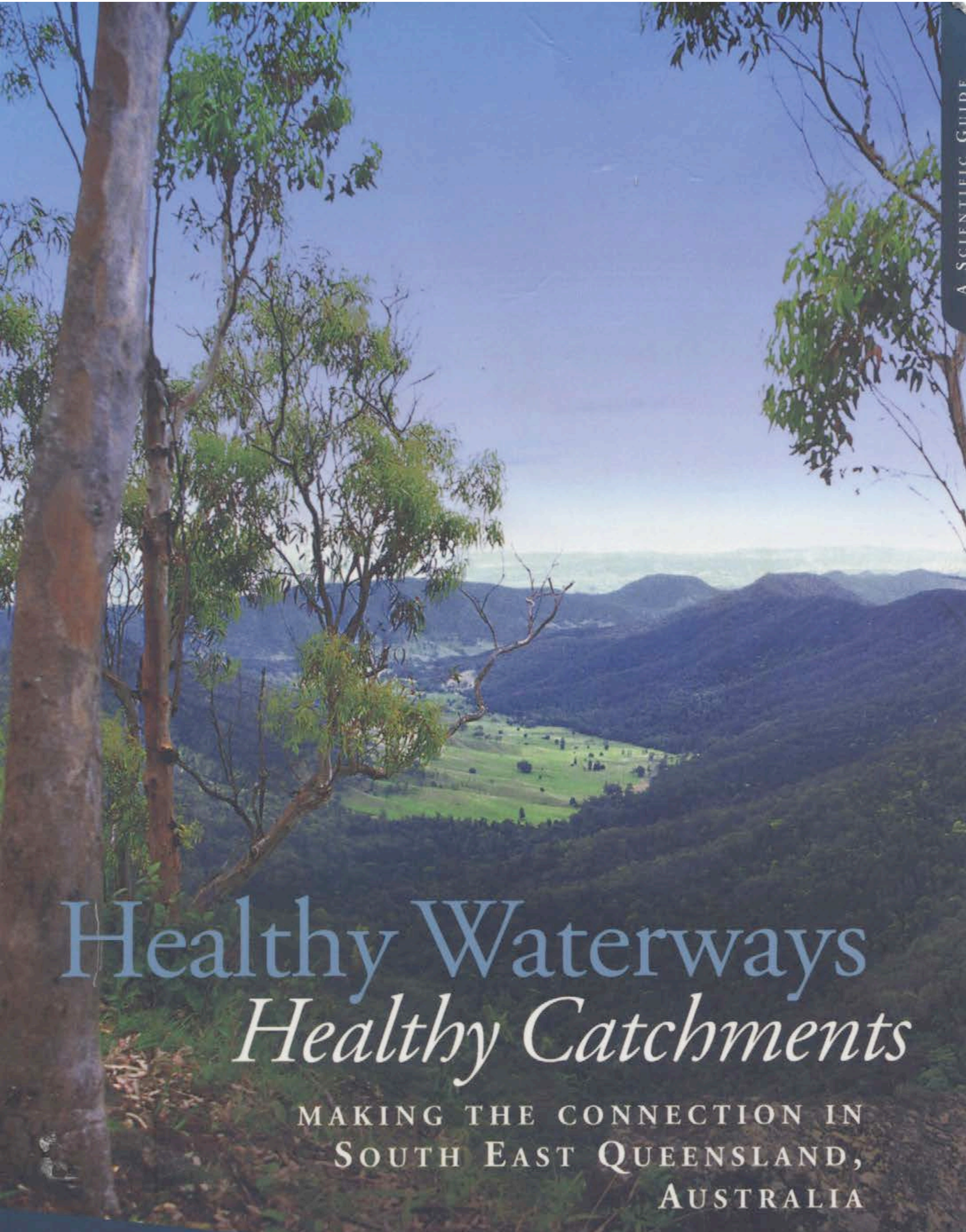

A SCIENTIFIC GUIDE

Healthy Waterways
Healthy Catchments

MAKING THE CONNECTION IN SOUTH EAST QUEENSLAND, AUSTRALIA

HEALTHY WATERWAYS
Because we're all in the same boat

Healthy Waterways
Healthy Catchments

MAKING THE CONNECTION IN
SOUTH EAST QUEENSLAND, AUSTRALIA

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HEALTHY WATERWAYS
Because we're all in the same boat

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Chapter 4 photo – Rural landscape in South East Queensland – Environmental Protection Agency
Chapter 5 photo – Stream overgrown by algae – Healthy Waterways Library
Chapter 6 photo – *Lyngbya* growing on seagrass – Chris Roelfsema, Marine Botany, UQ
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Preface

This book provides the context and scientific findings of Stage 3 of the Healthy Waterways Campaign. A companion book, 'Discover the Waterways of South East Queensland', published in 2001, provides a more general guide to the key processes and impacts that are described in this book. Two previous books have been published as part of the Healthy Waterways Campaign. The first book, published in 1998, was 'The Crew Members Guide to the Health of Our Waterways', an introduction to the Healthy Waterways Campaign. The second book, published in 1999, was 'Moreton Bay Study: A Scientific Basis for the Healthy Waterways Campaign', which presented the scientific findings of Stage 2. Collectively, these books provide a chronicle of the key findings and important steps that we have taken to achieve our vision of healthy waterways.

The broader scope of this book reflects the whole-of-catchment approach that the Healthy Waterways Campaign has embraced. The Moreton Bay Study (Stage 2) was focused on Moreton Bay and river estuaries up to the tidal limit, within the jurisdiction of six local government councils. The expanded scope of the South East Queensland Study (Stage 3) included the waterways of the entire Moreton Bay catchment and the waterways of the coastal catchments of the Sunshine Coast and Gold Coast to the north and south of Moreton Bay, respectively. This broader effort included jurisdictions of 19 local government councils. In many ways, this expanded scope was more appropriate for achieving the healthy waterways vision. This study area now coincides more closely with the 'human footprint' of the Brisbane region. The 'human footprint' refers to the entire region that an urban centre requires to supply the living space, food, water and recreational resources to support it. Developing the management, research and monitoring resources to address issues at the scale of the human footprint is essential to achieve sustainable outcomes.

As in the other Healthy Waterways books, a team effort was involved in the collection of the data and in the production of this book. The lead authors of each chapter are indicated to represent their responsibility of interpreting and integrating data from the various tasks. However, task leaders and many of the task participants contributed data and assisted in the interpretations included in each chapter. These task participants are listed in the beginning of this book. The editorial staff liaised with chapter authors, the science communicators and layout and design staff to produce the final product. The book and study, as a whole, would not have been possible without the tremendous support and vision of Professor Paul Greenfield and the Scientific Advisory Group that he chairs. In addition, the Stage 3 Management Team led by Barry Ball, Study Director and Trevor Lloyd, Study Manager and for the Moreton Bay Waterways and Catchments Partnership Director Diane Tarte, was instrumental in supporting the scientific efforts and ensuring that the recommendations were implemented. The science communicators (Catherine Collier, Lynda Curtis and Kate Moore) put together the photographs, maps, diagrams, graphs and tables in a way that allowed the message to be conveyed as intended by the authors. Scientific review was provided by Dr Des Lord, Dr Graham Skyring, Prof Barry Hart, Dr David Neil, Dr Phillip Ford, Mr Eddie Hegerl, Ms Diane Tarte, Mr Trevor Lloyd, Ms Elaine Green and Mr Stephen Nelson. Layout and design was ably accomplished by Leonie Witten.

Eva G. Abal, Stuart E. Bunn and William C. Dennison

BRISBANE 2005

Foreword

Can you "love" a place to death? An irony of environmental management worldwide is that the attractiveness of a natural feature, a locality or a region is often its own greatest threat. The attractiveness of many such areas relies crucially on the health of the ecosystems within the region; yet this attractiveness draws to the area increased numbers of individuals who wish to experience its special features, to work and bring up families in such regions, or just to enjoy holidays and recreational pursuits there. As individuals, we require food and water, we consume energy and we generate waste. Each of us contributes to these loads and impacts marginally, but collectively the impact on a region can be major.

This remains the position in which South East Queensland (SEQ) finds itself. An increasing number of people wish to live, work and play here. Over the next twenty years, it is estimated that an additional one million persons will move to the SEQ region covered by the Healthy Waterways program. Collectively, the potential burden from this demographic trend on the region's waterways will be huge. Yet, the quality of these waterways – the rivers, the estuaries, the bays, the beaches, the near coastal zones – is a major reason that the region is so attractive to live, work and play in.

A decade ago, six local councils in the Moreton Bay region together with a number of Queensland State Government departments came together to address a range of issues affecting the health of Moreton Bay and the rivers flowing into the Bay. The ongoing population growth in South East Queensland had led to deteriorating water quality in the rivers and Bay, reduced habitats for fish, turtles and dugongs, and a perception that the downward trends would continue. The initial focus was on the estuarine sections of the rivers and on the central and northern regions of Moreton Bay, and was funded from local, state and federal sources.

What is now termed the Moreton Bay Waterways and Catchments Partnership (or Healthy Waterways Partnership) was born. The Partnership now includes all nineteen local councils of SEQ, a number of key authorities and industries in the region and Queensland Government agencies. Funding continues to be provided from the three arms of government and, on a case by case basis, from other industry groups and agencies.

The book "Moreton Bay Study: A Scientific Basis for the Healthy Waterways Campaign", published in 1999, presented the scientific findings from Stages 1 and 2 of this work. As well as having a more limited geographic focus, Stages 1 and 2 were concerned primarily with the sources and impacts of the nutrients, nitrogen and phosphorus, and sediments, particularly from point sources. As a result of this work, participant councils and the Queensland Government have committed many millions of dollars in new and upgraded sewage treatment plants and other management actions.

This book, the second summary document over the decade, reflects the growth of the Partnership and its changing focus. There is greater emphasis on the upper regions of the catchments, which have been identified as the source of much of the sediment and nutrients reaching the lower regions and the Bay; there is greater recognition of the diversity of catchments, both in terms of their land-forms and ecology and in terms of their patterns of development; there has been greater emphasis on providing tools for specific management actions as the study has matured. Nutrient and sediment loads into the waterways, from both urban and rural localities, and their impacts remain the dominant themes.

In addition, the geographic spread has been extended north to Noosa, south to the New South Wales border and west to the Great Dividing Range. As mentioned earlier, this involves the jurisdictions of nineteen local councils and includes the waterways of the entire Moreton Bay catchment and the waterways of the coastal catchments of the Sunshine Coast and the Gold Coast.

What has not changed has been the fundamental approach. This approach can be characterized as adaptive, focused and collaborative. It is adaptive in that management actions are based on the outcomes of investigations, which are in turn determined by community views on what are the key issues, informed by effective monitoring. The approach recognizes that strategies may have been developed by Partnership members to address specific water quality and ecosystem issues and that management actions may already be in place. The approach is focused in that a limited number of investigations are carried out in any one period, based on the financial and human resource constraints facing the Partnership. The scientific approach is collaborative involving individuals from all local universities, CSIRO, consultants, industry and State Government agencies.

Other features of the earlier studies have also been maintained:

- ongoing use of conceptual models to help guide the investigations and communicate to our stakeholders (numerous examples are found in this Report);
- external peer review of individual projects, right from the scoping stage through to the final report; and
- ongoing interaction with stakeholders interested in or involved with the outcome of the studies.

The scientific outcomes of Stage 3 are summarised in this report. I would like to draw readers' attention to three key outcomes from this stage of the work.

Firstly, Stage 3 has documented the links between aquatic ecosystem health and land use practices. For both the urban and rural parts of the region, the message from Stage 3 is clear. Achieving the expectations of our communities in terms of maintaining and improving aquatic ecosystem health will not occur unless we address a range of major land use planning and management issues. Ongoing and proposed plans for the development of SEQ need to pay greater attention to the impacts of such development on aquatic ecosystem health if these expectations are to be realised.

Secondly, we now have a regional monitoring program for the freshwater, estuarine and marine regions for all of SEQ. Termed the Ecosystem Health Monitoring Program (Chapter 7), this represents a major achievement of collaboration between researchers, local and State governments and industry. Particular credit is due to the Queensland Environmental Protection Agency and the Department of Natural Resources and Mines for their very significant contribution of resources to the collection and analysis of data in the estuarine/marine and freshwater regions, respectively.

Thirdly, the increased frequency and severity of the episodic *Lyngbya* blooms (detailed in Chapter 6) are a constant reminder that the pressures exerted on our aquatic ecosystems by the burgeoning population will manifest themselves in sometimes unpredictable events. Whilst we know much more about the aquatic ecosystems of SEQ than we did a decade ago, we also know that we do not know it all.

As with Stage 2, there are many individuals who have contributed to the present work; they are identified at the end of each of the chapters. I wish to acknowledge the collaborative spirit of all members of the Scientific Expert Panels and, in particular, the efforts of Diane Tarte, Eva Abal and her team and Professor Stuart Bunn as Deputy Chair of the Scientific Advisory Group.

We live in a wonderful part of the world, and we would like it to remain that way. Enjoy the book and become engaged.

Paul Greenfield

CHAIR, SCIENTIFIC ADVISORY GROUP

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CHAPTER 1: CONCLUSIONS AND RECOMMENDATIONS 1

Overall conclusion:

Healthy catchments lead to healthy waterways.

Recommendations:

Strategy: Prioritise and conduct riparian protection and rehabilitation throughout all rural catchments, particularly near headwaters. Install stormwater quality improvement devices and apply water sensitive design in urban areas.

Research: Quantify diffuse pollutant sources, particularly fine grained sediments, dissolved organics and iron, and atmospheric nitrogen. Investigate effective methods and approaches for riparian protection and rehabilitation.

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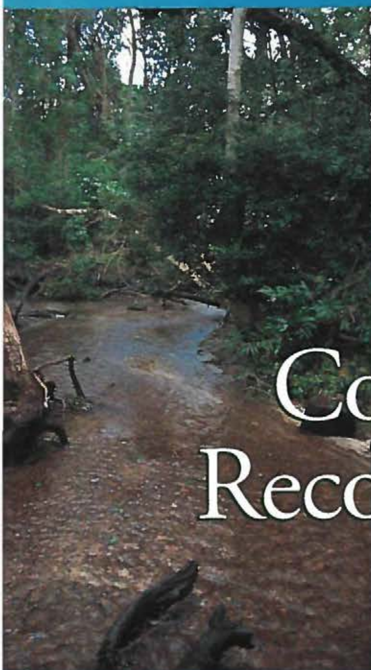
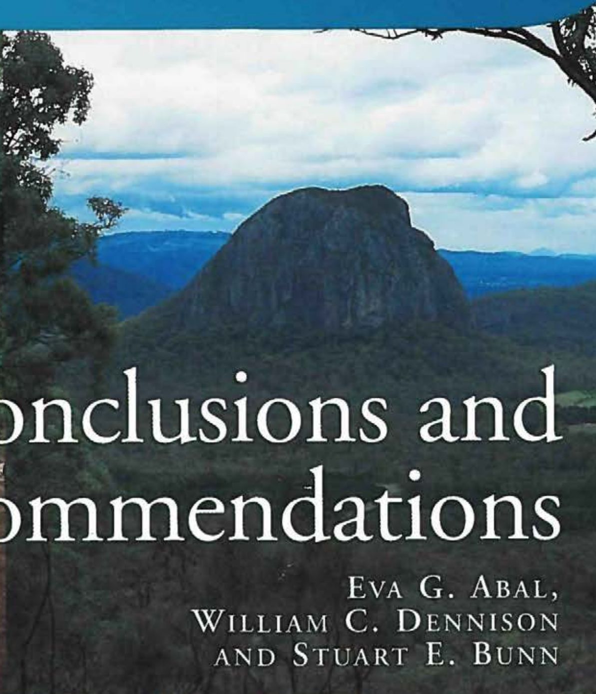
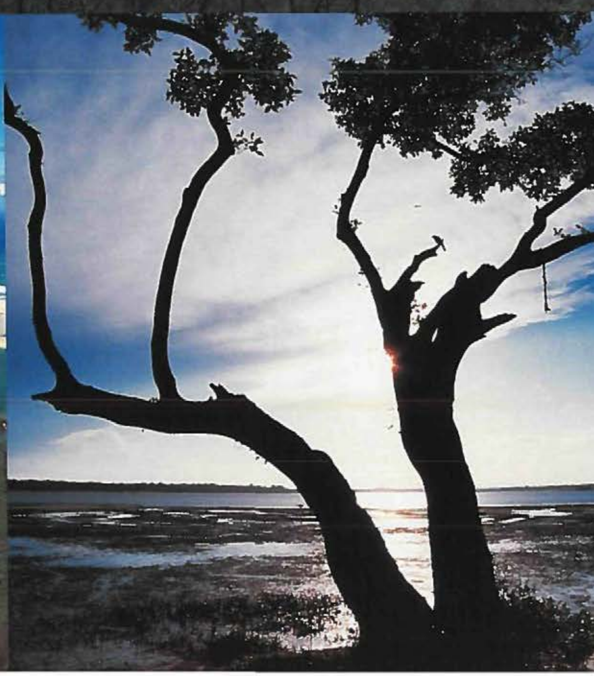



Conclusions and Recommendations

Eva G. Abal,
William C. Dennison
and Stuart E. Bunn

Chapter 1 Overall Conclusions and Recommendatio

Overall conclusion:

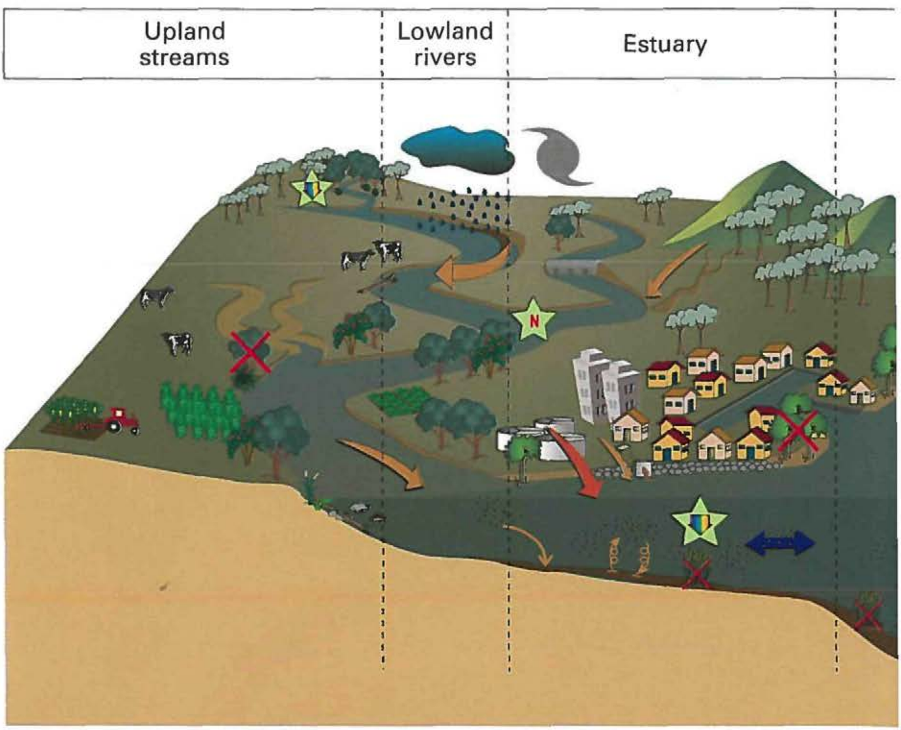
Healthy catchments lead to healthy waterways.

Recommendations:

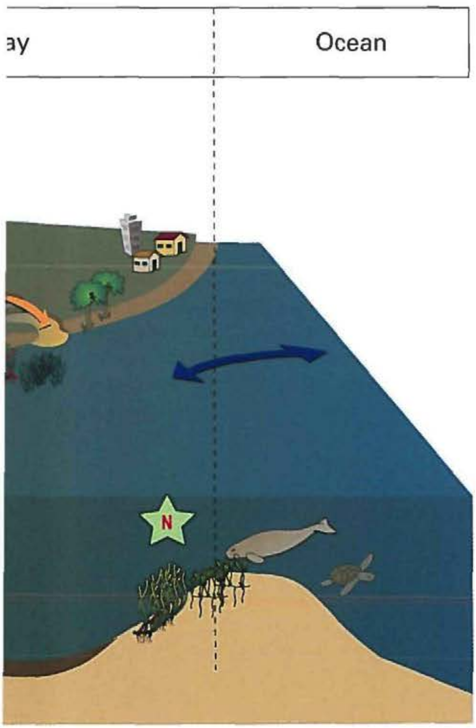
Strategy: Prioritise and conduct riparian protection and rehabilitation throughout all rural catchments, particularly near headwaters. Install stormwater quality improvement devices and apply water sensitive design in urban areas.

Research: Quantify diffuse pollutant sources, particularly fine grained sediments, dissolved organics and iron, and atmospheric nitrogen. Investigate effective methods and approaches for riparian protection and rehabilitation.

Monitoring: Expand current monitoring program to include all South East Queensland waterways by a) including the northern and southern region b) implementing ambient and load-based monitoring programs for freshwaters, and c) develop community monitoring linkages and socio-economic indicators.



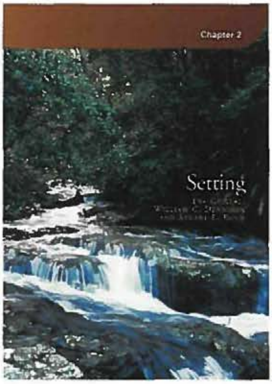
The South East Queensland region has been significantly altered since European settlement. Removal of native vegetation has resulted in more intensive run-off events and, combined with the loss of riparian vegetation, has led to increased sediment and nutrient delivery to our waterways. Protection and, where necessary, rehabilitation of riparian areas in headwater catchments will help to address this problem, as well as directly improve stream ecosystem health. Many streams in the region are dry for much of the time. Greater awareness on the influence that these systems can have on the health of downstream waterways is needed. Under conditions of sufficient light, nitrogen has been identified as the key nutrient limiting algal growth in freshwater, estuaries and marine areas. Bioavailable iron from land sources has been linked to blooms of toxic cyanobacteria, *Lyngbya majuscula*, in Moreton Bay. These and other findings of the scientific research undertaken in Stage 3 of the Healthy Waterways Campaign highlight that protection and enhancement of aquatic ecosystem health requires whole-of-water-cycle management. An Ecosystem Management Support System has been developed to enable stakeholders to integrate this information at appropriate spatial and temporal scales and model the likely outcomes of management scenarios.



Supporting information is provided in subsequent chapters in the form of text, photos, graphs, tables, maps and diagrams. Each chapter is comprised of section headings, which are the conclusions that can be drawn from the supporting information. An overall conclusion, drawn from the section headings, and recommendations based on chapter conclusions are presented. These recommendations identify a) the key strategy actions that would best achieve the Healthy Waterways vision, b) priority research questions for future investigation, and c) monitoring efforts that would provide effective feedback for the various stakeholder actions. Many of the recommendations have already been acted upon, due to the continual dialog between the scientific team, resource managers and stakeholders in the region.

1. Many of the South East Queensland waterways are dry for much of the year; rain falls in episodic events
2. Loss of riparian vegetation and aquatic habitat has ecosystem health impacts
3. Sediment derived primarily from channel erosion is transported, deposited, and resuspended in the estuaries and Bay
4. Nitrogen N is the major limiting nutrient when light is not limiting
5. *Lyngbya* blooms have possible links to the land as a source of bioavailable iron

Chapter 2 Setting



Overall conclusion:

South East Queensland's waterways are strongly influenced by rainfall and flow variability; the Healthy Waterways Campaign has been expanded to incorporate the entire catchment.

Recommendations:

Strategy: Target riparian rehabilitation programs in headwater streams and manage for large runoff events.

Research: Investigate climate variability and resolve uncertainties in load estimates.

Monitoring: Develop catchment health indices and capture data from event-based flows.

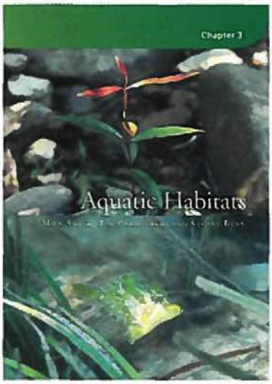
The 'Setting' chapter provides a context for the findings produced in this study by presenting relevant background information about the South East Queensland region and the South East Queensland Study. The first section focuses on climate, catchment characteristics and environmental values. The second section focuses on the scientific component of the integrated research, monitoring and management program. A brief history, scope, and key features of the scientific studies are elaborated.

The South East Queensland region has subtropical weather and, like much of Australia, has relatively low and highly unpredictable rainfall. On the scale of the Australian continent, the South East Queensland catchments are relatively small. The catchments can be divided into various subcatchments which drain into either Moreton Bay, or directly into the Pacific Ocean. The human 'footprint' on the region has been expanding as population growth has demanded more living space, farms to produce food and dams to capture drinking water. Intense rainfall events often associated with summer storms produce the majority of the sediment and nutrient delivery to Moreton Bay and the ocean.

The stakeholders in the region have identified environmental values that include being able to drink the (fresh)water, being able to swim, catch and safely eat fish, as well as having water of sufficient quality to support healthy ecosystems. The commercial, recreational and aquaculture fisheries resources also are an important environmental asset.

The South East Queensland Study, initiated in response to intensification of land use and expanding human populations, was conducted in stages. After an initial scoping stage, Moreton Bay and estuaries were the focus of Stage 2, while the catchments and freshwater were the focus of Stage 3 (reported here). The key attributes of the Study include a common vision, balanced approach of management, research and monitoring, effective communication and involvement of stakeholders at various levels and linked scientific tasks which fit into an ongoing adaptive management approach.

Chapter 3 Aquatic Habitats



Overall conclusion:

South East Queensland waterways support a wide variety of aquatic habitats which underpin the region's aquatic biodiversity.

Recommendations:

Strategy: Protect aquatic habitats and rehabilitate degraded waterways where habitat diversity has been reduced.

Research: Develop an understanding of habitat functions and connectivity between habitats; investigate the effects of diffuse disturbances on aquatic habitats.

Monitoring: Map changes in habitat area with a focus on gains/losses; develop habitat function indicators for monitoring program.

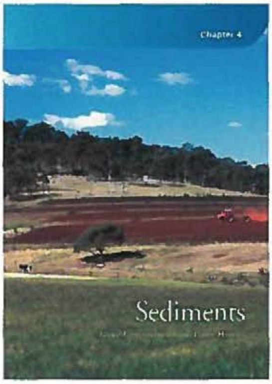
The waterways of South East Queensland support a wide variety of aquatic habitats which help to sustain aquatic biodiversity. These waterways can be divided into four broad categories: upland streams, lowland creeks and rivers, river estuaries, and the marine environment.

Upland streams occur in the hinterland at the top of coastal catchments and are generally fast flowing in the wet season due to their steep gradients. Most of these streams are intermittent in that they only flow for part of the year and often dry up, or recede to a series of pools, during the dryer months. In upland streams rocks and cobbles usually form the stream bed whereas in lowland creeks and rivers the substrate is usually comprised of sand, silt or mud. This is due to the deposition associated with slower flow and lower gradients in lowland areas.

Riparian (i.e. bank side) vegetation plays a critical role in the creation and maintenance of aquatic habitats in freshwater ecosystems. It shades the stream, limits aquatic plant growth, provides wood and leaf litter inputs which serve as habitat and food, and binds the soils on the bank to maintain erosion at natural rates. Given the key role that riparian vegetation plays in maintaining aquatic habitats and linking aquatic and terrestrial ecosystems, several riparian rehabilitation projects have been undertaken to test the efficacy of different rehabilitation options in small subcatchments in South East Queensland.

There are numerous estuaries in South East Queensland that support a diversity of habitats: mangrove, saltmarshes and benthic microalgae in the intertidal, fragile seagrass habitats in the subtidal, and diverse phytoplankton in the water column. Canal habitats are highly modified extensions of river channel habitat, and are increasing in area. Moreton Bay has strong gradients and diverse habitats, including macroalgae, mangroves, seagrasses, corals and benthic microalgae. A diverse assemblage of macroalgae exists on hard substrates. Mangroves, affected by natural and human impacts, exist along much of the shorelines of the lower estuaries and Moreton Bay. Seagrass distribution reflects gradients in disturbance and turbidity. Moreton Bay coral communities tolerate moderate turbidity. Jetty pylons form habitats that are prone to exotic species introductions due to shipping. Benthic microalgal populations both in the estuaries and Moreton Bay are affected by naturally occurring marine viruses.

Chapter 4 Sediments



Overall conclusion:

Soil from channel erosion processes, particularly in the Lockyer and Bremer subcatchments, leads to high turbidity and is transported into Moreton Bay.

Recommendations:

Strategy: Initiate riparian protection and rehabilitation to reduce channel erosion; promote ground cover and maintain soil structure to reduce hillslope erosion.

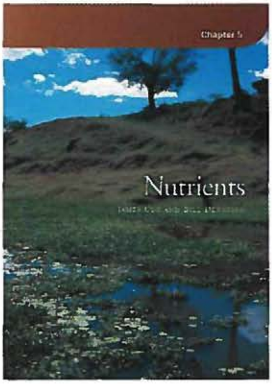
Research: Quantify sediment runoff and delivery downstream; investigate the effects of trawling on resuspension and nutrient dynamics in Moreton Bay.

Monitoring: Assess effectiveness of remedial action to reduce erosion and sediment delivery through automated measurement and sampling of diffuse loads and the light regime in receiving waters.

Soil erosion generates sediment that has negative environmental impacts, particularly with regard to seagrass loss in Moreton Bay. Soil erosion processes can be categorised as either channel erosion (gully and stream-bank erosion) or hillslope erosion (sheetwash and rill erosion). Both modelling results and tracer studies confirm the visual observations that indicate channel erosion is the dominant erosion process in South East Queensland. Hillslope erosion also contributes sediments, most significantly in the northern rivers. Not all catchments are equal in terms of sediment delivery, and sediments originating from soils developed on Marburg formation rocks are the main sediment sources into Moreton Bay. The Marburg formation is located primarily in the Lockyer and Bremer catchments. Urban areas have high loading rates per unit area, but are overall smaller sources than the rural areas.

The turbidity of the Brisbane River estuary is largely dominated by physical processes, particularly tidal resuspension. Turbidity maxima are found in the estuaries, with higher turbidity during spring tides and episodic flood events and lower turbidity in winter. Size and type of suspended sediment varies little throughout the Brisbane River estuary. Sediments deposited in central Moreton Bay have been rapidly accumulating, particularly over the past several decades. River mud is transported offshore following large floods as turbidity plumes, and contains high levels of nutrients.

Chapter 5 Nutrients



Overall conclusion:

Excess nutrient loading causes environmental degradation in many South East Queensland waterways.

Recommendations:

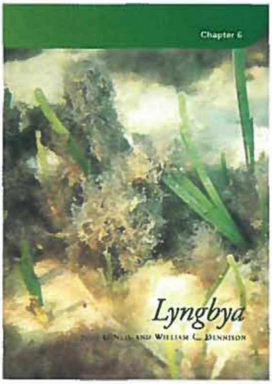
Strategy: Develop means of reducing nutrient flow into streams and rivers; increase canopy cover in small streams; develop combined nutrient reduction strategy (nitrogen and phosphorus).

Research: Investigate nutrient responses in freshwater storages to determine relative roles of nitrogen and phosphorus; develop a better understanding of nutrient cycles to predict ecosystem responses to changing nutrient loads.

Monitoring: Continually assess relative roles of light and various limiting nutrients; continue development of sewage tracers; incorporate storm event monitoring.

Light limitation of plant productivity is a common feature in the waterways of South East Queensland. In the smaller freshwater streams, shading by overhanging trees reduces the light reaching the streams. In the river estuaries and western Moreton Bay, turbidity reduces light penetration in the water. In locations where light is not limiting, the availability of nutrients can limit productivity. Responses of the microalgal communities in South East Queensland streams were measured with nutrient bioassays in which nitrogen and/or phosphorus was added. Additions of nitrogen stimulated the microalgae in 70% of the 32 streams tested, while additions of nitrogen plus phosphorus had the largest effects. Rates of denitrification, the conversion of dissolved nitrogen to nitrogen gas, were measured throughout the waterways and were highly variable. Under baseflow, denitrification could effectively reduce dissolved nitrogen concentrations in streams, but under high flow regimes, denitrification was relatively insignificant. In Moreton Bay, the sensitivity of denitrification to oxygen availability was variable. Atmospheric nitrogen loads appear to be significant in the region. Sewage nitrogen loads were measured using a stable isotope tracer, and sewage plume maps generated with data from macroalgae and oysters. The incorporation of sewage nitrogen into fish was also inferred using the stable isotope tracers. High organic carbon loads in the Bremer River created excessive bacterial growth. Bacteria as well as virus concentrations were associated with gradients in water column nutrients.

Chapter 6 *Lyngbya*



Overall conclusion:

Lyngbya majuscula blooms in Moreton Bay are a significant threat to ecosystem integrity and appear to be linked to nutrients including bioavailable iron, organics and phosphorus.

Recommendations:

Strategy: Reduce stained water runoff (humics containing iron and phosphorus) from disturbed areas and test various land use management strategies (e.g. varying land clearing practices).

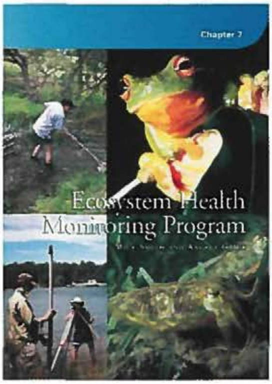
Research: Continue to investigate causes of blooms in the various sites of *Lyngbya* outbreaks.

Monitoring: Map blooms using remote sensing and field observations; develop real time monitoring of relevant environmental factors; assess impacts; and evaluate mitigation efforts.

Lyngbya majuscula blooms occur globally, and have been reported in several other locations around Australia, besides Moreton Bay. Large blooms have been occurring in Moreton Bay over the past several years, originally just apparent in Deception Bay, but now also on the Eastern Banks. Moreton Bay *Lyngbya* contains toxins with contact irritants and potential tumour-promoting effects on humans and fauna, but toxin levels are variable in space and time. *Lyngbya* responds to additions of dissolved iron, phosphorus and to various additions of soil extracts. The chemical oxidation state of the iron affects its bioavailability, and complexation of iron with dissolved organic substances plays a key role in both the oxidation state and the bioavailability of iron. Sediments can become a source of nutrients for sustaining *Lyngbya* blooms. Soil extracts from various land uses were tested with *Lyngbya* bioassays, and pine plantation soil extracts consistently stimulated *Lyngbya* photosynthesis and pigment content. Deception Bay *Lyngbya* blooms appear to be related to the recent short-term land clearing on Bribie Island. Heavily stained runoff from cleared pine plantations, agriculture and other land disturbances following rainfall stimulates *Lyngbya*.

As a nitrogen-fixing organism, *Lyngbya* can thrive in N-limited environments, and can be a significant source of nitrogen to the system upon decay. As a "truly" weed species, *Lyngbya* is quite versatile in its ability to utilise various forms of nutrients. *Lyngbya* blooms have led to seagrass and mangrove diebacks, nutrient enrichment and changes in the assemblages of animals. *Lyngbya* blooms also may be affecting dugongs, turtles and fisheries. Various potential *Lyngbya* grazers were tested in feeding trials, and while rabbitfish did not preferentially graze on *Lyngbya*, *Stylocheilus* sea hares did actively graze on *Lyngbya*. Viruses affect *Lyngbya* and may account for the rapid disappearance of blooms. Remote sensing techniques that may be useful for long-term monitoring and studies on historical changes were developed for mapping *Lyngbya*. Various management strategies to minimise the introduction of factors (nitrogen, phosphorus, organics, bioavailable iron) causing *Lyngbya* blooms are being formulated.

Chapter 7 Ecosystem Health Monitoring Program



Overall conclusion:

Integrated ecosystem health monitoring programs for freshwater and estuarine waterways of South East Queensland have been developed and are currently being implemented.

Recommendations:

Strategy: Expand current ambient monitoring program to include a load-based monitoring program, and integrate regional EHMP with local monitoring programs.

Research: Develop new ecosystem health indicators that provide a more comprehensive evaluation system including socio-economic indicators; construct ecological models to synthesise and interpret monitoring data; improve understanding of the causes and effects of diffuse disturbances on aquatic ecosystems.

Monitoring: Continue EHMP monitoring and liaise with community and catchment groups to expand monitoring network.

Ecosystem health monitoring is important for assessing ecological condition and trends, and quantifying the effectiveness of management actions aimed at improving the health of aquatic ecosystems. A comprehensive and integrated monitoring program has been developed for the freshwater, estuarine and marine waterways of South East Queensland. The estuarine/marine component commenced in January 2000 and the freshwater component in September 2002. Prior to the commencement of the freshwater component of the program, a field trial was performed to determine which indicators were most effective at detecting land use impacts in streams across South East Queensland. This trial showed that five categories of indicator were sensitive to the diffuse forms of disturbance that commonly affect stream health in the region. These five categories include measures of: freshwater fish communities; aquatic invertebrate communities; key ecosystem processes; nutrient assimilation by algae; and physical and chemical (i.e. water quality) attributes. Each indicator provides information on one of the three key attributes of healthy ecosystems (i.e. vigour, organisation and resilience), and together, they paint a comprehensive picture of the ecological condition of the waterway. In addition, and to complement the freshwater component of the program, a number of riparian rehabilitation projects were monitored to test the efficacy of different rehabilitation options in small subcatchments in South East Queensland. The Bay and estuarine monitoring program is focused on western Moreton Bay and the river estuaries. These areas are most heavily influenced by sediment and nutrient inputs. Strong temporal (wet vs. dry) and spatial (east vs. west) gradients in water quality are evident. Seagrass depth range trends revealed ongoing seagrass loss in Moreton Bay. Benthic surveys indicate seagrasses are influenced by *Lyngbya* and *Caulerpa* distributions. Phytoplankton bioassays identified light to be the major controlling factor in estuaries and nitrogen to be important in western Moreton Bay. Water quality mapping identified new nutrient inputs and delineated the impacts of a moderate flood event. Brisbane River turbidity appears to be improving and sewage plumes appear to be decreasing. Monitoring results are communicated through annual report cards and regular newsletter and web site updates.

Chapter 8 Integration

Overall conclusion:

A whole-of-catchment ecosystem perspective with stakeholder input identified links between land uses and waterways which can be modelled and compared with other locations.

Recommendations:

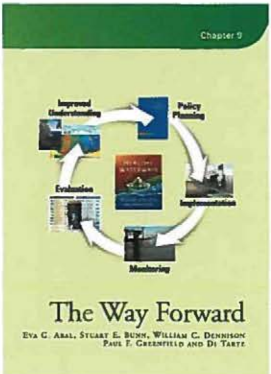
Strategy: Develop a multi-pronged approach to improve waterway health through a variety of stakeholder actions, targeted in specific areas to achieve desired outcomes.

Research: Nutrient and sediment budgets need better quantification; measurements of atmospheric nitrogen inputs and other data are needed to calibrate models; continued model development should incorporate economic and social values.

Monitoring: Integrate model outputs with monitoring efforts.

An ecosystem modelling support system was developed with considerable stakeholder involvement to provide an improved predictive capacity for the region. The ecosystem modelling support system provided a framework for linking models across the South East Queensland region. A data base of pollutant concentration was used to provide input terms for the models. The means of providing uncertainty estimates in model predictions was developed. Various management actions (land use change, urban stormwater controls, point source controls and riparian management) were represented in the future scenario analyses. Sediment and nutrient budgets help develop a better understanding of ecosystem function. Resolution of the atmospheric inputs of nutrients remains an ongoing challenge. New budget estimates of diffuse phosphorus and nitrogen runoff are still equivocal, requiring more and better measurements to quantify these inputs. Investigation of diffuse inputs from catchments revealed that not all subcatchments are equal in terms of pollutant loads, and some land uses yield more pollutants than others. Not all nutrient and sediment runoff makes it into the Bay due to processing and trapping that occurs in the waterways and on floodplains. The delivery of pollutants to the waterways is changing, and model adjustments will need to continue.

Chapter 9 The Way Forward



There are several key lessons that have emerged from the Healthy Waterways Campaign that may have application in other similar programs globally. These include the development and implementation of innovative and novel scientific techniques such as tracers for source identification; scientifically rigorous and defensible Ecosystem Health Report Cards that are presented to stakeholders; and a comprehensive program that uses conceptual diagrams to explain study findings and their implications to a broad range of stakeholders. With today's increasing emphasis on regional natural resource management, there is a strong need to deliver to resource managers an enhanced capacity to make decisions on appropriate management actions. Hence, a new partnership, the Moreton Bay Waterways and Catchments Partnership, has been created to assist with the delivery of the healthy catchments and healthy waterways vision. The adaptive management approach, one of the operating philosophies of the Partnership, is based on the recognition that we often need to act on the basis of an imperfect understanding of the systems within which management action occurs. The Partnership framework illustrates a unique integrated approach to water and catchment management whereby scientific research, community participation, and development of management actions are done collaboratively.

