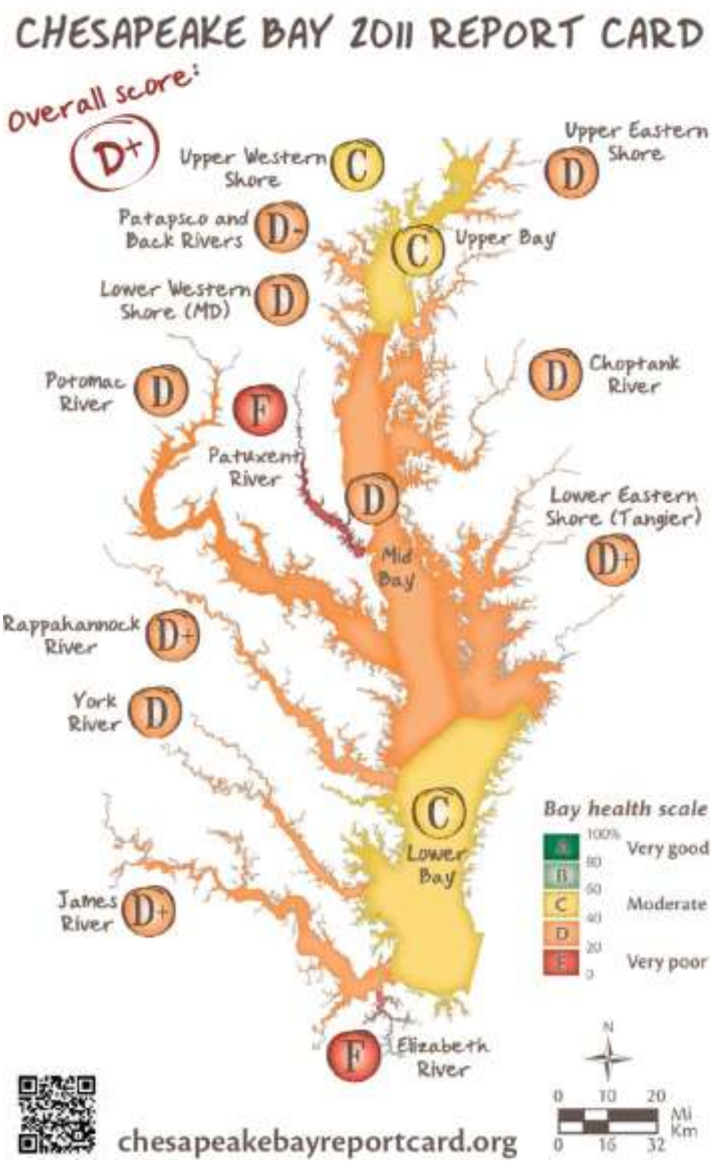

Figure 8.1: Example of a graphic from the Chesapeake Bay Report Card 2011(Source: Chesapeake Bay Report Card 2011; http://ian.umces.edu/pdfs/ian_report_card_365.pdf)

Another popular method that is used to communicate scores of individual indicators is the use of graphical shapes such as circles, triangles, pentagons and hexagons, with colours that easily identify the condition of each indicator. An indicator, a suite of indicators or an index usually occupies each section of the shape. These types of graphics are used in report cards such as the SEAP (Figure 8.2), SWAN (Figure 8.3), Strickland River (Figure 8.4) and EHMP (Figure 8.5) report cards.

The SEAP symbology is clear for the reader, however much like the lettering method, it is necessary to refer to the technical report to establish how each score has been calculated. The symbols used in

SWAN reporting are also very clear; however this program only takes four water quality indicators into consideration and may not be easily applied to a more complex report that has a larger suite of indicators. If graphical shapes are chosen to communicate results for a large suite of indicators, the approaches of the Strickland River and EHMP report cards are more amenable. The EHMP graphics provide more information than the graphics used in the Strickland River report card, giving the indicator sections a gradient of colour rather than a simple block colour, to allows the reader to judge comparative health of each indicator (Figures 8.4 and 8.5). Using colour-graded graphics allows a large amount of information to be displayed in a report card while retaining an easy to interpret design.

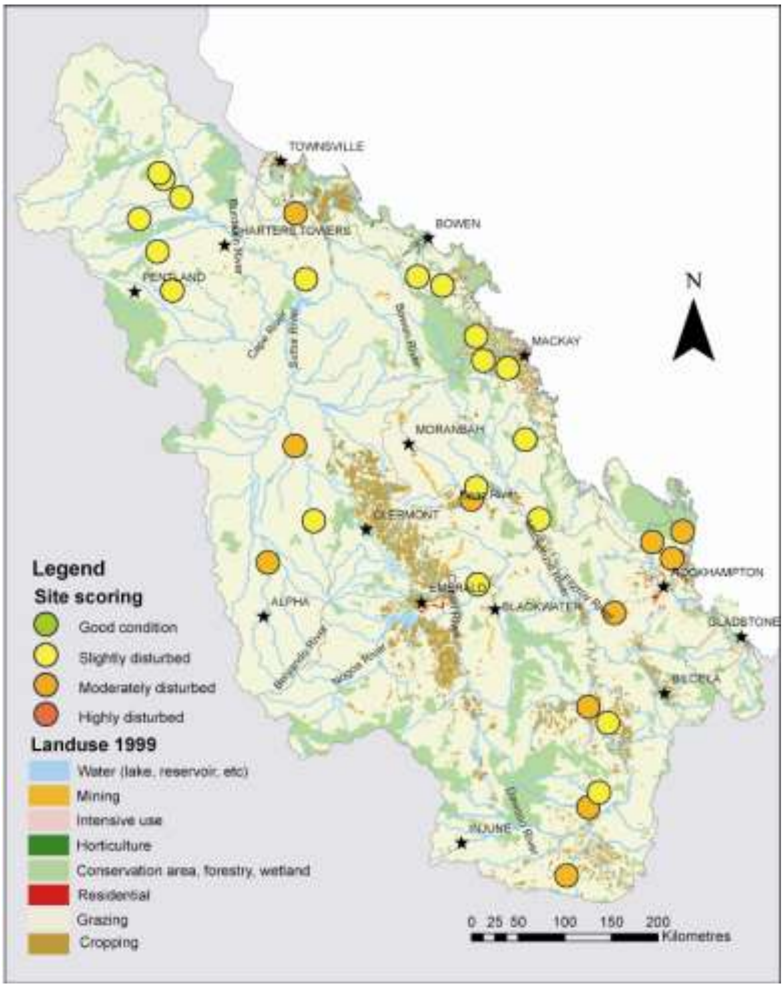

Figure 8.2: Example of scoring graphics used in the SEAP (Source: (Negus *et al.*, 2011a) http://www.derm.qld.gov.au/water/monitoring/pdf/seap-cpr-2008.pdf)

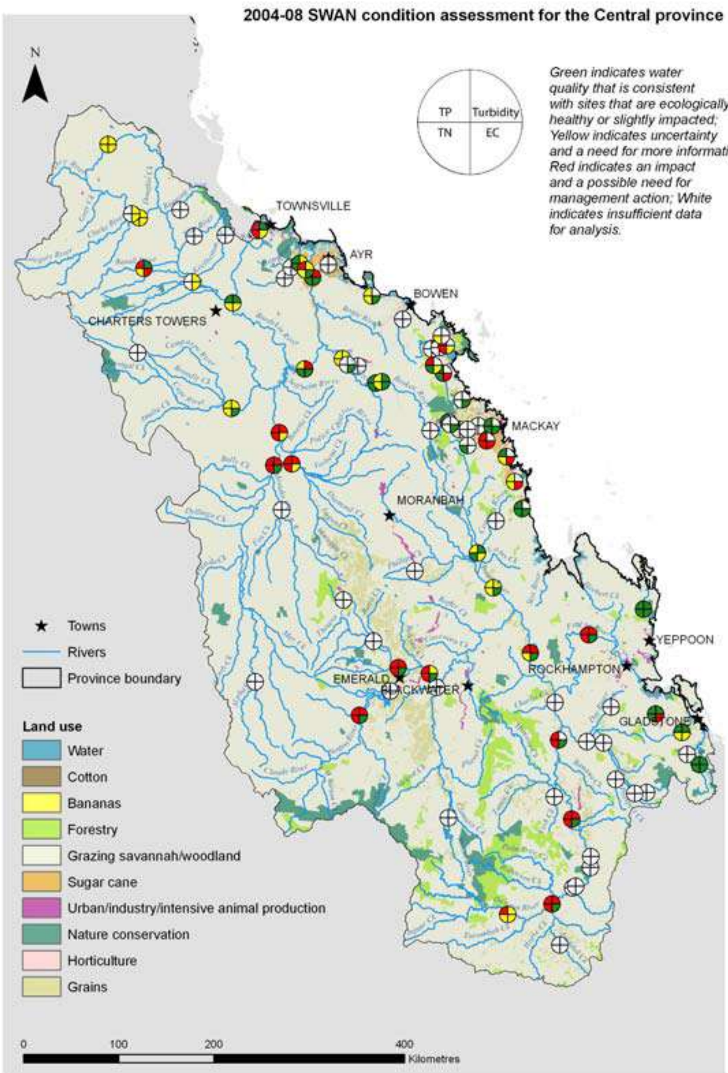

Figure 8.3: Example of scoring graphics used the in the SWAN summary report (Source: DERM 2011: http://www.derm.qld.gov.au/water/monitoring/qld_ambient_program/qld-ambient-reports.html)

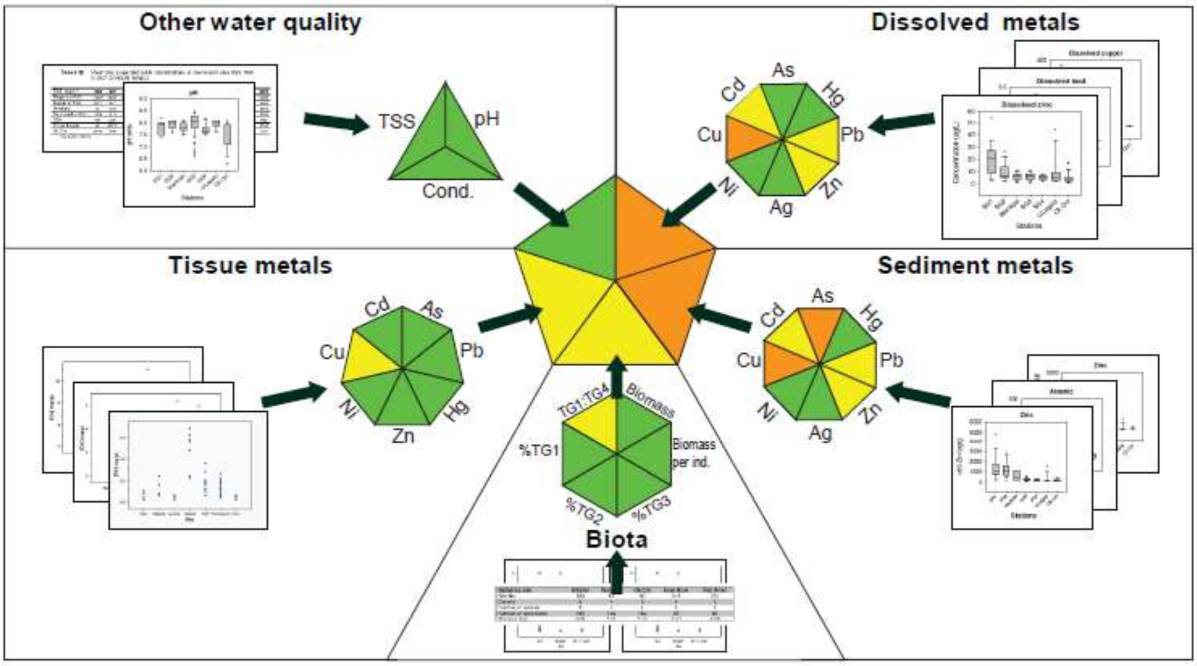

Figure 8.4: Description of pentagon graphics used in the Strickland River Report Card (Source: Strickland River Report Card 2009: http://www.peakpng.org/resources/Porgera-report-card-081109-spread.pdf)

Figure 8.5: Explanatory diagram of the EcoH plot graphics used in the EHMP report card (Source: EHMP website, Upper Brisbane Catchment 2011: http://www.health-e-waterways.org/reportcard/2011/catchment/Upper%20Brisbane%20Catchment**)**

An alternative method for presenting scores for individual ecosystem health indicators or indices is using a combination of colour and bar graphs. Reports that use this method include the Australia-China Environment Development Partnership's Gui River report card (Figure 8.6) and the US EPA's NCCR report card (Figure 8.7). This method allows the reader to clearly identify ecosystem health scores for each indicator. The Gui River report card includes an accompanying map with the overall rating of the catchment, whereas the NCCR report illustrates the overall health of the catchment by the use of a coloured star graphic.