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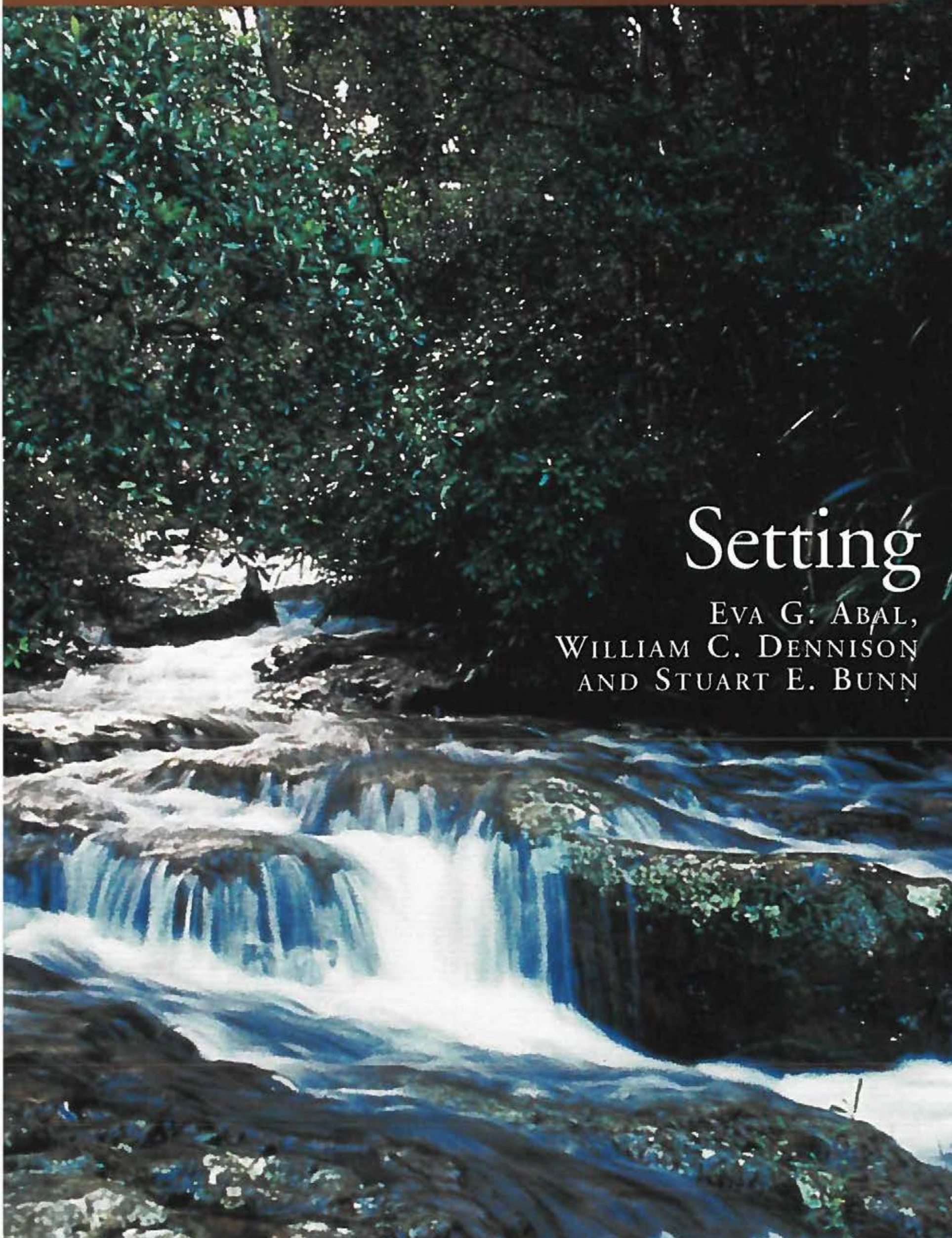
Chapter 2



Setting

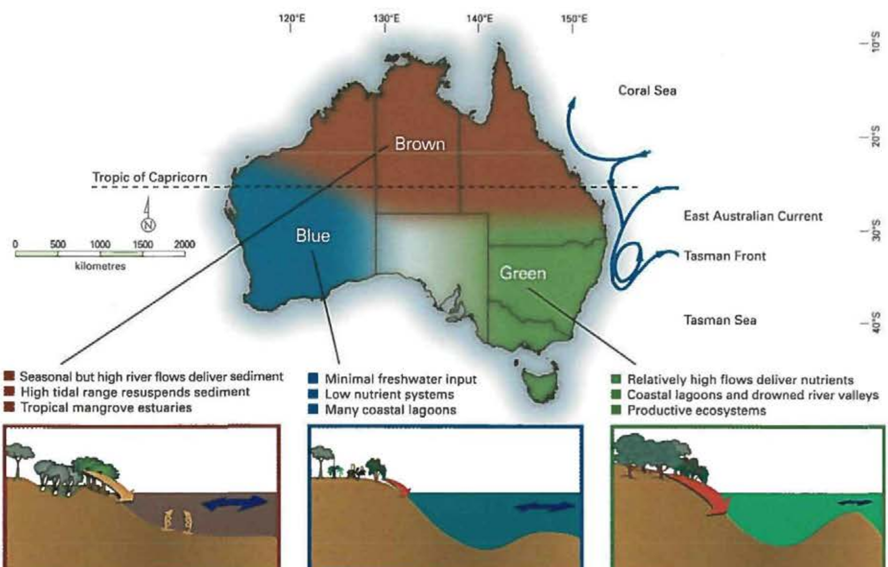
Eva G. Abal,
William C. Dennison
and Stuart E. Bunn

South East Queensland: subtropical weather, warm water currents offshore

Moreton Bay is located from 27-28°S latitude, ~400 km south of the Tropic of Capricorn. The Bay is affected by a climate in which the principal weather and oceanographic patterns are influenced by both tropical and temperate features. A major feature of Moreton Bay is that it is at the juxtaposition between the northern portion of the continent where sediment issues predominate leading to the "brown" category estuaries and south-eastern quadrant of the continent where eutrophication issues associated with nutrient runoff produce "green water" estuaries.

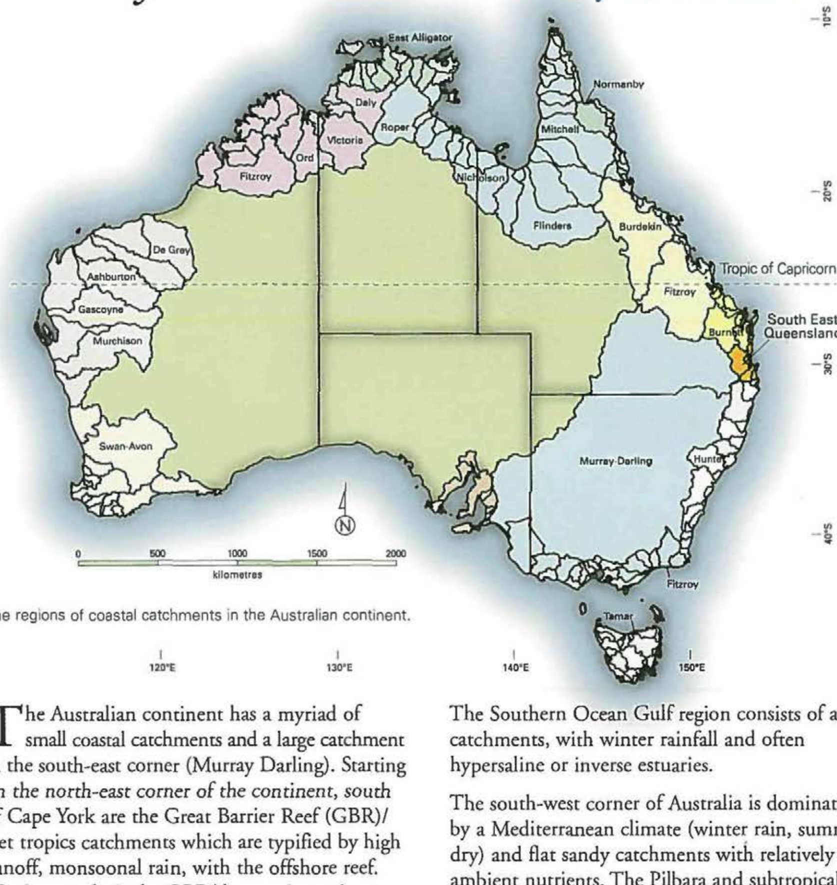
The weather and oceanographic current patterns influencing the Bay are dominated by the south-flowing East Australian Current (EAC). The EAC is a 'western boundary current' producing a part of the large subtropical oceanographic gyre, an anti-clockwise circulation of water across the entire South Pacific Ocean. The EAC has its origins in the equatorial Coral Sea and produces a flow of warm low-nutrient waters, moving relatively fast (up to 4 knots) southward past Moreton Bay. The presence of EAC offshore of Moreton Bay has the following implications: transport of tropical larvae into Moreton Bay, relatively consistent water temperature and low frequency of upwelling events in which cool, nutrient-rich deep ocean water is brought to the surface.

Summer winds from the north-east and south-west prevail in Moreton Bay, while the weather fronts from the west to east bring cool dry westerly winds in winter. Monsoonal low pressure systems bring rain to the region particularly in the summer and early autumn. The seasonal rainfall leads to periods of high runoff and occasional floods.



The predominant offshore water currents which influence Moreton Bay, showing the East Australian Current.

Relatively small catchment on a dry continent



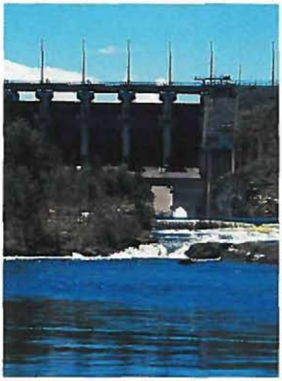
The regions of coastal catchments in the Australian continent.

The Australian continent has a myriad of small coastal catchments and a large catchment in the south-east corner (Murray Darling). Starting on the north-east corner of the continent, south of Cape York are the Great Barrier Reef (GBR)/ wet tropics catchments which are typified by high runoff, monsoonal rain, with the offshore reef. Moving south, is the GBR/dry tropics region, influenced by periodic rainfall leading to pulsed runoff. The subtropical east coast of Australia, where Moreton Bay fits in, has a dominant summer rainfall, sand barrier islands, fringing mangroves, saltmarshes and subtidal seagrass meadows. South of Moreton Bay, the rainfall is more uniform and average, and more temperate flora and fauna exist. Southern Ocean and Bass Strait catchments, influenced by mostly winter rainfall, are characterised by rugged rocky coastline with temperate rocky reefs, and large algal beds.

The Southern Ocean Gulf region consists of arid catchments, with winter rainfall and often hypersaline or inverse estuaries.

The south-west corner of Australia is dominated by a Mediterranean climate (winter rain, summer dry) and flat sandy catchments with relatively low ambient nutrients. The Pilbara and subtropical west coast are dominated by arid coastline, high tidal range, high evaporative input and sporadic runoff. The Kimberleys in the north-west of Australia are steep rocky catchments with extreme tide ranges, monsoonal rainfall, cyclones, and very turbid estuaries. The top end of Australia is also dominated by monsoonal rainfall and cyclones, but has flat and more sandy catchments. Tasmania has diverse coastal catchments, often small and with steep relief, uniform winter rainfall and some oceanic upwelling influences.

The catchments within South East Queensland are diverse



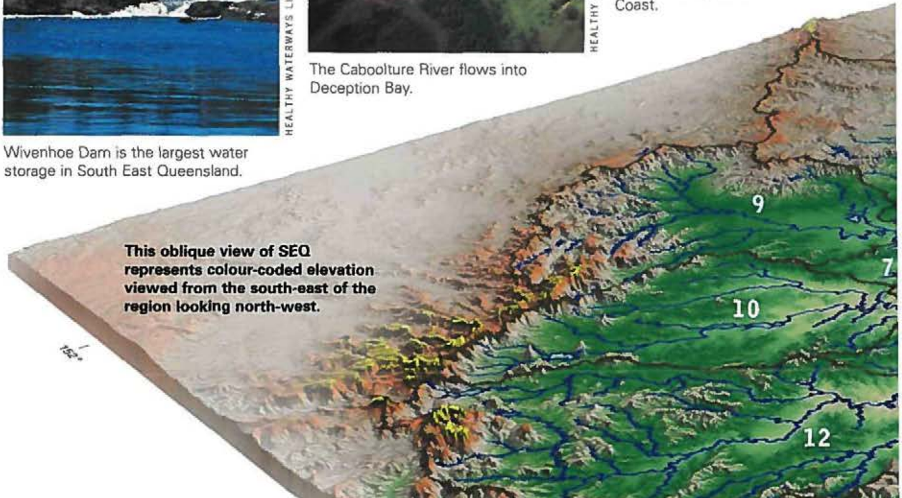
HEALTHY WATERWAYS LIBRARY

Wivenhoe Dam is the largest water storage in South East Queensland.

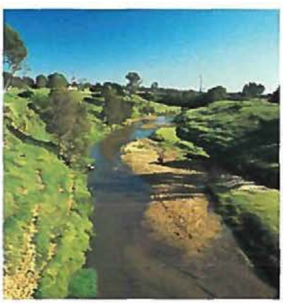
HEALTHY WATERWAYS LIBRARY

The Caboolture River flows into Deception Bay.

The Maroochy River on the Sunshine Coast.



This oblique view of SEQ represents colour-coded elevation viewed from the south-east of the region looking north-west.



HEALTHY WATERWAYS LIBRARY

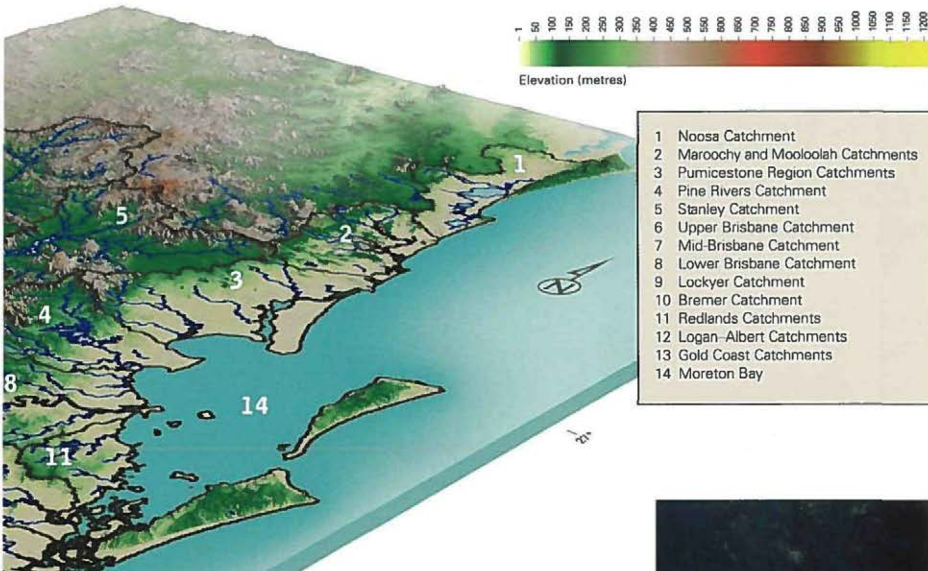
The Logan River flows across an extensive floodplain.

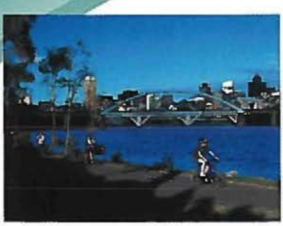
HEALTHY WATERWAYS LIBRARY

The Nerang River flows into the Gold Coast Broadwater.

The South East Queensland region contains both small and large catchments, the largest of which are the Brisbane River and Logan River catchments. Brisbane, Logan, Caboolture, Pine Rivers and other smaller creeks flow into Moreton Bay. The three major rivers in the Gold Coast catchment: the Pimpama, Coomera and Nerang Rivers, all flow into Southern Moreton Bay. There are also the Northern Rivers: Maroochy, Mooloolah and Noosa Rivers, which drain directly into the ocean.

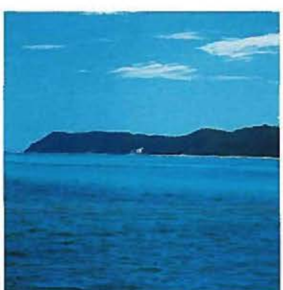
The series of sand islands, Moreton, North Stradbroke and South Stradbroke islands form an offshore barrier on the eastern boundary of Moreton Bay. Elevations in the region are grouped into coastal floodplain, low relief regions and high relief mountains forming the edge of the catchment. In a sense, South East Queensland sits within a bowl formed by the Lamington Plateau and the Western Boundary Ranges into which the activities and much of the human footprint of the 2.6 million people living within this region are contained.





BRISBANE CITY COUNCIL

The tidal Brisbane River catchment is a highly modified region.



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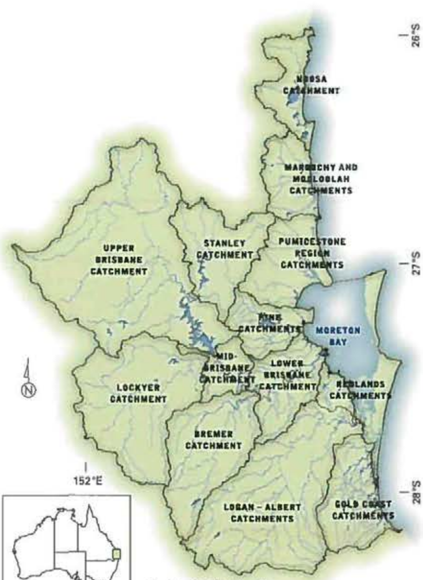
Moreton Island is one of the three major islands enclosing Moreton Bay.

HEALTHY WATERWAYS LIBRARY

The Pine River flows through rural residential areas before entering the urbanised lower catchment.

South East Queensland can be divided into a *series of subcatchments*

South East Queensland is divided into a series of subcatchments. The Noosa catchment is dominated by the Noosa River and a series of freshwater and brackish water lakes flow into the Pacific Ocean and through the shire of Noosa. South of the Noosa River are the Maroochy and Mooloolah catchments. The Maroochy and Mooloolah Rivers both flow into the Pacific Ocean near the town of Maroochydore. Further south is the Pumicestone Region which includes a series of small coastal creeks flowing into an oceanic inlet. This inlet separates Bribie Island from the mainland. In addition, the Caboolture River flows directly into western Moreton Bay. South of the Pumicestone catchment is the Pine Rivers catchment, consisting of the North and South Pine Rivers, and flowing into Moreton Bay. There are two dams in the catchment, Lake Samsonvale on the North Pine River and Lake Kurwongbah on Sideling Creek. The South Pine River remains relatively unregulated.



The South East Queensland region is divided into 13 subcatchments.

The Brisbane River catchment, the largest in South East Queensland, is broken up into 6 subcatchments, including the Stanley catchment to the north, the Upper Brisbane River catchment extending the furthest to the west, the Lockyer catchment, the Bremer catchment and the mid and lower Brisbane catchments. South of the Brisbane River catchment is the next largest catchment in the region, the Logan-Albert catchment. The Logan and Albert Rivers flow from south to north through Boonah and Beaudesert and empty into Southern Moreton Bay. The Redlands catchments, which also include the offshore barrier islands, are located on the coastal area east of the Brisbane River catchment and north of the Logan-Albert catchment.

A series of streams and rivers of Gold Coast catchments flow either directly into the Pacific Ocean or flow into the Broadwater region.

Laidley Creek subcatchment in SEQ situated in the Western Catchment of South East Queensland

South East Queensland catchments *drain into Moreton Bay and the Pacific Ocean*

The satellite image of the region shows the catchment as well as the adjacent ocean. The combined catchment area of creeks and rivers discharging into Moreton Bay is 21,220 km^2, and compared to the area of the Bay itself (1523 km^2), represents a catchment to Bay ratio of about 14:1. The Brisbane and Logan River catchments, the largest catchments, are the major contributors of both sediment and nutrient into Moreton Bay.

Exchange between Moreton Bay and the ocean is through the North and South Passages, as well as Jumpinpin and the Gold Coast seaway. Tidal exchange between Moreton Bay and the ocean plays a major role in the transport and fate of sediments, nutrients and other substances. Most of the oceanic exchange occurs via the North Passage. The exchange through South Passage is more restricted and influences flushing in the southern Moreton Bay region. Jumpinpin has a narrow opening with a shallow bar, and thus has the least oceanic exchange. The position of these four openings of the Bay into the ocean, the width of the openings, the tidal deltas that restrict water exchange through the openings, and the bathymetry of the Bay, interact to produce complex patterns of oceanic exchange. The oceanic exchange coefficients, together with the tidal prism and volume of the Bay determines the gradients in residence times in Moreton Bay. Residence time refers to the length of time that a parcel of water remains at a certain location.

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Jumpinpin Bar, one of the four openings of Moreton Bay into the ocean.

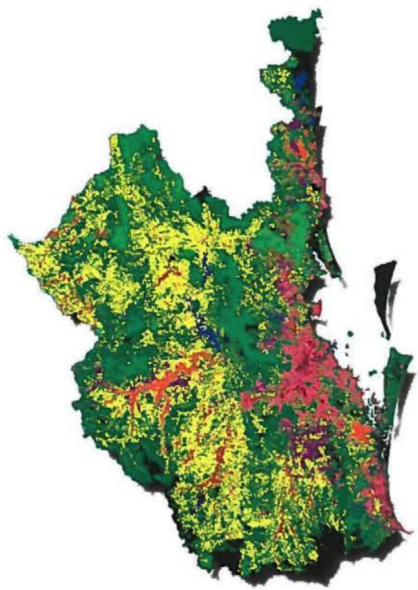
AUSTRALIAN CENTRE FOR REMOTE SENSING

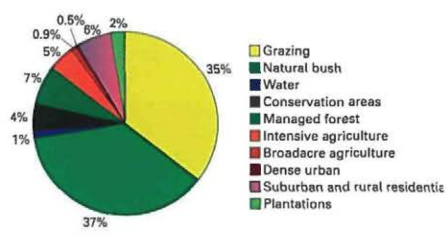
Major rivers and creeks drain into Moreton Bay (white arrows). Oceanic exchange in Moreton Bay occurs via the (1) North Passage, (2) South Passage, (3) Jumpinpin and (4) Gold Coast Seaway (red arrows).

Expanding human footprint on catchments since European settlement

South East Queensland has one of the fastest growing populations in Australia, with just over 2.6 million people, increasing by 2.9% per annum. This increase in population is expected to result in about 75 km² of bushland, agricultural land and other rural land being converted annually to housing and other urban purposes. Thus, the human footprint on the catchment is rather extensive today and promises to be more extensive in the future.

Land use maps of South East Queensland catchments indicate that the urban and suburban developments are concentrated in the Brisbane River corridor, and expanding into the areas along the north and south coasts. Intensive agricultural land occurs largely in the Maroochy River to the north, the Bremer and the Lockyer Rivers, subcatchments of the Brisbane River and the Logan catchments. Large tracts of grazing land also occur particularly in the western portions of the catchment and the upper Brisbane and Stanley. There are extensive areas of conservation, managed and plantation forests which occur throughout the region, particularly along the upper catchment boundary. Headwaters of the streams are largely in the forested regions and in the elevated agricultural areas of the region.



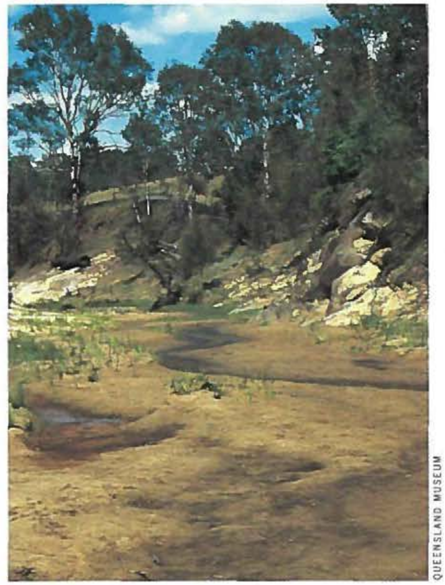


Landuse in South East Queensland.

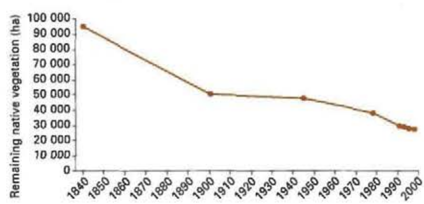
South East Queensland has one of the fastest growing populations in Australia.

Historically intact vegetation and unregulated flows pre European settlement

South East Queensland land use scenario circa 1770.



Open eucalypt forest in the Logan River catchment.



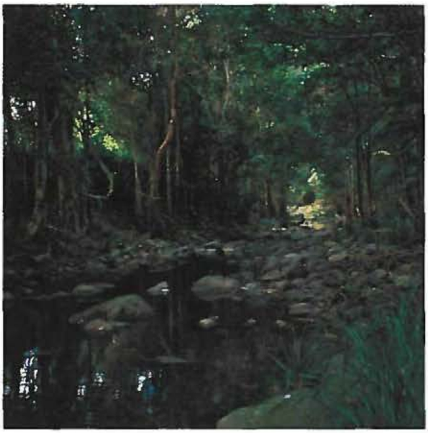
Decreasing extent of native vegetation in South East Queensland.

Based on sketches from early settlers, the vegetation in the region consisted of dense forest vegetation along the coastal strip and in the high elevation regions and open forest extending throughout the broad areas of the upper Brisbane and Logan catchments. The rivers in the historical catchment (1770) were totally unregulated.

Aboriginal occupation of the region dates back at least 22,000 years. The current coastal areas were formed about 6,000 years ago following sea level rise and most intensive aboriginal occupation occurred over the last 4000 years. Aboriginal "fire stick farming" practices, typical of much of Australia, influenced the forest vegetation growth and forest type, favouring the open eucalypt forest and grasslands over the closed forest types.

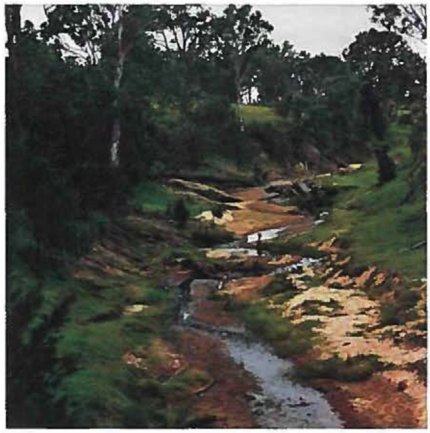
Settlement which began in 1823 led to intensive clearing of the forest and the development of agriculture in the 1840s. Since the start of European settlement in 1823, 6,700 km^2 (two-thirds of the original 9,800 km^2 of woody vegetation in South East Queensland, has been cleared). Clearing of vegetation continues today, but less for agricultural activities and more for urban development.

Rainfall is *spatially variable*



MICK SMITH, GRIFFITH UNIVERSITY

The Mooloolah River catchment receives high rainfall.



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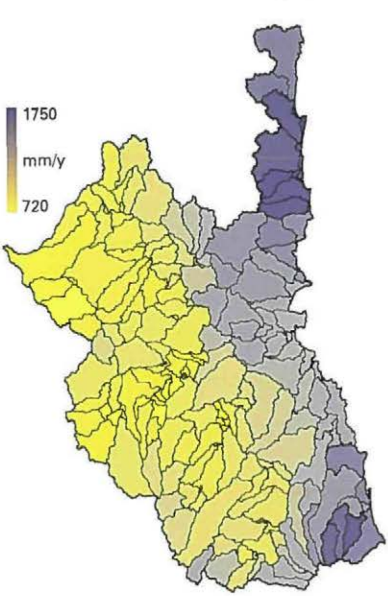
The Logan River catchment receives low rainfall.



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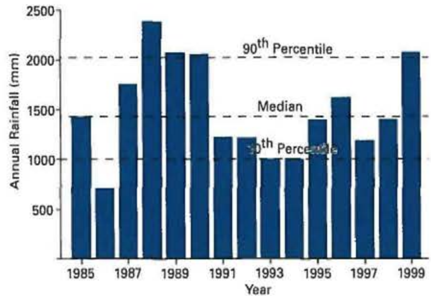
Rainfall patterns in South East Queensland catchment.

In South East Queensland, rainfall varies dramatically not only from year to year (alternating between drought and flood), but also spatially (coastal vs. non-coastal catchments). This is due to the region's elevation and juxtaposition with the coast. In general, coastal subcatchments receive much higher rainfall than the western region of the SEQ catchments. At a finer scale, the smaller catchments of the Northern Sunshine Coast and Southern Gold Coast receive two to three times more rain than the western catchments. The higher rainfall of the steep coastal catchments has to do with the onshore winds and adiabatic cooling (i.e. as the clouds rise over the coastal ranges; they are cooled, leading to precipitation). These spatial patterns of rainfall have implications in terms of vegetation type and runoff occurring across the catchments.

Rainfall: *Temporally variable between and within years*

Rainfall variability from year to year alternates between drought and flood and depends on large-scale weather patterns which are dominated in this region by the El Niño Southern Oscillation (ENSO). These patterns occur at large time scales and result in changes in air pressure and sea temperature in different parts of the Pacific Ocean. These in turn, affect the intensity of the summer south-east trade winds, causing them to carry more or less moisture into the region and resulting in either more or less rainfall. Rainfall in dry years is less than half of the rainfall of the wet years. The median rainfall in the region is about 1500 mm. The decade of the 1990's was typified by relatively low rainfall, the late 1980's were defined by very high rainfall. This pattern of rainfall has been found throughout rainfall records of the region. There is also high variability of rainfall within years, with the majority of the annual rainfall occurring during the summer months. In the spring and summer months, high intensity thunderstorms are formed, delivering rain in short, sharp bursts to the catchment.



Variability in annual rainfall in South East Queensland over a 15-year period.

The climatic variation has a big influence on the way in which the waterways function. The rivers flow in pulses, often flooding after a heavy rain. During most times of the year, however, many of the SEQ streams are dry or restricted to a series of disconnected pools.

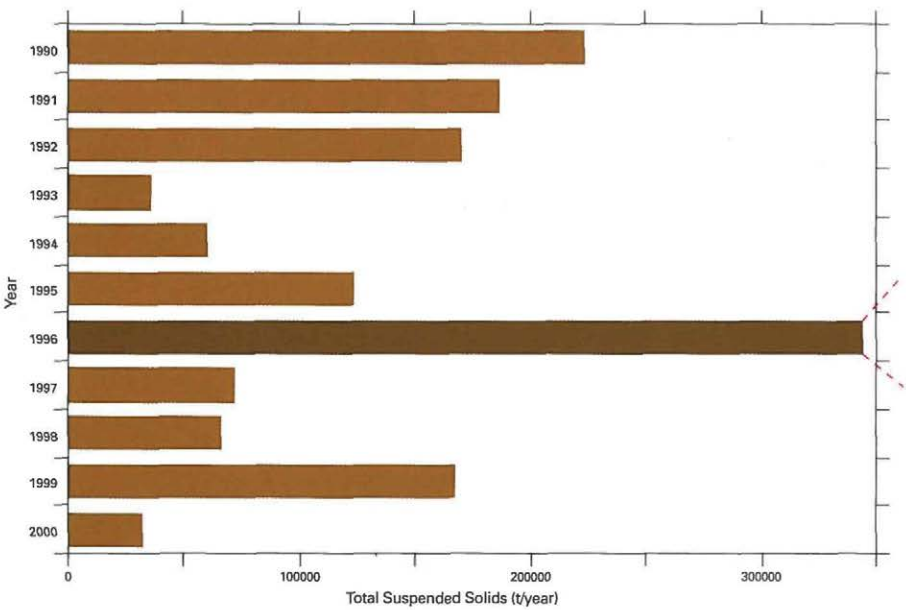
Kedron Brook, a highly-modified urban stream, during a flood event.

Delivery of sediments/nutrients predominates during high flow events

High flow events deliver increased loads of sediments and nutrients to the waterways and the Bay.

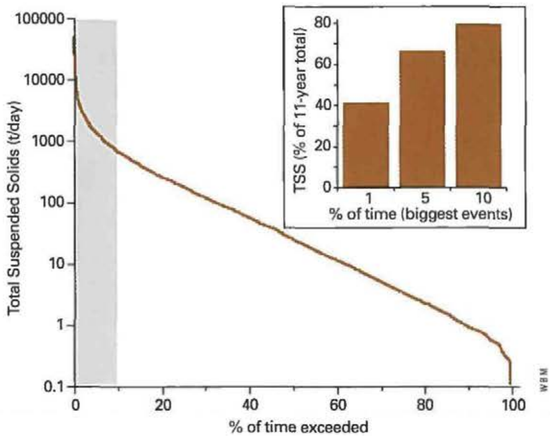
Sediment and nutrient loads into the rivers of the SEQ region vary dramatically through time. Predictions of Total Suspended Solids (TSS) loads (for different time scales) entering Moreton Bay indicate considerable inter-annual variation in TSS loading to the Bay for the 1990 – 2000 period. The greatest annual load during this period was delivered in 1996, with most of the sediment loading occurring during the month of May. About 90% of that TSS load moved in the first six days of that month, when major flooding occurred in the region.

A predicted cumulative frequency distribution of daily TSS loads entering Moreton Bay for the period 1990 – 2000 indicates that the vast majority of the TSS load moved in a very short

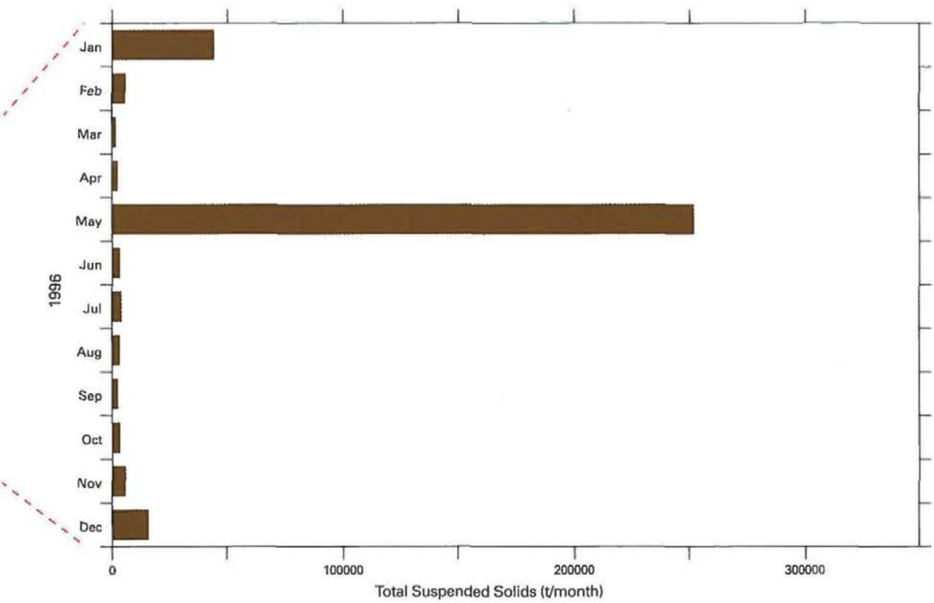


Delivery of sediments and nutrients to Moreton Bay is episodic. A high flow event in May 1996 is shown by increased levels of sedim period of time. It was predicted that 42% of the TSS load entered the Bay during 1% of the 11-year period (40 days), and that 66% and 80% of the total TSS load were delivered in 5 and 10% of that time (200 and 400 days), respectively. Although these predictions indicate strong episodicity in sediment delivery to the Bay, they probably underestimate this because the Environmental Management Support System (EMSS) applies a constant Event Mean Concentration (EMC) value across flow events of all magnitudes.

Delivery of sediments is also time associated with delivery of nutrients from the catchments. Hence, it is predicted that similar patterns of sediment delivery will apply to nutrient delivery from the catchment.



Daily total suspended solids (TSS) exceedances for Moreton Bay.



utrients entering the Bay. These predictions were made by using the Environmental Management Support System (EMSS), (see chapter 8).

People in SEQ *value their waterways*

The waterways always have been a precious resource to the people of South East Queensland. The waterways provide drinking water, food and recreational amenities like fishing, swimming and boating. They also provide various ecosystem values, wildlife habitat and visual amenity. In addition, the waterways supply essential water resources for agriculture, aquaculture and industrial source.

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Rowing is a popular recreational activity on our waterways.

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Camping grounds are often located adjacent to waterways.

Community Value Table
Aquatic ecosystems e.g. Healthy seagrass which supports dugong and turtles
Wildlife Habitat e.g. Habitat for native species like the green tree frog
Human Consumers e.g. Shellfish and fish that are safe to eat
Primary Recreation e.g. Clean waters to swim in
Secondary Recreation e.g. Clean water for sailing and fishing
Visual Amenity e.g. Vistas of clean water and healthy coastline
Cultural Heritage e.g. Protection of indigenous values
Industrial Use e.g. Economic development with sustainable water use
Aquaculture e.g. Prawn farms using best practice
Drinking Water e.g. sufficient safe water supplies
Irrigation e.g. sufficient water for crops
Stock Watering e.g. sufficient water for cattle
Farm Supply e.g. sufficient clean water for rural residents

Environmental values of South East Queensland waterways.

CHRIS ROELFSEMA, MARINE BOTANY, UQ

The seagrass *Halophila ovalis* provides food for dugong and turtles.

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Crop irrigation in the Albert River catchment.

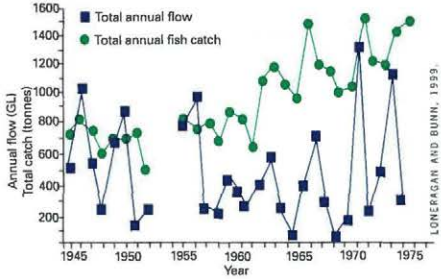
SEQ has *considerable fisheries resources*

Moreton Bay comprises 3% of the total Queensland coastline but represents approximately 30% of the State's recreational fishing effort and 15% of the State's total commercial catch. Approximately 350 licensed commercial fishing boats, with an estimated value of more than $50 million in equipment, operate in Moreton Bay. Recreational fishing is also popular in the Bay, with approximately 300,000 recreational fishermen harvesting 250 tonnes of crab and 1250 tonnes of finfish annually. With 7 farms, totalling 125 ha, the Logan/Albert Catchment in South East Queensland supports the highest intensity of prawn aquaculture in the state.

Research has shown that high river discharge affects the catch of commercial and recreational fisheries. The seasonal patterns and magnitudes of river flow play important roles in fisheries production. Maintaining the natural seasonal pattern of flow is clearly as important as maintaining the magnitude of total annual flow for fisheries production.

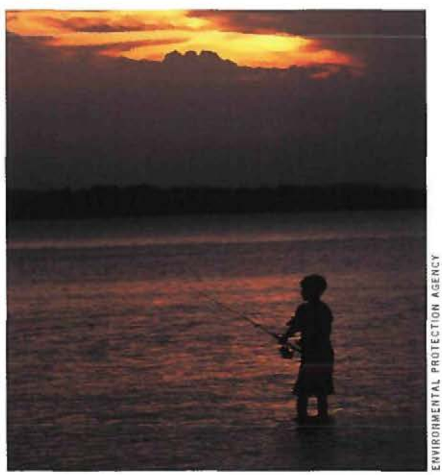
% of total Queensland fisheries catch caught in Moreton Bay (tonnes/year) (DPI)

	Queensland	Moreton Bay	%
Prawns	7500	1040	14%
Estuarine Fish	5983	1623	27%
Crabs	1385	418	30%



Total annual flow in the Logan River and total annual fish catch for three landing ports in Moreton Bay, 1945-1975.

Aquaculture in the Logan River catchment.



Recreational fishing in the Pumicestone Passage.

SEQ Study was initiated in response to concerns about impacts of expanding population

As the year 2000 drew near, the projections for population growth and intensified land use in the South East Queensland were setting off alarm bells. The present and future health of natural ecosystems in the region was clearly under threat. The South East Queensland Regional Water Quality Management Strategy (SEQ Study) was motivated by the need for a robust scientific understanding of the waterways of the region and Moreton Bay to underpin an effective management strategy.

Originally, the SEQ Study consisted of a collaboration of six local governments and the (then) Queensland Departments of Environment and Heritage and Natural Resources. In July 2001, the SEQ Study merged with the Brisbane River Management Group (under the auspices of the Environmental Protection Agency) to become the Moreton Bay Waterways and Catchments Partnership (MBWCP or the Partnership).

The area covered by the Partnership stretches from the Queensland/NSW border in the south to Noosa in the north and west to the Great Dividing Range. It covers nearly 22,000 square kilometres and supports over 2.6 million Australians.