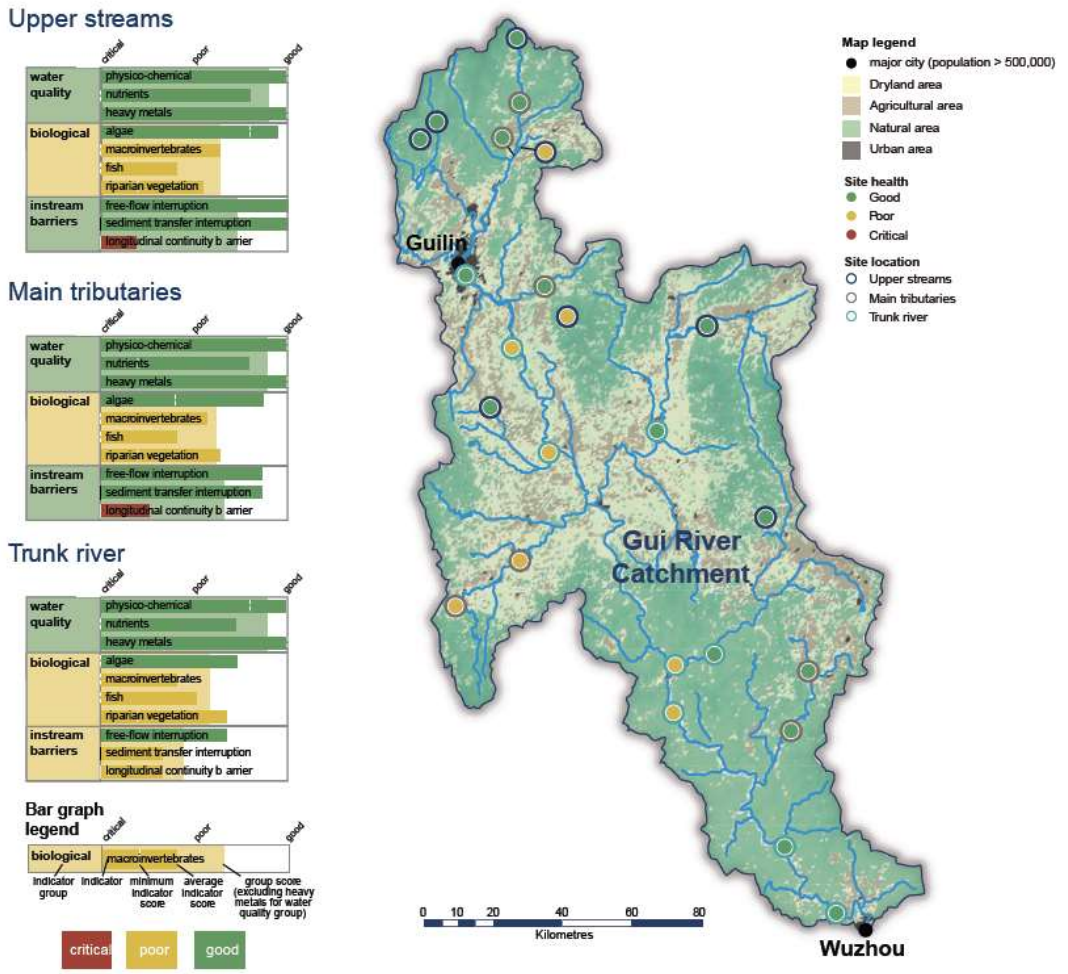

Figure 8.6: Map showing condition by site on the Gui River health report card (Source: Gui River river health report card 2012: http://www.watercentre.org/research/rhef/attachments/report-cards/river-health-report-card-gui-river)

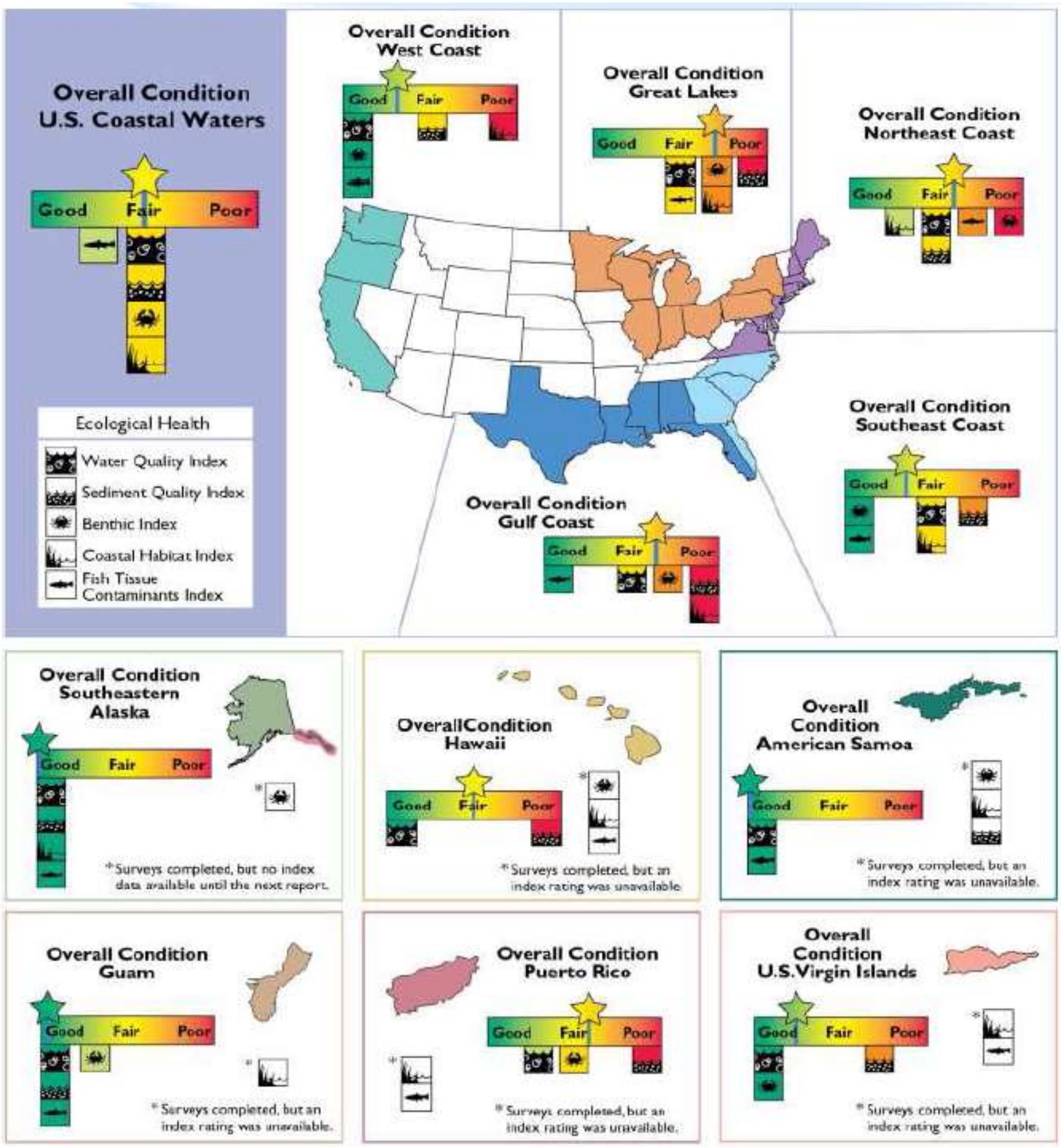

Figure 8.7: Graphic used to display categorised and overall scores in the US EPA National Coastal Condition Report (Source: The National Coastal Condition Report IV 2012: http://water.epa.gov/type/oceb/assessmonitor/nccr/upload/Final-NCCR-IV-Fact-Sheet-3-14-12.pdf)

The Mackay Whitsunday Region WQIP employs a unique method for displaying scores of key pollutants. The benefit of this reporting style is that it allows for the inclusion of clear objectives for short term and long term targets (Figure 8.8). This approach places an emphasis on the discrepancy between ecosystem health scores and targets. A second figure on the report card illustrates how land use practices can be improved to help reduce key pollutants and an approximate cost of implementing changes (Figure 8.9). This format is particularly useful for decision makers.

Key Pollutant	Event Load Freshwater Quality Values: Objective 2050	Current Condition 2007	Target 2014	% reduction CC to Target	Action	Pollutant Source
Dissolved Inorganic Nitrogen Tonnes/yr	1310	2100	1550	27	L H	C I U
Particulate Nitrogen Tonnes/yr	1210	1770	1410	20	L H	C I U G
Filterable Reactive Phosphorus Tonnes/yr	130	350	250	30	L H	C I U
Particulate Phosphorus Tonnes/yr	280	650	500	23	L H	C I U G
Total Suspended Sediment Tonnes/yr	520000	528000	520000	2	L H	C I U G
Ametryn kg/yr	120	160	120	25	L H	C I U
Atrazine kg/yr	1210	1620	1210	25	L H	C I U
Diuron kg/yr	2870	4680	3510	25	L H	C I U
Hexazinone kg/yr	890	1190	890	25	L H	C I U
Tebuthiuron kg/yr	60	80	60	25	L H	G

Figure 8.8: Mackay-Whitsunday Region current condition report for event load freshwater quality Source: (Drewry *et al.*, 2008)

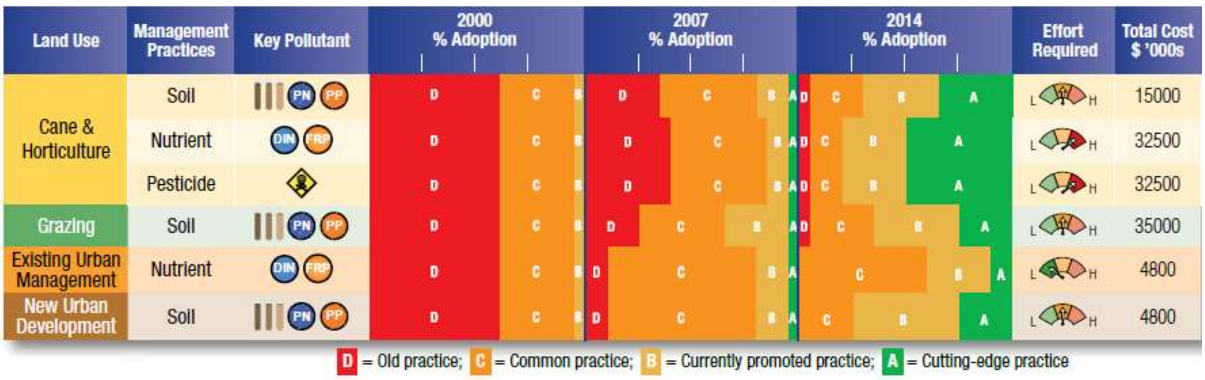

Figure 8.9: Mackay-Whitsunday Region improving management practices Source: (Drewry *et al.*, 2008)

The first Reef Rescue MMP report card for the Fitzroy Region presents scores for ecosystem health indicators in several ways. Column graphs illustrate scores for land practice (grazing, horticulture and grain) (Figure 8.10), and catchment loads (Figure 8.11); catchment results are illustrated using bar graphs (Figure 8.12); and a pie chart is used effectively to display the scores of water quality, coral and seagrass monitoring indicators, providing a large amount of information while retaining an easy to read and understand format (Figure 8.13).

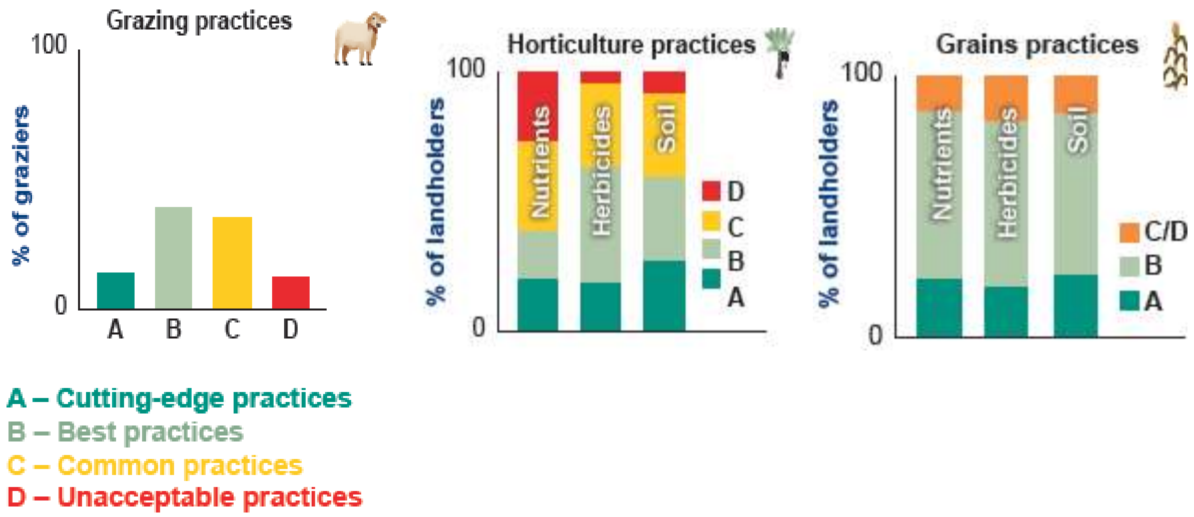

Figure 8.10: Reef Water Quality Fitzroy Region land practice results and framework legend (Source: Reef Water Quality Protection Plan Secretariat 2011: http://www.reefplan.qld.gov.au/about/regions/assets/reef-plan-fact-sheet-fitzroy.pdf)

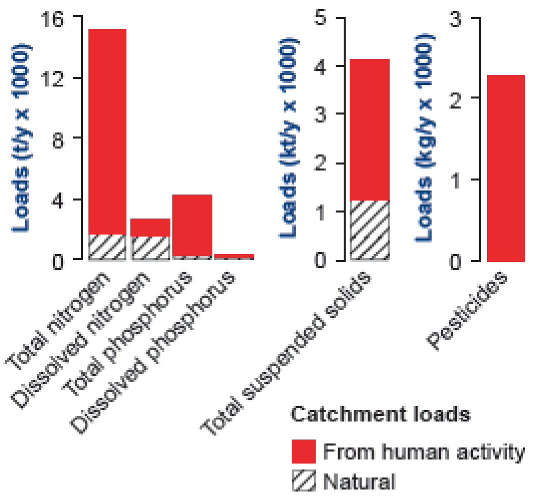

Figure 8.11: Reef Water Quality Fitzroy Regions catchment loads (Source: Reef Water Quality Protection Plan Secretariat 2011: http://www.reefplan.qld.gov.au/about/regions/assets/reef-plan-fact-sheet-fitzroy.pdf)

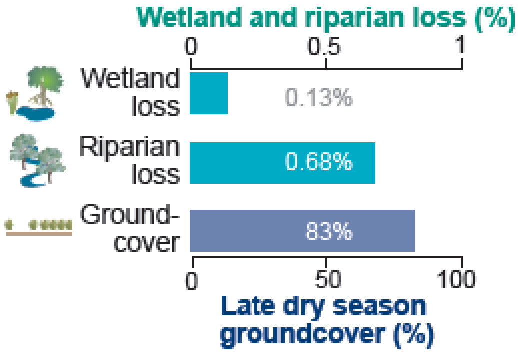

Figure 8.12: Reef Water Quality Fitzroy Regions catchment results (Source: Reef Water Quality Protection Plan Secretariat 2011: http://www.reefplan.qld.gov.au/about/regions/assets/reef-plan-fact-sheet-fitzroy.pdf)

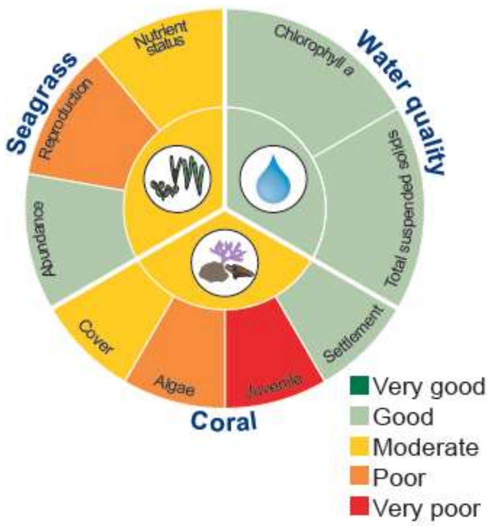

Figure 8.13: Reef Water Quality Fitzroy Regions marine indicator results (Source: Reef Water Quality Protection Plan Secretariat 2011: http://www.reefplan.qld.gov.au/about/regions/assets/reef-plan-fact-sheet-fitzroy.pdf)

A combination of the positive attributes of existing report cards, such as an overall grade or rating for the catchment combined with figures that incorporate shape and colour to illustrate how each indicator, or category of indicators, has performed (e.g. similar to the EHMP, the Gui River or the NCCR report cards) may be suitable for the FPRH report card. Many of the report cards reviewed use a map graphic to separate results within the monitoring program by region/location. This would also be an effective mechanism for displaying the results from the 10 catchments, estuary and marine areas included in the Fitzroy Basin Report Card. Adopting some of the Mackay-Whitsunday WQIP tools such as short term and long term target objectives for indices may also benefit future report cards.

There are benefits in retaining a similar layout to the South East Queensland EHMP reporting. Adapting the EHMP layout to the FPRH Fitzroy Basin report card would make it easier for decision makers and others who are already familiar with the EHMP to rapidly interpret the Fitzroy Basin outputs. It would also allow for rapid cross-checks of ecosystem health between the two regions. While there would necessarily be differences between the two as a result of the differing pressures, state and impacts, retaining a similar formatting style where possible could provide benefits to both programs.

9.0 Conclusions and recommendations

The development by FPRH of an Ecosystem Health Index and Report Card for the Fitzroy Basin will play a vital role in bringing together disparate monitoring program datasets, assessing ecosystem health in the waterways of the Fitzroy Basin, raising awareness about aquatic and marine ecosystem health and providing information to industry, government, other stakeholders and the community. The index and report card will be developed in a form that communicates simply and comprehensively the health of the catchment to a range of stakeholders and the community. It is important that the index is based on a robust design and development methodology and provides an avenue for not just assessing but also improving ecosystem health.

This report aims to provide FPRH with the information required to develop an appropriate set of ecosystem health indicators, develop a process to evaluate the condition of the Fitzroy in a simplified index system and develop an ecosystem health report card. Part of this process, including a review of FPRH data, is included in the second volume of this report *"Part B: Analysis and interpretation of data for the Fitzroy and application to an Ecosystem Health Index and Report Card"*. This first volume of the report provides a review of current knowledge about the Fitzroy Basin and ecosystem health indicators, and a framework and methodology for deciding upon indicators for inclusion in the index. The reviews and information provided in both volumes of the report will be used by FPRH in conjunction with advice from a Science Coordinator, the Science Panel and other activities to decide upon a framework and process for developing the initial report card.

The following ten recommendations have been developed to assist FPRH and the Science Panel with the development of an Ecosystem Health Index and Report Card for the Fitzroy Basin.

RECOMMENDATION ONE.

That the objectives of the Ecosystem Health Index for the Fitzroy Basin are to:

1. understand ecosystem health of waterways in the freshwater catchments, estuarine and marine environments in the Fitzroy Basin, its delta and Keppel Bay;
2. identify changes in ecosystem health taking into account natural variations;
3. synthesise complex data at a regional scale into easily interpretable scores;
4. provide information on ecosystem health in the Fitzroy Basin which is accessible and interpretable by government, stakeholders and the community;
5. provide information which can be used to advise policy makers on areas of declining ecosystem health, in order to drive management change; and
6. assess ecosystem health within a causal framework that helps to link management responses to current and future changes in condition.

It is important that the objectives of the Ecosystem Health Index and Report Card are established early and are specific enough to guide decisions in the development and continuing maintenance of the program. The objectives need to adequately cover the intent of the index and what can realistically be achieved to ensure that as the index develops over time the intent of the program and its outputs are not obscured.

RECOMMENDATION TWO.

That the Driving force-Pressure-State-Impact-Response (DPSIR) framework is used to conceptualise the causal chain of ecosystem health in the Fitzroy Basin, as a basis for deciding upon potential indicators that may be included in the index.

The use of an established framework for indicator selection provides benefits including increased transparency, public confidence, and clarification of the interpretation and validation of information provided by indicators (Niemeijer and de Groot, 2008). Causal chain frameworks also allow for the conceptual validation of indicators and may provide benefits in terms of not just monitoring and assessing ecosystem health but also, over time, improving it. The DPSIR framework has been recommended in this instance as it is sufficiently detailed to allow for the full range of ecosystem characteristics, including natural variations and anthropogenic impacts in the Fitzroy Basin, while remaining simple enough to be meaningful in a relatively data-poor environment. The conceptual separation of impacts from state is particularly useful as it allows for the recognition of sequential impacts caused by interactions between ecosystem health indicators.

RECOMMENDATION THREE.

That water quality issues within the Fitzroy Basin are classified into freshwater, estuary and marine zones, and that the freshwater zone is differentiated into a number of sub-catchments.

Water quality issues within the Fitzroy Basin can be classified into three geographic zones: freshwater, estuary and marine. Within the freshwater zone, substantial variability can be further captured by differentiating the basin into a number of sub-catchments. Classification of the basin into different zones and sub-catchments allows for more appropriate evaluation of indicators against expected conditions, addressing the variability of conditions across the region. It also allows for an environmental health index to be reported by zone and sub-catchment, improving the usefulness of the index.

RECOMMENDATION FOUR.

That existing guidelines, indices and successful monitoring programs at both national and international levels are taken into account when selecting indicators for inclusion in the Ecosystem Health Index and Report Card for the Fitzroy Basin.

The development of an Ecosystem Health Index for the Fitzroy Basin should be cognisant of current scientific knowledge and existing programs to ensure accuracy and predictability of the index, maximise acceptance and trust by the scientific community and general public, and allow for comparability and consistency with other key ecosystem health monitoring programs. The water quality guidelines, water quality objectives and ecosystem health indices available for the Fitzroy Basin as well as ecosystem health monitoring programs that are being run in the Fitzroy Basin and elsewhere are summarised in Section 6.0 of this report.

RECOMMENDATION FIVE.

That the following categories are used to define indicators selected for inclusion in the Ecosystem Health Index and Report Card for the Fitzroy Basin:

1. Physical and Chemical
2. Nutrients
3. Toxicants
4. Ecology

An Ecosystem Health Index represents a summary of data across a range of indicators in a standardised form (index numbers) so that the indicators can be consolidated and summarised. There are several reasons why it is desirable to summarise indicators into groups or categories rather than across all available indicators. First, some indicators are more related to each other (e.g. nutrients), and it is conceptually more appropriate to group them together. Second, summarising data into indexes means that information and detail is lost in the process, but this loss can be limited by summarising into related groups first. Third, the use of categories helps in the communication of results, and can be more relevant to analysis and policy recommendation than a single condition score. Fourth, the use of categories can help to ensure that an index is designed in a systematic way, avoiding substantial gaps or overlaps in the influence of indicators. Fifth, the use of categories helps to check and adjust the weightings of different groups of indicators in the overall index.

RECOMMENDATION SIX.

That the potential indicators suggested in Appendix IV are considered for inclusion in the Ecosystem Health Index and Report Card for the Fitzroy Basin.

The list of potential indicators provided in Appendix IV of this report was generated using the DPSIR framework with 'State' as a central point. Potential indicators were listed on the basis of scientific literature, other monitoring programs (including EHMP) and expert knowledge. This initial list is all encompassing and is refined significantly in the second volume of this report *"Part B: Analysis and interpretation of data for the Fitzroy and application to an Ecosystem Health Index and Report Card"* such that only a small subset of the list will ultimately be chosen as indicators suitable for inclusion in the final index. The process for refinement includes grading each indicator against selection criteria and analysing existing data to determine the best indicators for inclusion in the index, as described in section 5.1.

The DPSIR framework and information on the environmental assets within the Fitzroy Basin were used to categorise the potential indicators listed in Appendix IV into seven groups. The major objectives of categorising the indicators are to provide a framework for summarising indicators into an index and to improve communication of ecosystem health scores in the index and report card.

RECOMMENDATION SEVEN.

That the selection criteria described in Table 7.1 of this report are used to finalise the subset of indicators to include in the Ecosystem Health Index and Report Card for the Fitzroy Basin and also to identify indicators which may be useful but for which further research or monitoring will be required before future inclusion in the index.

The selection criteria were developed based on a combination of scientific literature, expert knowledge and the criteria used for existing programs. Criteria are split into four categories: Data; Interpretation and communication; Relevance; and Practicality and timeliness. Each category includes four selection criteria. Three of the selection criteria have been flagged as "disqualifying" criteria – two relating to data availability and reliability and one relating to the availability of relevant guidelines. Due to the critical importance of these three criteria it is recommended that an indicator that scores poorly on any of the three is disqualified from further consideration for inclusion in the index. However disqualification in the index development phase should not exclude an indicator from consideration in future iterations of the index; many of the indicators that are excluded in the initial formulation of the index may be good candidates for further research and monitoring projects to enable their future inclusion.