The Partnership brings together State agencies, all the local governments in SEQ, industry and community organisations, operating through a wide variety of consultative, participatory, advisory, planning, decision making and regulatory processes.

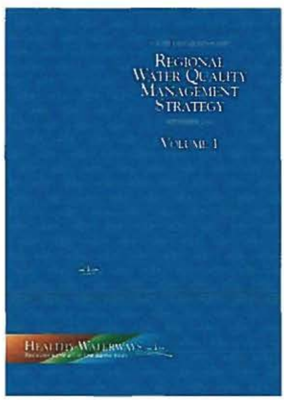
A critical element in focussing the SEQ Study has been the collaboratively developed Healthy Waterways Vision. The Healthy Waterways Vision Statement provides both an aspirational target and a yardstick to measure the success of management actions. The tagline on the colourful logo – *"Because we are all in the same boat"* – underlines the collective nature of the problems and the solutions. The Vision was originally developed for the estuarine and coastal regions of Moreton Bay. It has been expanded to recognise the inter-relationship between all the waterways and catchments in the region with the health of the Bay.

The SEQ Study provides a regional blueprint that prioritises management actions to achieve healthy waterways and catchments. Seventy-two agreed actions are now being progressively implemented by over sixty-three partners.

The Partnership is guided by the Healthy Waterways Vision that:

By 2020, our waterways and catchments will be healthy ecosystems supporting the livelihoods and lifestyles of people in South East Queensland, and will be managed through collaboration between community, government and industry.

SEQ Healthy Waterways logo.

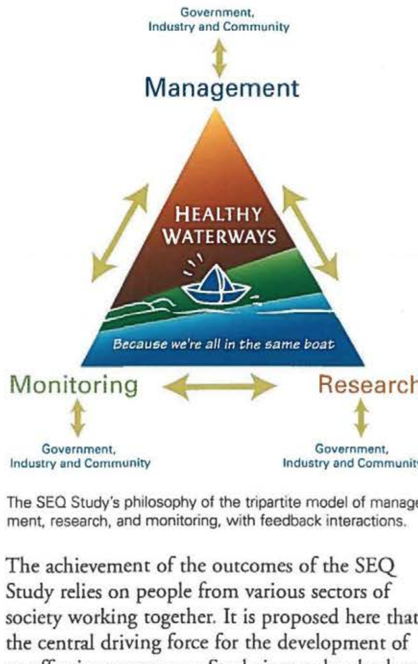


2001 South East Queensland Regional Water Quality Management Strategy.

Balanced approach

A key element in the SEQ Study is the balance between management, research and monitoring. The natural checks and balances provided by the tripartite model of management, research and monitoring provide the foundation for the Study. Strong communication links have been established between these elements, and with different sectors of society.

The interactions between management, research and monitoring involves a two-way flow of information. Management, with input from the community, provides environmental values and resource management objectives and identifies key environmental issues. Research addresses the key issues, gathers information to narrow the knowledge gaps and provides the scientific linkages that support and create the various indicators used by resource managers involved in monitoring. Monitoring provides feedback to researchers in the form of prioritised research based on patterns observed during the assessment of the ecosystem. The interactions between monitoring and management are somewhat similar to the management-research interactions. In both cases, management, with input from the community, provides the environmental values and resource management objectives. The major difference is that monitoring provides management with the feedback on various management actions invoked.



The SEQ Study's philosophy of the tripartite model of management, research, and monitoring, with feedback interactions.

The achievement of the outcomes of the SEQ Study relies on people from various sectors of society working together. It is proposed here that the central driving force for the development of an effective program or Study is not the absolute amount of scientific or management activity or expertise; rather it is the appropriate balance between management, research and monitoring.

(1) UQ MARINE BOTANY
(2) HEALTHY WATERWAYS LIBRARY
(3) QPWS

(1) Scientists perform research to address knowledge gaps raised by stakeholders. (2) Working with our stakeholders: communicating results, facilitating strategic planning, developing solutions together to achieve the Healthy Waterways vision. (3) Community participation and input into the Study ensure issues are relevant and prioritised.

Timeline – Staged approach

The SEQ Study has taken a staged approach; each stage with a different scope and objectives interspersed with a review period in order to develop, re-evaluate and re-assess objectives and achievements.

Stage 1 of the Study was a scoping stage in which the scientific team was formed, literature reviewed and priorities developed for the ensuing stages of the Study. Stage 1 focused on background studies and initial scoping of the terms of reference for the scientific tasks. It was during this stage that a Scientific Advisory Group was formed to ensure quality control and rigorous peer review of research direction, prioritisation and activities.

Stage 2 focused on the river estuaries and Moreton Bay, addressing point source issues, specifically in terms of nitrogen vs phosphorus removal. Based on an initial conceptual diagram developed by the Scientific Advisory Group, in consultation with the stakeholders, a coordinated set of tasks focussing on point sources in Moreton Bay was then developed to address research gaps. The tasks included the design of an estuarine and Bay monitoring program.

Key outcomes of Stage 2 included the development of a Receiving Water Quality Numerical Model for the estuaries and Bay, as well as the identification of zones of sewage impacts, sediment delivery, deposition and resuspension, nearshore seagrass loss and primary nitrogen limitation in Moreton Bay.

The outcomes of Stage 2 highlighted the need for expansion into the freshwaters of South East Queensland. Stage 3 focussed on catchment sediment and nutrient delivery and processing, design of a freshwater monitoring program and toxic cyanobacteria (*Lyngbya*) blooms in our waterways. Stage 3 took on the challenge of addressing non-point or diffuse sources from the catchment. A decision support tool (Environmental Management Support System, EMSS) was developed to assist stakeholders in evaluating the efficacy of various management actions aimed at the improvement of water quality.

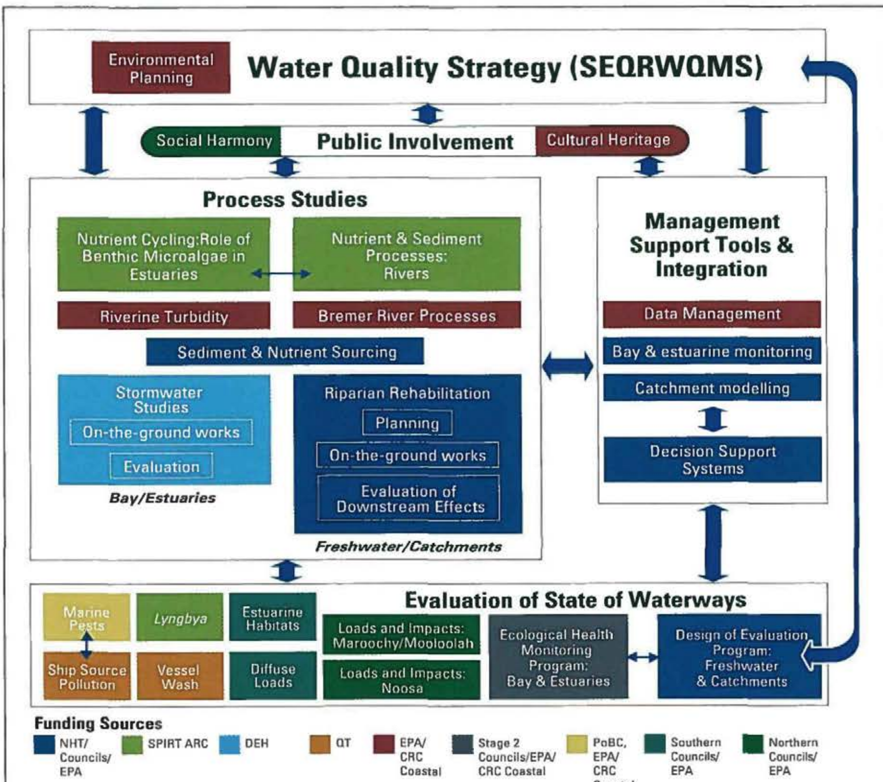
The current focus of the Moreton Bay Waterways and Catchments Partnership focuses on the integration of Moreton Bay, estuaries and freshwaters with the catchment to develop sustainable loads for these waterways.

1994 – 1997	1997 – 1999	1999 – 2002	2002 onwards
Stage 1 **Scoping**	**Stage 2** **Bay and Estuaries Focus**	**Stage 3** **Rivers and Catchment Focus**	**Integrated Partnership** **Waterways Management Land to Sea; Sustainable Catchment**
■ Background Studies	■ Pilot studies ■ Design of Estuarine & Marine Monitoring Program	■ Ongoing studies ■ Estuarine & Marine Monitoring ■ Design of Freshwater Monitoring Program ■ Regional Decision Support Tools ■ Regional Process Studies	■ Integrated Freshwater, Estuarine & Marine Monitoring ■ Design of Load-Based & Human Health Monitoring Program ■ Decision Support tools for Implementation ■ Process Studies ■ Socio-Economic Studies ■ Sustainable Loads
■ 6 Local Councils ■ State & Federal Governments	■ 6 Local Councils ■ State & Federal Governments	■ 19 Local Councils ■ State & Federal Governments	■ 19 Local Councils ■ State & Federal Governments ■ NAP & NRM Iniatives

A staged approach was adopted by the Study, with each stage having a different focus, targeted objectives and clear outcomes.

Linked Scientific Tasks

The initiation of Stage 3 in 1999 has seen the switch in focus to freshwater and catchment issues and an expansion of the geographical scope to incorporate the northern, southern, and western regions of SEQ. The overall objective of the scientific task framework as seen below is the delivery of the best available scientific information for the development of the 2001 South East Queensland Regional Water Quality Management Strategy. Scientific tasks consisted of process studies conducted in the freshwater areas and catchment, the development of management support tools for integration and tasks aimed at providing an evaluation of the state of waterways. Appropriate management support tools integrate scientific results into the delivery of the *2001 South East Queensland Regional Water Quality Management Strategy.*



Stage 3 task architecture, showing the integration and linkages of tasks aimed at providing input into the development of the SEQ Regional Water Quality Management Strategy.

Our understanding of SEQ waterways has rapidly evolved

Initial understanding of the South East Queensland waterways was restricted to the estuarine and marine components and it was recognised early on that little vertical stratification occurred but significant horizontal stratification was evident. Zones were created to differentiate riverine reaches, tidal estuaries, variable seasonal estuaries and the marine sections. A gradient of limiting factors between nutrients and light was noted and the point and non-point sources of sediment and nutrients were identified. Seagrass, turtles and dugong in eastern Moreton Bay were seen as significant ecological, and community assets.

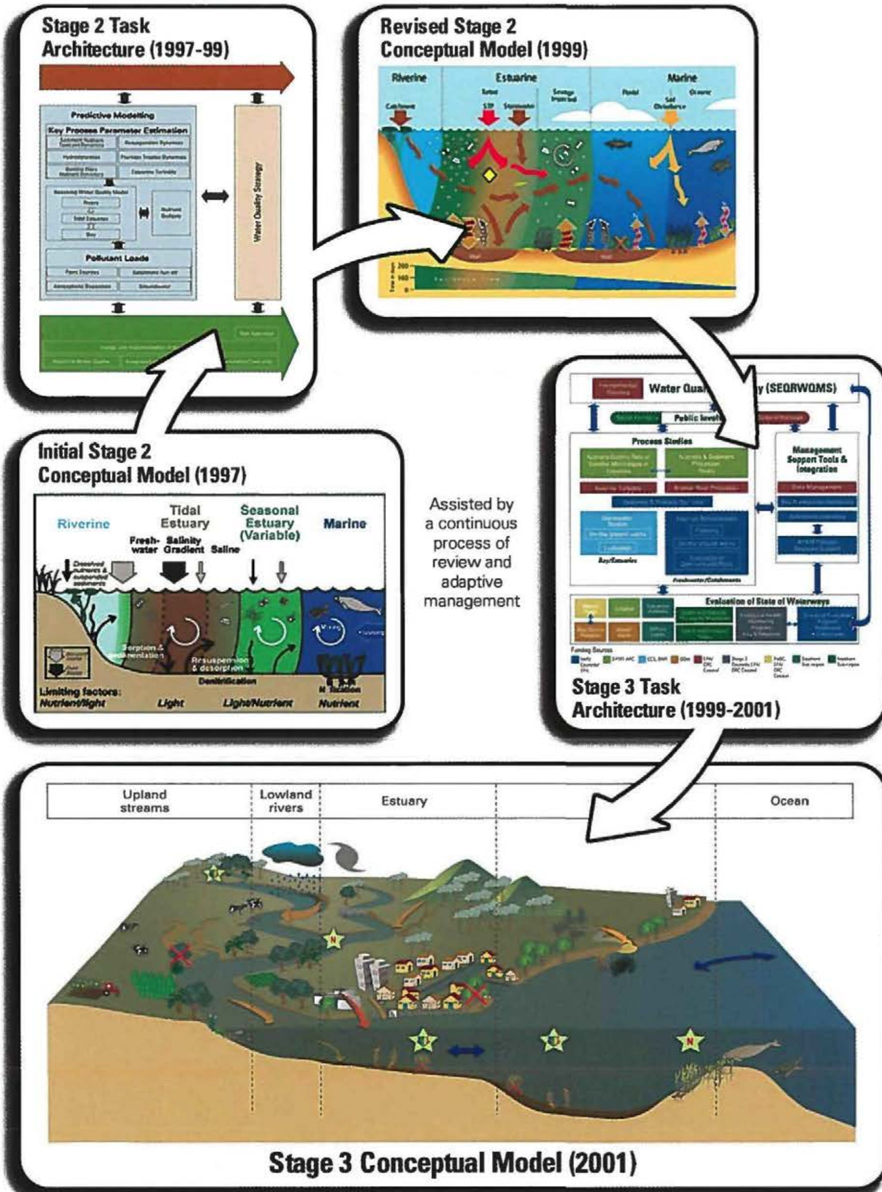
At the end of Stage 2 of the SEQ Study, sewage plumes were delineated and mapped using stable nitrogen isotope data. The over-all conclusion of this stage was that environmental degradation was evident in river estuaries and western regions of Moreton Bay, but that the rich and diverse ecosystems of eastern and northern Moreton Bay were essentially intact. There was preliminary understanding of the processes of inputs of sediments and nutrients from catchment sources. Sediment resuspension and light reduction leading to seagrass loss were identified as significant issues. Nitrogen was identified as a major limiting nutrient in Moreton Bay and the river estuaries.

Finally, a catchment-focus in Stage 3 resulted in an understanding of the consequences of variable rainfall and runoff patterns, as well as the sources of erosion and sediment delivery from the upper catchment. The extensive loss of riparian vegetation and degradation of aquatic habitats were noted. An understanding of the dynamics and occurrence of *Lyngbya* blooms in the Bay was developed. Stage 3 highlighted the connectivity of the freshwaters, estuaries and Moreton Bay and more importantly, their linkages with the catchment and vice-versa. Only by ensuring that we have healthy catchments can we have healthy waterways.

At each of these stages of the Study, a conceptual diagram was drafted and widely circulated to stakeholders to illustrate preliminary understanding incorporate the environmental values that the community held and facilitate the prioritisation of issues and identification of gaps which need to be addressed through research. The diagrams were then revised to incorporate any new knowledge acquired. This improved understanding of the science and attempted to incorporate some of the environmental values that the community held.

Three-dimensional conceptual model for the catchments and waterways of South East Queensland, highlighting the connectivity between catchments and waterways (Stage 3).

How our understanding of SEQ waterways evolved



CONTRIBUTORS (in alphabetical order)

Elaine Green, Paul Greenfield, Tony McAlister and Diane Tarte.

FURTHER READING

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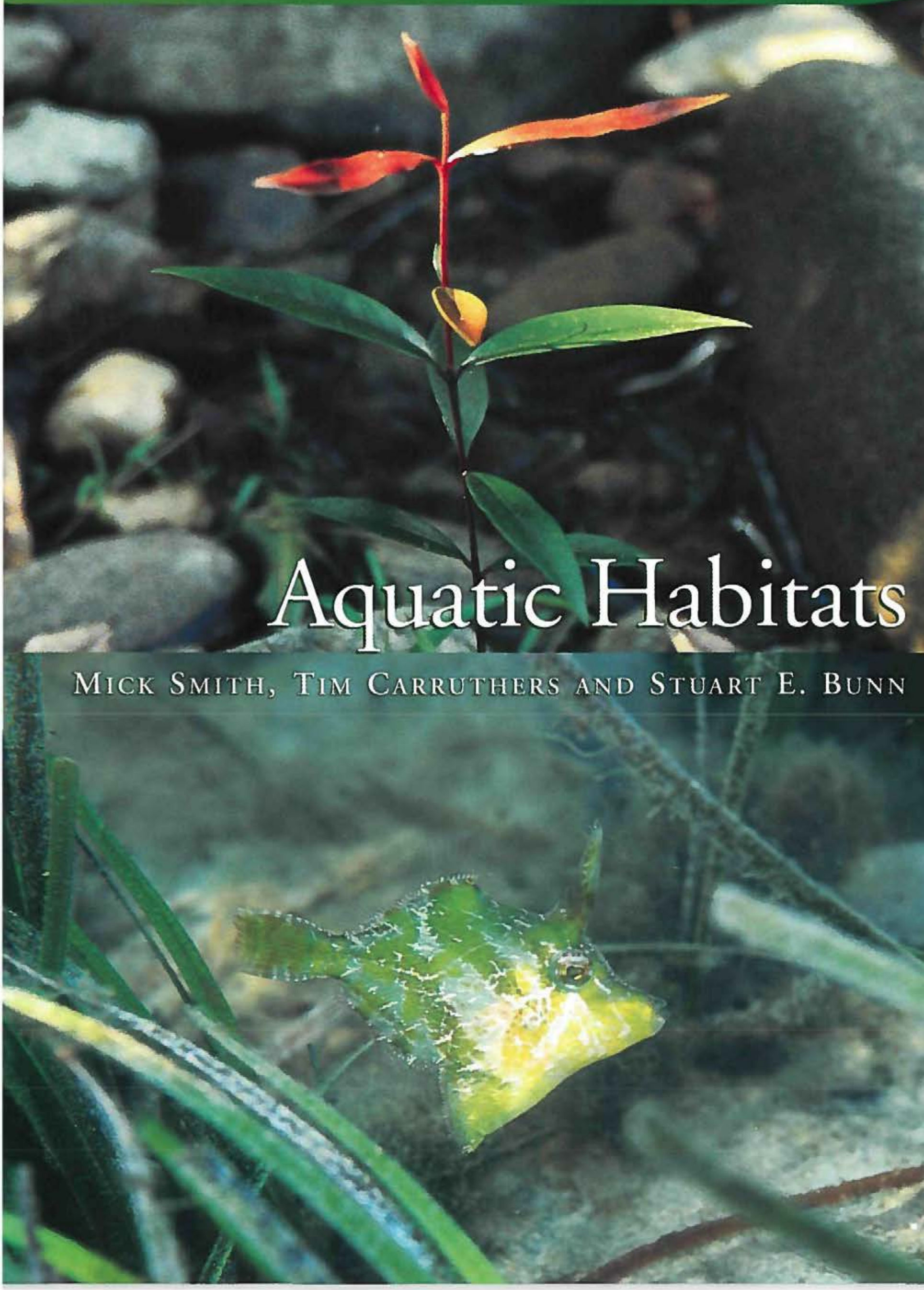
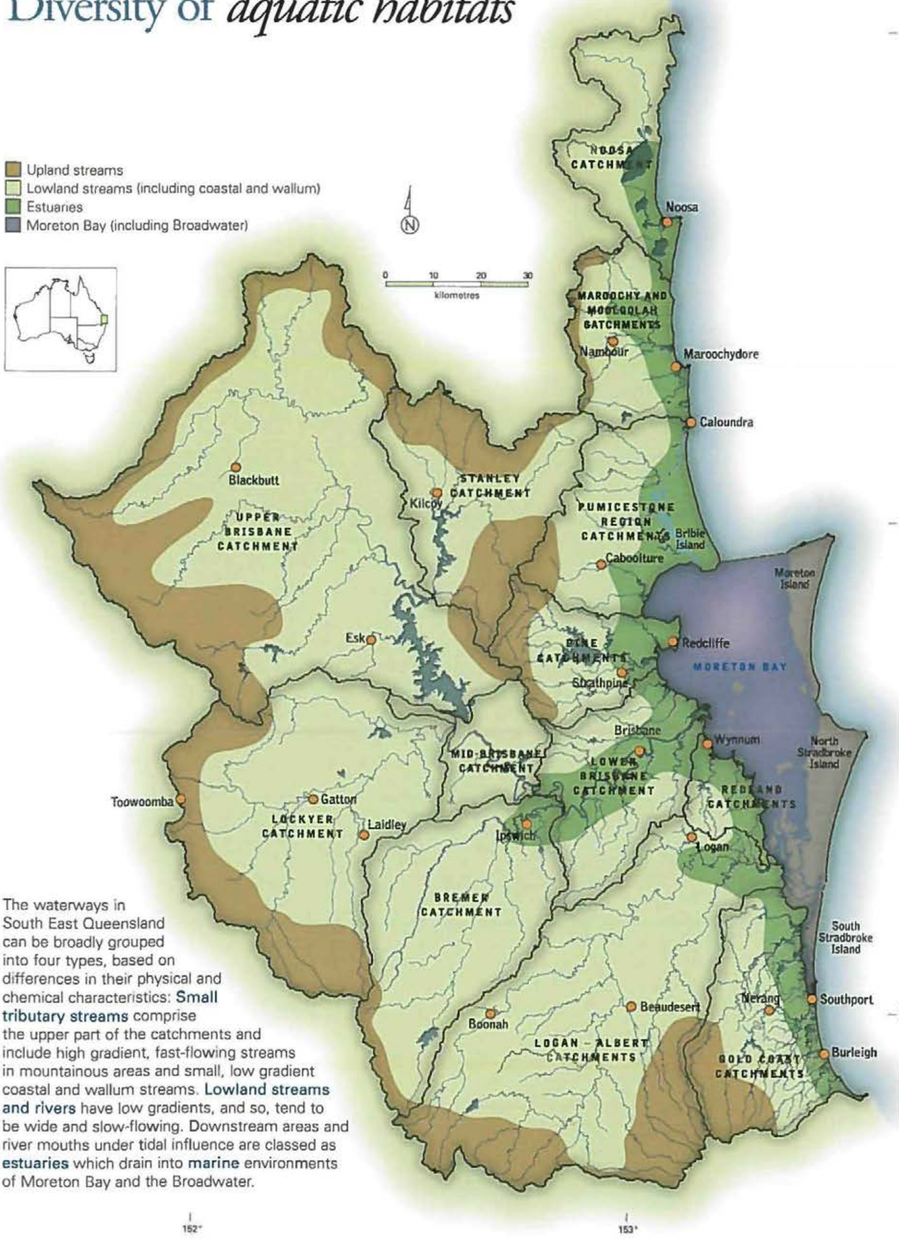


Chapter 3

Aquatic Habitats

Mick Smith, Tim Carruthers and Stuart E. Bunn

Diversity of *aquatic habitats*



The waterways in South East Queensland can be broadly grouped into four types, based on differences in their physical and chemical characteristics: **Small tributary streams** comprise the upper part of the catchments and include high gradient, fast-flowing streams in mountainous areas and small, low gradient coastal and wallum streams. **Lowland streams and rivers** have low gradients, and so, tend to be wide and slow-flowing. Downstream areas and river mouths under tidal influence are classed as **estuaries** which drain into **marine** environments of Moreton Bay and the Broadwater.

Aquatic habitats in South East Queensland are many and varied, but can be broken into four broad categories:

A SMALL CREEKS AND TRIBUTARY STREAMS

Small tributary streams are those <10 m in channel width and include both steep upland streams and lower gradient, lowland tributaries. In their natural state, small streams are often densely shaded by riparian vegetation because their entire width is easily shaded by large trees. In upland areas, small streams provide a variety of flow environments including riffles, pools and runs. Also, they offer a range of substrates such as bedrock, boulders, cobbles, and gravels. These physical attributes combine to provide a variety of freshwater habitats which contain a diverse and sometimes unique fauna.

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Stoney Creek in the Stanley River Catchment, a small upland stream.

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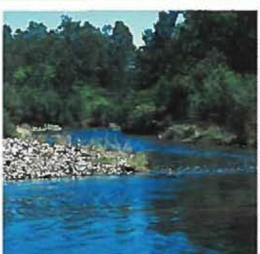
Neara Creek: a tributary of the upper Brisbane River.

B LARGER STREAMS AND RIVERS

Larger streams and rivers are those >10 m in channel width. They typically have low gradients and the flow environment is generally more uniform than that of small streams (predominantly long deep pools and runs). The stream bed is usually comprised of finer materials such as gravel, sand, silt or clay; while under-cut banks, branches and logs, as well as the water column all provide important habitat for aquatic fauna. Larger streams are often associated with extensive floodplains and wetlands, and the links between these areas and the stream are important in maintaining both habitat diversity and biodiversity.



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Brisbane River, downstream of Wivenhoe Dam, is the largest river in South East Queensland.

C ESTUARIES

Estuaries are characterised by variable salinity, and are the waterways occurring between the coast and the tidal limits of a river. The dominant feature of these waterways in South East Queensland is variable intensity runoff from the land created by summer (December-March) rains. Periodic river flow results in increased sediment loads, salinity fluctuations and scouring which combine to make these habitats spatially dynamic and seasonally variable. Estuarine systems contain a large diversity of habitat types.

HEALTHY WATERWAYS LIBRARY

Brisbane River Estuary.

D MARINE

Moreton Bay is a large marine embayment sheltered by Moreton Island, and North and South Stradbroke Islands. Water quality in Moreton Bay is dominated by seasonally pulsed riverine inputs from the west and oceanic flushing with tidal exchange through North Passage, South Passage and the Jumpinpin bar. This provides a large diversity of subtidal and intertidal habitats which support seagrass, mangrove, phytoplankton, benthic microalgae, macroalgae (seaweed) and coral communities.

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The Broadwater, a marine environment.

Characteristics of *small tributary streams*

In South East Queensland, only a few spring-fed streams flow year-round. Most small streams flow seasonally or intermittently, meaning sections of their channel remain dry for brief or extended periods. The extent of these dry periods, and the presence of pools which act as refuges during dry spells, are critical in determining both the distribution and abundance of aquatic plants and animals.

Where there is flowing water, small streams provide a variety of flow environments for aquatic organisms such as:

- Riffles – shallow, fast flowing areas where water is aerated, usually with coarse substrates such as boulders, cobbles and coarse gravels;
- Runs – areas of moderate depth where water flows swiftly but the surface is not broken, and
- Pools – deeper areas, where water is still or flows very slowly. Sediments can be coarse or fine depending on stream power.

A key characteristic of small streams is that the majority of primary productivity (plant and algal growth) occurs on the stream bed rather than in the water column. The amount of productivity that occurs is dependent on light, temperature and nutrients, and as such, well-shaded streams are generally less productive than unshaded streams. It should be noted here that unlike farming or business, a high level of productivity is often undesirable in aquatic systems. The accumulation of aquatic plants can lead to loss of habitat, a decline in water quality (particularly low oxygen), and subsequent decline in ecosystem health.

Small tributary streams can be further divided into two types: **upland streams** and **lowland tributaries.**

(1) Mt Barney Creek: a tributary of the Logan River, with cobble and boulder substrates (2) Oxley Creek: a lowland tributary of the Brisbane River, has fine sediment substrate.

Small streams provide important habitat to a diverse range of aquatic plants and animals. Adequate shading is important in maintaining healthy streams. Excessive plant growth, brought about by excessive light, can lead to loss of habitat and major declines in water quality which result in poor stream health.

Small streams – high biodiversity

We often think of **upland streams** as fast-flowing creeks with cool, clear waters. However, for much of the time, upland streams in South East Queensland consist of a series of relatively isolated pools connected by only a trickle of flow. During the wet season, the steep upland gradients mean that water flows quickly and the stream bed is usually made up of bedrock or boulders, cobbles and gravel because finer materials are washed downstream. Spaces between rocks and gravel provide complex habitat for a variety of small animals. Very few species of fish are found in these upland streams because water is not always present and because barriers such as waterfalls and dams prevent access. The aquatic fauna is dominated in terms of diversity and abundance by invertebrates, especially the larvae of insect groups such as mayflies, stoneflies and caddisflies. Other conspicuous invertebrates include crayfish and shrimps. Very few aquatic macrophytes (large plants) are present due to light limitation from riparian shading and scouring during wet season flows.

(1) Lamington Freshwater spiny crayfish, a resident of headwater streams in the Gold Coast hinterland (2) Stonefly nymphs are found in cooler streams (3) Long finned eels are one of the few fish found in upland streams.

(1) ENVIRONMENTAL PROTECTION AGENCY (2) KARLIE HAWKING (3) QUEENSLAND MUSEUM

Lowland tributaries (*includes many urban streams* and the small tributaries of lowland rivers) also flow intermittently; however, their low gradients create moderate to slow-flowing streams which often recede to a series of pools. The more gentle gradients result in fewer riffles and runs, and the stream bed is usually comprised of fine gravel, sand or silt. In urban areas, streams are often channelised and much of the 'roughness' associated with logs and riparian vegetation is removed to reduce the risk of flooding. This usually results in a simplified channel with little available complex habitat. Water in lowland tributaries is generally warmer than at higher altitudes and aquatic invertebrate communities tend to be comprised of more temperature-tolerant species, and animals adapted to living in soft sediments. Fish communities are more diverse than those of their upland counterparts with up to a dozen species in healthy lowland creeks.

(1) Decapod (*Macrobrachium australiense*) (2) Damselfly nymph (*Austrolestes psyche*) (3) and Caddis Fly larvae (*Ecnomus pansus*).

(1) + (3) JOHN HAWKING (2) KARLIE HAWKING

In South East Queensland there are a number of small, lowland streams that meander through coastal Wallum heath (typically comprised of *Melaleuca* and *Banksia* species). These sandy streams are more acidic than other streams of the region, and are usually tea-coloured because of tannins leaching from the paperbarks. Wallum streams used to be common along the east coast; however, urbanisation of the coastal fringe has meant these streams have become scarce. This is of concern, because they are home to the Oxleyon Pygmy Perch and the Honey Blue Eye: two rare fish species which are only found in the region.

Native fish (1) Oxleyon pygmy perch (*Nannoperca oxleyana*) (2) Honey Blue Eye (*Pseudomugil mellis*).

(1+2) GUNTHER SCHMIDA

Small streams are big players in terms of waterway health

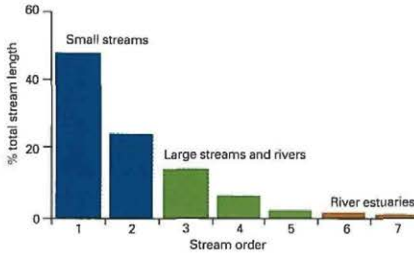
We often use the term "stream order" to reflect the position of a stream in the overall catchment network. Using the Strahler system, a "first order" stream has no tributaries upstream. Two first order streams join to form a second order stream and, where two second order streams join, a third order stream forms, etc. First and second order streams are often referred to as headwater streams because they occur at the head of the catchment. Generally stream size increases with stream order and larger, higher order streams are found lower down the catchment.

Small streams dominate stream network – A Geographic Information System (GIS) has been used to determine the total length of the South East Queensland stream network and the relative proportion of different sized streams. Results showed that small streams (i.e. first and second order streams) comprise 73% of the stream network or more than 11,500 km of an estimated 15,500 km of stream.

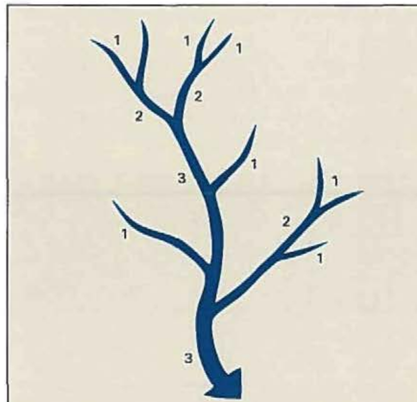
Because they dominate in terms of total length and because they are linked tightly with their catchments, small streams have a big influence on the health of waterways downstream. They not only deliver water and essential nutrients, but can also be major sources of pollutants (e.g. sediment and excess nutrients) if the catchments are cleared for urban or agricultural development.

The smaller intermittent-flowing streams (and the vast network of associated gullies) are of particular importance in this regard. Although they provide little habitat for aquatic biota, degraded small streams and gullies generate most of the sediment and nutrients that contaminate our waterways, filling river pools, dams and estuaries with sediment, increasing turbidity, and potentially contributing to downstream algal blooms.

For these reasons, the health of receiving waters, such as lowland rivers, water storages and estuaries, cannot be improved without addressing the health of headwater streams.



Small streams comprise 73% of the total stream length in South East Queensland.



Waterway	Order	% of total stream length
Small streams	1	48
	2	25
Larger streams and rivers	3	14
	4	7
	5	3
River estuaries	6	2
	7	1

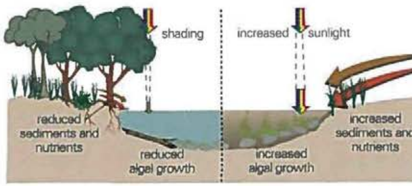
Healthy riparian zones mean healthy streams

In South East Queensland, healthy riparian vegetation is the single, most important factor affecting the health of small streams. It is critical because it performs the following functions:

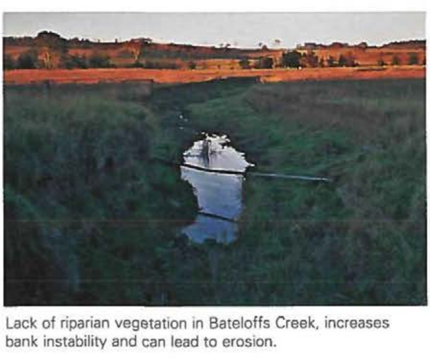
- Stabilises banks and reduces channel erosion – a major source of sediment to Moreton Bay
- Slows flow to small tributaries and reduces erosive power
- Traps sediment, nutrients and other contaminants
- Shades streams so that in-stream productivity (i.e. plant growth) is maintained at natural rates
- Moderates stream temperature and helps keep oxygen levels high
- Provides food and habitat for aquatic animals in the form of leaf litter, logs and branches
- Provides terrestrial habitat for the adult stages of aquatic insects and amphibious organisms such as frogs and turtles

The importance of riparian vegetation in South East Queensland

Investigations into the health of the lower Brisbane River and Moreton Bay have shown that sediments and nutrients are the main pollutants of our waterways. Other studies have shown that the majority of these pollutants enter the waterways during the large storm events which are a regular feature of the sub-tropical climate in South East Queensland. As such, it is clear that the key to improving waterway health is to minimise bank erosion and sediment inputs during these events by establishing healthy riparian vegetation along the banks of creeks and gullies.

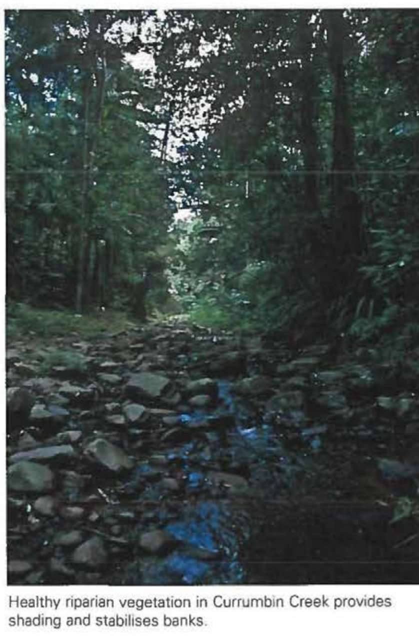


Healthy riparian vegetation (left) reduces sediment and nutrients entering the waterway, provides valuable shading and restricts algal growth. When riparian vegetation is cleared, increased volumes of sediment and nutrient enter the waterway, shading is reduced, and excess algal growth can be a problem (right).



HEALTHY WATERWAYS LIBRARY

Lack of riparian vegetation in Bateloffs Creek, increases bank instability and can lead to erosion.



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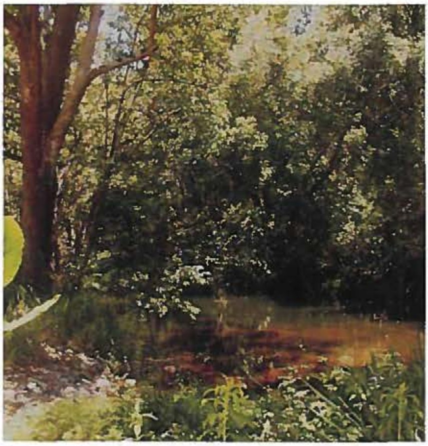
Healthy riparian vegetation in Currumbin Creek provides shading and stabilises banks.

Riparian vegetation stabilises stream banks



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Stable banks on Enoggera Creek in Brisbane Forest Park.

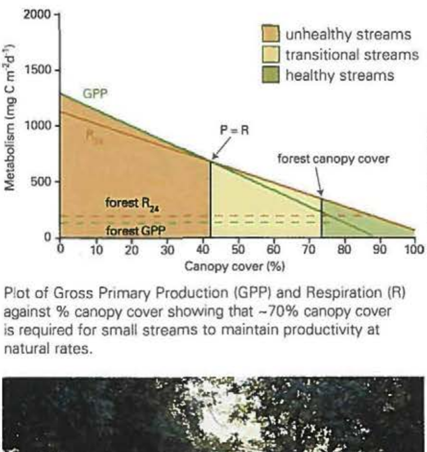
Unstable banks on a tributary of Cressbrook Creek.

Erosion is an essential and natural process of stream systems; however, since European settlement, rates of erosion have increased dramatically due to land clearing and loss of riparian vegetation. The additional sediment that results from increased erosion is a major cause of environmental degradation in aquatic ecosystems downstream. It smothers plants, animals and their habitats, and reduces light penetration, resulting in lower-than-natural rates of productivity in lowland rivers, estuaries and the marine environment (e.g. seagrasses). While riparian vegetation does not stop erosion, it can significantly reduce the rate, and prevent major erosion events like bank slumping.

The main means by which riparian vegetation stabilises stream banks is by reinforcing the soil with tree roots. The roots also buffer the force of flowing water on the stream bank and thereby reduce scour. In addition, riparian vegetation serves several other functions. First, riparian vegetation physically impedes overland flow, reducing the water's velocity and its ability to collect and carry sediments and nutrients. Second, by slowing overland flows, riparian vegetation assists in trapping sediment, allowing it to remain on land rather than be carried into the stream. This process is best served by riparian ground cover such as grasses and shrubs. For this reason, rehabilitation programs usually include planting trees, shrubs and groundcover species. Third, again by slowing overland flows, riparian vegetation allows more time for water to soak into the soil and re-charge aquifers. Riparian lands often have highly porous soils with large organic loads that allow water to seep into the water table where the roots of riparian vegetation can absorb salts and nutrients that would otherwise flow into the stream.

Riparian vegetation maintains cool, healthy streams

In small streams, particularly upland streams, healthy riparian vegetation shades most of the channel and limits the amount of algal/plant growth by limiting the amount of light that reaches the stream. The removal of riparian vegetation increases the amount of available light and often leads to dramatic increases in the growth of nuisance plants and algae, particularly when excess nutrients are available. Excessive plant growth can result in a major decline in stream health as algae and large aquatic plants smother natural habitats, choke stream channels, and increase the likelihood of floods. In addition, the growth and subsequent decay of these plants can severely deplete the water column of oxygen.



BUNN *et al.*, 1999

Plot of Gross Primary Production (GPP) and Respiration (R) against % canopy cover showing that ~70% canopy cover is required for small streams to maintain productivity at natural rates.

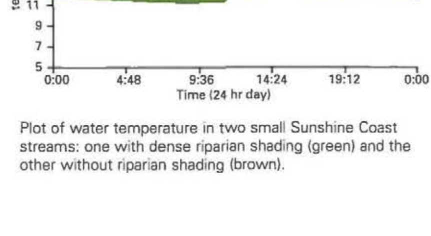
HEALTHY WATERWAYS LIBRARY

Well-shaded streams have cooler water temperatures and smaller temperature ranges.

MICK SMITH, GRIFFITH UNIVERSITY

Small streams often experience excessive algal growth when riparian canopy is lost and excess light and nutrients are available.

Riparian vegetation also maintains aquatic habitats by buffering stream water from temperature extremes. In South East Queensland, water temperature only varies by a few degrees each day in small streams with dense riparian canopy. In contrast, water temperature in small streams without riparian vegetation may vary by between eight and ten degrees Celsius each day! Such wide temperature ranges have been shown to be detrimental to the growth, development and reproduction of fish and aquatic insects and crustaceans. Moreover, the concentration of dissolved oxygen decreases with increasing water temperature and this may also lead to harmful conditions for the aquatic biota.



Plot of water temperature in two small Sunshine Coast streams: one with dense riparian shading (green) and the other without riparian shading (brown).

Riparian zones link aquatic and terrestrial ecosystems

The riparian zone represents an important 'ecotone' intimately linking streams with their catchments and is the place where nutrients and energy are transferred from aquatic to terrestrial habitats and vice versa.

Terrestrial to aquatic

Leaf litter from riparian vegetation plays a critical role in food webs, particularly in small streams where dense shade limits plant growth. Many aquatic invertebrates use leaf litter as a food source or feed on algal films that form on leaves or wood. Others such as caddisfly larvae, rely on leaf litter to build portable cases to protect and camouflage them from predators. Terrestrial insects that fall from fringing vegetation contribute to the diets of fish and turtles. In larger streams, logs and branches provide important refuges and breeding habitat for native fish, while tree roots offer shelter for an abundance of species including the platypus, which relies on them to prevent burrows from collapsing.


JOHN HAWKING

Caddisflies from the family Calamoceratidae rely on leaf litter to help them create a portable home that is constructed using leaves and fastened with silk.

Aquatic to terrestrial

Similarly, riparian ecosystems are reliant on the neighbouring aquatic environment. Aquatic insects such as dragonflies that have terrestrial adult stages depend on riparian vegetation for food and shelter. Semi-aquatic predators such as birds (e.g. cormorants), water dragons, and water rats feed on fish, frogs and invertebrates and transfer nutrients from aquatic to terrestrial environments. Riparian zones are highly productive ecosystems because of the availability of moisture from the stream and fertile alluvial soils. They provide a microclimate that is less variable, cooler and more humid than adjacent environs and frequently have a higher diversity and abundance of animals and plants than surrounding lands. Riparian zones offer food, water, shelter and nesting sites for birds. They can act as a corridor for wildlife movement and provide the only suitable habitat for semi-aquatic animals such as frogs, turtles and water rats.

Small and large branches provide habitat for aquatic animals.

Healthy, dense riparian vegetation on Picabeen Creek near Mapleton.

Can *riparian rehabilitation* improve the health of waterways in South East Queensland?

(1,2,3,4+5) MICK SMITH, GRIFFITH UNIVERSITY

Rehabilitation of riparian vegetation was undertaken at five case study sites in South East Queensland. The streams were: (1) Sister Tree Creek, (2) Bunya Creek, (3) Echidna Creek, (4) Blackfellow Creek and (5) Rocky Creek.

In recent years, there have been numerous endeavours to rehabilitate the riparian vegetation along some of Australia's rivers and streams; however, very few of these studies have measured the effectiveness of this rehabilitation effort. To resolve this situation, and to demonstrate the benefits of riparian rehabilitation in improving the health of small streams, five rehabilitation projects have been undertaken at a range of sites in South East Queensland.

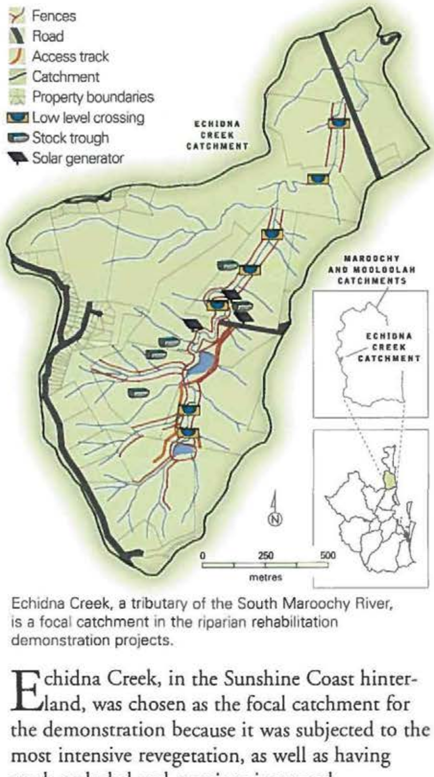
Sites were chosen based on the following criteria:

Stream size – a narrow first or second order stream that would allow significant shading
Catchment size – small subcatchment (<10 km^2)
Disturbance – heavily degraded riparian zone
Access – easy access to facilitate planting and fencing
Ownership – support and cooperation of landholders and local community.

The type and extent of rehabilitation differed at each site. At some sites, stream channels were fenced to exclude cattle and allow riparian vegetation to regenerate from seed. At other sites, extensive rehabilitation works were undertaken: thousands of trees planted, cattle and vehicle crossings were modified, fences were erected, and watering points were installed away from the stream.

The set of physical, chemical and biological indicators used in the freshwater Ecosystem Health Monitoring Program (see chapter 7) were measured before rehabilitation to gain a baseline of stream condition. These same indicators were applied again post-rehabilitation to test for changes in stream health. On-going monitoring will provide information on the rate of recovery for a range of ecological attributes and will quantify the benefits of riparian revegetation in terms of stream health.

Echidna Creek case study



Echidna Creek, a tributary of the South Maroochy River, is a focal catchment in the riparian rehabilitation demonstration projects.

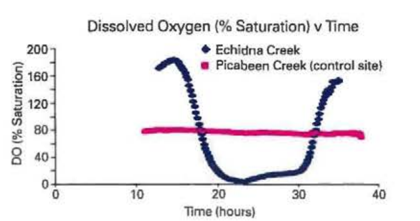
Echidna Creek, in the Sunshine Coast hinterland, was chosen as the focal catchment for the demonstration because it was subjected to the most intensive revegetation, as well as having stock excluded and crossings improved.

Apart from monitoring the health of several sites along Echidna Creek before, during and after rehabilitation, additional sites were chosen on streams of similar size within the same catchment. Some of these were minimally disturbed (positive control) sites and others were heavily disturbed (negative control) sites. Positive controls are used as *reference* sites to provide target levels for ecological health following rehabilitation. Negative controls are heavily disturbed sites, similar to the rehabilitation site, which are not being rehabilitated and

Echidna Creek before (left) and after (right) riparian rehabilitatio

are unlikely to improve over time. By comparing results from Echidna Creek sites against both positive and negative control sites, changes at Echidna Creek due to riparian rehabilitation can be differentiated from other, more widespread influence. It is hypothesised that the physical, chemical and biological attributes of Echidna Creek will *become more like those of the healthy,* positive control sites and less like the heavily disturbed sites.

To date, three assessments of ecosystem health have been performed: one before, one during, and one after rehabilitation. It is expected that the fast-growing "pioneer" species will shade much of the stream within two to three years and that the first changes will be detected within this period. Monitoring will continue over the coming decade in order to track changes in the ecological condition of Echidna Creek.



24-hour plots of dissolved oxygen concentration show greater variation in Echidna Creek prior to rehabilitation than in the vegetated control site, Picabeen Creek.

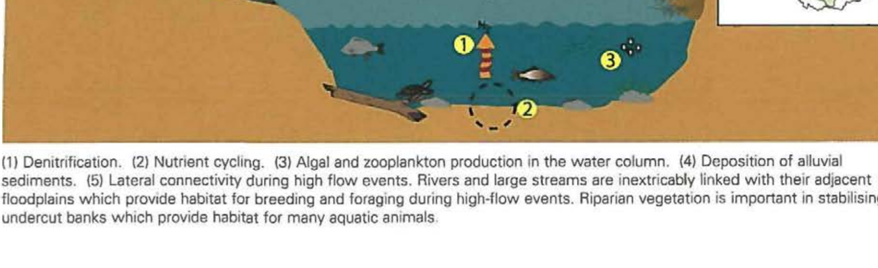
Characteristics of *rivers and large streams*

In South East Queensland, very few large streams maintain a continuous flowing channel all year round. Riffles and runs are found only occasionally, during the wetter summer months, with most rivers receding to a series of pools during the drier winter months. In terms of flow, large streams show less diversity than their small stream counterparts; however, they still provide a variety of important aquatic habitats including the water column, logs and branches, undercut banks, and floodplains. The stream bed is usually a uniform substrate comprised of sand, silt or mud that is deposited under low flow conditions. While such substrates do not offer the crevices and spaces provided by rocks and cobbles, they are more suitable for burrowing animals such as yabbies and mussels.

ENVIRONMENTAL PROTECTION AGENCY

Large streams and rivers are generally more turbid than small streams due to the resuspension of fine sediments.

In contrast to smaller streams, where most productivity occurs on the stream bed, the majority of plant growth in larger streams takes place in the water column. Light is the major limiting factor in both small and large streams, but riparian shading has less influence on wider streams because a smaller proportion of the stream is shaded. In this situation, productivity is more likely to be limited by turbidity, which prevents sunlight from penetrating deep into the water column. Larger streams are generally more turbid than their smaller counterparts because the fine sediments that are deposited in pools and on the inner (slow-flowing) bends of meanders are easily resuspended. Finally, large streams are often intricately linked with adjacent floodplains. Although these areas are rarely inundated they provide important inputs of detritus and nutrients, and critical habitat for breeding and foraging during flood events.



(1) Denitrification. (2) Nutrient cycling. (3) Algal and zooplankton production in the water column. (4) Deposition of alluvial sediments. (5) Lateral connectivity during high flow events. Rivers and large streams are inextricably linked with their adjacent floodplains which provide habitat for breeding and foraging during high-flow events. Riparian vegetation is important in stabilising undercut banks which provide habitat for many aquatic animals.

Why are *large streams and rivers* important?

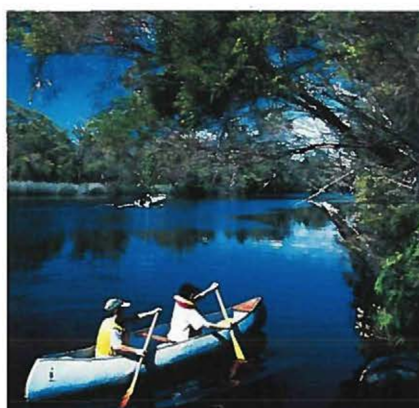
Although most drinking water in South East Queensland is stored in man-made lakes and dams, we depend on the health of our larger streams and rivers for supply of water to these storages and maintenance of good water quality. The natural processes or 'ecosystem services' provided by these waterways are often overlooked or taken for granted. For example, the Brisbane River delivers drinking water from Wivenhoe Dam to the water treatment plant at Mount Crosby. Along the way, the quality of water is maintained or improved as a result of ecosystem services (e.g. cycling and transformation of nutrients, trapping of contaminants). For this reason alone, large streams and rivers are essential for maintaining water quality and associated quality of life.

Water from large streams is essential for the irrigation of fruit and vegetables and vital in the production and maintenance of beef and dairy cattle in other catchments. These systems also provide important freshwater habitat for many native plants and animals including turtles, platypus and fish, and the people of South East Queensland place a high value on these waterways for recreational activities such as swimming, boating and fishing.

The Mary River Cod; a freshwater fish in South East Queensland.

A number of 'marine' animals also visit the freshwater reaches of large rivers. Some, such as the Bull Shark, will reside in freshwater rivers for extended periods, while others make brief visits to freshwater environments in order to rid themselves of parasites that cannot tolerate freshwater.

Irrigation of crops in the Albert River Catchment.



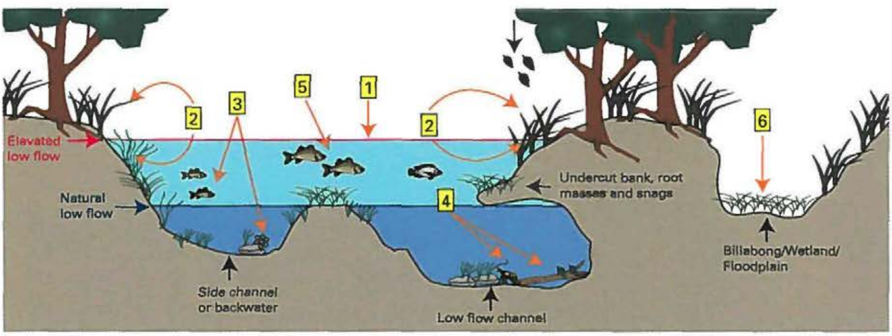
Boating, fishing and swimming are popular activities associated with our waterways.

Altered flow can result in *habitat modification*

(1)+(2) HEALTHY WATERWAYS LIBRARY

Somerset and Wivenhoe Dams are the largest water storages in South East Queensland.

The construction of large dams has many regional benefits in terms of flood mitigation, water supply for drinking and irrigation, and power generation; however, it does come at a cost to the health of lowland rivers and their estuaries. Alteration of flow regime is a major cause of habitat modification in large streams and rivers. The change of flow regime, and the subsequent loss of large flow events, means that the river is disconnected from its floodplain and that billabong and wetland habitats do not get flushed or replenished. Several native fish species use floods as a cue for recruitment because this signals the availability of suitable floodplain habitat to shelter and nourish their young. Unfortunately, these species are unlikely to reproduce successfully if both the cue for recruitment and the floodplain habitat are unavailable. Furthermore, the lack of 'lateral connectivity' reduces the opportunity for important nutrient exchanges between floodplain and river. Such 'flood pulses' are responsible for significant nutrient exchanges between the floodplain and river and are fundamental to maintaining prawn and fish populations in river estuaries and adjacent marine environments.



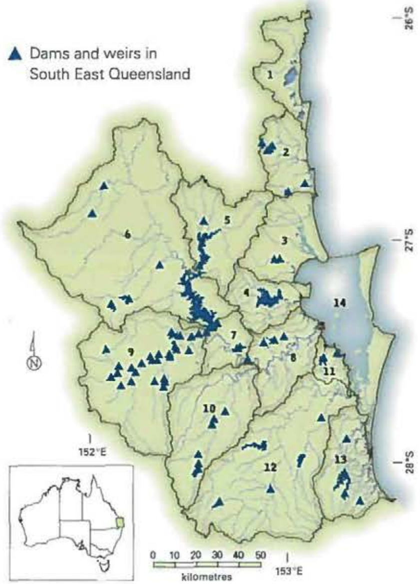
MARK KENNARD/MICK SMITH, GRIFFITH UNIVERSITY

Effects of flow regulation (elevated low flow, reduced temporal variability) on fish communities. (1) Elevated low flow increases overall aquatic habitat availability but decreases habitat diversity (riffles/runs/pools). (2) Elevated, stable low flows can lead to increased growth of submerged and emergent aquatic vegetation, potentially increasing habitat (refuge, spawning, foraging) for certain fish species. (3) Changes in flow may result in reduced availability of low velocity refuge areas for fish eggs, larvae and adults. (4) Changes in flow, decrease in substrate diversity and reduced abundance of submerged physical structures (woody debris, leaf litter) may reduce invertebrate food availability. (5) Change in temporal pattern of flow may cause loss of appropriate stimuli for fish movements, migrations and reproduction. (6) Loss of connectivity with wetlands results in loss of habitat for recruitment and foraging.

Dams and weirs can be barriers to fish migration

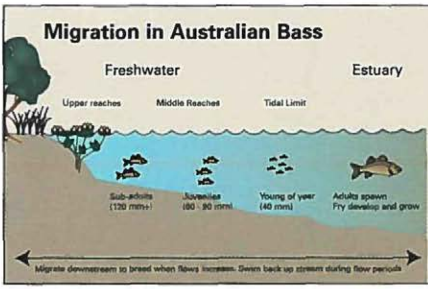
Most species of freshwater fish move up and downstream to forage and search for suitable habitat. Dams and weirs often act as barriers to this movement and isolate large areas of available habitat so that fish are confined to either the lower or upper part of a catchment. In addition, many freshwater fish are 'catadromous' in that adults swim to the sea or estuary to spawn. The construction of dams and weirs prevents these species from moving downstream to spawn, or, if they do happen to make it downstream, these barriers prevent them from moving back upstream.

The Australian Bass (*Macquaria novemaculeata*), a popular species with freshwater anglers, is a catadromous fish found only in coastal rivers in southeastern Australia. Females are larger than males and can grow to 600 mm and weigh up to 4 kg. Mature fish are carnivores, eating other fish, crustaceans and insects associated with riparian vegetation. Between May and August this species travels downstream from fresh water to estuaries to breed in salinities around seawater. The males often remain in tidal waters while females travel extensively upstream searching for suitable freshwater habitat. In South East Queensland, dams and weirs now obstruct access to more than half their potential freshwater habitat and the combination of barriers and fishing pressure has contributed to their decline in many river systems.



1 Noosa Catchment
2 Maroochy and Mooloolah Catchments
3 Pumicestone Region Catchments
4 Pine Rivers Catchment
5 Stanley Catchment
6 Upper Brisbane Catchment
7 Mid-Brisbane Catchment
8 Lower Brisbane Catchment
9 Lockyer Catchment
10 Bremer Catchment
11 Redlands Catchments
12 Logan–Albert Catchments
13 Gold Coast Catchments
14 Moreton Bay

There are more than 70 dams and weirs in the South East Queensland region.



The Australian Bass (*Macquaria novemaculeata*).

Submerged logs provide important habitat

Riparian vegetation along Petrie Creek provides branches and logs as habitat for stream biota.

Cornmeal Creek has had riparian vegetation removed and woody debris is no longer supplied to the creek.

Branches and logs are important in providing habitat in Australian rivers and streams. Eucalypts and many other Australian tree species are renowned for their hardness and can persist as logs in the stream for centuries. Such longevity has seen them become an important feature of the stream environment, particularly in large rivers where the stream bed is comprised of sand and silt and is frequently moving. In these waterways submerged logs provide the only permanent form of substrate. They are the only suitable habitat for algae that grow on hard surfaces and insect larvae that burrow into wood. In addition, a number of native fish species rely on large logs as refuges and for breeding. For example, the Mary River Cod (*Maccullochella peelii mariensis*), an ambush predator, hides amongst submerged branches and logs whilst waiting for prey. This species also lays its adhesive eggs in underwater tree hollows to protect them from flow and hide them from potential predators.

Large logs and branches also assist in creating variable flow conditions in streams with sandy substrates. These flow conditions lead to greater habitat diversity as water jets under and over the logs to produce shallow, fast-flowing runs and deep pools. Log jams, and associated scour pools, trap leaves and twigs and assist in creating areas of organic deposition that provide habitat for a variety of aquatic fauna.

In the past, logs have been removed from streams under river "training" or "improvement" programs, which aimed to alleviate flooding and make rivers easily navigable. While logs do contribute to stream roughness, their contribution to flooding has been overstated. These days, the physical and biological benefits associated with the presence of large logs in rivers often sees the re-introduction of large logs included as a key component of river rehabilitation projects.

Large logs providing habitat and stabilising the stream bed in the Albert River.

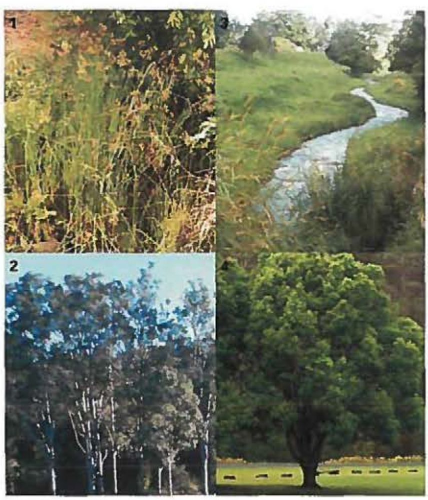
Introduced weeds choke our waterways

A number of introduced plants are responsible for habitat loss and degradation in larger streams. Numerous species of aquatic plants, used in garden pools and aquaria, have been "dumped" into local streams. They spread downstream during major flow events and can be transferred between streams by water birds and humans. Some of the most detrimental weeds are floating plants that grow rapidly into dense mats that "choke" channels. In shallow systems the density of plants can actually restrict the movement of aquatic animals along the stream and increase flooding. These surface mats prevent light penetration and their prolific growth can see them remove all the oxygen from a pool resulting in anoxic conditions that cause fish kills. Two particularly aggressive introduced species are Water Hyacinth (*Eichornia crassipes*) and *Salvinia* (*Salvinia molesta*). Both are declared noxious plants in Australia and are targeted for legislative control because of their ability to cause serious environmental degradation.

Invasive species also can modify riparian vegetation, which can lead to habitat degradation. Para Grass (*Urochloa mutica*) for example, is a fast-growing species native to tropical Africa that dominates disturbed coastal streams north of central NSW and is a weed of drainage channels and sugarcane fields. It displaces native reeds and sedges creating a homogeneous riparian habitat and causes sediment build-up that results in flooding and the loss of aquatic habitat through the narrowing of stream channels. Other introduced plants, or woody weeds, that thrive along watercourses and alter riparian communities include Chinese elm (*Celtis sinensis*), Camphor laurel (*Cinnamomum camphora*), and Lantana (*Lantana camara*). Introduced vines such as Cats claw (*Macfadyena unguis-cati*) and Morning glory (*Ipomoea indica*) are also damaging to riparian vegetation. Both are vigorous climbers that smother riparian trees, block sunlight and photosynthesis and eventually cause them to die.

(1) SEQ WATER (2,3+4) HEALTHY WATERWAYS LIBRARY

Aquatic weeds can choke our waterways (1) *Salvinia* (2) Water hyacinth (3) *Elodea*.



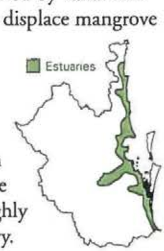
Native riparian vegetation: (1) River club sedge (2) Eucalypt. Introduced vegetation: (3) Para grass (4) Camphor laurel.

Numerous *estuaries* in South East Queensland

Above: The Noosa River estuary is considered to be one of the most pristine in South East Queensland.
Inset: The Brisbane River estuary is highly impacted by urban development.

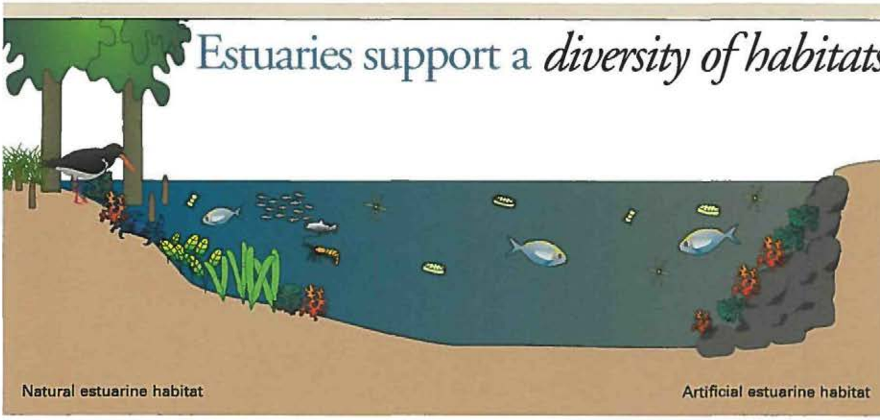
Estuaries are characterised by variable salinity, and are the waterways occurring between the coast and the tidal limit of a river. The dominant feature of these waterways in South East Queensland is variable intensity runoff from the catchment, resulting from summer (December/January) rains. Periodic river flow results in increased sediment loads, salinity fluctuations and scouring which combine to make these habitats spatially dynamic and seasonally variable.

Catchments of river estuary habitats support a large range of agricultural land use; predominantly sugar cane, beef cattle and dairy farming, as well as extensive forestry. These land use practices result in increased nutrient and sediment inputs through fertiliser, manure and increased erosion. Discharge from sewage treatment plants and urban runoff are also major nutrient sources. Ocean flushing and tidal exchange moderate both nutrient and sediment input to these habitats. Rates of water exchange are often impacted by canal and port developments, which also displace mangrove habitat and increase rates of sediment deposition and scouring.



In South East Queensland there is a range of estuaries from near pristine systems such as the Noosa River estuary, to the highly modified Brisbane River estuary.

Estuaries support a *diversity of habitats*



Natural estuarine systems (left) provide important habitats for diverse faunal and floral communities. Artificial systems (right) such as canals have a modified habitat structure.

Estuarine systems contain a large diversity of habitat types, which are important for nutrient processing and fisheries production. Mangrove habitat can be found around river mouths, often as a thin band along river banks as far upriver as the tidal limit. Behind the mangroves, saltmarsh habitat may occur and both mangroves and saltmarsh are vital in filtering nutrients and sediments from runoff before it reaches the waterway. Benthic microalgae inhabit the intertidal region of muddy banks along the edges of the estuary and are important in processing nutrients and supporting grazing faunal communities. The intertidal region and shallow subtidal regions are the habitat of estuarine seagrass, which help to stabilise sediments from erosion, support microbial communities important for nutrient cycling and support an algal epiphyte community and invertebrate fauna which are the food source of larval and adult fish. The water column of estuaries is constantly flowing in and out with the tide, but still provides an important habitat for a diverse community of phytoplankton, invertebrates and fish.

Population centres are generally located on the banks of estuaries and therefore, these habitats are the most impacted and also receive the highest recreational use of all waterways in South East Queensland.


HEALTHY WATERWAYS LIBRARY

Mangroves like these on the Noosa River are found around river mouths and along river banks throughout South East Queensland. Along with saltmarsh habitat, mangroves are vital in filtering sediments and nutrients from runoff.

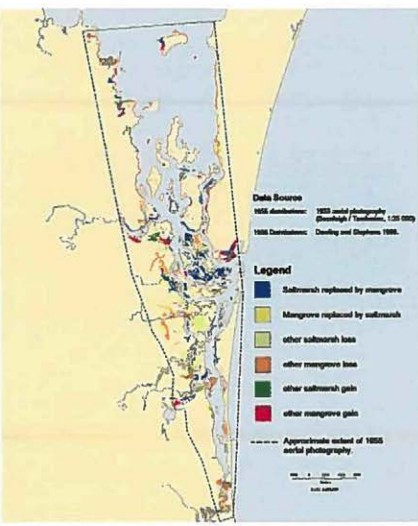

HEALTHY WATERWAYS LIBRARY

Canal estates are extensive in South East Queensland as waterfront living is popular.

Mangrove and saltmarsh habitats compete for space

In southern Moreton Bay, mangrove and saltmarsh habitats have been removed for canal, sand extraction and agricultural developments. Loss of saltmarsh has resulted from restriction of tidal inundation as a result of flood mitigation schemes where drainage canals and floodgates were constructed to protect agricultural lands (e.g. Pimpana River catchment). Erosion processes have resulted in some mangrove loss on the islands near Jumpinpin.

Not only has the total area been reduced, but there has been change between saltmarsh and mangrove habitats – with large areas of saltmarsh and saltpan being overgrown by mangroves. Changes in sediment loadings and water movement may influence the relative suitability of a region for saltmarsh or mangrove. The dynamic nature of these habitats and the large-scale changes over four decades indicate the susceptibility of these habitats to fragmentation and reduction of total area.



SKM, FRC AND HEALTHY WATERWAYS PARTNERSHIP

Changes in the distribution of mangrove and saltmarsh habitats from 1955 to 1998 in the Logan/Nerang region.

HEALTHY WATERWAYS LIBRARY

Mangroves around South East Queensland have been removed for development, but may be overgrowing saltmarsh in certain areas.

HEALTHY WATERWAYS LIBRARY

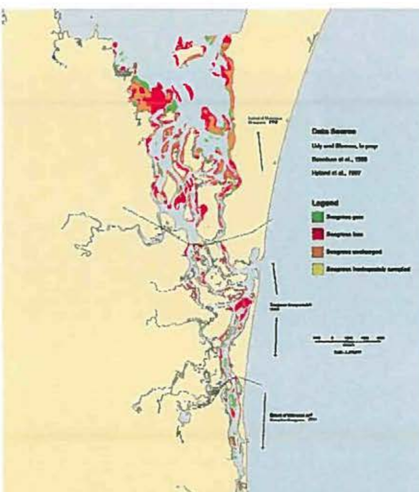
Saltmarsh habitats are susceptible to fragmentation and reduction in area.

	Mangrove (ha)	Saltmarsh (ha)
1956	7448	4087
1998	7626	657
Area lost	1732	3668
Area gained	1987	178
Net change	178	-3430

Estuarine seagrass habitats are important and fragile

CHRIS ROELFSEMA, MARINE BOTANY, UQ

Zostera capricorni is the dominant seagrass species in the estuaries and Moreton Bay, providing important habitat for fish and invertebrates.



SKM, FRC AND HEALTHY WATERWAYS PARTNERSHIP

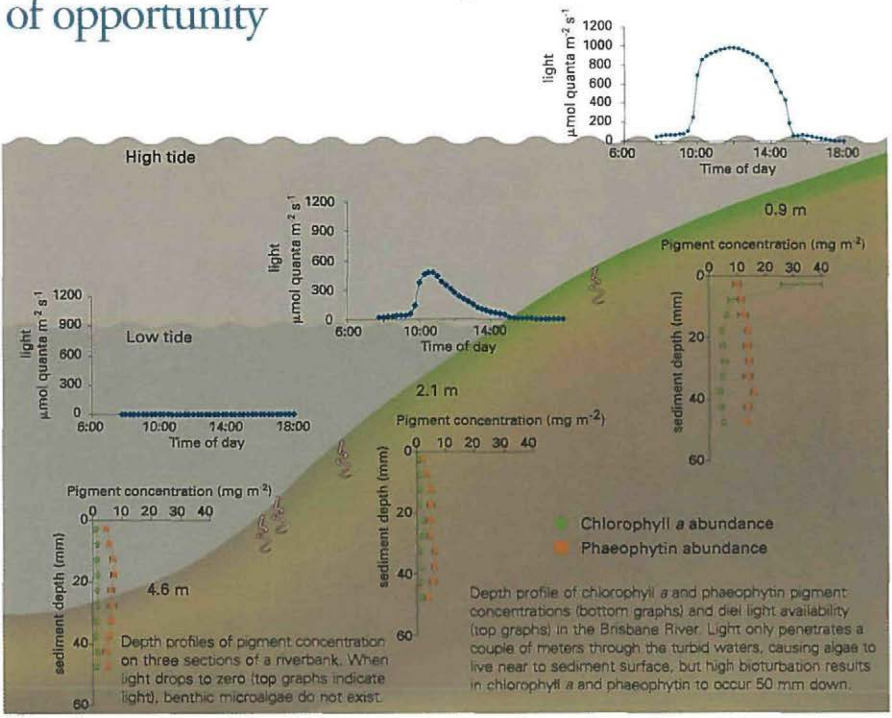
Changes in the distribution of seagrass from 1987 to 1995/2000 in the Logan/Nerang region.

Seagrass plays an important role in limiting channel erosion, provides shelter for fish and invertebrate fauna, which in turn attracts a variety of water birds and is the food of dugongs and turtles. The dominant seagrass species growing in estuaries in South East Queensland is *Zostera capricorni*, a thin-bladed leaf species. Paddleweed, *Halophila ovalis* is also sometimes present in these regions. Distribution of seagrass in Moreton Bay is related to light availability (influenced by sediment loads, phytoplankton and algal epiphytes), changes in water movement and therefore, scouring and changes in sedimentation.

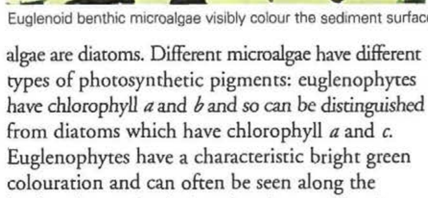
Between 1987 and 1997/2000, there have been substantial changes in the distribution of seagrasses in southern Moreton Bay, with an overall decrease of 2303 hectares. In some areas, such as around the mouth of the Logan River, seagrass meadows are known to be very variable from year to year with no clear directional gains or losses. However, at many sites such as Peel Island, on the Banana Banks, Pelican Banks, north-west of Coochiemudlo Island, southern Broadwater and Nerang River, there have been distinct declines in abundance of seagrass over time.

Seagrass (ha)	Northern area	Southern area
1987	5604	847
1997/2000	3385	763
Area lost	3115	557
Area gained	1431	473
Net change	**-2219**	**-84**

Estuarine benthic microalgae have a small window of opportunity

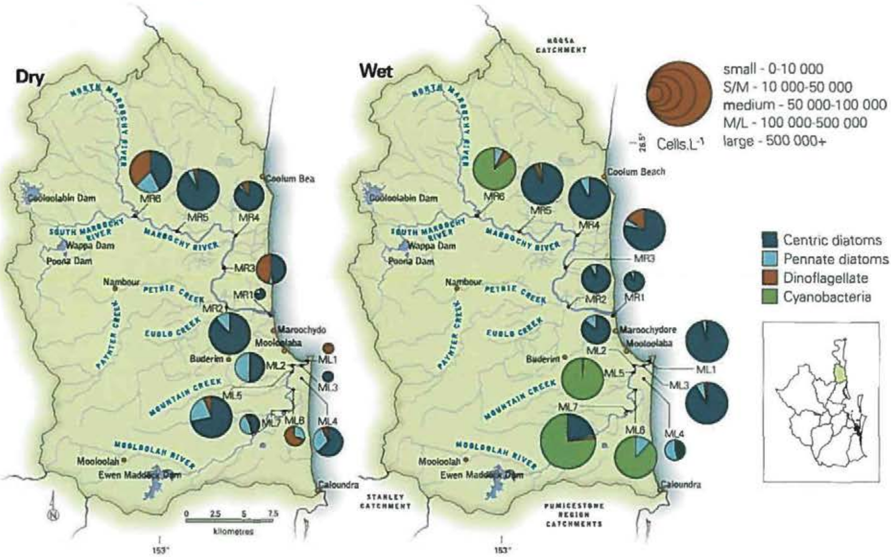


Benthic microalgal habitats in estuaries are dominated by pennate diatoms, however they also contain some dinoflagellates, cyanobacteria and euglenophytes. In the turbid regions of the Brisbane River, there is only a narrow region of the intertidal riverbank that can support benthic microalgae. The water is highly turbid and as soon as the tide rises over the sediment, the light drops to almost zero. The sediment is fine and so algae live close to the surface of the sediment, however high bioturbation results in chlorophyll occuring down to 50 mm. Phaeophytin (broken down chlorophyll) can also be detected down to 50 mm into the mud and also down in the centre of the river. Euglenophytes are abundant on the sediment surface of the river banks, whereas the few deeper algae are diatoms. Different microalgae have different types of photosynthetic pigments: euglenophytes have chlorophyll *a* and *b* and so can be distinguished from diatoms which have chlorophyll *a* and *c*. Euglenophytes have a characteristic bright green colouration and can often be seen along the banks of estuaries during the winter and spring.



Euglenoid benthic microalgae visibly colour the sediment surface.

Phytoplankton diversity influenced by season and salinity



In the Maroochy and Mooloolah Rivers, phytoplankton communities are dominated by centric and pennate diatoms during the dry season.

However, during the wet season in the upper sections of the rivers, the cyanobacteria, *Anabaenopsis* occur in higher numbers.

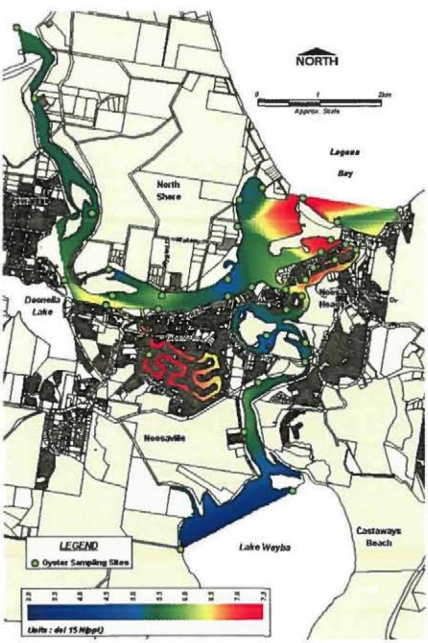
Phytoplankton are an important contributor to the food web. They are grazed upon by zooplankton (microscopic animals) and filter feeders (e.g. mussels and oysters) and are therefore, important in supporting fish communities.

(1) *Coscinodiscus*, one of the most common centric diatoms
(2) *Navicula* sp. is a pennate diatom often found living on and in intertidal sediments.

The phytoplankton community changes between dry and wet seasons. Phytoplankton communities of both the Maroochy and Mooloolah Rivers were dominated by centric (round) and pennate (cigar shaped) diatoms during the dry season. However, during the wet season, there were high numbers of the cyanobacteria *Anabaenopsis* in the upriver sites in both rivers. *Anabaenopsis* is a non-toxic cyanobacteria occurring in high and low nitrogen waters with low salinity. While the upper sites of the Maroochy River were brackish during the wet season (<2 ppt), the upper three sites of Mooloolah River had mean wet season salinity of 25±3 ppt. This suggests that the cyanobacteria population in Mooloolah River may have been flushed downstream from fresh sections further upriver.

Canals are a highly modified and expanding habitat

Canals have been a rapidly increasing waterway habitat in South East Queensland. About 99% of canals in Queensland are located in the southeast corner. On the Gold Coast alone, over 220 km of canals provide waterfront for at least 13,000 homes. Canals are created through modification or replacement of existing wetland habitats such as saltmarsh, mangroves and seagrass or by digging totally new waterways. The creation of artificial habitats raises concerns for the: loss of natural habitat and of habitat diversity, value of artificial habitats, and relationships that may exist between natural and artificial habitats. Canals with different designs and at different distances from open water have different structures and inputs and therefore have different potential for supporting biological communities. For example in Raby Bay favid corals have been recorded growing in canals. However, oysters found in the canal estates along the Noosa River, had elevated processed nitrogen ($\delta^{15}N$) signals. Canals are inevitably a focus for human activity and therefore, impact.



SCHLACHER AND CARRUTHERS, 2002

Oyster $\delta^{15}N$ values were highest in the canal estates near the mouth of the Noosa River.

HEALTHY WATERWAYS LIBRARY

Canal estates are well established in coastal areas such as Mooloolaba.

ENVIRONMENTAL PROTECTION AGENCY

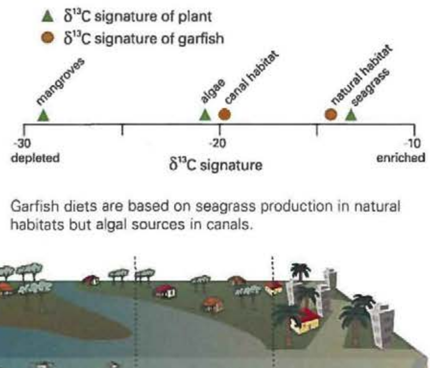
Canal development such as in Raby Bay, raises issues about the loss of habitat value and diversity.

Canal habitat is an extension of river channel

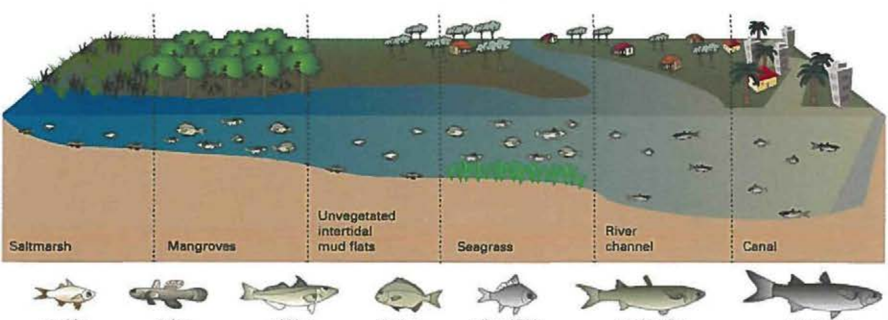
Comparisons of the fish communities between natural wetlands and canals show that canals can support a similar suite of species to the natural wetlands they replaced. Fish communities of canals are like those of natural unvegetated river channels, and include numerous economically important species. Fish communities of mangroves and seagrass are most different from those of canals, whereas fish from saltmarshes and intertidal mudflats are less different. The effects of canal developments on fish therefore depend on the habitats replaced.

All animals depend, directly or indirectly, on plant production for their energy (carbon). Carbon isotope analysis was used to determine whether fish in canals rely on plant material transported on currents from natural wetlands or on different plant sources available in canals. Garfish, which occur in natural wetlands and canals, rely on seagrass material in natural wetlands but on local algal production in canals. This is direct evidence that even where species inhabit natural and artificial waterways, they are dependent on quite different ecological processes.

Extensive canal systems have replaced natural wetlands along the Nerang River estuary.

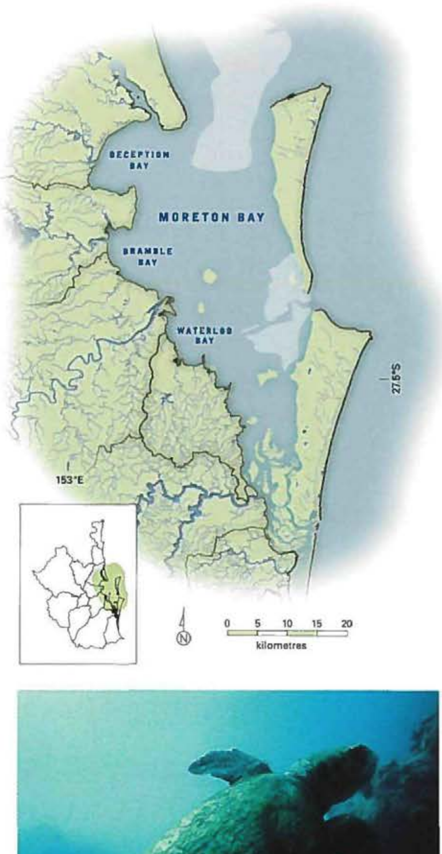


Garfish diets are based on seagrass production in natural habitats but algal sources in canals.