The development of an Ecosystem Health Index and Report Card for the Fitzroy Basin is the first step in resolving some of the limitations to indicator and benchmark interpretation described in this report. It allows for the identification of issues with existing data sets and practices that can be used to improve future iterations of an index and report card. Data gaps are always more apparent when significant effort is placed on finding and using data for particular purposes, and pinpointing these gaps is one of the major benefits of developing an ecosystem assessment and reporting framework.

RECOMMENDATION EIGHT.

That the existing benchmarks for indicators identified in section 6 of this report are adopted for interim use in the Ecosystem Health Index; and that the difficulties and limitations in interpreting indicators and benchmarks described in section 6 of this report are noted. The existing trigger levels and benchmarks will need to be improved over time to fully account for the unique nature of the Fitzroy Basin.

Where possible, existing benchmarks for both best case and worst case scenarios have been identified for the potential indicators listed in Appendix IV. Sources include the Fitzroy Basin Water

Quality Objectives, the Queensland Water Quality Guidelines, the ANZECC Guidelines, the GBRMPA Water Quality Guidelines (all as described in section 6.1 of this report) as well as existing monitoring programs including the EHMP (section 6.3). For some potential indicators benchmarks are not available (e.g. total metals and some ecology indicators).

There are a number of difficulties with interpreting indicators and benchmarks as described in section 6.2. Reasons include difficulties of accounting for variability in the Fitzroy Basin particularly in relation to flow, the ecological relevance of indicators and available data, understanding causality of changes in the state of the environment and predicting changes in ecosystem health, and scoring and weighting indicators within the Ecosystem Health Index. These difficulties are further analysed, discussed and solutions recommended in the second volume of this report *"Part B: Analysis and interpretation of data for the Fitzroy and application to an Ecosystem Health Index and Report Card"*.

RECOMMENDATION NINE.

That the designs used in other report cards is noted and successful elements from these, particularly the South East Queensland EHMP, are considered for adoption or modification to meet the needs of a Report Card for the Fitzroy Basin.

Report cards from other monitoring programs use a variety of approaches to communicate monitoring results. Some of these are more successful than others and they vary in their ability to meet the needs of a program such as FPRH. Some methods used to communicate ecosystem health indicators are described in section 7.0 of this report. There are particular benefits in selecting a similar layout to EHMP reporting, including ease of interpretation for decision makers and others who are already familiar with the EHMP, and to allow for rapid cross-checks of ecosystem health between the two regions. While there would necessarily be differences between the two as a result of the differing pressures, state and impacts, retaining a similar formatting style where possible could provide benefits to both programs.

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APPENDIX I: Alternative frameworks for indicator selection in an ecosystem health index

Pressure-State-Response (PSR)

The PSR framework conceptualises human pressures on the environment, the changes in quality and quantity of natural resources that result and alter the state (condition) of the environment and the consequential human response. It was developed by the United Nations Organisation of Economic Cooperation and Development (OECD) for environmental indicator development in the late 1980s and was used for a preliminary set of environmental indicators in 1991 (Figure A.1). The framework has been modified for various situations many times since, but the concept remains essentially the same. In a PSR framework, **Pressures** arise primarily from anthropogenic activities that affect ecosystems or ecosystem components (e.g. mining, agriculture, urban development). **State** is the resulting environmental condition resulting from the actions of one or many pressures. **Response** indicates the reaction of society and policy makers to environmental change including management actions aimed at reducing or mitigating pressures on the environment.

For example in the case of an agricultural pressure such as pesticide runoff, the resulting state would include deterioration in water quality and potentially changes in biotic assemblages. Responses to these changes may include changes in farmer behaviour (farm management practices), consumer reactions, responses by the agro-food chain (changes in technology, voluntary adoption of safety and quality standards), or government actions (policy changes, regulation, use of economic incentives or disincentives, training and education, research and development) (OECD, 1999).

A modified version of PSR, the Pressure-Stressor-Response framework, was adopted by the Queensland Government in the *Queensland Integrated Waterways Monitoring Framework* (DERM 2010). The framework is designed to convey the linkages between management actions and the ecological health of waterways while incorporating other influences such as climate and historic land and river management practices. The framework recognises a causal change consisting of **pressures** (forces that act on the environment from human and economic activities), **stressors** (components of the environment affected by pressures – e.g. water chemistry) and **responses** (societal reaction to those changes to change the pressures and the state of the environment). The FPRH has adopted the same framework in its program design document (FPRH, 2011).

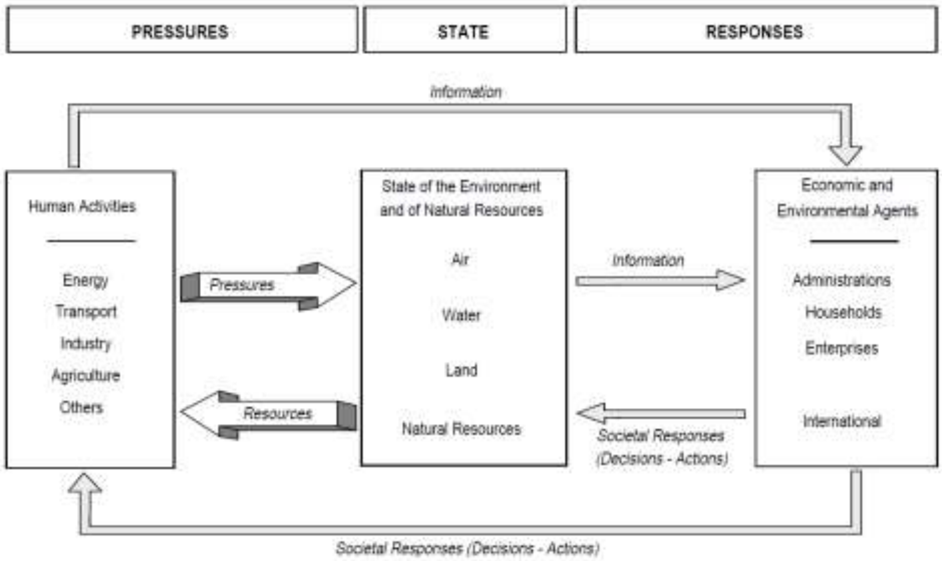

Figure A.1 – The OECD Pressure-State-Response Framework (OECD 1993).

Pressure-State-Response/Effects

The US EPA's Office of Policy, Planning and Evaluation expanded the PSR framework to (amongst other changes) include indicators of the interactions among pressures, states and responses, thereby adding an "effects" category to the PSR framework (Figure A.2). **Effects** indicators reflect the combined impacts of multiple stressors on ecological condition (Jackson et al., 2000).

Driving force-State-Response (DSR)

The DSR framework, derived from the PSR framework, is normally used for indicators for sustainable development. It has also been used as a framework for assessing agricultural lands (Niemeijer and de Groot, 2008). Rather than pressures, the DSR framework describes **Driving forces** including economic, social, environmental and institutional aspects of sustainable development, reflecting both positive and negative impacts (DESA, 2007). The DSR framework has been discontinued by the Commission on Sustainable Development because of its inability to address complex inter-linkages among issues, the ambiguity of classifying indicators into driving force, state or response, uncertainties over causal linkages, and inadequacy in highlighting the relationship between indicators and policy issues (DESA, 2007).

Driving force-Pressure-State-Impact-Response

Described in Section 2.4 of this report.

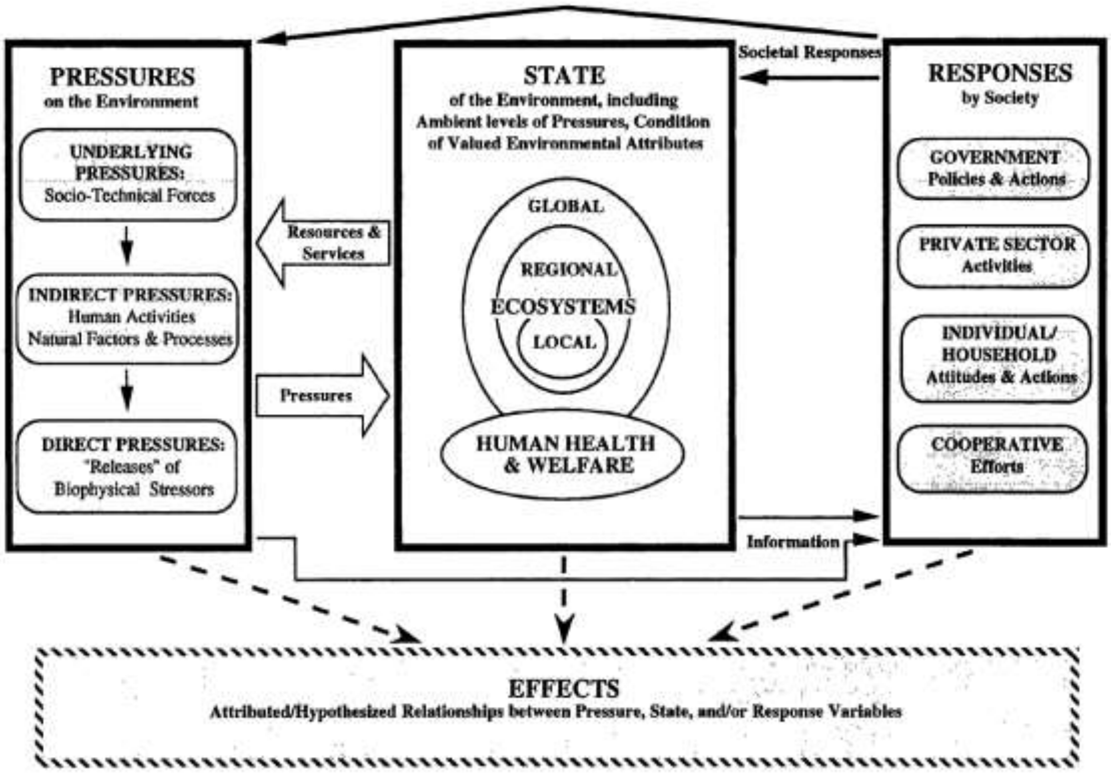

Figure A.2: Pressure-State-Response/Effects framework (source: EPA 1995)

Enhanced Driving force-Pressure-State-Impact-Response (eDPSIR)

The eDPSIR framework was designed as a way of selecting environmental indicators by putting the entire indicator set at the centre of the selection process rather than each individual indicator (Niemeijer and de Groot, 2008). The framework leads to an indicator set that is transparently designed, by applying the concept of a causal network with a focus on the inter-relation of indicators to identify the most relevant indicators for a specific issue and location (Niemeijer and de Groot, 2008). It works on the basis of looking at causal networks in which multiple causal chains interact; and each chain covers a specific issue (Figure A.3; Niemeijer and de Groot, 2008).

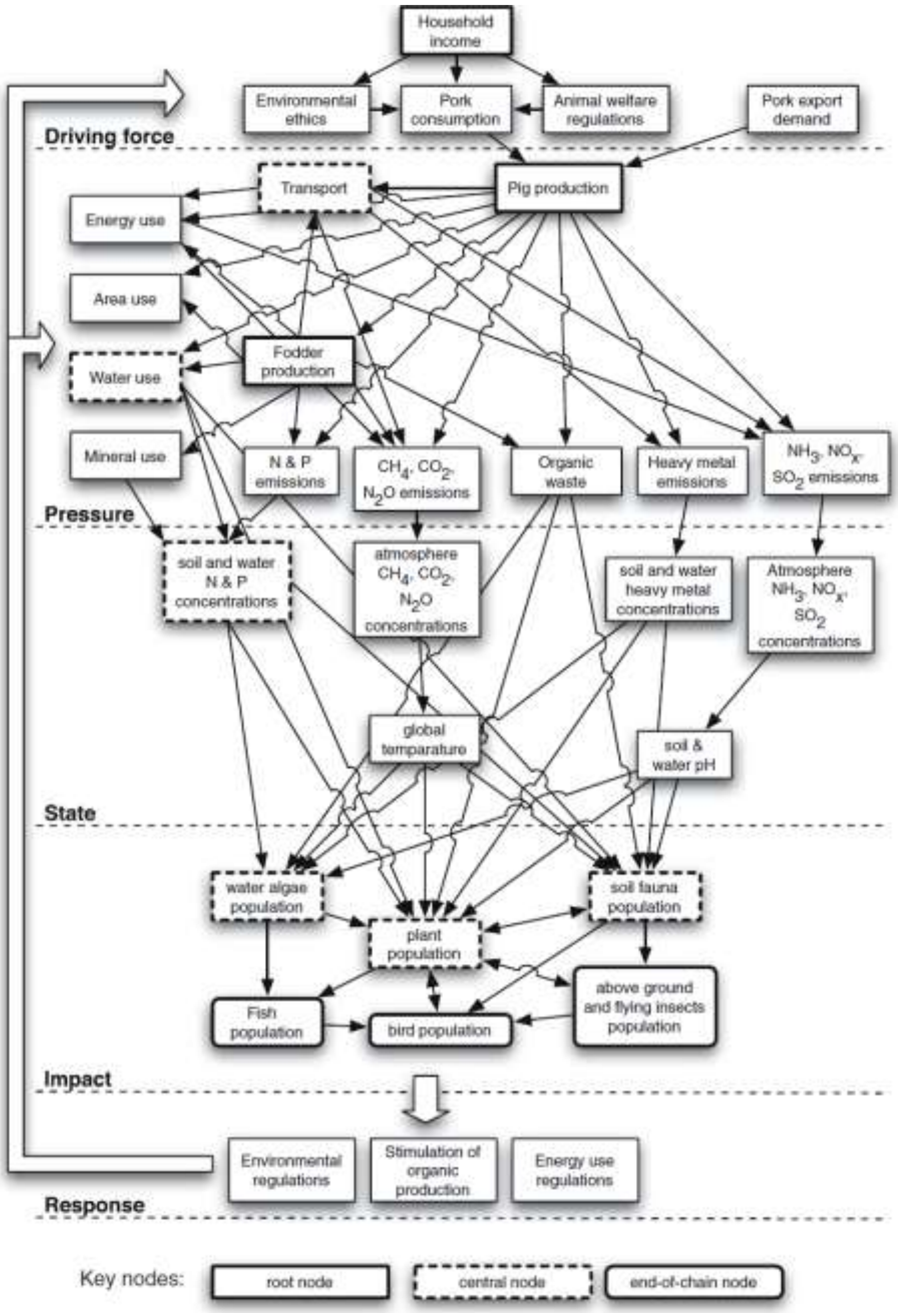

Figure A.3: Simplified causal network diagram for pork production (Source: Niemeijer and de Groot, 2008)