Fish communities of canals are like those of river channels, and are most different to those of seagrass and mangroves.

Moreton Bay: high diversity of habitat types



Moreton Bay is a large marine embayment sheltered by Moreton Island, North and South Stradbroke Island; The current coastline results from sea level rises between 10,000 and 6,000 yrs ago. In the last 6,000 years, sea level has been relatively stable. Due in part to the sub-tropical location of the Moreton Bay and also because of gradations in water quality and disturbance, the Bay has a high diversity of habitat types.

Water quality in Moreton Bay is dominated by seasonally pulsed riverine inputs in the west and oceanic flushing with tidal exchange through North Passage, South Passage and the Jumpinpin bar. A flushing gradient exists from the north to the south of the Bay due to the greatest flushing occurring through the North Passage followed by moderate flushing through South Passage and only minimal exchange through Jumpinpin bar. Moreton Bay has a moderate tidal range up to 2.5 m. During low tide, large tidal banks are exposed in the eastern Bay.

Moreton Bay supports one of Queensland's major fisheries, accounting for 15% of the State's commercial production of seafood. The catch includes a variety of fish (e.g. shark, mullet, bream, flathead and whiting) and crustaceans (e.g. sand, mud and spanner crabs; bay, king and tiger prawns). The Bay also supports hundreds of dugongs and dolphins and thousands of turtles and migratory wading birds.

Moreton Bay is home to thousands of turtles.

Hundreds of dugongs reside in Moreton Bay.

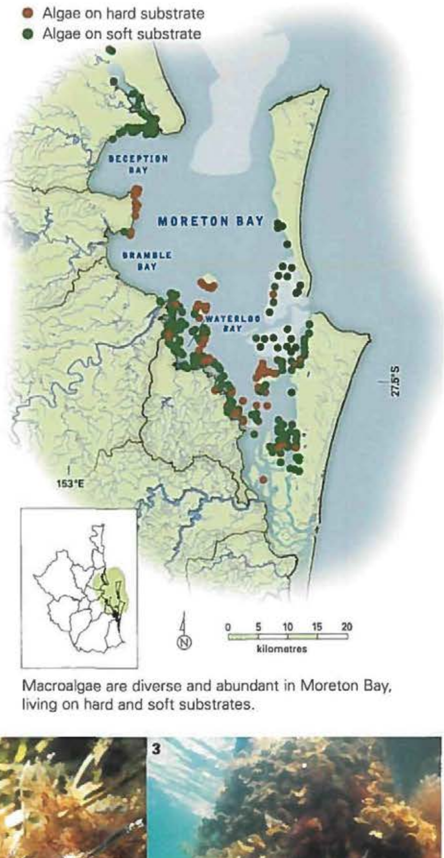
Diverse macroalgae assemblages on hard substrates

Moreton Bay has approximately 275 species of macroalgae (40% of species recorded for Queensland), comprising a mix of both tropical and temperate species. Macroalgae or seaweeds are multicellular algae which can be divided into reds (Rhodophytes), browns (Phaeophytes) and greens (Chlorophytes). Differences in colouration result from the presence of specific photosynthetic pigments. Macroalgae are found in three habitat types; rocky habitat, mangrove habitat and seagrass habitat.

Mangrove habitats along the muddy shores and river mouths of Moreton Bay have aerial roots (pneumatophores), which provide substrate for red algae such as *Catenella nipae*, and under high nutrient conditions the green algae *Ulva lactuca*.

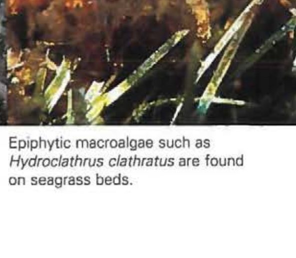
Seagrass habitats contain epiphytic algae such as filamentous red algae or the seasonally abundant brown macroalgae *Hydroclathrus clathratus*. Green algae such as *Caulerpa taxifolia* and *Udotea argentea* have stolons and rhizoids which allow some attachment into sediments amongst the seagrass.

Rocky habitats dominate the Redcliffe Peninsula and are also found on the Bay islands from Mud Island down to Peel Island. These habitats contain the highest diversity of macroalgae within Moreton Bay.



Macroalgae are diverse and abundant in Moreton Bay, living on hard and soft substrates.

Mangrove roots and pneumatophores provide habitat for a range of macroalgal species including *Catenella nipae*.



Epiphytic macroalgae such as *Hydroclathrus clathratus* are found on seagrass beds.

Rocky substrates dominate certain areas of Moreton Bay and contain the highest diversity of macroalgae, especially red algae.

Mangroves impacted by natural and human impacts

NORM DUKE, MARINE BOTANY, UQ

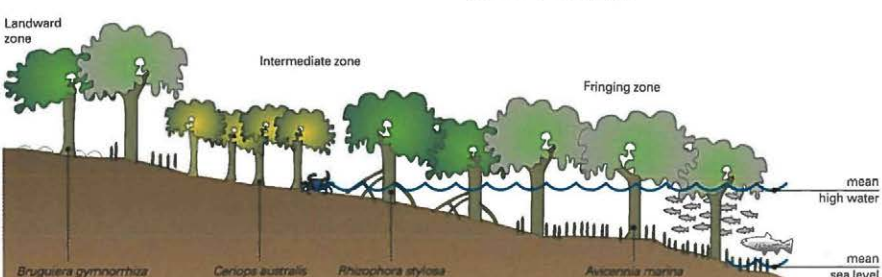
Petrochemical pollution can result in *Avicennia marina* propagules which lack normal pigmentation and appear "albino".

CHRIS ROELFSEMA, MARINE BOTANY, UQ

Hail storms can easily damage and kill mangrove trees, stripping leaves and bark.

Mangroves consist of a diverse assemblage of mostly flowering plants >0.5 m tall. Australia supports 37 species of mangroves. In Moreton Bay the dominant mangrove species is *Avicennia marina* and total area is approximately 15,300 ha. Mangrove forests are recognised as an important habitat and nursery area for juvenile fish, crabs and prawns. Two features of mangrove habitats are thought to support these communities. Firstly, mangrove detritus is an important food source. Secondly, the structural complexity of pneumatophores (aerial roots), fallen branches and overhead foliage can reduce predation upon juveniles.

Mangrove trees can live for more than 100 years and therefore can be used as records of change in conditions over time. Both natural and human impacts are reflected in forest condition. Natural impacts include hail and storm damage, changes in annual rainfall, relative sea level or natural changes in water movement. In 1997, hail stripped leaves and bark from mangroves in southern Moreton Bay. While the *Avicennia* trees resprouted, the hail killed the *Rhizophora, Ceriops* and *Bruguiera* trees. The dominance of *Avicennia* in Moreton Bay may indicate a large amount of historical natural disturbance. Human impacts on mangroves include direct cutting or clearing, impoundment, eutrophication, herbicides or oil spills. A genetic mutation in *Avicennia* associated with petrochemical pollution results in 'albino' propagules which lack normal pigmentation and do not survive to maturity.



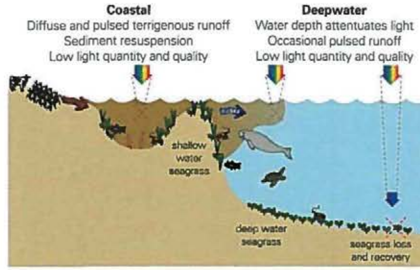
ABAL, et al., 1998

Mangrove species differ along the intertidal gradient. *Avicennia marina* is the dominant mangrove in Moreton Bay and prefers habitat lower on the shoreline covered by water at high tide.

Seagrass distribution represents gradients in disturbance and turbidity

Seagrasses are flowering plants with specialised adaptations for living in the marine environment. They are widespread in Moreton Bay and are highly productive as well as being important in nutrient cycling, sediment stabilisation and as a habitat for juvenile fishery species. Patterns of seagrass distribution are related to gradients of disturbance, caused by water movement and storms as well as grazing by dugongs and turtles. Slow growing, high biomass seagrasses such as *Zostera capricorni*, *Cymodocea serrulata* and *Syringodium isoetifolium* grow in regions with relatively low disturbance, while *Halophila spp* and *Halodule uninervis* grow rapidly and have high seed set, so are favoured in highly disturbed conditions. Generally, *Zostera capricorni* predominates in the more muddy but more stable regions of the western Bay, while *Halophila* and *Halodule* species predominate over the eastern banks, the site of major dugong and turtle grazing.

Moreton Bay contains hundreds of dugongs (*Dugong dugon*) and thousands of green sea turtles (*Chelonia midas*). While turtles clip off the seagrass leaves, dugongs remove the whole plant, favouring the succulent rhizomes of *Halophila* and *Halodule*. Intense grazing excludes slow growing species, however increases the rates of nitrogen fixation and therefore maintains the nutrient status of grazed areas for further seagrass growth. This positive feedback mechanism is referred to as cultivation grazing.



Seagrass distribution in Moreton Bay is related to several factors, disturbance gradients, runoff, light quantity and grazers

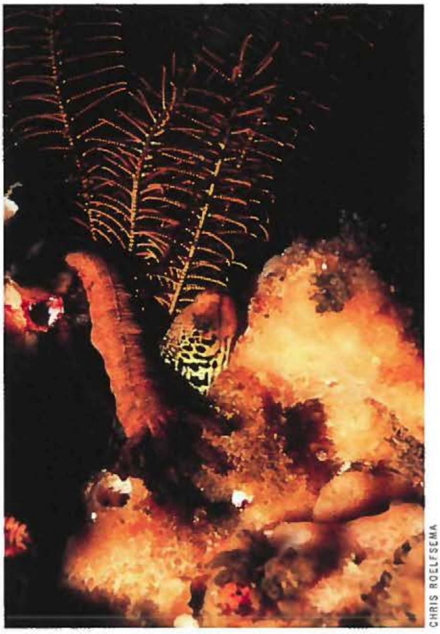
Halophila ovalis is a rapid growing seagrass species, predominating in the Eastern Banks and is the preferred food for dugongs.

Dugong grazing encourages the growth of faster growing *Halophila* and *Halodule* species (1) whereas in ungrazed areas, *Zostera* and *Syringodium* dominate (2).

Jetty pylons provide habitat to many organisms but have ships introduced pest biota species?

Moreton Bay consists mostly of soft sediments, with rocky headlands at Redcliffe and the Bay Islands. Many organisms such as macroalgae (seaweed) and invertebrates grow in abundance on hard substrates and jetty pylons provide a hard substrate in regions where otherwise these communities would not be supported. Amity Point Jetty supports an abundance of recreational fishing species such as blue swimmer crabs and fish.

Ballast water is required by large vessels in order to maintain stability during ocean voyages and is pumped into holding tanks when ships unload cargo. Between 1995 and 1998 at least 2625 cargo vessels visited the Port of Brisbane discharging a total of 6.8 million tonnes of ballast water into the Brisbane River. It can contain a variety of animals, plants, cysts, larvae and spores that may survive the journey to the next port where the ballast water is discharged while the vessel is loading cargo. The Port of Brisbane was surveyed for the presence of pest biota species. If pest biota are introduced through ballast water, they would be likely to recruit onto the nearby jetty pylons. None of the pest species specified by the Australian Introduced Marine Pest Advisory Council (AIMPAC) were present in the samples collected from the Port of Brisbane or adjacent waters.



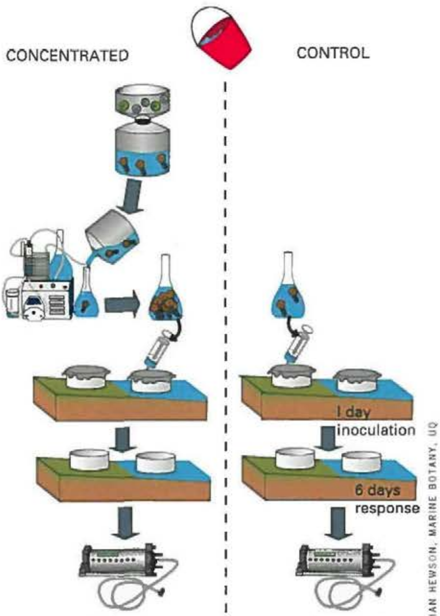
CHRIS ROELFSEMA

Moray eels, crinoids, holothurians and sponges all inhabit the Amity Point jetty, making it a popular site for SCUBA diving.

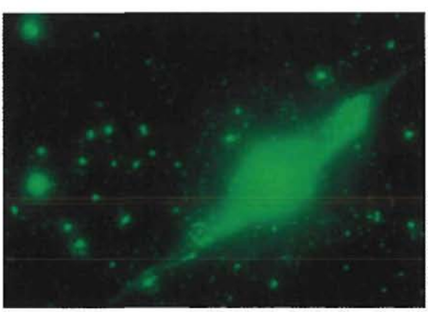
Suspected point of entry in Australia of introduced species sampled in Moreton Bay (Furlani, 1996 in Fearon and O'Brien, 2001). None of these species has AIMPAC pest status except *Alexandrium minutum*.
*Cryptogenic – species for which confusion exists in terms of their indigenous range.

Taxon	Species	Status	Year first recorded	Suspected Point of Entry
Phycophyta, Dinophyceae	*Alexandrium minutum*	target species	? unknown	? unknown
Chlorophyta	*Caulerpa taxifolia*	cryptogenic*	1855	(native species)
Crustacea, Isopoda	*Sphaeroma walkeri*	introduced	1927	Sydney, NSW
	Paradella dianne	introduced	1971	Queensland
	Synidotea laevidorsalis	introduced	1886	? unknown
Mollusca, Gastropoda	*Aeolidiella indica*	introduced	? unknown	NSW/Qld
	Maoricolpus roseus	introduced	1963	Huon Estuary, Tas.
Chordata, Ascidiacea	*Mogula manhattensis*	introduced	1967	Yarra Station, Vic.
	Styela plicata	introduced	1878	NSW
	Botrylloides leachi	introduced	1899	Port Jackson, NSW
	Botryllus schlosseri	introduced	1928	WA

Viruses abundant in marine habitats



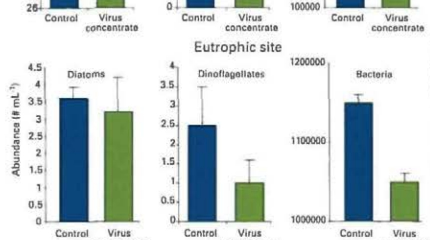
Site water was collected and for the treatment, virus like particles were concentrated using a tangential concentrator. This concentrated material and unconcentrated control were added to *in situ* benthic containers. After 6 days, benthic communities were assessed for the impact of the increased virus abundance.



Bacteria and viruses on a common diatom *(Cylindrotheca closterium)*.

Viruses are ubiquitous in the marine environment and also are the most abundant microorganisms in marine habitats. Abundance of microorganisms in the sediment is orders of magnitude higher than in the over-lying water column.

To assess the influence of virus-like particles on microalgae and bacteria in Moreton Bay, virus-like particles were added to contained areas of benthos *in situ*. At both the eutrophic and oligotrophic sites within Moreton Bay, addition of virus like particles to a microorganism community resulted in a reduction in live bacterial cells. The oligotrophic site, however, showed increased numbers of dinoflagellates with addition of virus-like particles. This suggests that lysis of bacteria at this very low nutrient site is providing nutrients for increased growth rates of dinoflagellates.



Addition of virus-like particles resulted in a reduction of live bacterial cells.

	Size (µm)	Abundance (# mL^{-1}) Benthos	Phytoplankton
Microalgae	40-200	110 000	9
Bacteria	1	19 000 000	1 200 000
Viruses	0.2	120 000 000	18 000 000

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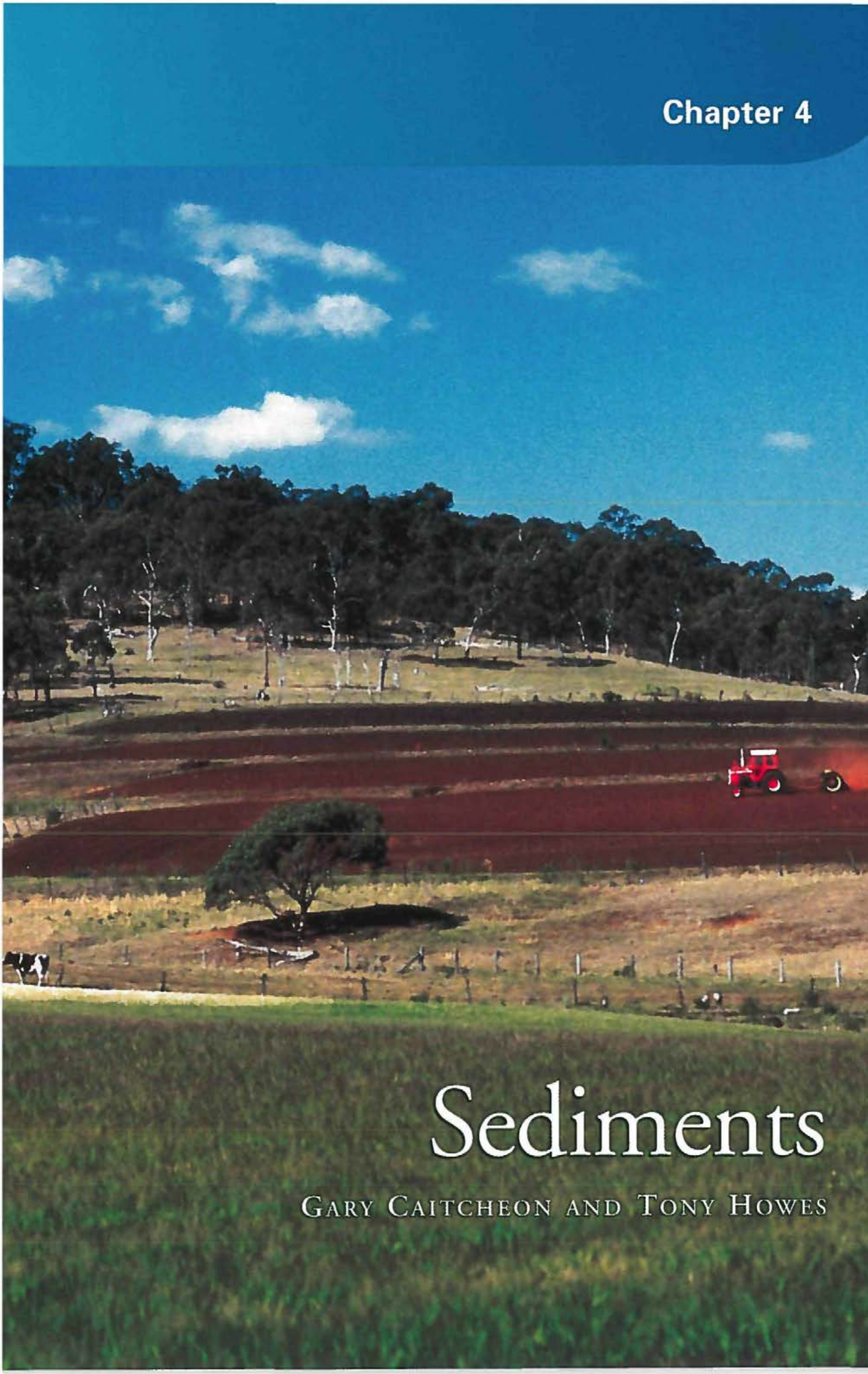

Chapter 4

Sediments

Gary Caitcheon and Tony Howes

Soil erosion generates sediment and has significant environmental impacts

The settlement and development of South East Queensland has significantly altered landscapes, and the riverine and estuarine environments. Land clearing and the introduction of European land use practices have disturbed the natural balance. Sediment generated from accelerated soil erosion has degraded water quality and physical habitat.

Transported sediment can bring with it nutrients and contaminants that have negative impacts on water quality. Nutrients such as phosphorus (P), carbon (C), and nitrogen (N) are transported in particulate form. Most of the P is associated with surface coating on the mineral grains, while N and C are transported as particulate organic matter in association with the mineral sediment. Similarly, many agricultural chemicals and heavy metals are transported into streams and estuaries in association with sediments. Suspended and bed sediments can act as sinks and sources of the nutrients and contaminants, depending on the prevailing environmental conditions.

Suspended sediment causes turbidity that can increase the amount of heat absorbed and retained in the water of shallow freshwater environments. This can be fatal to fish and insect species and reduce their reproductive ability. Turbidity also limits light penetration, disrupting the growth of photosynthetic organisms such as algae and macrophytes and has been linked to the loss of seagrass in western Moreton Bay and river estuaries.

High sediment loads lead to in-channel deposition, infilling river pools and clogging coarse sediments on the river bed with finer material. In upland streams gravel beds can become clogged with sand and coarse silt, while in lowland reaches, sand beds become overlaid with silts and clays. The infilling of river beds with sediment decreases the diversity of habitat on the bed, as well as changes its character. During and after floods, sediment settles out and may smother bottom-dwellers, or at least interfere with their physiology and behaviour. In estuaries and bays, sediment deposition can have similar detrimental impacts.

The Logan River in flood carries suspended sediment generated from soil erosion to the Bay.

Various *soil erosion processes*

There are many processes involved in the generation and delivery of sediment starting with soil erosion on hillslopes, in gullies and along stream banks (the last two are collectively termed *channel erosion*).

Hillslope erosion occurs on soil surfaces that may be covered by vegetation, but is more prevalent on bare soil, especially soil loosened and exposed by cultivation. Most sediment eroded on hillslopes is deposited further down the slope and in the short term it may not reach the drainage system. The proximity of hillslope erosion to a channel, and the presence or absence of buffering riparian vegetation are therefore important to sediment delivery from hillslopes to channels. Channel erosion in gullies and along stream banks contributes sediment directly into drainage systems, so it can have an immediate impact on water quality and physical habitat.

At the local level, it is common for either hillslope or channel erosion to be clearly the dominant source. The management of these two erosion types differs. For example, channel erosion is best

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Channel erosion in the Logan River catchment.

managed by reducing stock access to streams, protecting vegetation cover in areas prone to gully erosion, revegetating bare banks, and reducing sub-surface seepage in areas with erodible sub-soils. Hillslope erosion is best managed by promoting groundcover, maintaining soil structure, and promoting deposition of eroded sediment before it reaches a stream. It is therefore important to be aware of the dominant type of erosion before attempting local or catchment-wide management to control it.

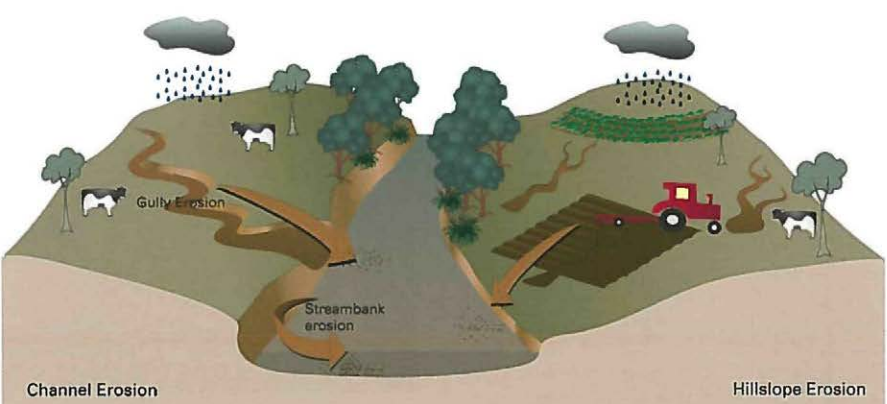
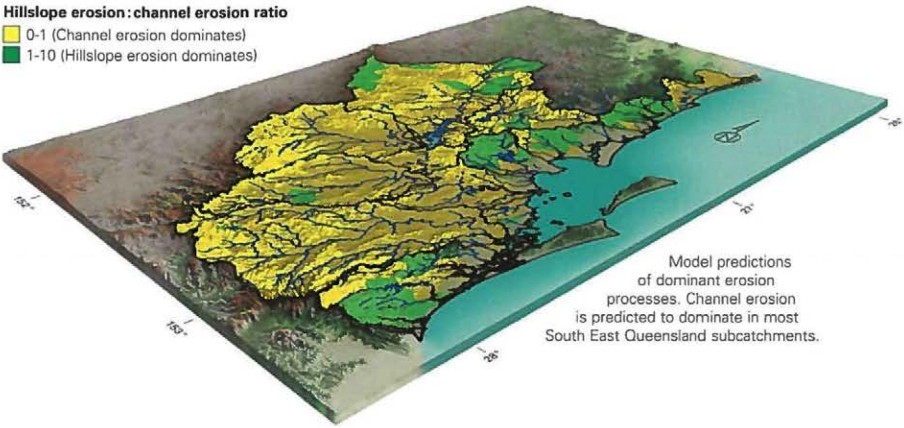


Illustration of channel and hillslope erosion processes. Channel erosion includes gully and streambank erosion and hillslope erosion includes sheetwash and rill (shallow [<20 cm] channel) erosion.

Model predicts that *channel erosion dominates* in SEQ Catchments



Model predictions of dominant erosion processes. Channel erosion is predicted to dominate in most South East Queensland subcatchments.

An erosion model was applied to the South East Queensland (SEQ) catchments to predict the spatial patterns of soil erosion processes. Limited measured data are available to determine spatial patterns of erosion, however, the factors controlling sediment transport are well understood and can be used to predict these spatial patterns. The model is a physically-based process model that uses simplified forms of equations that describe erosion and sediment transport. Data sources include rainfall, stream flow, digital elevation, remotely sensed land cover and measurements of river width and gully erosion from aerial photographs.

The erosion and sediment delivery model clearly predicted that channel erosion is the dominant form of erosion in SEQ. Hillslope erosion is predicted to be important in some coastal catchments, like the Maroochy and North Pine. These regional predictions are indicative of the average, long-term situation. They do not necessarily define the dominant form of erosion at a particular place and time, which may vary due to local factors such as the current land management and prevailing climatic conditions.

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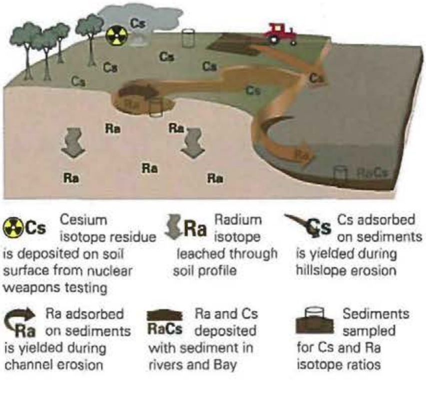
Channel erosion is predicted to dominate in South East Queensland.

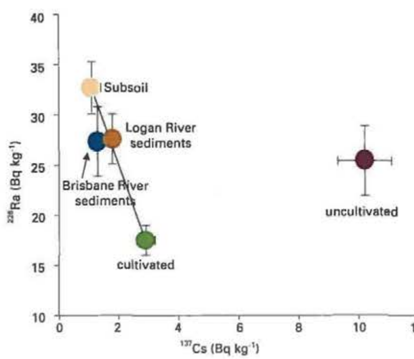
Erosion process tracing confirms model predictions

Sediment tracing methods provide us with an independent means of testing the model predictions. Surface soil samples were collected throughout the catchments from cultivated and uncultivated lands, and from subsoils in gullies and stream banks. These source types can be distinguished by measuring concentrations of cesium-137 (^{137}Cs) and radium-226 (^{226}Ra). ^{137}Cs is a product of atmospheric nuclear weapons testing that occurred in the 1950-70s. It accumulates in surface soil, and labels sediment eroded from top-soils. ^{226}Ra is a naturally occurring radio-nuclide that can occur in reduced concentrations in cultivated soils, possibly due to leaching. Together, these two radionuclides can give a good indication of the origin of sediment from the landscape.

Sediment samples collected from the lower reaches of the Brisbane and Logan Rivers upstream of the tidal estuaries, are likely to be well mixed during transport, and so should represent sediment delivered from many sources in their respective catchments. The mean ^{137}Cs and ^{226}Ra in the sediment sample values lie between the mean cultivated surface soil and subsoil values, while the mean uncultivated surface soil value lies well away from this group. Assuming that the mean sediment concentrations are a linear mix of the two primary sources, then we can estimate that 75 ± 25% of the sediments originate from subsoil (channel) erosion in the Brisbane and Logan catchments, while the remaining 25 ± 25% comes from cultivated surface soils. Note that these results have a relatively high statistical uncertainty (± 25%), which means that the variation in the contribution of surface soils and subsoils to river sediments is relatively high. On average, the subsoil contribution to the Logan and Brisbane Rivers will vary from 50-100%. These results do not exclude the likelihood that some sediment is also coming from uncultivated land, however, the contribution is relatively small.



Erosion processes were traced using the isotopes cesium (^{137}Cs) and radium (^{226}Ra). Used in combination, these two radionuclides can give a good indication about where sediment has originated from in the landscape.



Average radium (^{226}Ra) and cesium (^{137}Cs) values from cultivated and uncultivated soils (hillslope erosion) and subsoils (channel erosion), compared with average values obtained from sediment in the lower Brisbane and Logan Rivers. These results show that the river sediments mainly originate from subsoil erosion (75%), with most of the remaining sediment coming from erosion of cultivated soil.

Cultivated land also contributes sediments (hillslope erosion)

The model predictions do not exclude the fact the hillslope erosion also occurs in the areas that are predicted to be dominated by channel erosion. This was demonstrated by the tracing results, which show that erosion from cultivated land is also contributing sediment to the Brisbane and Logan Rivers. If we consider the model predictions for the main land uses in South East Queensland (SEQ), it is clear that across the region, soil erosion per unit area is significantly greater in cropping land.

However, here is much more grazing land than cropping land. Addition of the total predicted erosion from these land uses shows that on average, they produce similar annual total amounts. But erosion from cropping land is likely to dominate the supply of sediment produced from hillslopes. Most cropping land is on floodplains adjacent to the drainage system where eroded soil is more likely to be transported directly into streams. Conversely, soil eroded on grazing land is less likely to reach channels because, on average, transport distances on hillslopes are longer, so there is more opportunity for sediment trapping, particularly on well grassed slopes. Also, very little sediment from grazing land in the upper Brisbane River catchment (about one third of the area of SEQ) will reach the lower river because it is trapped behind Wivenhoe Dam.

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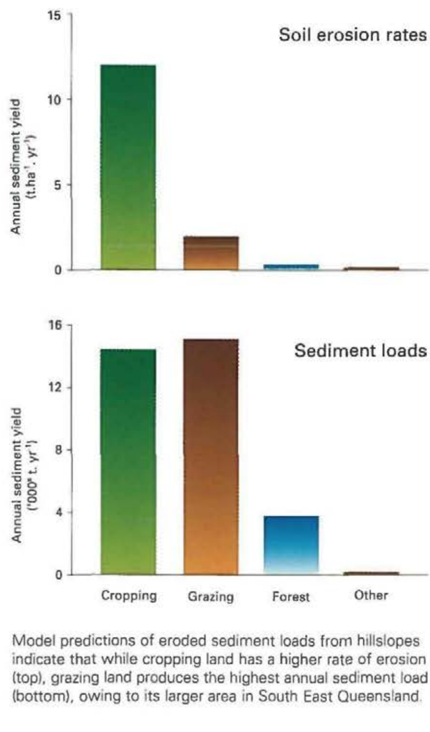
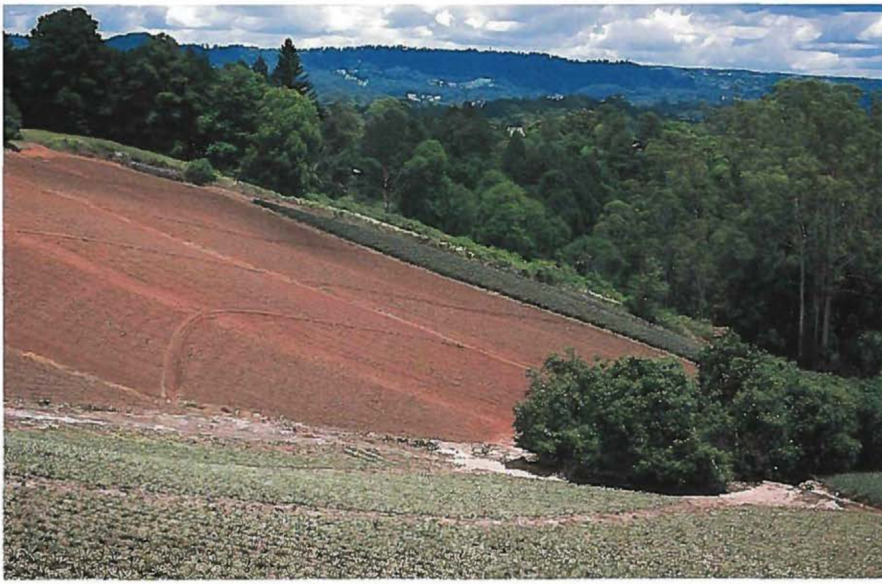
Hillslope erosion on disturbed soils.



Model predictions of eroded sediment loads from hillslopes indicate that while cropping land has a higher rate of erosion (top), grazing land produces the highest annual sediment load (bottom), owing to its larger area in South East Queensland.

Erosion processes in *coastal catchments* are more variable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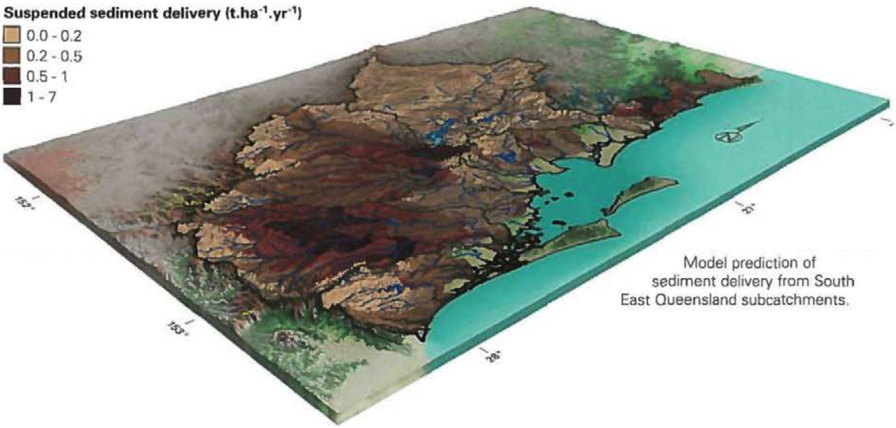
Hillslope erosion contributes to eroded sediment delivery to the Maroochy River. Erosion from cultivated land is a probable source.

Catchment	% Subsoil
Channel erosion dominated	
Mooloolah River	89
Caboolture River	>80
North Pine River	78
South Pine River	88
Kedron Brook	90
Bulimba Creek	98
Pimpama River	>80
Coomera River	83
Nerang River	78
Currumbin Creek	69
Tallebudgera Creek	84
Intermediate	
Maroochy River	51
Hillslope Erosion Dominated	
Noosa River	<20

The erosion process tracers indicate that most of the coastal catchments are dominated by channel erosion. The clear exception is the Noosa River catchment, which is dominated by hillslope erosion. The result from the Maroochy River catchment is more uncertain, so we have classified it as intermediate because channel and hillslope erosion are likely to be equally important. Parts of the Maroochy River catchment are intensively cropped, so hillslope erosion from cultivated land is a probable source. It is likely that variability in the relative importance of channel and hillslope erosion will be relatively high along the coastal catchments, because factors such as rainfall, topography, vegetation cover, and land use are more variable than they are inland in the Brisbane and Logan River catchments.

Not all catchments are equal in terms of *sediment delivery*



Model prediction of sediment delivery from South East Queensland subcatchments.

A lot of sediment is deposited and stored for lengthy periods before reaching the final receiving basin. Deposition of sediment means that the sediment yield per unit catchment area decreases with increasing catchment size. For suspended sediment the main places of net accumulation are floodplains and reservoirs. There is a low probability of sediment being transported from its source to the coast if there is significant deposition along the way. Thus the delivery of sediment downstream depends on the extent of floodplains and the proportion of total suspended load that is transported over the floodplains. This varies considerably from one place to another. Knowledge about sediment transport and deposition along river systems is therefore crucial to the management of sediment delivery to coastal estuaries and Moreton Bay.

A key model output is the contribution from each modelled subcatchment to the mean annual load at the river mouth. This is predicted in tonnes.hectare^{-1}.year^{-1} of sediment generated in each subcatchment. So the model predicts how much sediment delivered to the river in a sub-catchment actually reaches the end of the drainage system. The amount contributed to the coastal estuaries is a product of sediment delivery to the subcatchment from further upstream, and the probability of that sediment passing through each downstream subcatchment on the way to the end of the river system.

The most conspicuous outcome of the model is the very low sediment delivery to Moreton Bay from the upper Brisbane River catchment. This is because we estimate that Wivenhoe Dam traps >95% of the sediment delivered to it, effectively cutting off the sediment supply from the upper catchment to the lower reaches of the Brisbane River. This does not mean, however, that erosion is not occurring in the catchment above Wivenhoe.

It also is apparent from the model predictions that the most upland and lowland parts of the Logan and Brisbane catchments contribute relatively little sediment to the bottom of these rivers. A lot of sediment eroded from steeper upland areas is likely to be stored in channels and on floodplains in the lower gradient parts of the drainage system immediately downstream. The most lowland parts of the catchments generate relatively little sediment because of the low gradient. Note that the model does not predict sediment delivery from urban areas.

In the Brisbane catchment, high sediment delivery is predicted from the lower Brisbane River above the tidal limit, and lower reaches of Lockyer Creek. The efficiency of sediment delivery from these areas will be high because there is the least distance to travel to the mouth of the river, and peak flood discharges will be greatest. Some tributary areas of Lockyer Creek and the Bremer River also are predicted to make relatively high sediment contributions.

Most of the middle Logan catchment has a relatively high-predicted sediment delivery, particularly along parts of the Albert River and Teviot Brook. As discussed in the previous section, most of this sediment will originate from channel erosion. Observations made in this area indicate that stream bank erosion is the most likely source.

Soils on Lamington Rocks deliver more iron and phosphorus to the Logan River

The results of the spatial tracing show that sediment collected from the mouth of the Logan River mainly originates from the Marburg Formation (50%), Neranleigh-Fernvale Beds (21%), and Lamington Group volcanic rocks (17%). Because soils developed on Lamington Group rocks have high iron and phosphorus contents, this source contributes disproportionately to the total iron (30%), and total phosphorus (45%) contents of the Logan River sediments.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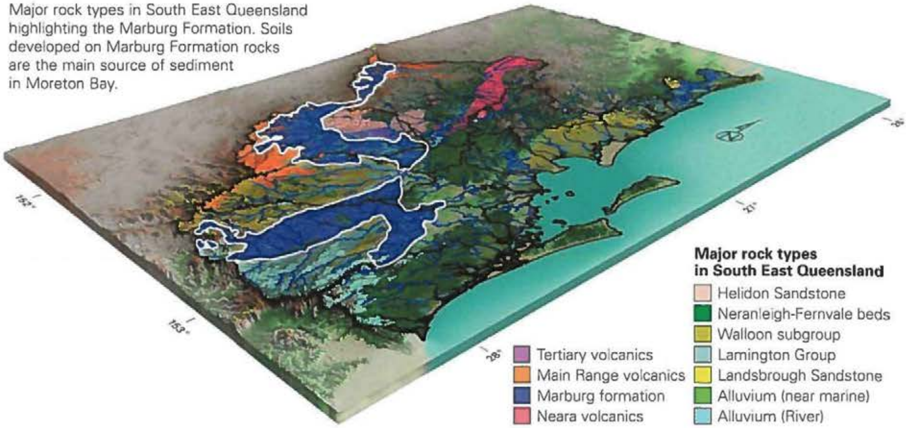
Channel erosion is a major source of sediment.

Soils developed on Marburg Formation rocks are the *main sediment sources*

Major rock types in South East Queensland highlighting the Marburg Formation. Soils developed on Marburg Formation rocks are the main source of sediment in Moreton Bay.



The modelling predicts that about 70% of the sediment is generated from subcatchments that occupy less than 30% of the region as a whole. This outcome is consistent with spatial tracing results, which show that most of the sediment produced in the Brisbane and Logan catchments originates from soils developed on Marburg Formation rocks.

The chemical properties of sediments can be used to determine their origins. This includes major and minor elements, as well as trace elements. Soils developed on major rock types normally have distinct geochemical signatures, as do the sediments derived from them. Geochemical tracing therefore involves sampling all of the major source types, and determining the relative source contributions in the resultant mix of sediment deposited further downstream in a river, estuary, or bay.

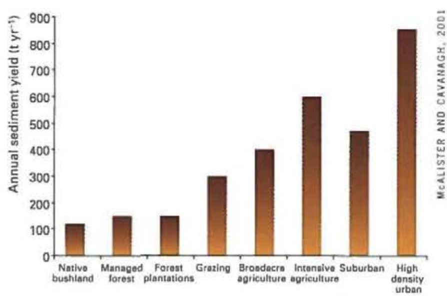
Catchment Soil End Member	% of soils derived from Catchment Soil End-Member		
	Central Bay	Southern Bay	Logan River
Marburg Formation	58 ± 9	54 ± 7	45 ± 7
Walloon Subgroup	13 ± 10	5 ± 1	3 ± 2
Neranleigh-Fernvale Beds	9 ± 9	13 ± 1	8 ± 9
Lamington Group	0 ± 1	3 ± 10	42 ± 8
Main Range Volcanics	19 ± 4	23 ± 7	0 ± 5
Neara Volcanics	1 ± 1	2 ± 2	2 ± 1

Samples were collected from soils developed on all of the major rock types. Soil sample measurements were then used in a mixing model to estimate the relative contributions of the sources to the fine sediment deposited in the Bay. They show that the dominant source of sediment (>50%) is soils developed on Marburg Formation rocks. This outcome confirms that the fine sediment deposited in the central and southern parts of Moreton Bay comes from the Brisbane River.

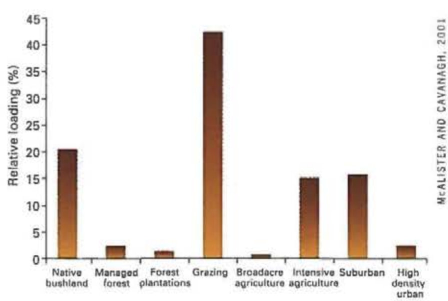
Sediment collected from the mouth of the Logan River also originates mainly from the Marburg Formation (50%), but this sediment also has contributions from soils developed on Neranleigh-Fernvale Beds (21%), and Lamington Group volcanic rocks (17%).

Urban waterways have small land use footprint, but high sediment loading rates

Revision of earlier sediment budgets for the South East Queensland (SEQ) region was carried out based on refined current land use data (Environmental Management Support System) and relevant Australian areal sediment load data, including local data sources. Based on these data it was determined that urban areas (separated to consider both suburban and dense urban) have the highest areal sediment loading rates (i.e. tonnes per hectare) in the SEQ region.



Areal sediment loading rates to Moreton Bay indicate that on a per area basis, urban areas contribute the highest sediment loads.



Relative suspended sediment loadings to Moreton Bay. Given the small area that the urban land use occupies, the overall loading of sediments from urban areas is low.

When considered on a regional basis however, urban areas have the smallest relative land use footprint, with dense urban and suburban occupying only 0.5% and 6% of the SEQ catchment, respectively. Taking this into consideration, urban areas contribute a much smaller proportion of the total annual sediment load from the catchment into Moreton Bay.

Despite this, urban areas remain a management concern as:

- they may be a much more significant localised source of sediment for some of the smaller tributaries in the area (e.g. Breakfast or Oxley Creeks):
- sediments from urban areas are typically fine in nature and may be contributing significantly to residual turbidity in SEQ receiving waters;
- they contain potentially greater quantities of adsorbed pollutants (especially heavy metals and hydrocarbons) than other sources of runoff, and
- sediment loads from urban areas can also come from minor storms, which occur during drier periods when upper catchment runoff is minimal.

Land use area	% of total area
	% of total area
Native Bushland and National Park	42
Managed Forest	7
Forest Plantations	2
Grazing	35
Broadacre Agriculture	1
Intensive Agriculture	5
Suburban	6
Water	1.5
High Density Urban	0.5

McALISTER AND CAVANAGH, 2001

Land use areas in South East Queensland.

Estuaries are the link to the Bay

An estuary is the zone of mixing between freshwater and saltwater in the lower reaches of the river. Estuaries receive sediment inputs from the catchment that have been transported through the river network. Through the river estuary, sediments make their way out of the river to the Bay or ocean.

The physical processes involved in the transportation, mixing, deposition and resuspension of sediments are complex but crucial for the understanding of their delivery to the Bay or ocean.

Estuaries experience tidal incursions of dense saline water which mixes with the freshwater riverine inputs. Tidal movements are a distinguishing feature of river estuaries and the flushing mechanism imparted by this movement is an important means for removing materials carried by the river. In the Brisbane River the tidal limit now extends to approximately 85 km upstream of the Brisbane River mouth, near the Mt Crosby Weir (Holland *et al.*, 2001).

Sediment is ultimately transported through to the Bay or ocean as suspended sediment which can be seen and measured as turbidity. Turbidity can be observed in many of South East Queensland's (SEQ) river estuaries as the water's brown colour. The Brisbane River, along with the Logan River, is the most turbid river in SEQ. Both anecdotal and historical data provide evidence that the Brisbane River is now more turbid than it was historically (Dennsion and Abal, 1999). Phyto-plankton bioassays indicate that without this high turbidity and resulting low light, however, the present high nutrient levels could facilitate the development of algal blooms (Dennison and Abal, 1999). Therefore, this high but changing turbidity is an important feature of the river, and poses significant ecosystem health implications.

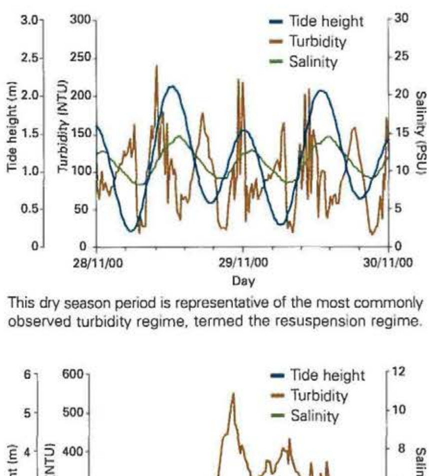
The Brisbane River estuary.

Large variations in *river turbidity* are observed during each tidal cycle

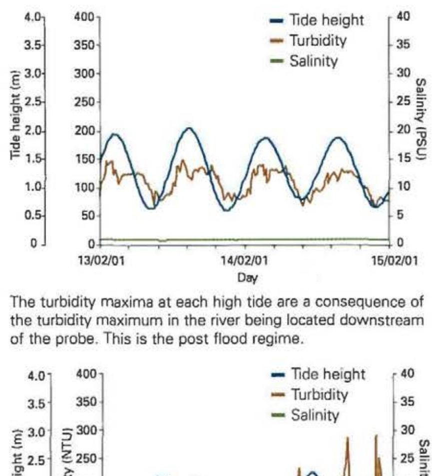
Given the increases in turbidity that have occurred in South East Queensland's river estuaries and the impacts this has on ecosystem health, a study was initiated to investigate the processes and the type of sediments causing turbidity in the Brisbane River. Salinity, turbidity and temperature measurements were taken by the Environmental Protection Agency approximately one hundred metres downstream of the Albert Bridge in the Indooroopilly reach of the Brisbane River, just downstream of the usual location of the turbidity maximum in the Brisbane River.

Turbidity varies on average nine fold throughout each daily tidal cycle. Maximum turbidities correspond to the largest tidal flow (and thus the greatest resuspension). When flow reversal takes place, there is a large and rapid decrease in the near-surface turbidity.

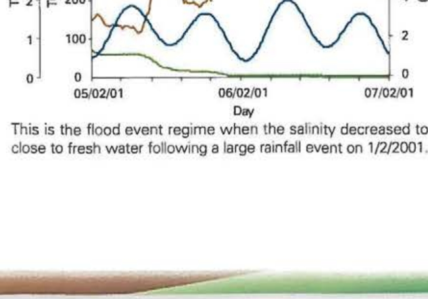
Three other regimes have been observed. During flood conditions the maximum turbidity occurs at low tide as runoff carrying sediment moves down the river. Soon after a flood event resuspension does not play an important role in turbidity formation. The final regime observed in the Brisbane River is associated with a period of low turbidity during the winter months.



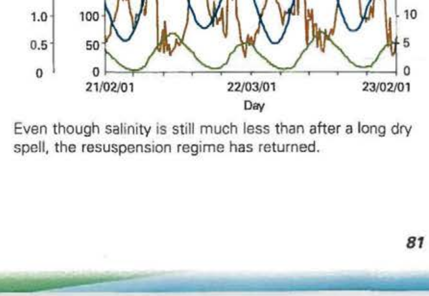
This dry season period is representative of the most commonly observed turbidity regime, termed the resuspension regime.



The turbidity maxima at each high tide are a consequence of the turbidity maximum in the river being located downstream of the probe. This is the post flood regime.

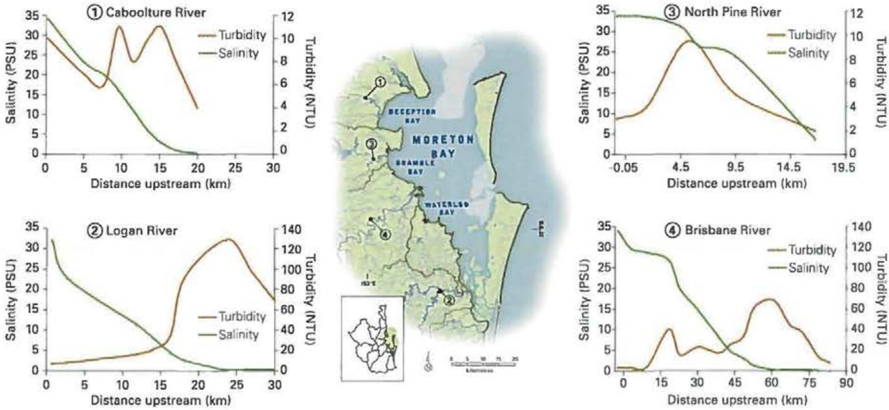


This is the flood event regime when the salinity decreased to close to fresh water following a large rainfall event on 1/2/2001.



Even though salinity is still much less than after a long dry spell, the resuspension regime has returned.

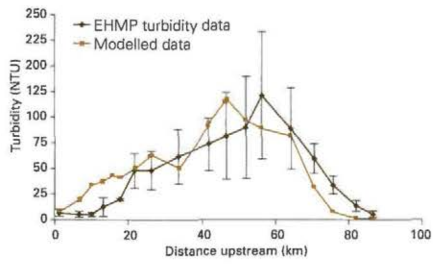
Physical processes lead to formation of *turbidity maxima in river estuaries*



Turbidity and salinity longitudinal profiles of four Moreton Bay river estuaries. The physical processes in the turbid Brisbane and Logan Rivers appear similar as the position of the turbidity maxima corresponds to the intrusion of salinity.

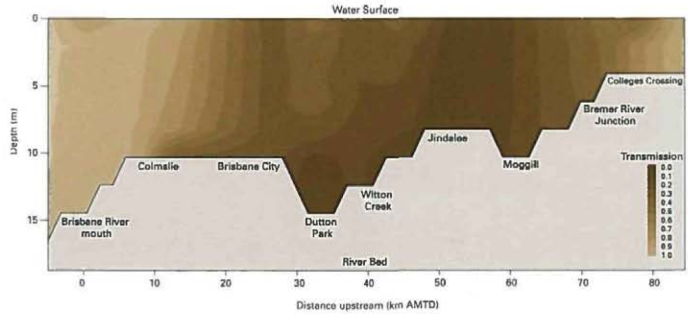
The physical processes causing turbidity in the Logan and Brisbane River estuaries may be different to the Caboolture and North Pine Rivers. The turbidity structure in the Brisbane and Logan Rivers is similar, with the turbidity maxima in both rivers corresponding to the farthest intrusion of salinity into the estuary. The Caboolture and North Pine estuaries show much lower turbidity levels and the turbidity maxima occur further downstream at higher salinity levels. The physics governing turbidity processes in these rivers are likely to be different from the Brisbane and Logan Rivers, however, turbidity is of less concern in these estuaries as levels are much lower.

Salinity in the Brisbane River estuary is vertically well mixed, with only low levels of stratification such as at the mouth of the river. The slight salinity stratification observed near the mouth was likely the result of the fresh water outflow from the nearby sewage treatment plant. Three dimensional hydrodynamic modelling confirms this salinity and turbidity profile observed in the field.

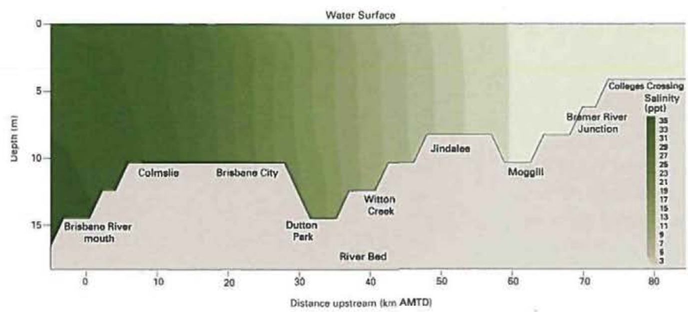


Depth averaged turbidity and modelled turbidity for January-June 2000. Model predictions are in close agreement with Ecosystem Health Monitoring Program (EHMP) measured data.

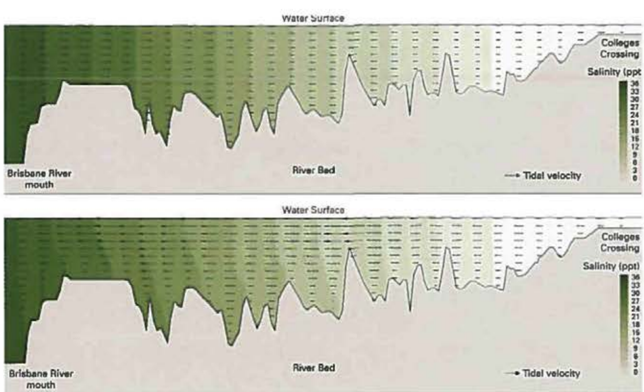
The Brisbane River is turbid especially around city reaches.



Transmission, a measure of water clarity, in the Brisbane River from the tidal limit (right) to the river mouth (left) on 22nd June 2000. The position of lowest transmission indicates highest turbidity and corresponds to maximum intrusion of salinity.



Salinity in the Brisbane River from the tidal limit (right) to the river mouth (left) on 22nd June 2000.

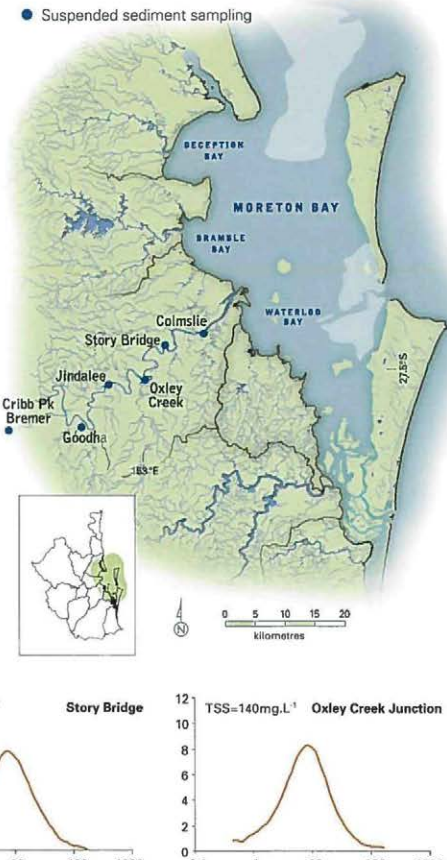


Predicted vertical distribution of salinity in flood (top) and ebb (bottom) tides during "dry weather" conditions of June 2000 from upper tidal limit (right) to the mouth (left). The Brisbane River is vertically well mixed during flood tide, but during the ebb tide there is some vertical stratification.

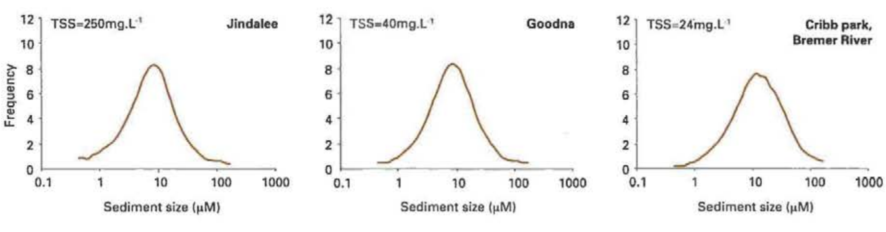
Size and type of suspended sediment varies little throughout the Brisbane River Estuary

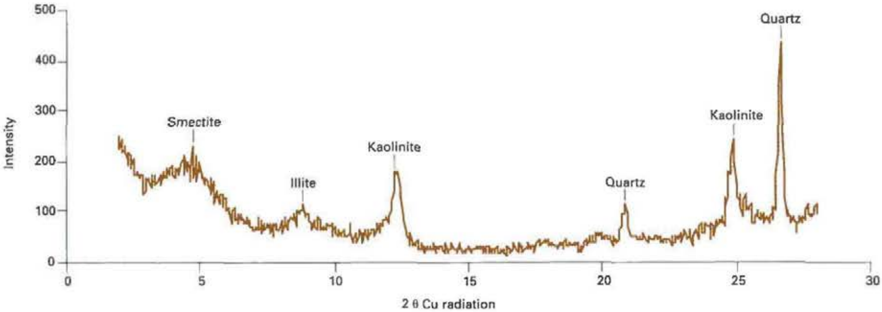
The size, shape and relative density of sediment particles determine how quickly they settle in water. Also, turbidity depends not only on the mass of particles but also on their size. Smaller particles scatter light more than large ones, and as a result, contribute more to turbidity than larger ones. Investigations were carried out into the size and type of suspended sediment in the Brisbane River to determine the influence that this may have on turbidity in the Brisbane River.

Sediment collected on an incoming tide during the dry weather was measured gravimetrically after the soluble salts were removed. The particle size distributions were determined using low angle laser light scattering. Although the total suspended solids varied throughout the river, the size distributions were fairly uniform. The median size range was from 7 to 12μ.

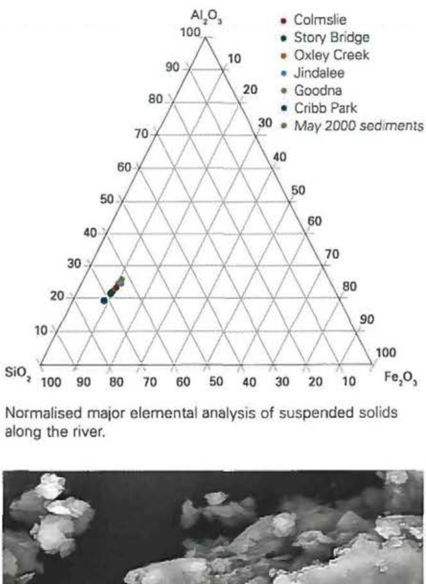


Suspended sediment size distribution in the Brisbane River on an incoming tide in summer 2000-2001. Size distribution of the sediment particles in the River were fairly uniform despite the high variation in Total Suspended Solids (TSS).





Mineral composition of suspended solids as measured by X-ray diffraction of the clay mineral structure. The labelled peaks correspond to a known diffraction pattern of each clay mineral structure.



Normalised major elemental analysis of suspended solids along the river.

Scanning Electron Microscope image of suspended solids collected from Jindalee 22/11/00.

An analysis of the common elements found in rocks of South East Queensland (SEQ) was performed on suspended sediments in the Brisbane River using X-ray fluorescence. The triangular plots show that the ratios of the major elements do not vary down the river further supporting the field observations that the Brisbane River estuary is well mixed. Within the suspended sediments there are different size and shape particles including both large particles and agglomerates of smaller particles.

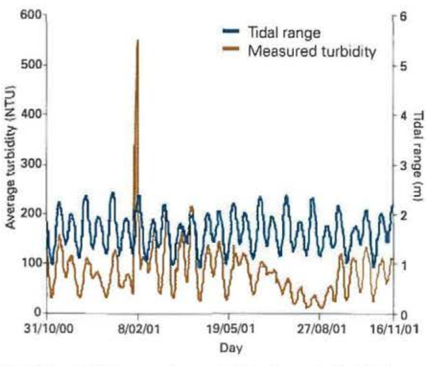
The types of minerals in the suspended solids can be identified by X-ray diffraction. This technique measures the phases, not the elements present. The relative amounts of these phases can then be compared with those present in the catchment soils. Different clay mineral assemblages are characteristic of different soils. The pattern shows that the suspended solid contains Smectite, Quartz, Kaolinite and a trace of Illite. The soils of the major stream floodplains and levees in SEQ are known to have high Smectite to Kaolinite ratios and only trace amounts of Illite, being formed on Alluvia of basaltic origin (Powell, 1987). These minerals are not dissimilar to the clays found in the black, cracking clay-rich soils (Vertosols) of the Lockyer Creek and Bremer River flood plains.

Brisbane River is *more turbid during spring tides* compared with neap tides

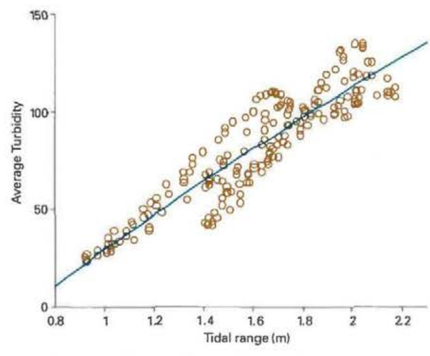
Average turbidity values (measured over a 25 hour period) indicate that turbidity in the Brisbane River varies on long time scales. The tidal range has been defined as the difference between the highest and lowest values over two consecutive pairs of high/low tides.

Tidal turbidity occurs in the absence of sediment input from catchment runoff, and is caused by tidal resuspension of sediment trapped in the estuary. Tidal turbidity results from both natural and anthropogenic influences on the river. When tidal turbidity dominates, there is a strong correlation between average turbidity and tidal range.

The period between 26 September and 15 November 2001 was chosen to determine the tidal turbidity fit in the Brisbane River estuary. When this fit was made, tidal turbidities ranged from 22 NTU to 144 NTU, for tidal ranges from 0.92 m to 2.42 m. During spring tides when the tidal range and therefore tidal velocity is largest, higher turbidities result. Neap tides have lower tidal range and tidal velocity and result in lower turbidities. The correlation illustrates the sensitivity of turbidity to tidal velocity, and again highlights how much tidal turbidity varies throughout the tidal cycle.



Turbidity and tidal range for more than 1 year in the Brisbane River at Indooroopilly. For most of the time, there is a clear correlation between tidal range and average turbidity. Spring tides (large tidal range) produce higher turbidities than neap tides (lower tidal range).



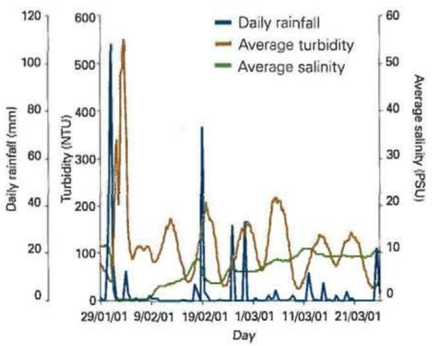
Turbidity versus tidal range in the Brisbane River at Indooroopilly from 26/09/2001 – 15/11/2001. The best fit curve is good for spring (large tidal range) and neap (lower tidal range) tides.

Episodic flood events *increase turbidity*

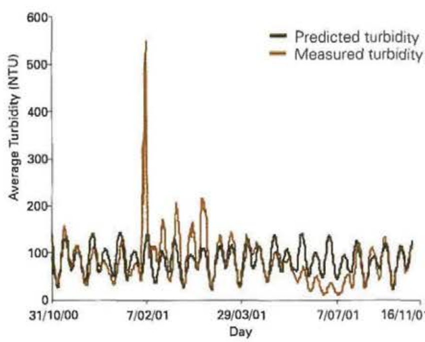
Estuarine turbidity is a combination of tidal and runoff turbidity. **Runoff** turbidity results when an extra particle of sediment is brought into the estuary by runoff. Turbidity during this time is in excess relative to **tidal** turbidity. Suspended sediment particles entering the system by runoff will either leave the estuary completely or eventually settle to the river bottom in a place where there is always sediment present, either near to the river banks, in a low bottom shear stress region of the river (a hole, for example), or in the lower estuary. As a result of settling, runoff turbidity will decay with time.

Runoff turbidity decays faster during neap tides when tidal range and tidal velocities are lower. Therefore, it could be expected that sediment would appear to leave the system more rapidly during neap tides. However, during the following spring tide, when tidal velocity and resuspension is greater, the sediment may become reincorporated into turbidity.

Using a best fit on long term turbidity data, with daily rainfall used as an indicator of sediment input, it is predicted that 50% of runoff turbidity would be present 5 days after sediment delivery. 10% and 1% of the sediment remains in the estuary after 16 days and 32 days, respectively. Runoff turbidity during spring tides decays at a slower rate (approximately 3-5 times slower), than the average rate at which runoff turbidity decays.



Rainfall, turbidity and salinity in the Brisbane River at Indooroopilly during and after a large rain event in February 2001. Increased levels of turbidity following rain events decay with time.



Measured turbidity and predicted tidal turbidity in the Brisbane River at Indooroopilly. Periods of excess turbidity occurred following runoff, when measured turbidity is greater than that predicted based on tidal resuspension only.

Reduced *winter turbidity*

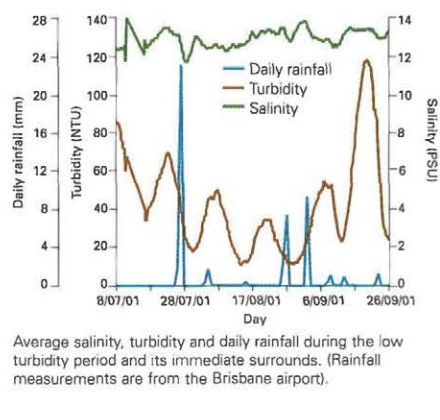
During the winter months of 2001, turbidity in the Brisbane River was lower than that seen for the remainder of the year. The mean turbidity from mid-July 2001 to mid-September 2001, was 36 NTU, compared with an average turbidity of 97 NTU for the previous 240 days (see previous page).

A decrease in turbidity in winter months has been anecdotally described in the Brisbane River (Gregory, 1996), "during the 1930s ... at winter, and at other times of low rainfall, the water in the lower reaches was clear to a depth of several feet", and "Sometimes its pretty clear, winter months especially". This winter clarity was ascribed to lack of rain and/or dredging.

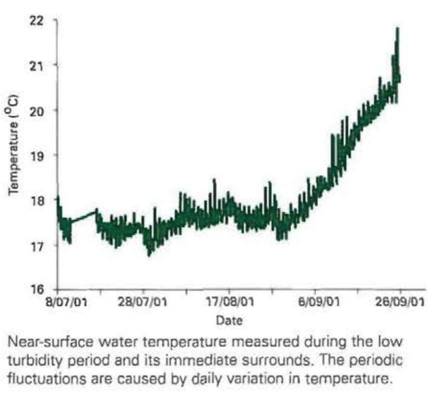
During the low turbidity period there were few times when daily rainfall exceeded 8 mm of rain. A dip in salinity coincided with each of these rainfall events. However, as turbidity levels increased, following the low turbidity period, there was not an associated change in river salinity nor did a runoff event occur. Rainfall does not appear to be the trigger for the increase in turbidity, suggesting that a lack of rainfall is not the reason for this winter low turbidity period.

Navigational dredging took place for much of the year in the Brisbane river down-stream of the Brisbane CBD. Between May and late October 2001 there was no such dredging in these lower reaches. The decrease in turbidity could be attributed to the fact that dredging (and its associated increase in effective resuspension near to the river mouth) was not taking place. However, the increase in turbidity in September took place well before dredging recommenced, so dredging was not a likely cause of the increased turbidity.

Surface temperature in the river remained in the range 17°C to 18°C through the period of low turbidity, and its rapid increase out of this range was at close to the same time as the observed increase in turbidity. It is possible that temperature is having some effect on either vertical mixing in the river, or on the ability of the sediment to resuspend sediment.

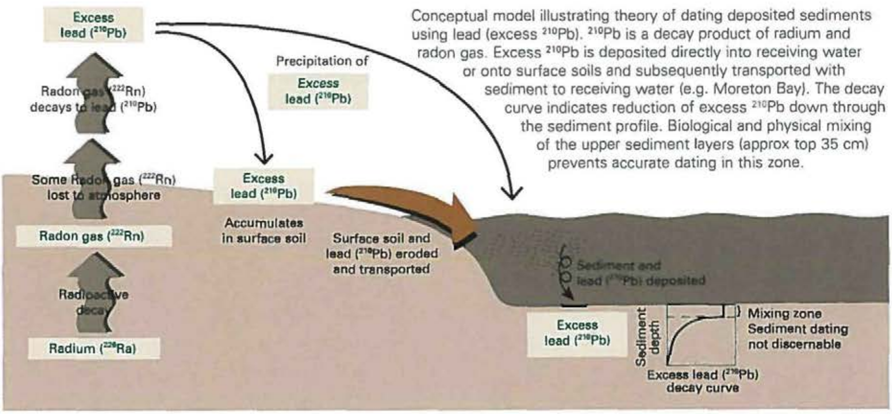


Average salinity, turbidity and daily rainfall during the low turbidity period and its immediate surrounds. (Rainfall measurements are from the Brisbane airport).



Near-surface water temperature measured during the low turbidity period and its immediate surrounds. The periodic fluctuations are caused by daily variation in temperature.

Sediment deposition in central Moreton Bay

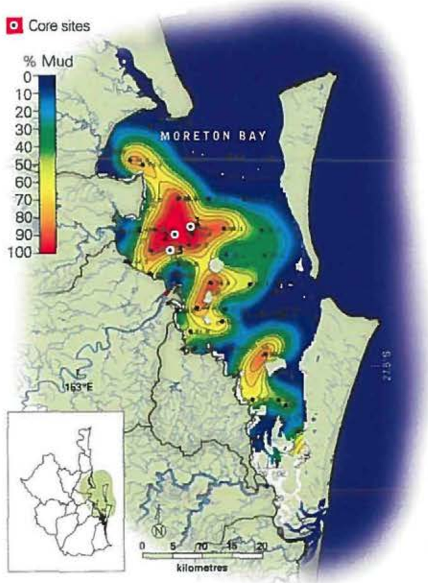


Conceptual model illustrating theory of dating deposited sediments using lead (excess ^{210}Pb). ^{210}Pb is a decay product of radium and radon gas. Excess ^{210}Pb is deposited directly into receiving water or onto surface soils and subsequently transported with sediment to receiving water (e.g. Moreton Bay). The decay curve indicates reduction of excess ^{210}Pb down through the sediment profile. Biological and physical mixing of the upper sediment layers (approx top 35 cm) prevents accurate dating in this zone.

Moreton Bay is the sink where sediments and contaminants are deposited. The deposition of mud from the Brisbane River is concentrated in central Moreton Bay.

Sediment accumulation rates in the mud deposition zone of Moreton Bay were estimated by examining sediment cores from the western (water depth 4 m), central (depth 9 m), and eastern (depth 13 m) regions. Profiles of fallout radionuclides (lead ^{210}Pb, cesium ^{137}Cs and beryllium ^{7}Be), and lithogenic radionuclides (radium and thorium isotopes) were measured to establish a chronology, and to measure the depth and rate of sediment mixing.

Sediment core inventories of ^{210}Pb show that fine sediment is being transported towards the eastern edge of the mud deposition zone. This trend is consistent with a process of resuspension and transport of sediment from shallow to deeper water. If the ^{210}Pb accumulation rate at the most central site of the mud zone is applied over the entire mud-dominated region, the fine-sediment load delivered to central Moreton Bay, averaged over the last 60 years, is roughly 450,000 tonnes/year of dry sediment.



Sediment core sampling sites in the mud deposition zone in Moreton Bay.

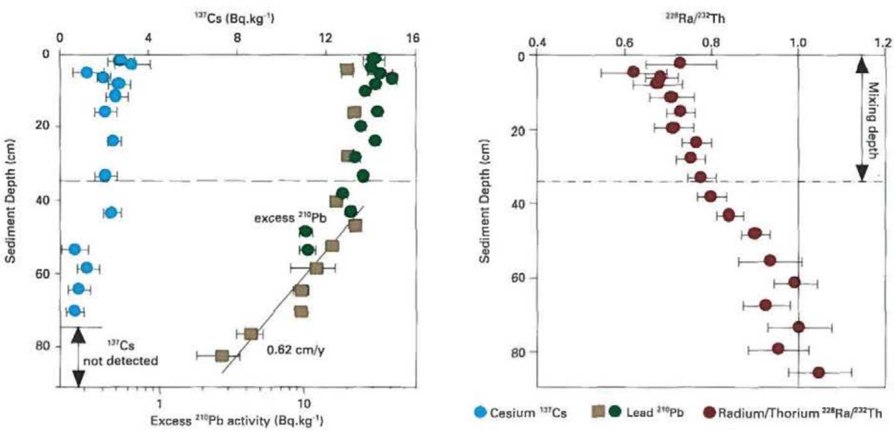
% MUD DATA FROM HEGGIE et al., 1999

Surface sediments in Moreton Bay are rapidly accumulating

The sediment mostly consisted of fine clay minerals with no apparent stratification down the cores. Profiles of radium and thorium isotopes show that post-depositional mixing (which is a homogenising process), is occurring to a depth of at least 35 cm. Beryllium-7 data (not shown) indicates that mixing is most rapid in the upper 4 cm, occurring on a time scale of weeks to months. Between 4 and 35 cm the time scale of mixing is less than 15 years. Although there is no direct evidence, slower mixing (on a time scale of 20 years or more) in sediment below 35 cm cannot be ruled out.

The presence of the mixed layer considerably reduces the temporal resolution of lead-210 dating, and the time frame over which it can be applied. A 2-layer mixing model was applied to the lead-210 profiles, where mixing below 35 cm was assumed to be negligible. This model yielded a mean bulk accumulation rate of 0.62 cm yr^{-1} (equivalent to 0.25 g cm^{-2} yr^{-1} of dry sediment) for the central part of the mud deposition zone. The bulk accumulation rate at the most easterly site is 1.2 cm yr^{-1} (0.48 g cm^{-2} yr^{-1} of dry sediment). These mean rates pertain to the last 60 years, and are considered upper limits due to the possibility of slow mixing below 35 cm.

The analysis indicated very little change in the geochemical composition of the sediment to a depth of 1.8 m. Exceptions were sulfur (S) and arsenic (As), both of which showed an overall increase with depth, which is probably due to in-situ chemical changes (formation of minerals). Lead decreased by 50%, and zinc by 20% with depth. Measurements of lead isotopes indicated that the higher lead concentrations near the surface are in part due to human activity. The overall enrichment in lead originating from human activity (e.g. industry, vehicle emissions) is 10-30% in Moreton Bay sediments. This enrichment is about 15% higher than it is in sediment originating from the Logan catchment, probably due to the greater amount of industrial and urban development in the Brisbane area. Some of this anthropogenic lead will be transported with sediment particles, and some will be deposited directly from the atmosphere.



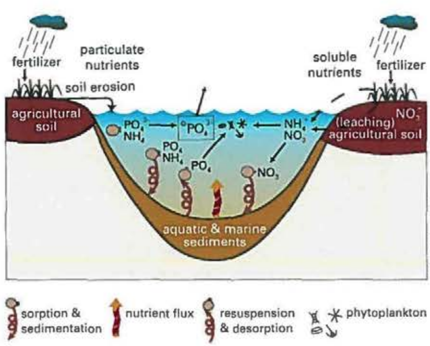
Sediment core profiles of isotopes used to determine sedimentation rates in Moreton Bay. Active mixing of the upper 35 cm of sediments occurs after sediment is deposited. Below this depth, sediment accumulation rates can be measured.

River silt is transported offshore following rain events: *Maroochy River*

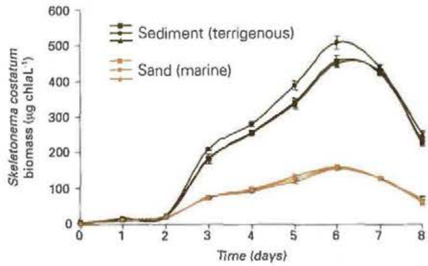
While a regional approach was taken to determine the sources of sediment to Moreton Bay and the river estuaries a more detailed study was carried out in the Maroochy River catchment to further elucidate the role that sediments and their associated nutrients play in stimulating phytoplankton blooms, particularly following flood events. Several months after a large flood (May 1999), sediment was collected from the Maroochy River, its catchment (major agricultural soils) and its flood plume area. The brown, sediment laden plume extended several kilometres offshore, past Mudjimba Island (4 km from the river mouth) and was easily visible. A thin film of clay and silt deposited in grooves and sheltered areas on rocky near-shore reef at Surprise Reef and Mudjimba Island, was easily distinguished from the underlying marine sediment.

Suspended sediments in the Maroochy River had elevated iron (Fe) oxide, extractable phosphorus (P) and total P concentrations comparable to fertilised soil. The deposited sediment sampled offshore of the river mouth appeared to be terrigenous in origin due to its similar composition (total P, Fe oxide P, total N, total carbon, total aluminium, total silicon) to estuarine suspended sediments and terrestrial soils.

– SOURCE: CHASTON 2001



Conceptual model depicting sediment and nutrient runoff to and processes within the Maroochy River. Nutrient-rich particles of terrigenous origin are being transported and deposited offshore during flood events.



Phytoplankton (*Skeletonema costatum*) response to addition of marine sands and fine sediments deposited offshore during a flood event. The fine terrigenous sediment was high in bio-available phosphorus and stimulated phytoplankton biomass.

Sampling sites in the *Maroochy River and its* flood plume area.

Flood plume extending from *the Maroochy River in May* 1999 past Mudjimba Island.

Nutrient content of different sediment types in the Maroochy River Catchment

Sediment *type*	**Total P *(mg kg⁻¹)***	**Bioavailable P *(Fe oxide P)* (mg kg⁻¹)**	**Total N *(mg kg⁻¹)***
Soil	410 (140)	7.4 (2.4)	1980 (881)
Fertilised Soil	888 (346)	68.5 (21.7)	NA
Suspended sediment	990 (637)	90.2 (46.0)	NA
River Sediment	420 (119)	4.2 (1.2)	1363 (376)
Marine sediment	103 (37)	5.3 (1.05)	110 (18)
Deposited sediment	1290 (159)	49.7 (8.8)	3630 (479)

Value in brackets denotes standard error of mean. NA = not available

CONTRIBUTORS (in alphabetical order)

Peter Bell, Kath Chaston, Steve Coombs, Melanie Cox, Grant Douglas, Gary Hancock, Sampson Hollywood, Andrew Hughes, Charles Lemckert, Tony McAlister, Andrew Moss, Luis Neumann, Jon Olley, David Page, Ian Prosser, Anthony Scott, Janelle Stevenson and Peter Wallbrink.