APPENDIX II: Legislation and protected species and habitats

International agreements:

- Ramsar Convention (Ramsar listed wetlands at Shoalwater and Corio Bay – beyond the Fitzroy Basin but within the planning area) www.ramsar.org
- World Heritage List (Great Barrier Reef) http://whc.unesco.org/en/list/154

National (Commonwealth) legislation and plans:

- *Environment Protection and Biodiversity Conservation Act 1999* http://www.comlaw.gov.au/Series/C2004A00485
- *Water Act 2007* http://www.comlaw.gov.au/Details/C2007A00137
- *Environment Protection (Sea Dumping) Act 1981* http://www.comlaw.gov.au/Details/C2012C00012
- *Great Barrier Reef Marine Park Act 1975* http://www.comlaw.gov.au/Details/C2011C00149
- *Great Barrier Reef Protection Amendment Act 2009* http://www.legislation.qld.gov.au/LEGISLTN/ACTS/2009/09AC042.pdf
- 25-Year Strategic Plan for the Great Barrier Reef World Heritage Area (1994) http://www.gbrmpa.gov.au/__data/assets/pdf_file/0004/5476/the-25-year-strategic-plan-1994.pdf

State (Queensland) legislation and plans:

- *Environmental Protection Act 1994* http://www.legislation.qld.gov.au/legisltn/current/e/envprota94.pdf
- Environmental Protection (Water) Policy 2009 (described in Section 4.1 below) http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/E/EnvProWateP09.pdf
- Queensland Water Quality Guidelines 2009 (described in Section 4.1 below) http://www.ehp.qld.gov.au/water/guidelines/queensland_water_quality_guidelines_2009.html
- Fitzroy Environmental Values and Water Quality Objectives (described in Section 4.1 below) http://www.ehp.qld.gov.au/water/policy/schedule1/fitzroy_scheduled_evs_wqos.html
- *Nature Conservation Act 1992* http://www.legislation.qld.gov.au/legisltn/current/n/naturecona92.pdf

- *Coastal Protection and Management Act 1995* http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/C/CoastalProtA95.pdf
- *Water Act 2000* http://www.legislation.qld.gov.au/legisltn/current/w/watera00.pdf
- *Wild Rivers Act 2005* http://www.legislation.qld.gov.au/LEGISLTN/ACTS/2005/05AC042.pdf
- *Fisheries Act 1994* http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/F/FisherA94.pdf
- *Sustainable Planning Act 2009* http://www.legislation.qld.gov.au/LEGISLTN/CURRENT/S/SustPlanA09.pdf
- *Vegetation Management Act 1999* http://www.legislation.qld.gov.au/legisltn/current/v/vegetmana99.pdf
- Reef Plan (described in Section 4.3 below) www.reefplan.qld.gov.au/index.aspx
- General description of legislation http://www.derm.qld.gov.au/water/health/pdf/qld-integrated-waterways-monitoring-framework.pdf

Species and habitats:

The Fitzroy Basin supports significant floral and faunal assemblages including a variety of protected species and habitats. A number of important aquatic species are found in the catchment (freshwater) areas of the Fitzroy Basin. One such species is the Fitzroy River turtle (*Rheodytes leukops*) which is known only from the Fitzroy River and its tributaries and is listed as Vulnerable under both the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and the Queensland *Nature Conservation Act 1992* (NC Act). Several fish species and subspecies are endemic to the region: southern saratoga (*Scleropages leichhardti*), leathery grunter (*Scortum hillii*) and Fitzroy golden perch (*Macquaria ambigua oriens*).

Several protected species are found in the estuarine river delta, including estuarine crocodiles (*Crocodylus porosus* –Marine and Migratory under the EPBC Act and Vulnerable under the NC Act) and in surrounding wetlands habitats, Capricorn yellow chat (*Epthianura crocea macgregori* – Critically Endangered under the EPBC Act and Endangered under the NC Act), Radjah shelduck (*Tadorna radjah* –Marine under the EPBC Act), eastern curlew (*Numenius madagascariensis* – Migratory under the EPBC Act and Near Threatened under the NC Act) and numerous other migratory seabirds. An ecological community – semi-evergreen vine thickets of the Brigalow Belt (Endangered under the EPBC Act) is also found in the surrounding coastal area.

Protected marine species found in the Fitzroy area include the Australian snubfin dolphin (*Orcaella heinsohni* –Migratory under the EPBC Act and Near Threatened under the NC Act), Indo-Pacific humpback dolphin (*Sousa chinensis* –Migratory under the EPBC Act and Rare under the NC Act), dugong (*Dugong dugon* –Marine and Migratory under the EPBC Act and Vulnerable under the NC Act), green sawfish (*Pristis zijsron* –Vulnerable under the EPBC Act), green turtle (*Chelonia mydas* –

Vulnerable, Marine and Migratory under the EBPC Act and Vulnerable under the NC Act), loggerhead turtle (*Caretta caretta* –Endangered, Marine and Migratory under the EPBC Act and Endangered under the NC Act), olive ridley turtle (*Lepidochelys olivacea* – Endangered, Marine and Migratory under the EPBC Act and Endangered under the NC Act), flatback turtle (*Natator depressus* – Vulnerable, Marine and Migratory under the EPBC Act and Vulnerable under the NC Act), and hawksbill turtle (*Eretmochelys imbricata* – Vulnerable, Marine and Migratory under the EPBC Act and Vulnerable under the NC Act). The Great Barrier Reef World Heritage Area is inscribed on the World Heritage List and protected by the Commonwealth *Great Barrier Reef Marine Park Act 1975* and the EPBC Act (as a nationally significant matter and Commonwealth marine area).

Appendix III: Examples of other ecosystem monitoring programs

Queensland-based Ecosystem Monitoring Programs (DEHP, 2012)

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting
Black Ross (Townsville) Water Quality Improvement Plan	2006 - 2008	Creek to Coral (Townsville City Council) Partners: Former Thuringowa City Council through Creek to Coral	Identify issues and help define the condition of water quality and any trends associated with land use. Inform catchment and water quality models. Determine end of catchment loads and assist with target setting.	Electrical conductivity (µS/cm) Total suspended solids (mg/L) Turbidity (NTU) Total filterable nitrogen (µg N/L) Ammonia (µg N/L) Nitrite (µg N/L) Nitrate (µg N/L) Particulate nitrogen (µg N/L) Total nitrogen (µg N/L) Total filterable phosphorus (µg P/L) Filterable reactive phosphorus (µg P/L) Particulate phosphorus (µg P/L) Total phosphorus (µg P/L)	A range of creeks and drains in the Black and Ross Basins	Monitored: During rainfall run-off events during the wet season. Reported: ACTFR WQ monitoring reports
Cattana Wetlands Monitoring	2010- ongoing	Cairns regional council	To monitor the ecological health of water and the impacts of surrounding cane land and urban run-off on water quality and the ability of the ecosystem to sustain fish and frogs	Total nitrogen Nitric oxide Nitrogen dioxide Ammonia Total phosphorous Filterable reactive phosphorus Biological oxygen demand Dissolved oxygen Suspended solids pH Temperature Salinity 2,4-D-sodium Gramoxine Glyphosate	Local scale; artificial lakes at Smithfield, Cairns	Annual monitoring reported to the Carins Regional Council

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting
				Suscon blue Throttle Shirtan		
Creek to Coral Community Monitoring	Louisa Creekwatch: 2001 Ross River Network, and Sachs, Mundy and Bluewater Creekwatch: 2006 Whites, Stuart and Bohle Creekwatch: 2007 All ongoing	Creek to Coral Initiative and Conservation Volunteers Australia Partners: Queensland Government, NQ Dry Tropics, Community groups, local schools	To involve the local community in catchment management activities, such as water quality monitoring. To help create local ownership of Townsville's waterways through education and involvement. *To* provide environmental benefits to the local environment and social benefits to volunteers, while also providing valuable data that may be used in decision making	Dissolved oxygen Electrical conductivity pH Temperature (air and water) Turbidity Fish (presence) Macro-invertebrates (SIGNAL score) Presence of other riverine flora and fauna	Local government area scale. Monitoring is conducted at a number of sites associated with Louisa Creek, Ross River, Sachs Creek, Mundy Creek, Bluewater Creek, Whites Creek, Stuart Creek and Bohle River in the Townsville local government area	Monthly monitoring with reporting to Creek to Coral Website
Great Artesian Basin Springs Monitoring Program	2011 -2016	Queensland Government	To examine the relationship between spring flows and vegetated wetland area in order to monitor groundwater flows from springs. This is to improve the water resource plans in the Great Artesian Basin	Extent of the wetted area of springs Flow of water from springs Flow of water in watercourses Date and time at which measurements are collected	Basin Scale. Monitoring at six sites across the Great Artesian Basin	Monitoring to be conducted at least every 3 years and results to be published as a report.
Lake Eyre Basin River Health Assessment	2011 – review in 10 years	Queensland Government Partners: South Australian Government,	To understand Lake Eyre Basin Condition and underpin responses to condition; form consistent messages about condition and guide ongoing research and monitoring.	Fish assemblages: Species richness, Abundance, Abundance of alien species, Recruitment, Population size structure, Abundance of detritivores, Prevalence of disease.	Basin scale monitoring. 82 sites, 28 in Queensland	Monitoring annually, 5 and 10 year assessments. Reported in the Lake Eyre Basin Agreement

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting
		Northern Territory Government		Water Quality – (spot readings only): Conductivity, pH, Dissolved oxygen (diel range), Turbidity, Water temperature (diel range). Hydrology – (data from gauging stations and data loggers): Total surface water availability, Water storage capacity, Water licensing, Filling of terminal lakes, Floodplain inundation, In-channel events, Persistence of key waterholes Note: Waterbirds, vegetation and physical habitats are all proposed indicators to be included at a later date.		
Lyngbya Monitoring Program	2000 - Ongoing	Queensland Government Partners: Local South East Queensland Governments and SEQ Healthy Waterways Partnership	To monitor presence of the potentially toxic cyanobacterium *Lyngbya* in South East Queensland (primarily Moreton Bay). Provide information to assist understanding of overall ecosystem health and assist research into causes and impacts of *Lyngbya*.	*Lyngbya* presence and coverage (by category 0-10 %, 10-40 %, 40-70 % and 70-100 %)	Regional Scale Central Moreton Bay , South-west Moreton Island, Horseshoe Bay, Deception Bay, Pumicestone Passage , Eastern and Southern Moreton Bay, targeted foreshores in Moreton Bay Regional Council and Redland City Council areas	Monitoring is conducted 2 monthly, monthly and may be increased to fortnightly in some areas if large blooms occur. Opportunistic inspections may occur if Lyngbya is reported. Information is collated monthly and reported through EHP