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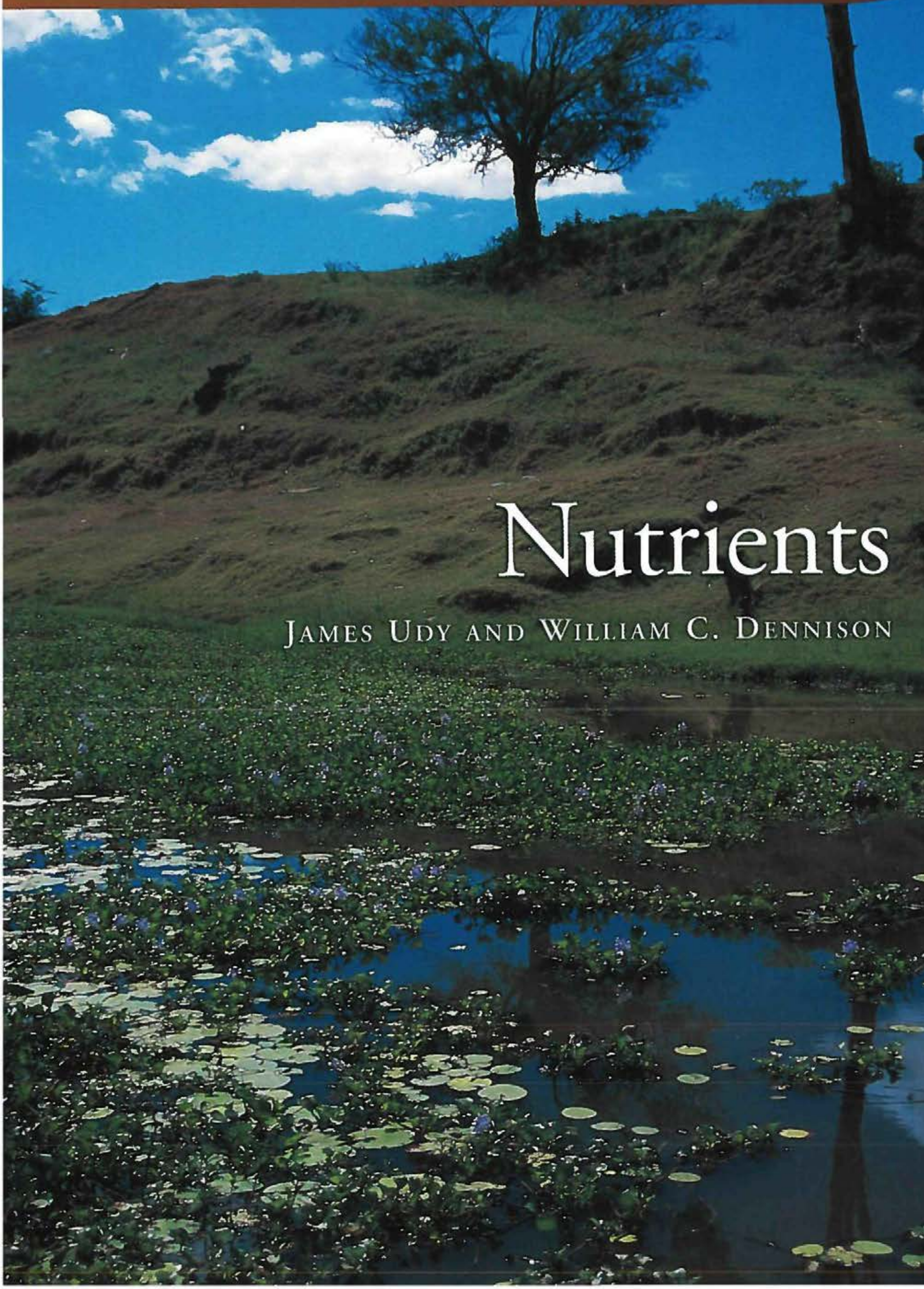
Chapter 5

Nutrients

JAMES UDY AND WILLIAM C. DENNISON

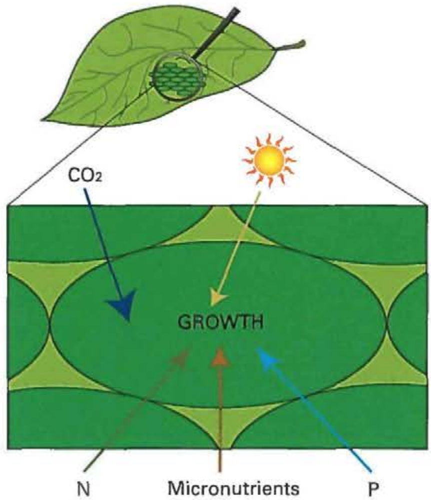


Nutrients limit plant growth when excess light is available

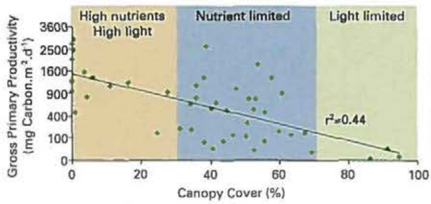
Light is the energy needed for plant growth, while nutrients are the building materials. Plants need many different nutrients to form their cells. Other than carbon, more nitrogen (N) and phosphorus (P) are required than any other nutrient. Consequently, these nutrients commonly limit plant growth when light availability is sufficient. Light and nutrient availability are the environmental variables that usually control aquatic plant growth. Changes in light or nutrient availability due to either natural or human disturbances will affect aquatic plants. Since aquatic plants like seagrasses provide habitat for invertebrates, fish and other aquatic organisms, light and nutrients have significant ecosystem impacts.

Nutrients stimulate rather than reduce plant growth, hence they generally do not cause the same type of environmental impacts as toxic chemicals. Nutrients may become an environmental problem, however, when the rate at which they are delivered to an ecosystem exceeds the rate at which they enter the food chain. This results in excessive plant growth and accumulation of aquatic plants and is often referred to as eutrophication.

Aquatic plant growth in small streams is usually limited by light availability. However, when light availability is increased, through canopy clearing or stream widening, nutrient availability becomes important in controlling algal growth. Nutrient availability is especially important in dams, estuaries and the lower reaches of rivers where riparian vegetation cannot shade the whole width of the watercourse (>10 m).



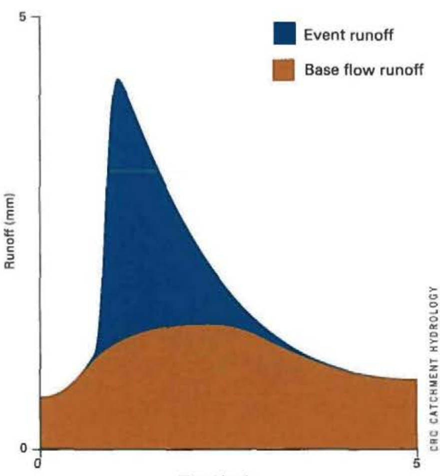
Energy from sunlight is converted into chemical energy through the process of photosynthesis. Carbon dioxide (CO_2) from the atmosphere is converted into chemical compounds which are used as building blocks for plant growth. In addition to the carbon from carbon dioxide, nitrogen, phosphorus and other micro-nutrients must be obtained from the surrounding environment.



The uptake of carbon dioxide (CO_2) can be used as a measure of photosynthesis that leads to plant growth. The gross primary productivity is the total amount of carbon that is used for plant growth. There is an inverse relationship between gross primary productivity and the canopy cover of small streams of South East Queensland. Increasing canopy cover leads to lower gross primary productivity, which is a result of the reduced light reaching the stream.

Nitrogen (N) and phosphorus (P), while both important for plant growth, perform different functions in a cell. N is an essential element needed to form amino acids, that are the building blocks of proteins. P is an essential constituent in the molecules that transfer chemical energy, as well as in genetic molecules. Due to the different tasks that N and P perform in cells, they are required in specific ratios to make a healthy cell. A shortage in either nutrient will result in a reduction in the rate of plant growth.

The optimal ratio of N:P required to form healthy cells in aquatic plants is approximately 16:1 (Redfield ratio; see Moreton Bay Study page 70), with 16 molecules of N being required for every molecule of P. This ratio was determined by oceanographer A. C. Redfield by taking the worldwide average of phytoplankton in the open ocean and will, therefore, vary slightly for different types of aquatic plants (e.g. seagrass). In general, plants will always require between 10 and 20 times more N than P to grow.



A generalised time course of a runoff event is depicted, with the event flow distinguished from the base flow. Event flow runoff rises rapidly as a result of a rainfall event, but tapers slowly for several days following the rainfall. Base flow is also affected by the rainfall event, but only slightly.

When nutrient availability increases in an ecosystem to the point of causing excessive algal growth, it is important to determine which nutrient (N or P) is in the shortest supply relative to the plants' needs. This is defined as the *"limiting nutrient"*. The availability of the limiting nutrient will control algal growth rates. Hence, if water quality managers are able to reduce the rate of supply of the limiting nutrient to an environment, it is likely that algal growth will also be reduced.

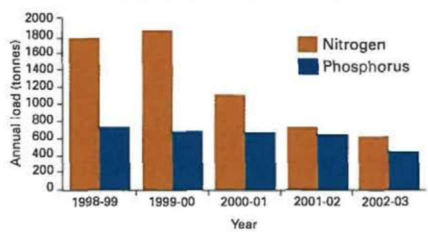
Concentration of nutrients, by themselves, are not likely to be good indicators of ecosystem health as they often do not relate to the rate of nutrient delivery which is an important aspect of ecosystem health. For instance, concentrations of nutrients in freshwater streams of South East Queensland, alone, do not suggest either N or P limitation, and are often low in both natural and degraded waterways.

Nutrient delivery to waterways of South East Queensland is continuous and increases during episodic rain events (i.e. storms). A steady supply of nutrients is delivered through the movement of groundwater into streams, overland flows, catchment runoff, and point source discharges from sewage treatment plants and other forms of industrial wastes. The movement of groundwater into streams is a natural process of water movement that maintains the flow of rivers and streams during dry periods, often referred to as a stream's 'base flow'. Factors that will affect the nutrients delivered to a stream during periods of 'base flow' are the nutrient concentrations in the groundwater, influenced by land use practices in the catchment, and the amount of nutrients in point source discharges. In addition to the 'base flow' delivery of nutrient to the waterways, there are large amounts of nutrients delivered to streams and transported downstream to the estuaries during high rainfall events.

Various *nutrient sources*

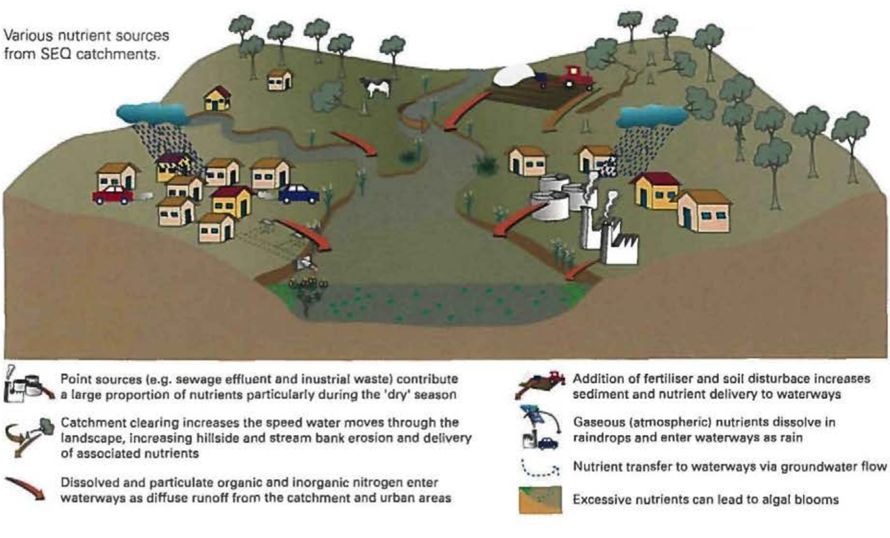
Catchment activities affect the delivery of nutrients to streams and rivers. Catchment disturbance usually results in an increase in the rate at which nutrients are supplied to aquatic ecosystems by altering nutrient sources and delivery processes. Catchment clearing is often the first impact that influences the nutrient cycle by exposing soil and increasing the speed at which water can move through a landscape. This practice results in water reaching the streams and waterways faster than it would in an undeveloped catchment, causing an increase in both hillslope erosion and gully erosion. Many land use practices involve the addition of nutrients to the land, further increasing the quantity of nutrients available for transport to aquatic ecosystems.

Industrial and urban developments increase the quantity of nutrients in the environment through the emission of both gaseous and liquid waste products that eventually enter waterways. Industrial emissions and the exhaust from cars increase atmospheric nutrients, particularly in developed catchments. These airborne nutrients can then enter aquatic ecosystems through either 'dry fall' or in raindrops with most atmospheric nutrients being dissolved in raindrops as they fall through the atmosphere. Large quantities of nutrients are also discharged from sewage treatment plants and industries into waterways of South East Queensland. However, recent commitments by local councils and industries to improve wastewater treatment are dramatically reducing these inputs.



Annual nitrogen and phosphorus loads from six major sewage treatment plants in SEQ (Luggage Point, Loganholme, Cleveland, Redcliffe, and all Gold Coast City Council STP's), showing reduction in N and P loads to Moreton Bay.

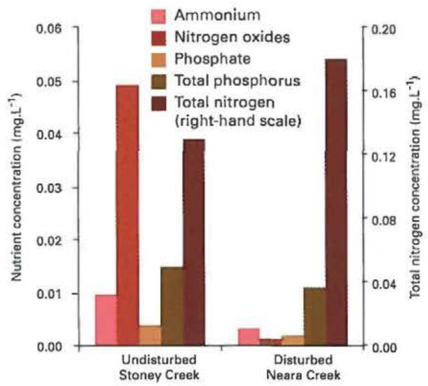
Various nutrient sources from SEQ catchments.



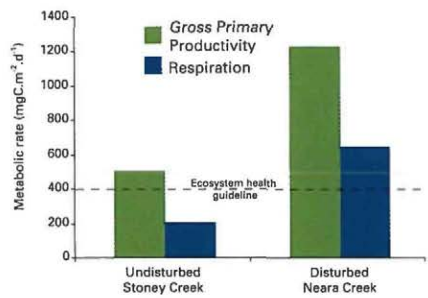
Nutrient supply rates are more important than concentrations

The rate of nutrient supply to a waterway will determine the impacts on the ecosystem more than the concentration of nutrients in the water column. This is demonstrated by comparing two sites that were surveyed as part of the development of a freshwater *Ecosystem Health Monitoring* Program. Stoney Creek, in the Stanley River catchment, is a relatively undisturbed site with minimal human impact in its catchment. The concentration of nutrients at this site meet the water quality guidelines for a healthy stream. In addition, the measurements of biological processes, gross primary production and respiration are indicative of a healthy stream. In contrast, Neara Creek in the adjacent Upper Brisbane River catchment, is heavily impacted by land clearing and grazing. Although Neara Creek has many signs of being degraded, the concentration of nutrients meets water quality guidelines for a healthy stream – in fact, nutrient concentrations were even lower than the relatively undisturbed Stoney Creek site. The rates of biological processes, gross primary production and respiration in Neara Creek, however, exceeded the guideline values for a healthy stream and were almost double that of Stoney Creek.

Nutrient concentrations reflect the 'left over' nutrients. In Neara and Stoney Creek, all nutrients are rapidly used by plants. Hence, assessment of their biological processes results in an improved understanding of their ecological condition.



Nutrient concentration at Stoney Creek (undisturbed) and Neara Creek (disturbed).



Gross Primary Productivity and Respiration at Stoney Creek (undisturbed) and Neara Creek (disturbed).

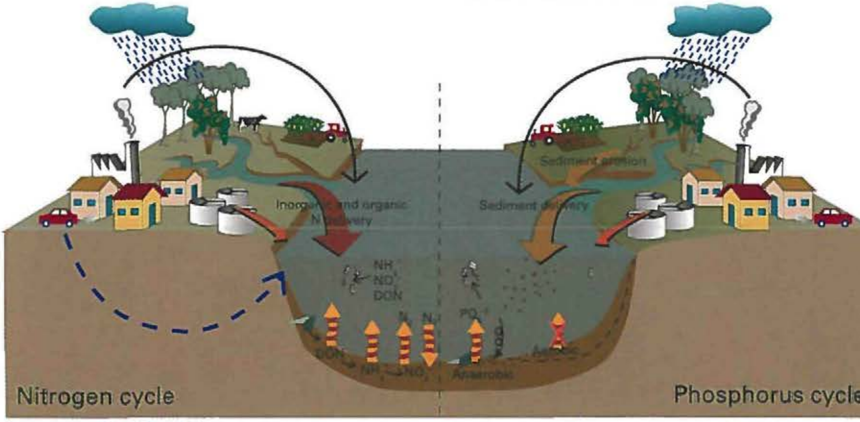
Stoney Creek in the Stanley River catchment is a near pristine waterway with minimal catchment disturbance.

Neara Creek in the upper Brisbane River catchment is heavily impacted.

Biological processes dominate nitrogen cycle; *Erosion and deposition* dominate phosphorus cycle

Nitrogen (N) can occur in many different forms, some of which can be easily incorporated into plant growth (bio-available) and others that are relatively inert such as nitrogen gas (N_2). Because N can form so many different molecules, it has a relatively complex cycle. Various biological processes convert N between its different forms. Two particularly important transformations of N which convert N between bio-available and inert forms are N fixation (N gas into organic N) and denitrification (nitrate into N gas). N can be delivered to aquatic systems dissolved in the water column and attached to sediment particles.

In contrast to the N cycle, the phosphorus (P) cycle is relatively simple and is dominated by the transformations between dissolved P and P attached to sediment particles. There are no major biological transformations of P. The majority of P present in aquatic systems occurs attached to sediment particles and is usually released to the water column from the sediment. The close binding of P with sediment particles means that any increase in the rate of sediment transport due to increases in catchment erosion will lead to an increase in the P loading to aquatic systems. The flux of P from sediments is strongly affected by oxygen availability with higher P fluxes occuring when oxygen concentrations are low.



Nutrients (nitrogen and phosphorus) are transferred to waterways via a number of mechanisms including, diffuse loads, point source loads, atmospheric deposition, and groundwater flow

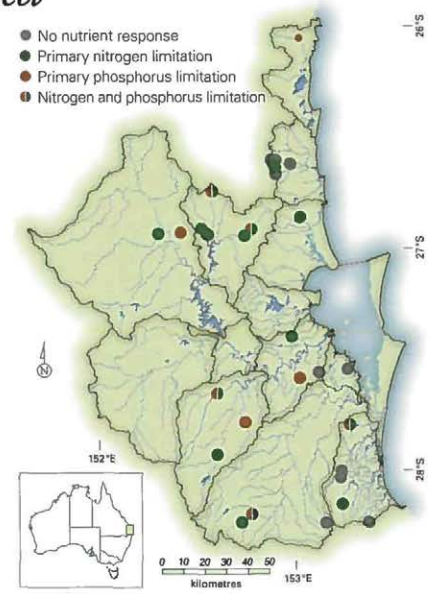
- Diffuse sources of nitrogen enter waterways as dissolved inorganic and dissolved or particulate organic form
- Decomposition of organic matter releases Dissolved Organic Nitrogen (DON)
- Ammonification converts DON into ammonium (NH_4^+) which may be released into the water column if not converted further
- Nitrification converts NH_4^+ into nitrate (NO_3^-) which is generally denitrified to nitrogen gas (N_2) and released
- Dissolved nitrogen is available for uptake

- Diffuse sources of phosphorus predominantly enters waterways attached to sediment particles
- Phosphorus is deposited with sediments
- Phosphorus release is prevented when sediments are aerobic
- P release occurs when sediments are anaerobic
- Dissolved P is available for uptake

Nutrient cycles. Major inputs and key processes for nitrogen and phosphorus.

Nutrient limitation assessed in 32 freshwater streams

Nutrient limitation was assessed throughout freshwater streams of South East Queensland, using bioassays, to determine the relative roles of nitrogen (N) and phosphorus (P). Bioassays involve incubating natural populations of algae with various nutrients. The technique developed for South East Queensland freshwater streams utilised small pots covered with a fine mesh, which served as a substrate for algal establishment and growth. Nutrients were added to each pot with the following treatments: 1) no nutrients added to act as a control, 2) N only added, 3) P only added, and 4) N and P added together. Two replicate trays, each with all four treatments, were placed into 32 freshwater streams throughout South East Queensland in natural flow conditions. The pots were collected after 28 days and the amount of algal growth that had accumulated on the mesh of the pots was measured.



Sites used for nutrient bioassays.

The amount of algal growth in the nutrient addition treatments was compared to the algal growth in the control (no nutrient addition) treatments. If there was a significant increase in algal growth with an added nutrient, either N or P, then that nutrient was considered a 'primary limiting nutrient'. If there was a significant increase in algal growth with one of the added nutrients, but an even larger increase with both nutrients added, then the nutrient with the largest response was considered the 'primary limiting nutrient' and the nutrient with the additive effect was the 'secondary limiting nutrient'.

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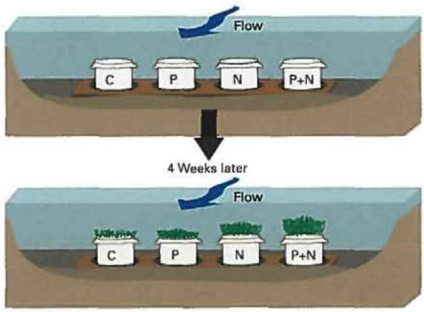
Nutrient bioassay pots *in situ*.



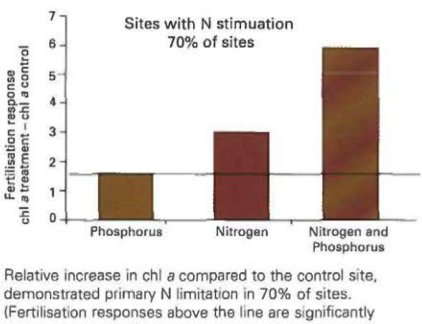
Bioassays in freshwater streams were carried out by filling small pots with different nutrients. Algal growth on mesh covering the pots was then monitored after 28 days of *in situ* incubation.

70% of freshwater streams demonstrated *primary N limitation*

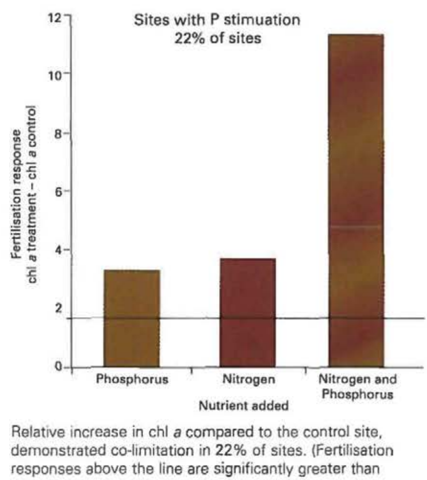
Seventy percent of the small freshwater streams sampled in South East Queensland had significantly more algal growth (measured by chlorophyll *a)* in response to the nitrogen (N) only treatment than the control treatment, indicating primary N limitation of algal growth. The N only treatments at these sites had chlorophyll *a* concentrations that ranged between 1.6 and 13 times the concentration of the control treatment from the same site. This suggests that an increase in the rate at which N is delivered to these streams will cause an increase in algal growth. It also suggests that altering land management practices and the disposal processes for liquid waste (industrial and sewage effluent) to reduce the input of N to freshwater streams will improve the stream health of many South East Queensland waterways by reducing algal growth rates.

While N was the primary limiting nutrient for algal growth in many streams of South East Queensland, the addition of P only also led to significant increases in algal chlorophyll *a* relative to control treatments at 22% of sites. At some of these sites, algal growth was stimulated by both the addition of N only and P only (co-limitation). At other sites, addition of P only (and not N) stimulated algal growth, demonstrating that P is occasionally the primary limiting nutrient.

The largest algal biomass occurred in the N + P treatment. This demonstrates that P is often a secondary limiting nutrient in freshwater streams, even though N is the major limiting nutrient.



Relative increase in chl *a* compared to the control site, demonstrated primary N limitation in 70% of sites. (Fertilisation responses above the line are significantly greater than control.)



Relative increase in chl *a* compared to the control site, demonstrated co-limitation in 22% of sites. (Fertilisation responses above the line are significantly greater than control.)

Algal responses to nutrient addition.

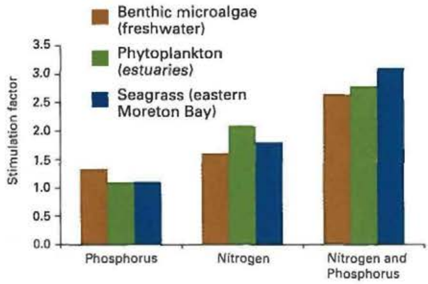
Response	Interpretation
All treatments respond equally	No nutrient limitation
N response is greater than P but may equal N+P response	Primary N limitation
N and P response are equal but lower than N+P response	Co-limitation
P response is greater than N but may equal N+P response	Primary P limitation

Freshwater, estuarine and marine waterways *respond primarily to nitrogen addition*

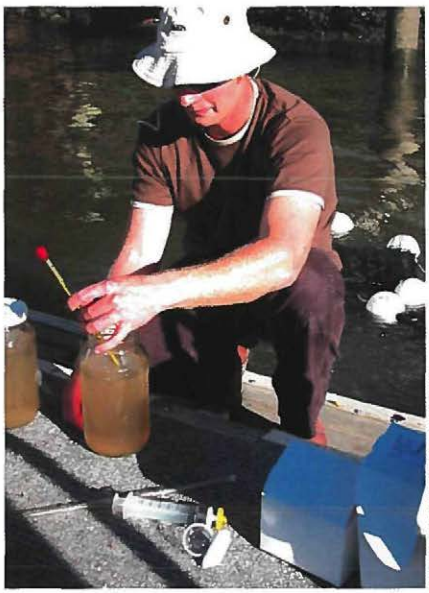
In addition to nitrogen (N) being an important nutrient in freshwater streams, it has also been demonstrated that N is the most important nutrient regulating aquatic plant growth in most other South East Queensland (SEQ) waterways. Bioassay studies conducted in the tidal estuarine sections of the major rivers (Logan, Brisbane and Caboolture) have demonstrated that, when light is not limiting growth, the availability of N is likely to control phytoplankton growth rate and biomass. Studies on the seagrass meadows of Moreton Bay have demonstrated that N availability is the major factor that controls seagrass growth in eastern Moreton Bay, where seagrasses are not limited by light availability.

This common trend for N to be the primary limiting nutrient throughout most SEQ waterways suggests that the reduction of N inputs to all SEQ waterways should be a high priority for managers.

While N is the primary limiting nutrient in most SEQ waterways, phosphorus (P) availability alone has stimulated algal growth in some SEQ streams. In particular, excess P availability is likely to increase the occurrence of cyanobacterial (or blue green algae) blooms, as they are able to fix N from the atmosphere and, therefore, N is rarely limiting to their growth. Furthermore, the combined addition of both N and P consistently causes the greatest growth response of aquatic plants in SEQ waterways. Therefore, while N is a key management focus, P and other potentially limiting nutrients (e.g. iron limitation of cyanobacterial growth) cannot be ignored.



Benthic algae in freshwater streams, phytoplankton in river estuaries and seagrasses in Moreton Bay all demonstrate primary nitrogen limitation (as nitrogen causes a greater response than phosphorus alone), and secondary phosphorus limitation (as the combination of nutrients causes the greatest nutrient response).



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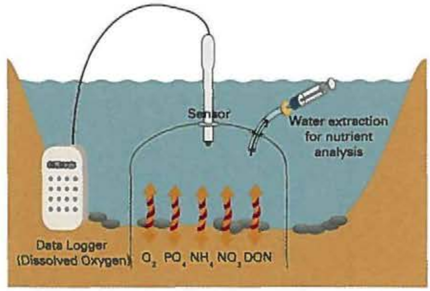
Nutrient bioassay experiments in the Brisbane River.

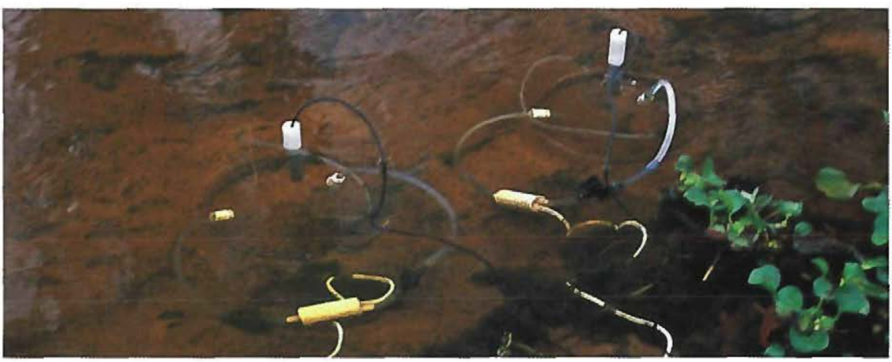
Measuring nutrient flux from the sediment to the water column

The sediments at the bottom of streams, rivers and Moreton Bay contain a large quantity of nutrients in both organic and inorganic forms. Typically, the nutrient concentrations within sediments are 10 or 100 times higher than in the overlying water. This strong gradient between sediment and water column concentrations results in a diffusion of nutrients from higher concentration to lower concentration, often termed sediment nutrient flux. This nutrient flux can also occur in the opposite direction, depending on relative concentrations. The total amounts and direction of nutrient fluxes are related to plant growth and ecosystem processes, and influence the calculation of nutrient budgets.



Nutrient flux from the sediment to the water column is measured within a dome that seals off an area of sediment and overlying water column from the surrounding water. Changes in the nutrient and oxygen concentration of the water inside the chamber over time can then be used to measure both the nutrient flux and oxygen demand/production of the sediment. The concentrations of oxygen (O_2), phosphate (PO_4^{3-}), ammonium (NH_4^+), nitrate (NO_3^-) and dissolved organic nitrogen (DON) are measured.

Sediment nutrient fluxes can be measured using various systems. A very straightforward method, however, involves isolating a portion of the sediment with overlying water and measuring changes in nutrient concentration over time. This method has been used for the waterways of South East Queensland. A small area of the sediment and known quantity of overlying water are sealed from the surrounding environment, but maintained at ambient environmental conditions. Water samples are then taken from the overlying water at different times and the changes in nutrient concentrations over time are used to calculate the nutrient flux of the sediment. This rate can then be extrapolated to calculate the total nutrient load transferred between the sediment and water column for any given area of similar sediment type. Using this approach, nutrient fluxes have been measured in small freshwater streams, the tidal reaches of the Bremer River and in Moreton Bay.



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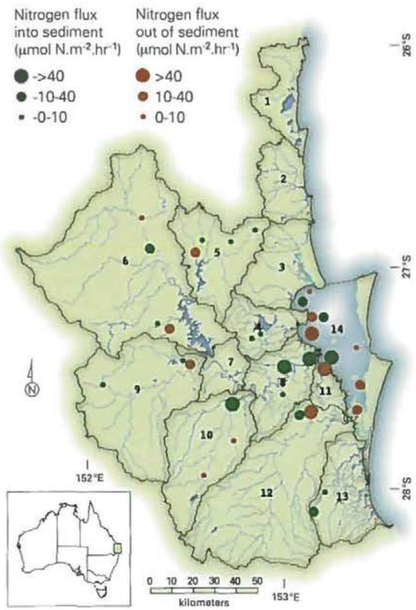
Nutrient flux chambers were deployed in South East Queensland waterways.

Low rates of nutrient flux in streams, estuaries and Bay

The rates of nitrogen (N) flux measured in sediments of South East Queensland were highly variable. N fluxes into sediments (depicted as negative values), as well as N fluxes out of sediments (depicted as positive values), occured. Fluxes in freshwater streams, estuaries and Moreton Bay were not consistently negative or positive, with the majority of the flux measurements being low (<40 μmol N $m^{-2}h^{-1}$). The estuaries and western Moreton Bay had the largest fluxes, either negative or positive, compared with the freshwater sites or the eastern Moreton Bay sites.

At a catchment scale, the overall net nutrient flux between sediments and the overlying waters is relatively small. Sites with positive nutrient fluxes, cancelled out sites with a negative flux, with appreciable differences between sites, even when sites were relatively close to one another. These differences could affect the nutrient budgets of specific waterways of South East Queensland. However, the overall effect of the positive, negative and near zero fluxes is that little assimilation of anthropogenic nutrients occurs in the region as a whole.

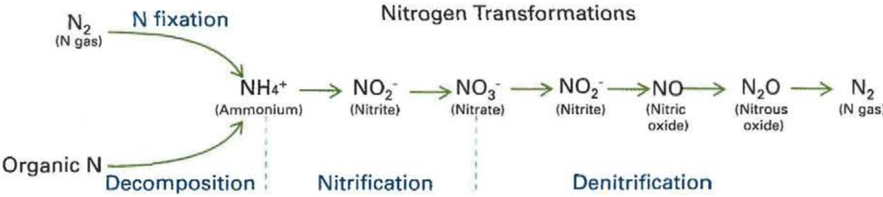
The median rate of nitrogen flux into the sediments of small streams from the water column was an uptake of only 1 μmol N $m^{-2}h^{-1}$. This indicates that sediments in South East Queensland streams are not a major source or sink of nutrients. This is because similar quantities of N are being removed from the water column of small streams by sediment denitrification and plant uptake as are being released by the decomposition of organic matter. Hence, nutrients that find their way into South East Queensland waterways are more than likely to end up in the river estuaries, Moreton Bay and the coastal ocean.



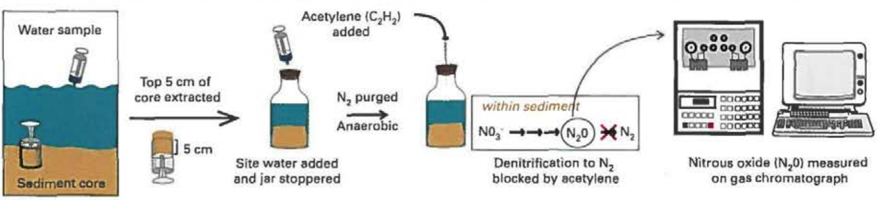
1	Noosa Catchment	8	Lower Brisbane Catchment
2	Maroochy and Mooloolah Catchments	9	Lockyer Catchment
3	Pumicestone Region Catchments	10	Bremer Catchment
4	Pine Catchments	11	Redlands Catchments
5	Stanley Catchments	12	Logan-Albert Catchments
6	Upper Brisbane Catchment	13	Gold Coast Catchments
7	Mid-Brisbane Catchment	14	Moreton Bay

N flux in streams, estuaries and Moreton Bay. Overall net N fluxes are relatively low.

Denitrification measured in freshwater streams



N transformations occurring during the process of denitrification.



Denitrification methodology using acetylene blockage technique.

Denitrification is a biological process that converts bio-available nitrogen (N) into N_2 gas. Its conversion is considered a loss of N from the environment as most organisms are unable to utilise N_2 gas as a nutrient. The specialised bacteria that perform this conversion of N from a biologically active form of N to a biologically inert form usually live in soil or sediment. Denitrification rates are primarily influenced by the availability of nitrate (NO_3^-) (which is converted to N_2 gas through denitrification) and organic matter (which is decomposed during the denitrification process). Most of the denitrification that occurs in South East Queensland waterways probably occurs as two linked chemical reactions: nitrification coupled with denitrification. Nitrification converts ammonium (NH_4^+) into nitrate (NO_3^-) which can then be denitrified to nitrogen gas (N_2). However, nitrification requires oxygen and denitrification occurs in the absence of oxygen. Hence the highest rates of denitrification in a natural system usually occur when there are many small micro-zones of aerobic (with oxygen) and anaerobic (without oxygen) sediments adjacent to each other.

The rates of denitrification in the sediments of waterways throughout South East Queensland have been measured using two different techniques, acetylene blockage and nitrogen:argon ratios. The acetylene blockage technique has been used in several studies to estimate rates of denitrification in the freshwater streams and throughout Moreton Bay, while changes in the nitrogen:argon ratio in water overlying the sediment has been used in another study that focused on denitrification in western Moreton Bay (see page 105).

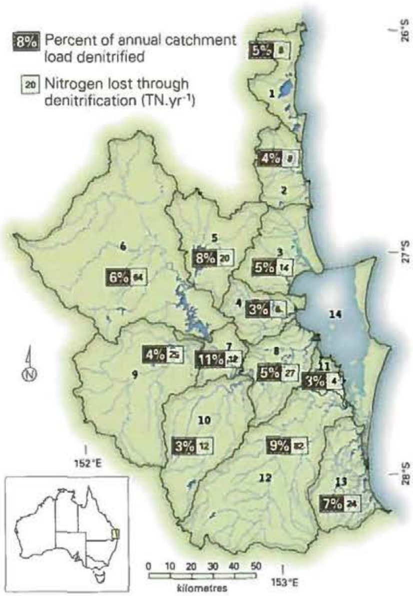
The acetylene blockage technique uses acetylene to block the last step of denitrification resulting in the accumulation of nitrous oxide (N_2O). Sediment cores are placed in a gas tight container with surface water and acetylene gas and the rate at which nitrous oxide accumulates in the gas space above the sediment water slurry is used to estimate the rate of denitrification in the natural environment.

Denitrification rates are *spatially variable*

Denitrification rates vary 10 fold between different sites in South East Queensland waterways. This variation in rate is due to local environmental factors. There is no consistent difference between the different types of waterways, with a similar range of rates being measured in the three major waterway types: small freshwater streams, brackish estuaries and Moreton Bay.

In general, denitrification rates increase as the availabilities of nitrate and organic carbon increase. Consequently, the highest denitrification rates in South East Queensland waterways were recorded close to sewage effluent discharges. At the extreme end, however, aquatic environments with very large loadings of organic carbon and nitrogen frequently had the lowest rates of denitrification. This is most probably due to oxygen depletion in the sediment porewater as a result of consumption by organic decomposition. As a consequence of low oxygen, nitrate formation in the sediment is slowed and denitrification reduced (see previous page).

Most of the small streams in South East Queensland had rates of denitrification less than 40 μmol N m²d⁻¹. Rates higher than 40 μmol N m²d⁻¹ occurring in urban streams or downstream from sewage effluent discharges appeared to indicate a local input of nitrogen and organic carbon. However, rates less than 40 μmol N m²d⁻¹ were measured in streams with low inputs as well as those with high inputs, suggesting that denitrification rates can be inhibited by substrate availability in some SEQ streams.



1	Noosa Catchment	8	Lower Brisbane Catchment
2	Maroochy and Mooloolah Catchments	9	Lockyer Catchment
3	Pumicestone Region Catchments	10	Bremer Catchment
4	Pine Catchments	11	Redlands Catchments
5	Stanley Catchments	12	Logan–Albert Catchments
6	Upper Brisbane Catchment	13	Gold Coast Catchments
7	Mid-Brisbane Catchment	14	Moreton Bay

Map of South East Queensland showing the estimated percentage of the total N loads removed by denitrification in small freshwater streams.

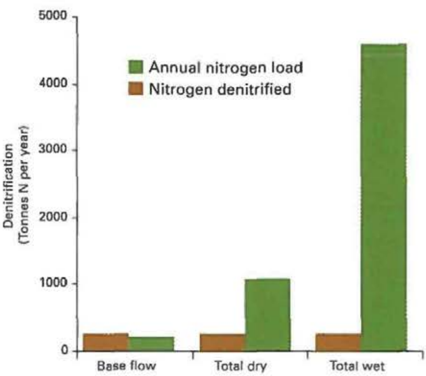
Ability of denitrification to reduce N load to SEQ streams is low

During dry periods, denitrification is the key process of nitrogen removal from streams and can account for all of the estimated nitrogen (N) load under base flow conditions. This also explains the relatively low ambient nutrient concentrations observed in many South East Queensland streams during low flow periods.

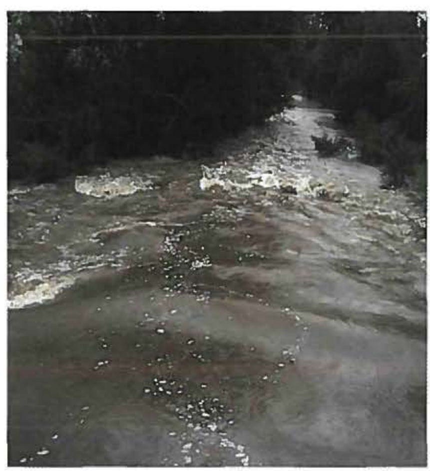
During storm events, however, the proportion of the N load removed by denitrification is minor. Small streams dominate the length of waterways in South East Queensland and provide the greatest potential area for sediment denitrification to occur. However, event runoff is rapidly flushed out of these streams and into larger water bodies, such as dams, estuaries and the Bay. Consequently, there is little opportunity for small streams to remove N from loads received during storm events.

In an average rainfall year, approximately 90% of the entire N load delivered from the catchments to SEQ waterways arrives during storm events. As denitrification within the streams is not able to remove much of this event N load, the majority o the annual N load to streams is delivered to down stream receiving water bodies. The sediments of larger water bodies may remove some of this exce: nitrogen through denitrification, but it is unlikely that the denitrification rate in these relatively sma regions of nutrient deposition are sufficient to remove the large amount of nutrients delivered during rain events. We estimate that denitrificatio in South East Queensland streams can remove between 3% and 11% of the predicted annual N load from catchments.

As denitrification appears unable to reduce the larg amounts of N delivered in storm water run off, it is important that waterway management practices (e.g. provision of riparian buffers) target episodic storm events rather than the dry conditions that predominate for most of the year. This will maximis the effectiveness of these management actions at reducing nutrient loads to waterways.



Calculated N denitrified (per year) in all SEQ streams (up to and including 5th order), as compared to the N load received by these waterways during base flow only in an average year, as well as base flow and storm water run off in a dry and wet year. Streams have a limited capacity to denitrify so, as loads increase, the proportion of the load denitrified is reduced. The percentage of the total N load denitrified each year, therefore, is likely to vary depending on the catchment N load.

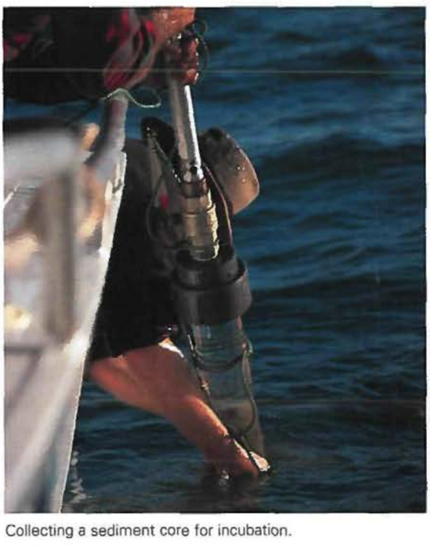


During storm events, the proportion of nitrogen load removed by denitrification is minor.