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting
Moreton Bay Regional Council Waterway Health Monitoring Program	1991-Ongoing	Moreton Bay Regional Council	Monitor the ecosystem health of waterways within the Moreton Bay region to produce stream health maps for strategic infrastructure and town planning. Track the effectiveness and performance of management initiatives under the Total Water Cycle Management Plan.	Biological: For freshwater streams - species level macroinvertebrates identification For estuarine waters - species level phytoplankton identification. Physical/chemical: Temperature, conductivity, salinity, dissolved oxygen, pH, turbidity, chlorophyll *a*, total nitrogen, ammonium – N, nitrate – N, nitrite – N, particulate – N, dissolved organic – N, total phosphorus, orthophosphate – P, particulate – P , dissolved organic – P, total suspended solids. Sediment samples at selected sites: arsenic, cadmium, chromium, copper, lead mercury, nickel, silver, zinc.	Local Government area. About 900 kilometres of freshwater streams in the Moreton Bay Regional Council local government. 160 sites over a four-year cycle. An extra 115 kilometres of estuarine environment.20 sites on a quarterly basis.	Variable monitoring reports by council
Murray-Darling Basin Authority Basin Salinity Management Strategy Annual Reporting and Audit	2001- 2024	Queensland Government Partners: Murray Darling Basin Authority	To monitor its compliance with end-of-valley salinity targets and present this information in an audited annual report.	Date, total daily stream flow (ML), mean daily electrical conductivity.	Basin Scale Ten end-of-valley salinity target sites located (downstream of irrigation) in the Queensland and northern New South Wales sections of the Murray-Darling Basin.	Daily continuous loggers, results reported in Annual Reports

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting
					Four interpretive sites.	
South East Queensland Catchments Community Water Quality Monitoring Program	2005 - ongoing	SEQ Catchments and a number of agencies, governments, volunteers and water authority	To assess finer spatial trends from ambient sampling, raise the awareness of surface and groundwater conditions, identify areas for remediation, validate existing data and assist local councils with their monthly monitoring programs.	Conductivity, pH, turbidity, water temperature, salinity, chlorophyll-*a*, air temperature, nitrates, phosphorus, dissolved oxygen, Secchi depth	Regional sampling conducted in the 13 recognised level 2 sub-catchments in SEQ	Monthly and bimonthly monitoring. Data available from SEQ catchments.

National Ecosystem Monitoring Programs

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting	Reference
National action Plan (NAP) on Salinity and Water Quality	2004 -2006	National Government?	To collect sediment and nutrient data during storm run-off events to quantify the typical event mean concentration values for ephemeral catchments across Queensland for a range of land uses. To use the collected data to define parameters for catchment water quality models such as E2 and SedNet, and to calibrate and validate these models.	Total suspended solids Total nitrogen Total phosphorus Total Kjeldahl nitrogen Total organic carbon Filterable reactive phosphorus Nitrate Nitrite Ammonia	A total of sixteen sites were monitored across Reef catchments in the Fitzroy, Burdekin and Burnett Mary natural resource management regions. Monitoring was also conducted in a number of non-Reef catchments.	Monitoring was conducted from 2004 to 2006. Monitoring is continuing at many of these sites through other programs, such as Reef Water Quality Protection Plan I5 event monitoring.	(Department of Natural Resources and Water, 2008)

Name of Monitoring Program	**Dates of operation**	**Who's involved**	**Objectives**	**Indicators**	**Scale and Sampling Location**	**Monitoring and Reporting**	**Reference**
Molonglo River Rescue Action Plan, ACT (Monitoring and Evaluation)	2008 – Ongoing	ACT Natural Resource Management Council And a number of other partners.	To rehabilitate the Molonglo River	Dissolved Oxygen Phosphates Turbidity Electrical conductivity Temperature Nitrates/Nitrites pH Frogs Platypus Photos (of riparian vegetation condition and rehabilitation)	Pilot restoration of 20km of the River corridor and restoration of strategic drainage channels identified as having a high impact on the water quality of the river. The pilot will be located between Carwoola, NSW and Fyshwick, ACT and will connect with recent riparian restoration in the Molonglo Gorge on the ACT/NSW border.	Ongoing monitoring is undertaken by ACT Waterwatch and community volunteers.	http://www.molonglocatchment.com.au/Projects/MRR.htm and (Bowman and Keyzer, 2010)
Lake Burley Griffin Water Quality Monitoring Program	1981 – Present	National Capital Authority	To monitor the overall environment of the Lake as well as the bacterial quality and algal conditions during specific periods at specific sites (to support the recreational use of the Lake).	Turbidity, Suspended solids Phosphorus Nitrogen Ammonia Total Algae Cyanobacteria Chlorophyll-a Conductivity pH Faecal Coliforms Dissolved Oxygen Metals (water and sediment)	Routine testing of midstream samples; Microbiological monitoring of designated recreational sites; Algal monitoring program Other tests (e.g. event based tests, stormwater monitoring, sampling variability investigation; pathogenic free-living protozoans).	Midstream samples for five sites – usually monthly. Weekly bacterial monitoring between mid October to mid April. Routine algal monitoring in selected locations.	(National Capital Authority, 2012)
River Murray Water Quality Monitoring Program	1978 - Ongoing	Murray Darling Basin Authority (MDBA)	To periodically report and assess water quality, to understand the variability and to determine trends, to guide management actions along the River Murray and the lower	A number of physical and chemical parameters.	36 sites along the River Murray and the lower reaches of its tributaries.	Depending on the class of station, between 5 and 18 physico-chemical parameters are measured at weekly, monthly and	http://www.mdba.gov.au/programs/water-quality-monitoring-program

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting	Reference
			reaches of its tributaries and storages.			quarterly intervals.	
MDBA Biological monitoring program: Macroinvertebrates			Systematically sample and record the aquatic macroinvertebrate populations of the rivers to provide a substantial long-term biological record to complement the physico-chemical parameters.	Aquatic macroinvertebrate populations, dissolved oxygen(DO), pH, electrical conductivity (EC), turbidity and water temperature are measured at deployment and retrieval of artificial substrates.	8 locations on the River Murray and Lower Darling rivers.	Sampling is conducted bi-annually in Autumn and Spring.	
Gippsland Lake Intensive Water Quality Monitoring Program	2006 -2007	Victorian EPA	To increase understanding of the current environmental condition of the Lake King and Lake Victoria sections of Gippsland Lakes. To help develop models to assess and forecast the ecological health of the lakes.	In-lakes study: salinity, dissolved oxygen, chlorophyll-a, light attenuation, suspended solids and nutrients. Riverine nutrient load study: nutrient loads, suspended particulate matter and coloured dissolved organic matter.	Eight sites in Lakes King and Victoria – intensive monitoring due to occurrence of toxic algal blooms Lower priority sites are monitored at lower frequencies under existing Victorian EPA programs.	Salinity, dissolved oxygen, chlorophyll-a are monitored continuously (in-situ). Suspended solids, nutrients and light Attenuation, discrete samples collected on a monthly basis (EPA fixed-sites program).	(EPA Victoria, 2008)
Sustainable Rivers Audit	2004-	Initiative of the Murray-Darling Basin Commission Partners: state,	The Sustainable Rivers Audit (SRA) is a systematic assessment of the health of river ecosystems in the Murray–Darling Basin	Environmental metrics derived from field samples and/or modelling are combined as indicators of condition in five	The first audit completed assessments of condition and ecosystem health at the valley scale and in altitudinal zones, and future reports will include trend assessments.		(Davies *et al.*, 2010)

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting	Reference
		territory and federal governments; Independent Sustainable Rivers Audit Group	(MDB), Australia. It is designed to represent functional and structural links between ecosystem components, biophysical condition and human interventions in the MDB.	themes (Hydrology, Fish, Macroinvertebrates, Vegetation and Physical Form). Condition indicator ratings are combined using expert-system rules to indicate ecosystem health, underpinned by conceptual models. Reference condition, an estimate of condition had there been no significant human intervention in the landscape, provides a benchmark for comparisons.			
National Land and Water Resources Audit	1997-2008	Collaborative program between all States, Territories and the Australian Government.	Second Phase NLWRA (2002-2008): to develop information to support the assessment of change in natural resources as a result of government programs.	Various	National Scale	Numerous reports and scientific documents can be found at nlwra.gov.au	http://lwa.gov.au/programs/national-land-and-water-resources-audit nlwra.gov.au

International Ecosystem Monitoring Programs

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting	Reference
Gui River, China	April 2010	Australia-China Environment Development Partnership	To establish a method for selecting suitable indicators of river health and to make an initial assessment of river health in the Gui River catchment.	Water quality, benthic macroinvertebrates, fish, algae, aquatic and riparian vegetation. (For each of these indicator groups, a range of different indicators was assessed to determine whether indicator values changed in a predictable way with changes in levels of disturbance in the catchment and whether they were suitable for reflecting changes in river health).	Twenty-five sites across the Gui River catchment, located in the Pearl River Basin in China's south-east.	Results were discussed in a technical document and also presented as a report card.	(Bond *et al.*, 2012)
The EU Water Framework Directive – Integrated river basin management for Europe	Member States were required to set up monitoring programmes by December 2006	All member states of the EU	The directive aims establishes a legal framework to protect and restore clean water across Europe and to ensure its long-term, sustainable use. To achieve "good ecological status" of all surface waters by 2015.	Chemical composition of water, a number of key biological elements, and the hydrological and morphological characteristics of water bodies. Groundwater quality and quantity. Member states to decide the best method based on local conditions and existing national approaches.	Long-term surveillance monitoring, operational monitoring, investigative monitoring and more detailed analysis in areas that are protected for drinking water or for natural habitats and species.	Output – Ecological status classification: High, Good, Moderate, Poor, Bad.	http://ec.europa.eu/environment/water/water-framework/index_en.html

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting	Reference
				"Quality elements" to be used in determining ecological status: phytoplankton; other aquatic flora; benthic invertebrate fauna; and fish fauna.			
Chesapeake Bay , USA Monitoring Programs	1984 - Ongoing	Chesapeake Bay Program Partners: Federal and state agencies, local governments, non-profit organisations and academic institutions	To detect changes. To improve understanding of the natural environment. To reveal trends over time. Provide information to policy makers.	19 phys-chem and biological parameters. Monitoring includes measurement of: freshwater inputs, nutrients and sediment, chemical contaminants (including organic compounds and heavy metals), plankton, benthos, shell fish, fish, grasses, temperature, salinity and dissolved oxygen (including depth profiles).	Monitored 20 times a year within the Bay and its tributaries.		(2012) http://www.chesapeakebay.net/about/programs/modeling
San Francisco Bay, USA Water Quality Monitoring in the San Francisco Bay Area Network (SFAN)	2006-onwards	National Park Service	To determine existing ranges, variability, and long term trends in water quality through analysis of selected parameters, as well as to determine the extent to which selected sites meet federal and state water quality criteria.	Water temperature, dissolved oxygen, pH, specific conductance, and discharge; coliform bacteria (total coliform and *E. coli*); nitrate, ammonia, and total Kjeldahl nitrogen (TKN)	Eleven watersheds separated into two groups that are sampled in alternate two-year periods	Between 1 October 2006 and 30 September 2007, 255 sampling visits to 25 sites were made.	http://science.nature.nps.gov/im/units/sfan/vital_signs/water_quality/water_quality.cfm
South African River Health	1994-	The Department of Water Affairs	To serve as a source of information regarding	In-stream and riparian biological communities (e.g.	South African provinces – note:		http://www.csir.co.za/rhp/

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting	Reference
Programme (Now part of the National Aquatic Ecosystem Health Monitoring Program)		and Forestry (DWAF) Dept. of Environmental Affairs and Tourism Water Research Commission	the overall ecological status of river ecosystems in South Africa. To characterise the response of the aquatic environment to multiple disturbances.	fish, invertebrates, vegetation).	implementation is voluntary.		
Environmental Monitoring and Assessment Program (EMAP), USA	1990 -2006	US EPA	EMAP aimed to advance the science of ecological monitoring and ecological risk assessment. Guide national monitoring with improved scientific understanding of ecosystem integrity and dynamics, and demonstrate multi-agency monitoring through large regional projects. EMAP also investigated designs that addressed the acquisition, aggregation, and analysis of multiscale and multitier data.	EMAP developed indicators to monitor the condition of ecological resources. Including, contaminant indicators: Fish tissue analysis for mercury, 21 pesticides, 20 PCB congeners, 6 PBDEs, % moisture and lipid content, stable isotope analysis; sediment toxicity.	Multiple spatial and temporal scales		http://www.epa.gov/emap/greatriver/indicator/LazorchakContaminantIndicators.pdf http://www.epa.gov/emap/html/about/ordemap.pdf

Name of Monitoring Program	Dates of operation	Who's involved	Objectives	Indicators	Scale and Sampling Location	Monitoring and Reporting	Reference
Strickland River system environmental Monitoring, PNG	1990-ongoing	Porgera Joint Venture Report card: Porgera Environmental Advisory Komiti (PEAK)	The major focus is on heavy metals and other potential mining related contaminants.	Five groups of indicators: Dissolved metals (silver, arsenic, cadmium, copper, mercury, nickel, lead and zinc); Sediment metals; other water quality (conductivity, total suspended solids, pH and cyanide); metals in fish tissues and fish composition (which is broken up into a further 6 indicators): B – Biomass of fish caught in standardised sample; B/I - Average biomass per individual fish (I); TG1 - Biomass proportion of top predators (trophic group 1); TG2 - Biomass proportion of aquatic invertivores (trophic group 2); TG3 - Biomass proportion of terrestrial insectivores (trophic group 3); TG1/TG4 - Biomass ratio of top predators (TG1): detritivores (TG4).	Riverine system from just downstream of the Porgera mine (Porgera River) to Lake Murray on the Strickland River floodplain.	(The 2008) Reporting uses a system of trigger levels of concern for ecosystem health. The median value for each index is calculated for each site for the year in relation to a pre-determined reference value (RV) and two trigger levels of concern. For each index, the 80th percentile of all data collected to date is used as the reference value (RV) for each reporting region. The results are conveyed in a report card that shows indicators with median values below the RV as Green; results outside of trigger values as amber, and parameters of moderate concern are coloured yellow. The overall average colour of a suite of indicators (e.g of all dissolved metals) is the colour displayed on the report card.	http://www.barrick.com/files/porgera/PEAK-Porgera-Report-Card-2010.pdf

Appendix IV: List of the potential indicators and benchmarks identified

KEY
Fitzroy Estuarine Guidelines
Fitzroy WQOs
ANZECC Guidelines for Moderately Disturbed Aquatic Ecosystem
ANZECC Interim Sediment Quality Guidelines- high
ANZECC Interim Sediment Quality Guidelines- low
GBRMPA
State of the Environment Reports
NA = Not applicable

Note: Actual guidelines should be consulted for further details on all benchmarks listed (e.g. some guidelines have determined two levels for protection of 95% or 99% of species, but only one value is listed in this table, alternatively guidelines may have been determined with differing levels of reliability). Some benchmarks exist but were too detailed to be listed; these are colour coded to direct readers to the appropriate guideline. If two guidelines exist for one parameter, then the most local one is listed.

Ecosystem Health Category	Indicator	Units	Benchmark																		
			Fresh													Estuarine			Marine		
			Callide	Comet	Nogoa	Theresa	Mackenzie	Upper Isaac	Lower Isaac	Connors	Upper Dawson	Lower Dawson	Fitzroy (main river trunks/channels)	Fitzroy (River floodplain habitat)	Freshwater lakes/reservoirs	Upper Estuary	Mid Estuary	Enclosed coastal/ lower estuary waters	Open Coastal	Mid shelf	Offshore
Physical/ Chemical	Sulfate	mg/L	20	5	15	25	10	25	5	5	5	25	15	15							
Physical/ Chemical	Fluoride																				
Physical/ Chemical	Secchi Depth	m																1.0/1.5	2.0	0.45	0.4
Physical/ Chemical	*k*dPAR																				
Physical/ Chemical	Turbidity	NTU	50	50	50	50	50	50	50	50	50	50	50	50	20	30					
Physical/ Chemical	Temperature	^{0}C																			
Physical/ Chemical	Diel temperature																				
Physical/ Chemical	pH Value		6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.5	6.5-8.0	7.0-8.4	7.0-8.4	8.0-8.4			
Physical/ Chemical	Colour																				

Physical/ Chemical	**Electrical Conductivity @ 25°C**																				
Physical/ Chemical	**Conductivity base flow**	µS/cm	1150	375	350	340	310	720	410	430	370	340	445	445							
Physical/ Chemical	**Conductivity high flow**	µS/cm	600	210	210	250	210	250	210	250	210	210	250	250							
Physical/ Chemical	**DO**	% Saturation	85-110	85-110	85-110	85-110	85-110	85-110	85-110	85-110	85-110	85-110	85-110	85-110	90-110	70-100	85-100	90-100			
Physical/ Chemical	**ORP**																				
Physical/ Chemical	**Diel DO range**																				
Physical/ Chemical	**Total Dissolved Solids @180°C**																				
Physical/ Chemical	**Suspended Solids**	mg/L	30	30	165	10	110	55	30	15	30	10	85	85				5.0/15	2.0	2.0	0.7
Physical/ Chemical	**Alkalinity**																				
Physical/ Chemical	**Chloride**																				
Physical/ Chemical	**Calcium**																				
Physical/ Chemical	**Magnesium**																				
Physical/ Chemical	**Sodium**																				
Physical/ Chemical	**Potassium**																				

Physical/ Chemical	**Total Anions**																				
Physical/ Chemical	**Total Cations**																				
Physical/ Chemical	**Ionic Balance**																				
Physical/ Chemical	**SAR**																				
Physical/ Chemical	**RA**																				
Physical/ Chemical	**DO depth profiles**																				
Nutrients	**Ammonia as N**	μS/cm	20	20	20	10	20	20	20	20	20	20	20	20	10	30	10	8			
Nutrients	**Nitrite as N**																				
Nutrients	**Nitrate as N**																				
Nutrients	**Nitrite + Nitrate as N**																				
Nutrients	**Oxidised N**	μg/L	60	60	60	60	60	60	60	60	60	60	60	60	10	15	10	3			
Nutrients	**Organic N**	μg/L	420	420	420	420	420	420	420	420	420	420	420	420	330	400	260	180			
Nutrients	**Total Kjeldahl Nitrogen as N**																				
Nutrients	**Total Nitrogen as N**	μg/L	500	500	1070	500	775	500	455	485	620	500	500	500	350	450	300	200			
Nutrients	**Total Phosphorus as P**	μg/L	20	20	20	20	20	20	20	20	20	20	20	20	5	10	8	6			

Nutrients	**Reactive Phosphorus as P**	µg/L	20	20	20	20	20	20	20	20	20	20	20	20	5	10	8	6			
Nutrients	**Particulate Nitrogen**																		20	20	17
Nutrients	**Particulate Phosphorus**																		2.8	2.8	1.9
Nutrients	**Chlorophyll-a concentration**	µg/L																2.0	0.45	0.45	0.4
Toxicant	**Tebuthiuron**	µg/L	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2				0.2	0.2	0.2
Toxicant	**2,4-D-sodium**																				
Toxicant	**Gramoxine**																				
Toxicant	**Glyphosate**	µg/L	370	370	370	370	370	370	370	370	370	370	370	370	370						
Toxicant	**Suscon blue**																				
Toxicant	**Throttle**																				
Toxicant	**Shirtan**																				
Toxicant	**Dissolved Al**	µg/L	55	55	55	55	55	55	55	55	55	55	55	55	55						
Toxicant	**Dissolved As**	µg/L	13	13	13	13	13	13	13	13	13	13	13	13	13						
Toxicant	**Dissolved As**	µg/L	24	24	24	24	24	24	24	24	24	24	24	24	24						
Toxicant	**Dissolved B**	µg/L	370	370	370	370	370	370	370	370	370	370	370	370	370						
Toxicant	**Dissolved Cd**	µg/L	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2						0.7
Toxicant	**Dissolved Cr**	µg/L																			27.4
Toxicant	**Dissolved Cr**	µg/L	1	1	1	1	1	1	1	1	1	1	1	1	1						4.4

Toxicant	**Dissolved Co**	µg/L																			1
Toxicant	**Dissolved Cu**	µg/L	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4						1.3
Toxicant	**Dissolved Fe**	µg/L																			
Toxicant	**Dissolved Pb**	µg/L	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4						4.4
Toxicant	**Dissolved Mn**	µg/L	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900						
Toxicant	**Dissolved Hg**	µg/L	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06						0.1
Toxicant	**Dissolved Mo**	µg/L																			
Toxicant	**Dissolved Ni**	µg/L	11	11	11	11	11	11	11	11	11	11	11	11	11						7
Toxicant	**Dissolved Se**	µg/L																			
Toxicant	**Dissolved Ag**	µg/L	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05						1.4
Toxicant	**Tributyltin (as Sn)**	µg/L																	0.0004	0.0004	0.0004
Toxicant	**Dissolved U**	µg/L																			
Toxicant	**Dissolved V**	µg/L																			100
Toxicant	**Dissolved Zn**	µg/L	8	8	8	8	8	8	8	8	8	8	8	8	8						15
Toxicant	**Total Aluminium**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Arsenic**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Boron**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Cadmium**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA

Toxicant	**Total Chromium**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Cobalt**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Copper**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Iron**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Lead**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Manganese**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Molybdenum**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Nickel**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Selenium**	µg/L	5	5	5	5	5	5	5	5	5	5	5	5	5						
Toxicant	**Total Silver**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Uranium**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Vanadium**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Zinc**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**Total Mercury**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA			NBA
Toxicant	**C6 - C9 Fraction**																				
Toxicant	**C10 - C14 Fraction**																				
Toxicant	**C15 - C28 Fraction**																				

Toxicant	**C29 - C36 Fraction**																				
Toxicant	**C10 - C36 Fraction (sum)**																				
Toxicant	**C6 - C10 Fraction**																				
Toxicant	**C6 - C10 Fraction minus BTEX (F1)**																				
Toxicant	**>C10 - C16 Fraction**																				
Toxicant	**>C16 - C34 Fraction**																				
Toxicant	**>C34 - C40 Fraction**																				
Toxicant	**>C10 - C40 Fraction (sum)**																				
Toxicant	**Benzene**	µg/L	950	950	950	950	950	950	950	950	950	950	950	950	950						500
Toxicant	**Toluene**																				
Toxicant	**Ethylbenzene**																				
Toxicant	**o-xylene**	µg/L	350	350	350	350	350	350	350	350	350	350	350	350	350						
Toxicant	**m-xylene**																				
Toxicant	**p-xylene**	µg/L	200	200	200	200	200	200	200	200	200	200	200	200	200						
Toxicant	**m+p-xylene**																				
Toxicant	**total BTEX (BTEXN/ BTEXS)**																				

Toxicant	**Chlordane**	µg/L	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03						
Toxicant	**DDT**	µg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01						
Toxicant	**Endosulfan**	µg/L	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03				0.005	0.005	0.005
Toxicant	**Endrin**	µg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01						
Toxicant	**Heptachlor**	µg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01						
Toxicant	**Lindane**	µg/L	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2						
Toxicant	**Toxaphene**	µg/L	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1						
Toxicant	**Azinphos methyl**	µg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01						
Toxicant	**Chlorpyrifos**	µg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01						0.01
Toxicant	**Diazinon**	µg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01				0.00003	0.00003	0.00003
Toxicant	**Dimethoate**	µg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02						
Toxicant	**Fenitrothion**	µg/L	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2						
Toxicant	**Malathion**	µg/L	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02						
Toxicant	**Parathion**	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0						
Toxicant	**Temephos**																				0.05
Toxicant	**Carbofuran**	µg/L	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06						
Toxicant	**Methomyl**	µg/L	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5						
Toxicant	**Esfenvalerate**	µg/L	0	0	0	0	0	0	0	0	0	0	0	0	0						
Toxicant	**Diquat**	µg/L	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4						
Toxicant	**2,4-D**	µg/L	280	280	280	280	280	280	280	280	280	280	280	280	280				0.8	0.8	0.8

Toxicant	**2,4,5-T**	µg/L	36	36	36	36	36	36	36	36	36	36	36	36	36						
Toxicant	**Molinate**	µg/L	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.4						
Toxicant	**Thiobencarb**	µg/L	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8						
Toxicant	**Thiram**	µg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01						
Toxicant	**Atrazine**	µg/L	13	13	13	13	13	13	13	13	13	13	13	13	13				0.6	0.6	0.6
Toxicant	**Simazine**	µg/L	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2				0.2	0.2	0.2
Toxicant	**Trifluralin**	µg/L	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6						
Toxicant	**Diuron**	µg/L																	0.9	0.9	0.9
Toxicant	**MEMC**	µg/L																	0.002	0.002	0.002
Toxicant	**Ametryn**	µg/L																	0.5	0.5	0.5
Toxicant	**Hexazinone**	µg/L																	1.2	1.2	1.2
Toxicant	**Linear alkylbenzene sulfonates**	µg/L	280	280	280	280	280	280	280	280	280	280	280	280	280						
Toxicant	**Alcohol ethoxyolated sufate**	µg/L	650	650	650	650	650	650	650	650	650	650	650	650	650						
Toxicant	**Alcohol ethoxylated surfactants**	µg/L	40	40	40	40	40	40	40	40	40	40	40	40	40						
Toxicant	**Aroclor 1242**	µg/L	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3						
Toxicant	**Aroclor 1254**	µg/L	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01						
Toxicant	**Napthalene**	µg/L	16	16	16	16	16	16	16	16	16	16	16	16	16						50
Toxicant	**Anthracene**																				

Toxicant	**Phenanthrene**																				
Toxicant	**Fluoranthene**																				
Toxicant	**Benzo(a)pyrene**																				
Toxicant	**Mussel bioaccumulation**																				
Toxicant	**Oyster bioaccumulation**																				
Toxicant	**Enterococci**																				
Toxicant	**N15 uptake in macroalgae**																				
Toxicant	**1.2-Dichloroethane-D4**																				
Toxicant	**Toluene-D8**																				
Toxicant	**4-Bromofluorobenzene**																				
Toxicant	**Volatile Acids as Acetic Acid**																				
Toxicant	**Silica Si02 - dissolved**																				
Toxicant	**Sulphide as S2**																				
Toxicant	**Ammonia**	µg/L	900	900	900	900	900	900	900	900	900	900	900	900	900						910
Toxicant	**Chlorine**	µg/L	3	3	3	3	3	3	3	3	3	3	3	3	3						

Toxicant	**Cyanide**	µg/L	7	7	7	7	7	7	7	7	7	7	7	7	7						4
Toxicant	**Nitrate**	µg/L	700	700	700	700	700	700	700	700	700	700	700	700	700						
Toxicant	**Hydrogen sulfide**	µg/L	1	1	1	1	1	1	1	1	1	1	1	1	1						
Toxicant	**Ethanol**	µg/L	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400	1400						
Toxicant	**1,1,2-trichloroethane**	µg/L	6500	6500	6500	6500	6500	6500	6500	6500	6500	6500	6500	6500	6500						1900
Toxicant	**Hexachloroethane**	µg/L	290	290	290	290	290	290	290	290	290	290	290	290	290						290
Toxicant	**Aniline**	µg/L	8	8	8	8	8	8	8	8	8	8	8	8	8						
Toxicant	**2,4-dichloroaniline**	µg/L	7	7	7	7	7	7	7	7	7	7	7	7	7						
Toxicant	**3,4 -dichloroaniline**	µg/L	3	3	3	3	3	3	3	3	3	3	3	3	3						150
Toxicant	**Nitrobenzene**	µg/L	550	550	550	550	550	550	550	550	550	550	550	550	550						150
Toxicant	**2,4-dinitrotoluene**	µg/L	16	16	16	16	16	16	16	16	16	16	16	16	16						
Toxicant	**2,4,6-trinitrotoluene**	µg/L	140	140	140	140	140	140	140	140	140	140	140	140	140						
Toxicant	**1,2-dichlorobenzene**	µg/L	160	160	160	160	160	160	160	160	160	160	160	160	160						
Toxicant	**1,3-dichlorobenzene**	µg/L	260	260	260	260	260	260	260	260	260	260	260	260	260						

Toxicant	**1,4-dichlorobenzene**	µg/L	60	60	60	60	60	60	60	60	60	60	60	60	60						
Toxicant	**1,2,3-trichlorobenzene**	µg/L	3	3	3	3	3	3	3	3	3	3	3	3	3						
Toxicant	**1,2,4-trichlorobenzene**	µg/L	85	85	85	85	85	85	85	85	85	85	85	85	85						20
Toxicant	**Phenol**	µg/L	320	320	320	320	320	320	320	320	320	320	320	320	320						400
Toxicant	**2-chlorophenol**	µg/L	340	340	340	340	340	340	340	340	340	340	340	340	340						
Toxicant	**4-chlorophenol**	µg/L	220	220	220	220	220	220	220	220	220	220	220	220	220						
Toxicant	**2,4-dichlorphenol**	µg/L	120	120	120	120	120	120	120	120	120	120	120	120	120						
Toxicant	**2,4,6-trichlorophenol**	µg/L	3	3	3	3	3	3	3	3	3	3	3	3	3						
Toxicant	**2,3,4,6-tetrachlorophenol**	µg/L	10	10	10	10	10	10	10	10	10	10	10	10	10						
Toxicant	**Pentachlorophenol**	µg/L	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6						11
Toxicant	**2,4-dinitrophenol**	µg/L	45	45	45	45	45	45	45	45	45	45	45	45	45						
Toxicant	**Dimethylphthalate**	µg/L	3700	3700	3700	3700	3700	3700	3700	3700	3700	3700	3700	3700	3700						

Toxicant	**Diethylphthal ate**	µg/L	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000						
Toxicant	**Dibutylphthal ate**	µg/L	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9	9.9						
Toxicant	**Poly(acryloni trile-co-butadiene-co-styrene)**	µg/L	530	530	530	530	530	530	530	530	530	530	530	530	530						250
Toxicant	**Corexit 8667**	µg/L																			1100
Toxicant	**Sediment Antimony**	mg/kg dry wt	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2			2
Toxicant	**Sediment Antimony**	mg/kg dry wt	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25			25
Toxicant	**Sediment Cadmium**	mg/kg dry wt	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5			1.5
Toxicant	**Sediment Cadmium**	mg/kg dry wt	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1
Toxicant	**Sediment Chromium**	mg/kg dry wt	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80			80
Toxicant	**Sediment Chromium**	mg/kg dry wt	370	370	370	370	370	370	370	370	370	370	370	370	370	370	37 0	370			370
Toxicant	**Sediment Copper**	mg/kg dry wt	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65	65			65
Toxicant	**Sediment Copper**	mg/kg dry wt	270	270	270	270	270	270	270	270	270	270	270	270	270	270	27 0	270			270
Toxicant	**Sediment Lead**	mg/kg dry wt	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50			50
Toxicant	**Sediment Lead**	mg/kg dry wt	220	220	220	220	220	220	220	220	220	220	220	220	220	220	22 0	220			220
Toxicant	**Sediment Mercury**	mg/kg dry wt	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.1 5	0.15			0.15

Toxicant	**Sediment Mercury**	mg/kg dry wt	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1
Toxicant	**Sediment Nickel**	mg/kg dry wt	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21	21			21
Toxicant	**Sediment Nickel**	mg/kg dry wt	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52	52			52
Toxicant	**Sediment Silver**	mg/kg dry wt	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			1
Toxicant	**Sediment Silver**	mg/kg dry wt	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7			3.7
Toxicant	**Sediment Zinc**	mg/kg dry wt	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200			200
Toxicant	**Sediment Zinc**	mg/kg dry wt	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410	410			410
Toxicant	**Sediment Arsenic**	mg/kg dry wt	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20			20
Toxicant	**Sediment Arsenic**	mg/kg dry wt	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70			70
Toxicant	**Sediment Tributyltin (as SN)**	µg/kg dry wt	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5			5
Toxicant	**Sediment Tributyltin (as SN)**	µg/kg dry wt	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70			70
Toxicant	**Algal concentration**																				
Toxicant	**Cyanobacteria e.g lyngbya concentration**																				

Ecology	**Total surface water availability**																				
Ecology	**Water storage capacity**																				
Ecology	**Filling of terminal lakes**																				
Ecology	**Floodplain inundation**																				
Ecology	**Macroinvertebrate Taxa Richness (composite)**		12-21	12-21	12-21	12-21	12-21	12-21	12-21	12-21	12-21	12-21	12-21								
Ecology	**Macroinvertebrate Taxa Richness (edge habitat)**		23-33	23-33	23-33	23-33	23-33	23-33	23-33	23-33	23-33	23-33	23-33								
Ecology	**PET Taxa Richness (edge)**		2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5								
Ecology	**PET Taxa Richness (composite)**		2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5	2-5								
Ecology	**Macroinvertebrate SIGNAL index (composite)**		3.33-3.85	3.33-3.85	3.33-3.85	3.33-3.85	3.33-3.85	3.33-3.85	3.33-3.85	3.33-3.85	3.33-3.85	3.33-3.85	3.33-3.85								

Ecology	**Macroinvertebrate SIGNAL index (edge habitat)**		3.31-4.2	3.31-4.2	3.31-4.2	3.31-4.2	3.31-4.2	3.31-4.2	3.31-4.2	3.31-4.2	3.31-4.2	3.31-4.2	3.31-4.2								
Ecology	**Macroinvertebrate % Tolerant Taxa (composite)**		25-50	25-50	25-50	25-50	25-50	25-50	25-50	25-50	25-50	25-50	25-50								
Ecology	**Macroinvertebrate % Tolerant Taxa (edge habitat)**		44-56	44-56	44-56	44-56	44-56	44-56	44-56	44-56	44-56	44-56	44-56								
Ecology	**Hyporheic**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA								
Ecology	**Stygofauna**		NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA	NBA								
Ecology	**Macrophyte cover**																				
Ecology	**Abundance of aquatic weeds**																				
Ecology	**Zooplankton Individual species**																				
Ecology	**Zooplankton Diversity**																				
Ecology	**Infauna Individual species**																				
Ecology	**Infauna Diversity**																				

Ecology	**Coral condition of fringing reefs**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Coral cover**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Macro algae cover**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Juvenile hard coral density**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Settlement of coral spat**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Marine mammals and reptiles**	E.g. Australian snubfin dolphin abundance (as an indicator species)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Marine Pests and Animal Pests**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Freshwater Pest animals**	e.g. Goldfish, carp, mosquito fish, guppies, tilapia and red-eared slider turtles																			

Ecology	**Freshwater Pest Plants**	e.g. Alligator weed, pond apple, cabomba, water hyacinth, Senegal tea plant, hygrophila, limnocharis, water lettuce, salvinia.																			
Ecology	**Aquatic animals**	Types, presence, abundance e.g. Frogs, platypus, water birds																			
Ecology	**Fitzroy River Turtle**	Presence / Abundance																			NA
Ecology	**Wetland Loss**																				
Ecology	**Ground cover**																				
Ecology	**Riparian Vegetation Condition**																NA	NA	NA			NA
Ecology	**Riparian Vegetation Extent**																NA	NA	NA			NA

Ecology	**Riparian Vegetation Composition**																NA	NA	NA			NA
Ecology	**Riparian Vegetation Connectivity**																NA	NA	NA			NA
Ecology	**Presence of woody debris**																NA	NA	NA			NA
Ecology	**Seagrass abundance**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Seagrass reproduction**		NA	NA																	
Ecology	**Seagrass tissue C:N ratio**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Seagrass tissue N:P ratio**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Seagrass tissue C:P ratio**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Seagrass epiphyte abundance**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Salt marsh extent**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						
Ecology	**Mangrove extent**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						

Ecology	**In stream connectivity**																				
Ecology	**Bank level**																				
Ecology	**Bank condition Category**																				
Ecology	**Bank condition value**																				
Ecology	**Marine Debris**	amount/ extent																			
Ecology	**Nekton (fish) diversity and health**																				
Ecology	**Native fish species (observed: expected ratio ≥1)**																				
Ecology	**Exotic fish species (present/abs ent)**																				
Ecology	**Fish tissue Contaminant s index**																				

Ecology	**Fish indicator species**	e.g Barramundi abundance and recruitment to nursery areas																			
Ecology	**Fish tissue mercury, pesticides, PCB congeners, PBDE, % moisture and lipid content**																				
Ecology	**B – Biomass of fish caught in standardised sample;**																				
Ecology	**B/I - Average biomass per individual fish (I);**																				
Ecology	**TG1 - Biomass proportion of top predators (trophic group 1);**																				

Ecology	**TG2 - Biomass proportion of aquatic invertivores (trophic group 2);**																				
Ecology	**TG3 - Biomass proportion of terrestrial insectivores (trophic group 3);**																				
Ecology	**TG1/TG4 - Biomass ratio of top predators (TG1): detritivores (TG4)**																				
Ecology	**Presence of instream barriers**																				
Ecology	**Sedimentation Daily maximum**	$mg/cm^2/d$																	15	15	15
Ecology	**Algal compostion**																				
Ecology	**Phytoplankton community compostion**																				

Ecology	**seasonal flow volume**																				
Ecology	**Rainfall residual mass**																				
Ecology	**Groundwater Levels**																				
Ecology	**Pathogen types**																				
Ecology	**Pathogen concentrations**																				
Ecology	**Total coliform concentration**																				
Ecology	**E. coli concentrations**																				
Ecology	**phytoplankton**																				
Ecology	***Legionella pneumophila* Sg 1-14**																				
Ecology	***Legionella* species (not *pneumophila*)**																				
Ecology	**Tannins**																				
Ecology	**Chemical Oxygen Demand**																				

Ecology	**Biochemical Oxygen Demand**																				
Ecology	**Estuarine Benthic index of biotic integrity (B-IBI)**		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA						NA
Ecology	**Phytoplankton**																				
Ecology	**Flow: years since mean annual flow**																				
Ecology	**Flow: period since monthly median flow exceeded**																				
Ecology	**Flow: low flow periods**																				
Ecology	**Benthic Production**																				