Denitrification efficiency in Moreton Bay influenced by oxygen availability

At a number of Moreton Bay sites (mud pit off Redcliffe, Bramble Bay, Waterloo Bay) denitrification was measured using the nitrogen: argon method. Denitrification rates (N_2 flux) decreased by up to 60% towards the later part of the incubations, in association with an increase in ammonium flux from the sediment. This occurred in the dark incubations, as dissolved oxygen concentrations reduced to approximately 90 µM. Since nitrification requires oxygen and denitrification occurs in the absence of oxygen, the highest rates of denitrification occur when aerobic (with oxygen) and anaerobic (without oxygen) sediment are adjacent to each other. However, only a small area of sediment and overlying water were isolated in the cores, allowing respiration in the sediment to consume available oxygen. Without oxygen, nitrification is prevented and a build-up of ammonium occurs. This is observed as a reduction of N_2 flux from the sediment as denitrification slows.

Sediment collected from the central muddy area off Redcliffe, where the highest rates of denitrification occurred, was the most sensitive to reductions in oxygen availability. Sediment in Bramble Bay, which had a lower initial rate of denitrification, was also sensitive to oxygen depletion but showed only a 25% decrease in the denitrification rate after 7 hours of incubation. Waterloo Bay had a similar initial rate of denitrification as Bramble Bay but maintained a constant rate over the entire 12 hour incubation.



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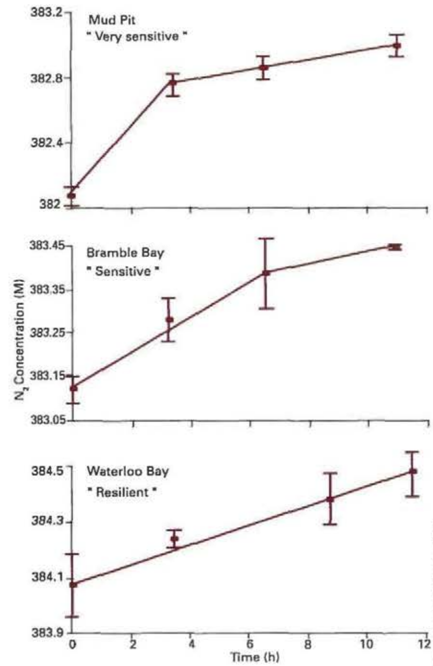
Collecting a sediment core for incubation.



EYRE AND FERGUSON 2001

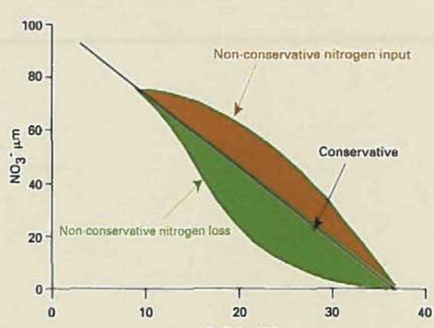
Gaseous nitrogen (N_2) flux (indicative of denitrification) from sediments in western Moreton Bay is more sensitive to reduced oxygen in sediments taken from the 'mud pit', followed by Bramble Bay and, then, Waterloo Bay.

Estuarine denitrification is insignificant

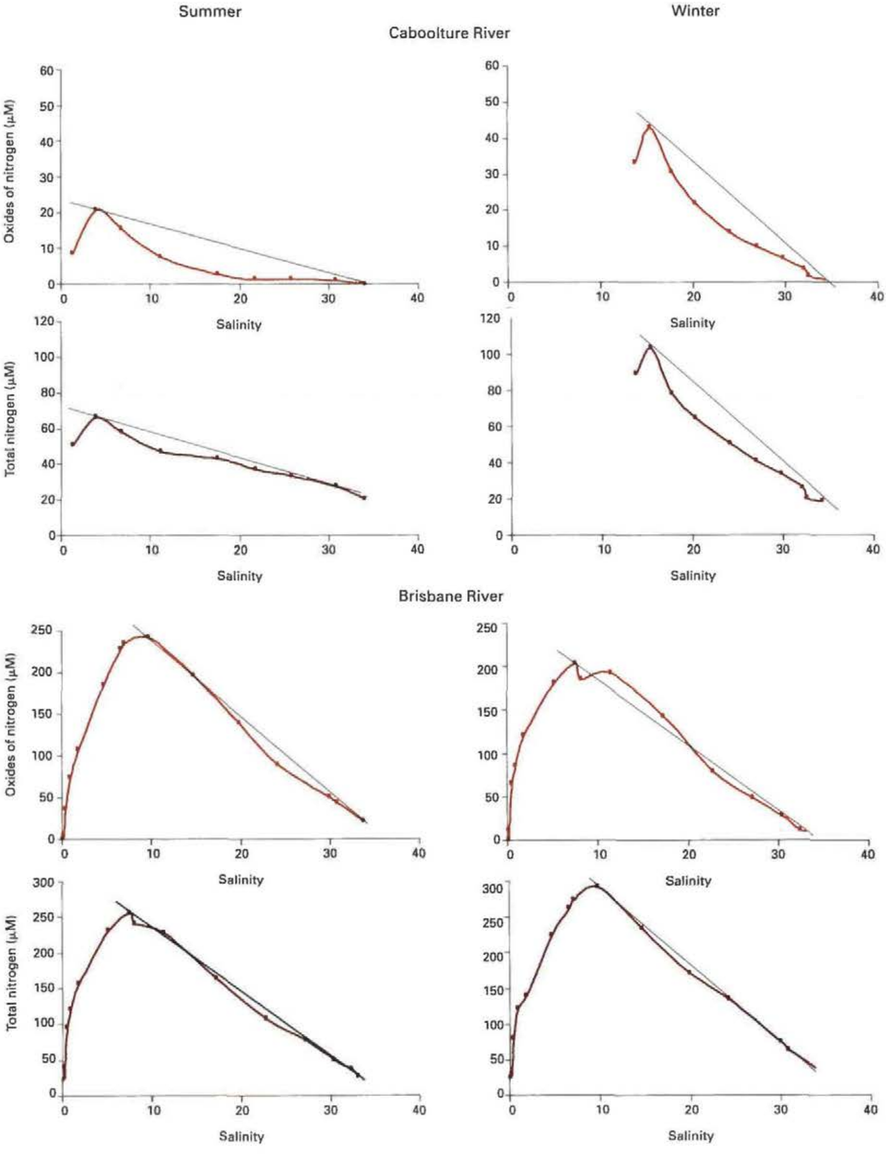
Nitrate (NO_3^-) is the soluble and bio-available form of nitrogen (N) used in the denitrification process. Nitrate concentration is measured throughout the estuaries and plotted against salinity. A conservative relationship between salinity and nitrate concentrations indicates no net loss or gain of nitrate from the system. A convex relationship may indicate denitrification to N_2 gas or uptake and conversion to other nitrogen (N) compounds, such as uptake and incorporation into organic molecules. Measurement of total N in conjunction with nitrate establishes if changes in nitrate concentration are due to loss of N (denitrification to N_2 gas) or conversion to other forms (e.g. uptake by phytoplankton).

Nutrients in Moreton Bay's river estuaries are measured frequently by the Ecosystem Health Monitoring Program. Seasonally averaged (winter and summer) mixing plots of nitrogen oxides and total nitrogen indicate that denitrification is an insignificant process in the removal of N from river estuaries. The relationship of nitrate and total nitrogen concentration against salinity follows an almost straight line relationship in both summer and winter in the Logan, Brisbane and Pine Rivers. In these rivers, tidal flushing and physical mixing are the dominant processes responsible for the lowering of nutrient concentrations toward the river mouths. In the Caboolture River, convex deviation of nitrate from the conservative line indicates that processes other than tidal flushing remove nitrate from the river estuary. Total nitrogen has a similar relationship as nitrate, suggesting that the reduction of nitrate in this system is due to N removal (denitrification to N_2 gas) and not just conversion of N to other forms.

What is a mixing plot?



Within an estuary, catchment inputs of nutrients are delivered by the river and mixed with and flushed by tidal incursions of saline water with a lower nutrient concentration. A decline in nutrient concentration from the source (upper estuarine/freshwater limit) to the estuary mouth, which is more heavily flushed by the saline water, is expected. Mixing plots illustrate this relationship between salinity and nutrients. They are represented by plotting salinity against nutrient concentration. A straight line relationship (conservative) will occur if tidal flushing of the nutrients is the only mechanism involved in nutrient removal from the estuary. Concave or convex deviations from the linearity indicate a dynamic characteristic of nutrient conversion (convex) or nutrient production/ input (concave).



Mixing plots of salinity vs nitrate and total nitrogen for the Caboolture River and Brisbane River in summer and winter.

Tracing sewage nitrogen using stable isotopes ($\delta^{15}N$)

Sewage discharged into coastal and estuarine waters has been implicated in eutrophication occurrences worldwide. Detection of the source and extent of sewage in receiving waters is a critical component of monitoring programs. Of the various techniques that detect the source and extent of sewage discharge in estuarine waters, the use of nitrogen (N) stable isotopes ($\delta^{15}N$) enables detection and delineation of sewage-derived N. In South East Queensland (SEQ) the implementation of this tool has enabled the intensity and distribution of sewage-derived N in river estuaries and Moreton Bay to be mapped.

Plant biological indicators (such as algae and mangrove leaves) act as sentinels, enabling early detection of sewage N in receiving waters and indicates the long term availability of sewage N. The Ecosystem Health Monitoring Program (estuarine/marine) uses stable isotope signatures ($\delta^{15}N$) of macroalgae and other plants in Moreton Bay and river estuaries to trace sewage impacts.

Macroalgae (*Catenella nipae*), collected from a low nutrient environment in eastern Moreton Bay, are deployed at half secchi depth at 250 estuarine and marine sites in South East Queensland. After 4 days, the algae is collected and analysed for its $\delta^{15}N$ signature. Results can be spatially integrated into maps, providing information on the source and extent of sewage-derived N.

Luggage Point sewage treatment plant.

In addition to plant bioindicators, the use of oysters and fish as indicators of sewage N has been tested in the northern SEQ Rivers (Mooloolah, Maroochy and Noosa Rivers). Animal indicators detect whether the $\delta^{15}N$ signature is assimilated through the food web. Oysters are filter feeders, obtaining their nutrition by removing organic material from the water column. In addition, they are sessile, remaining attached to their substrate for the duration of their life. Fish, on the other hand are mostly carnivorous, occurring at a higher trophic level. Fish are more broadly distributed but may migrate between areas experiencing different levels of sewage input.

What is $\delta^{15}N$?

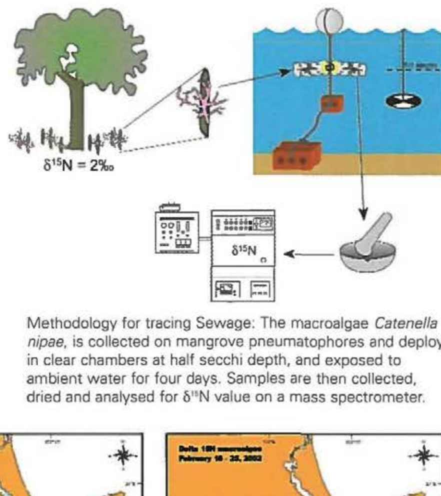
Atmospheric N exists in two stable isotopic forms, ^{14}N and ^{15}N. The most abundant form is ^{14}N (~99.6%), with ^{15}N comprising a much smaller fraction (~0.4%). The relative proportion of ^{14}N to ^{15}N compared to a world-wide standard is referred to as $\delta^{15}N$ and is measured in parts per thousand (‰). Sewage is generally enriched in ^{15}N compared to ^{14}N and, therefore, the N signatures of effluent are elevated (approximately 10‰). This results in an elevated $\delta^{15}N$ signature in receiving waters of sewage treatment plants.

Sewage plumes track decrease in nitrogen loads from STP into Moreton Bay

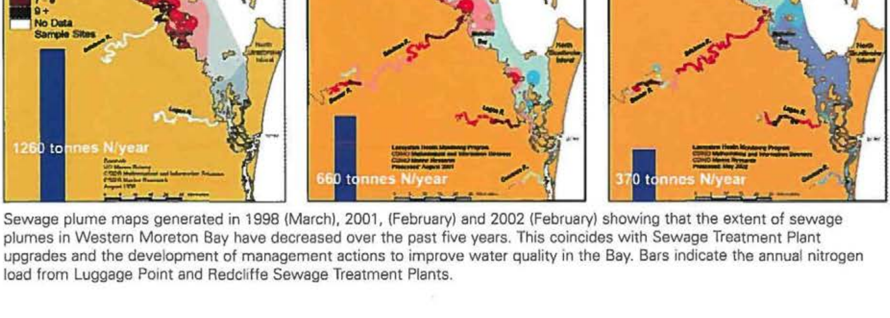
Sewage plumes in Moreton Bay and its river estuaries, although temporally variable (as previously reported in Dennison and Abal, 1999), can track the extent of nitrogen loads from sewage treatment plants. The intensity and distribution of sewage-derived nitrogen can be mapped using the gradient in $\delta^{15}N$ values of macroalgae with distance from sewage nutrient inputs.

The mapping of sewage plumes in South East Queensland estuarine and marine waters began in 1998 and since 2001 has been conducted annually. Sewage plumes extend into Moreton Bay from the many Sewage Treatment Plants on the Western side of the Bay. The Brisbane River was a major contributor to the Moreton Bay sewage plume in 1998, extending into Bramble and Waterloo Bay. However, since 1998, the spatial extent of the sewage plume in Bramble Bay has been significantly reduced, with the intensity of the sewage signal at the Brisbane River mouth also decreasing from 9 to 5-7‰. There also appeared to be little sewage extending southward into Waterloo Bay or into central Moreton Bay.

The reduction in the size and intensity of the sewage plume in Bramble may be due to significant upgrades that have occurred to sewage treatment plants in Redcliff and Brisbane City Councils. Natural variation in river flow and nutrient delivery to Moreton Bay between years is also likely to have contributed to observed pattern.



Methodology for tracing Sewage: The macroalgae *Catenella nipae*, is collected on mangrove pneumatophores and deployed in clear chambers at half secchi depth, and exposed to ambient water for four days. Samples are then collected, dried and analysed for $\delta^{15}N$ value on a mass spectrometer.

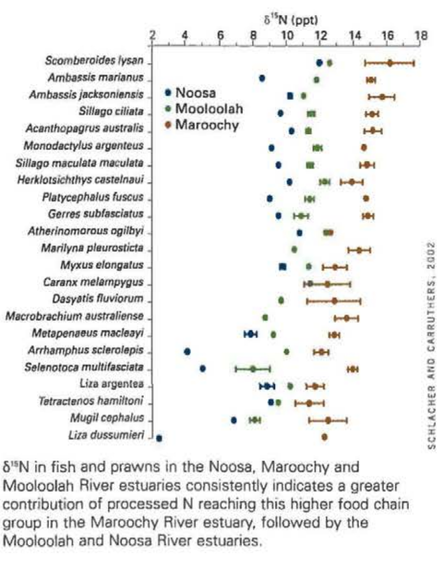


Sewage plume maps generated in 1998 (March), 2001, (February) and 2002 (February) showing that the extent of sewage plumes in Western Moreton Bay have decreased over the past five years. This coincides with Sewage Treatment Plant upgrades and the development of management actions to improve water quality in the Bay. Bars indicate the annual nitrogen load from Luggage Point and Redcliffe Sewage Treatment Plants.

Sewage nitrogen in oysters and fish

The sewage plume mapping technique implemented in the Ecosystem Health Monitoring Program has been further developed to utilise $\delta^{15}N$ in the body tissue of consumers (oysters and fish) as a tracer of sewage-derived nitrogen (N). The basic rationale for analysis of ^{15}N content of animal tissue is the same for that of macroalgae and plants (i.e. sewage N is enriched in ^{15}N relative to other sources). In contrast to macroalgae and other plants, where incorporation of the sewage signal occurs via direct uptake of dissolved ^{15}N, transfer of sewage-derived N to animal tissue occurs through the food chain.

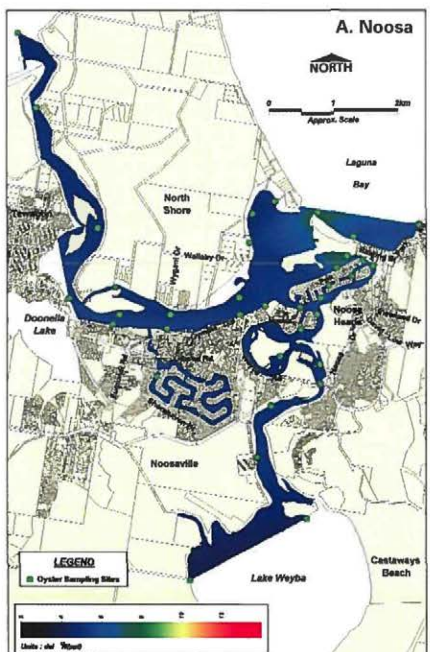
The technique was trialed in the Mooloolah, Maroochy and Noosa river estuaries. These catchments have different levels of sewage input and catchment development and, therefore, serve as a useful demonstration of the ability of the technique to detect varying levels of these impacts. Over 50 species of fish were collected by seine netting (for the small fish component), angling and speargun (for larger fish) to capture a broad range of fish species.



$\delta^{15}N$ in fish and prawns in the Noosa, Maroochy and Mooloolah River estuaries consistently indicates a greater contribution of processed N reaching this higher food chain group in the Maroochy River estuary, followed by the Mooloolah and Noosa River estuaries.

Without exception, each species of fish which was sampled in all three river estuaries had a lower $\delta^{15}N$ signature if taken from the Noosa River, followed by the Mooloolah River and then the Maroochy River (with known sewage inputs). This indicates that the detection of processed N can extend into higher trophic levels.

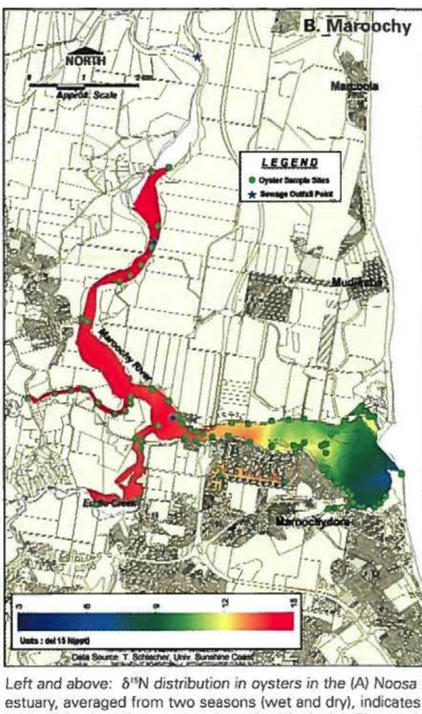
The data indicate that fish, with a longer integration of conditions and representing a



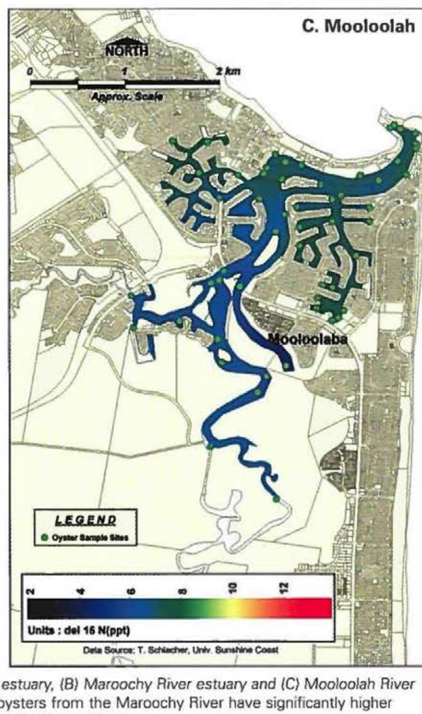
diversity of ecological types and functions, have incorporated sewage derived nitrogen through the food chain. In addition, despite the geographical proximity of these rivers, the signatures indicate little migration of fish occurs between rivers.

A greater spatial resolution for the detection of sewage-derived nitrogen (N) is possible through the analysis of sessile organisms, such as oysters. Oysters were collected from over 30 sites in the Noosa River and over 50 sites in the Maroochy and Mooloolah Rivers. Regional evaluation of $\delta^{15}N$ in oysters is consistent with that of fish, with a greater $\delta^{15}N$ signal in the Maroochy River than in the Mooloolah and Noosa Rivers.

Mapping the spatial extent of oyster $\delta^{15}N$ in the Maroochy River provides a strong indication that elevated $\delta^{15}N$ is predominantly linked to sewage-derived N. Six sewage treatment plants are located on the Maroochy River, with the largest of these discharging near Eudlo and Petrie Creeks. Downstream of these outfalls, the $\delta^{15}N$ of oysters rapidly declines. However, other sources of elevated ^{15}N (e.g. in-stream nutrient processing, stormwater and septic systems) are likely to contribute to locally elevated $\delta^{15}N$ values in all rivers, as elevated signatures are also detected away from known point source inputs of sewage nitrogen (e.g. Cornmeal Creek).



SCHLACHER AND CARRUTHERS, 2002



SCHLACHER AND CARRUTHERS, 2002

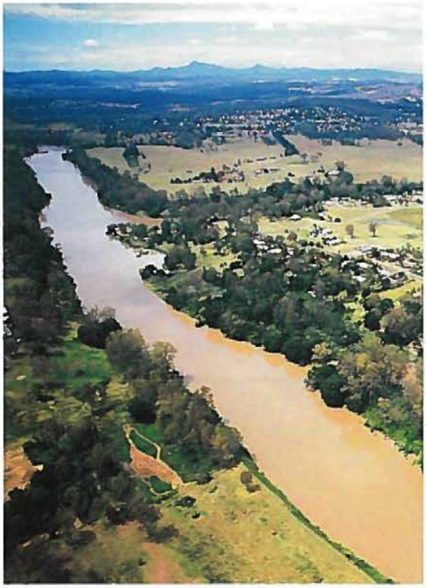
Left and above: $\delta^{15}N$ *distribution in oysters in the (A) Noosa River estuary, (B) Maroochy River estuary and (C) Mooloolah River* estuary, averaged from two seasons (wet and dry), indicates that oysters from the Maroochy River have significantly higher body $\delta^{15}N$ values than oysters from the Mooloolah River and, finally, the Noosa River.

High carbon loads lead to declining water quality

The Bremer River estuary is characterised by high nutrient loads and turbidity, high phytoplankton biomass, light-limited phytoplankton growth and abundant bacteria. The river has been historically described as a once-pristine waterway that, over time, deteriorated because of pressures from land use in the surrounding catchment. Pollutants in the river and its tributaries include litter, pesticides, nutrients, heavy metals, chemicals and discharges from a range of industries. A long residence time of 190 days (the highest in Moreton Bay region) means that there is little flushing of the system to remove nutrients and pollutants.

Among the nutrients flooding the Bremer river, organic carbon is an important contaminant. Carbon is present naturally in all rivers, particularly in summer when heavy rain washes contaminants into waterways. This carbon is used as a food source by bacteria and released as carbon dioxide. Usually the rate of this process slows down when there is no rainfall as the amount of carbon and other nutrients entering the river is less. However, in the Bremer, the rate of carbon turnover remains high throughout the year indicating that the high rate of bacterial growth in the river is driven by a continuous supply of carbon and other nutrients, which is gradually reducing the average concentration of dissolved oxygen in the estuary.

In recent decades, there have been improvements in management practices resulting in reduced pollution of the river. For example, since the 1970's, intervention by local and State government authorities has reduced the majority of acutely dangerous pollutants, including toxins and heavy metals. Unfortunately, the more insidious and chronic pollutants such as nutrients and sediments remain a major impact on the river and, eventually, on downstream receiving waters of the Brisbane River and Moreton Bay. Such conditions have resulted in the poor ecosystem health of the river estuary.



The Bremer River catchment.

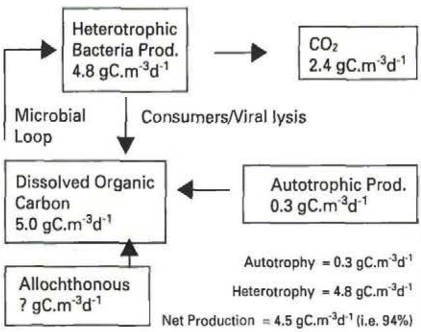
Summary of Ecosystem Health Indices (EHI's) of the different parameters used for Report Card ratings in the Bremer River. Water quality objectives taken from the *2000 South East Queensland Regional Water Quality Management Strategy* were used. (N – nitrogen, P –phosphorus, Chl *a* – chlorophyll *a*, DO – dissolved oxygen).

Note: The EHI is a measure of the proportion of a reporting zone that complied with environmental objectives for key indicators. EHI is represented by a 1 for full compliance, ranging to 0 for non-compliance.

		EH Index	Turbidity	N Total	Chl *a*	P Total	DO
2000-01	F	0.31	0.00	0.00	0.54	0.00	1.00
2001-02	F	0.12	0.00	0.00	0.54	0.00	0.06

Unknown carbon source in the Bremer estuary

Biological processes in the Bremer can act as both a source and a sink of carbon. Algal production is the major biological carbon source, however, measurements in the Bremer River indicated that algal production only results in just less than one tonne of carbon per day. In contrast, the amount of carbon required to sustain the high bacterial productivity in the river is 3-8 tonnes of carbon per day. Hence, there must be an external source of carbon.

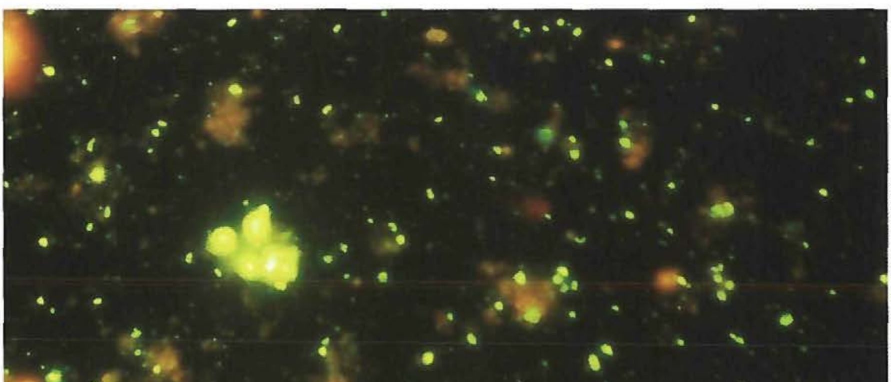


POLLARD, 2000

Estimate of the carbon budget for the Bremer River in the dry season. The ecosystem is net heterotrophic.

Modelling results of the Bremer River supported the presence of the unknown source of carbon in the Bremer estuary with a magnitude of approximately one tonne per day. The weight of evidence strongly supports the presence of a significant volume of carbon reaching the Bremer from a source other than a direct licensed discharge (e.g. diffuse sources such as land-discharged effluents, urban or commercial stormwater or agricultural runoff). This unknown source acts cumulatively with the known sources of carbon and other nutrients to support high bacterial growth and respiration, which in turn depletes dissolved oxygen in the river.

The carbon budget for the Bremer in the dry season assumes that bacteria are at least 50% efficient at converting the dissolved organic carbon (DOC) into their own biomass and the remainder is lost through respiration (CO_2). Overall the net production is negative with only 6% of DOC coming from primary production. Thus most of the heterotrophic bacterial production is not supported by the primary productivity. This suggests other external sources of DOC are supporting the high rates of bacterial growth in the Bremer River.



PETER POLLARD, GRIFFITH UNIVERSITY

Heterotrophic bacteria dominate the Bremer River.

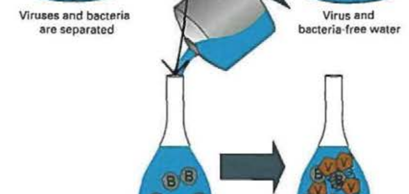
Virus and bacteria concentrations and production follow nutrient gradients

Viruses are the smallest members of marine microbial communities – ranging in size from 20 to 200 nm – roughly 1/10 the size of a bacterium. In many oceanic systems throughout the world, they are very important in controlling photosynthesis in phytoplankton and production in bacteria. They are present in astonishing numbers – typically ranging from 1,000,000 to 100,000,000 virus particles per litre. Bacteria are typically 10 to 100 times less abundant than viruses but carry out the majority of primary production in aquatic ecosystems.

Virus-like particles and bacteria in sediments and the water column of Moreton Bay were counted using an epifluorescence microscopy technique. This was coupled to a virus dilution technique to estimate virus production. Virus and bacteria abundances in the water column and sediments follow nutrient gradients in the Brisbane River and Moreton Bay estuary and also in the Noosa River estuary (facing page). Since bacteria remineralise nutrients (i.e. take organic nutrients and make them available to other organisms) in both the water column and sediments, it is expected that in areas of high nutrients, there would be many more bacteria than in nutrient depleted areas. Since the primary hosts of viruses in the marine environment are bacteria, these are expected to follow bacterial abundances. Interestingly, the number of viruses per bacterium is elevated in areas with high nutrient concentrations, which may be related to the greater availability of resources for making new virus particles.

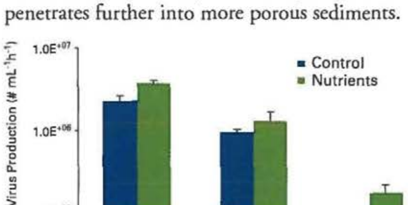
Production of viruses also follows nutrient gradients, with highest production rates in the most nutrient-rich areas. Bacteria (the primary hosts of viruses) typically have higher turnover rates in more nutrient rich areas, so elevated virus production rates are probably due to gradients in bacterial production.

Virus abundances were also found to be far higher (10 to 100 times greater) in sediments than in the water column. This is not surprising, since sediments are typically enriched with detritus, which stimulates bacterial production. The amount of detritus entering sediments follows nutrient gradients since organic matter from primary production in the water column sinks and is stored in sediments. Consequently sediment virus abundances follow water column productivity and nutrient gradients. Within sediments, there are more viruses near the sediment surface due to the more recent input of organic matter into this layer (and consequent high bacterial production rates). This distribution pattern changes in low-nutrient environments, however, where recently-arrived organic matter penetrates further into more porous sediments.



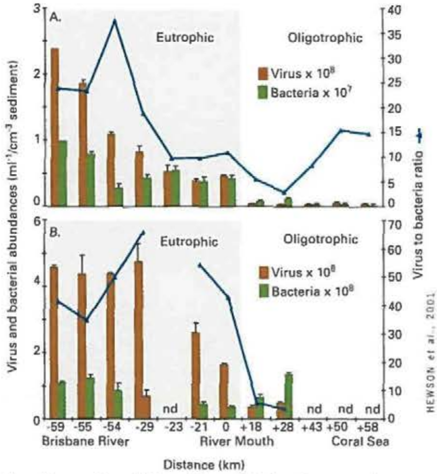
HEWSON *et al.*, 2001

Methods used to determine virus productivity rates.

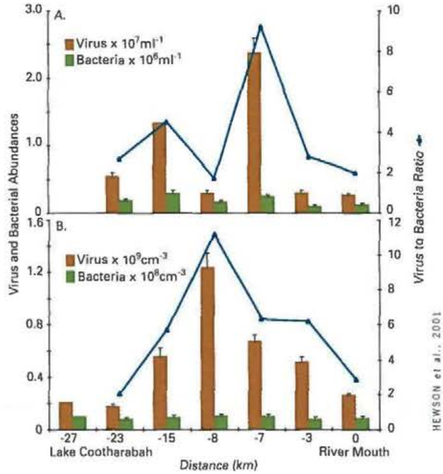


HEWSON *et al.*, 2001

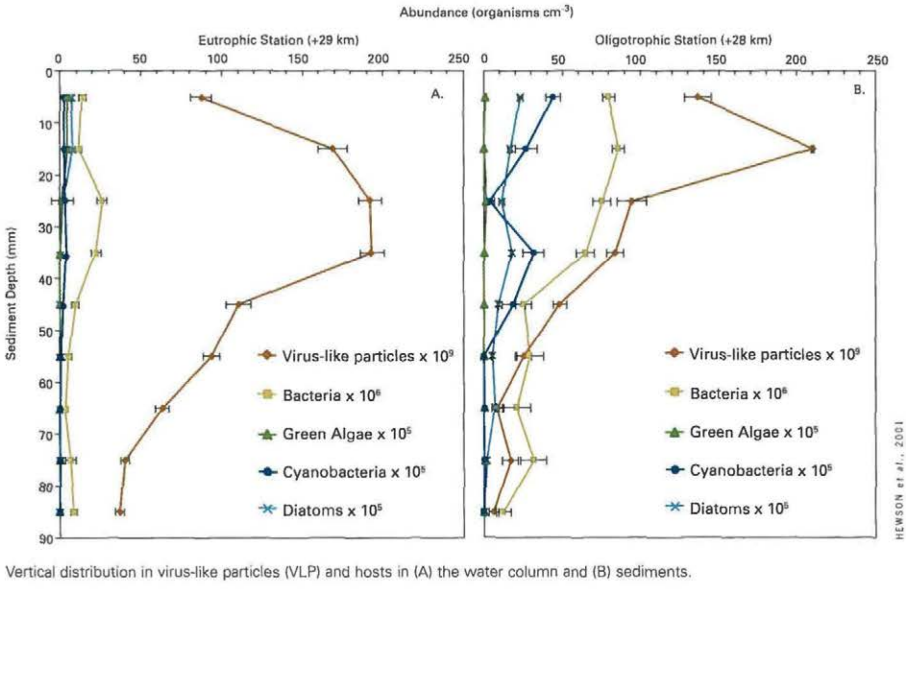
Virus productivity in the water column at 3 sites (Brisbane River, Moreton Bay and the open ocean) with and without nutrient additions.



Virus-like particles (VLP) and bacterial abundances and changes in the ratio of viruses to bacteria along a gradient from the Brisbane River to Moreton Bay in (A) the water column and (B) sediments.



Virus-like particles (VLP) and bacterial abundances and changes in the ratio of viruses to bacteria along salinity gradient in Noosa River in (A) the water column and (B) sediments.



Vertical distribution in virus-like particles (VLP) and hosts in (A) the water column and (B) sediments.

CONTRIBUTORS (in alphabetical order)

Eva Abal, Stuart Bunn, Ian Hewson and Peter Pollard.

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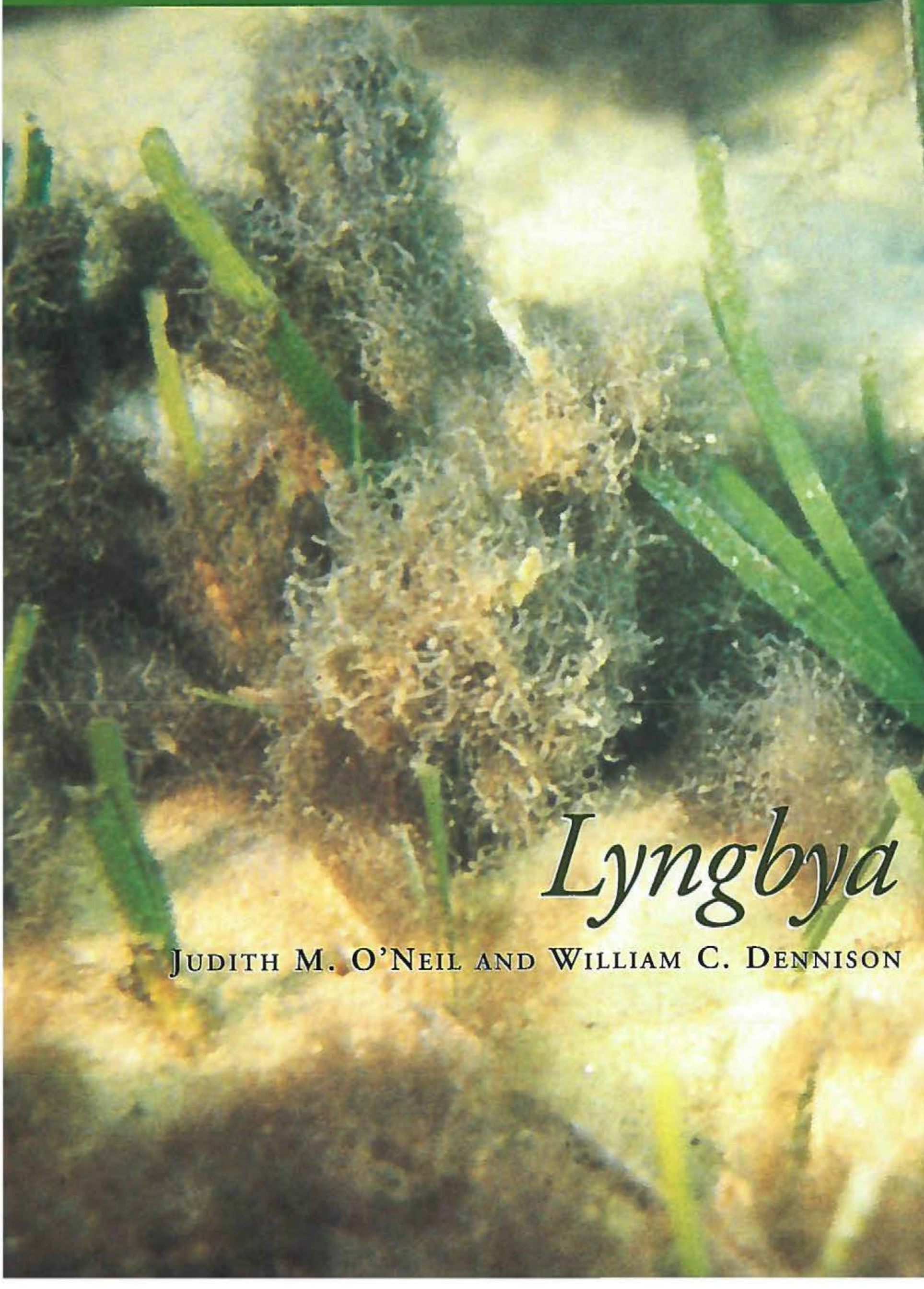
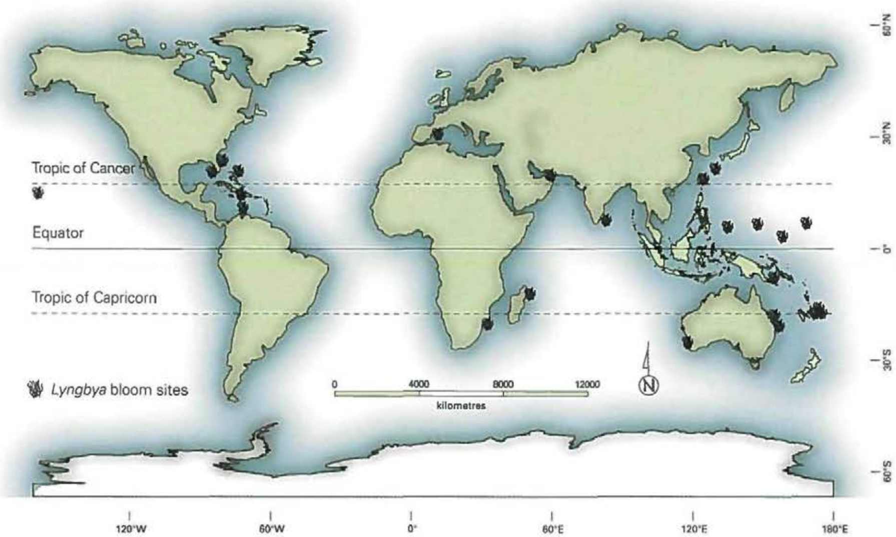
Chapter 6



Lyngbya

Judith M. O'Neil and William C. Dennison

Lyngbya blooms occur globally



Lyngbya majuscula has been reported in tropical and subtropical marine regions throughout the world.

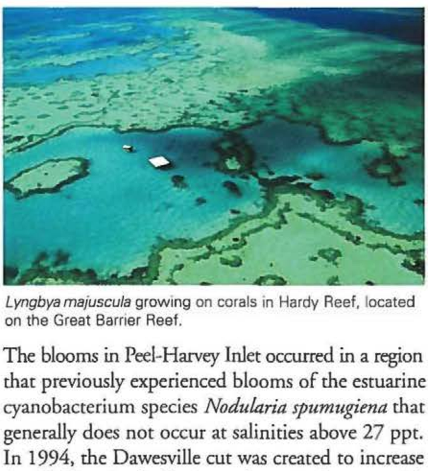
Lyngbya majuscula is a filamentous macroscopic non-heterocystous cyanobacterium that has a pan-global distribution in tropical and subtropical marine regions. It is a natural component of the ecosystem, however in some locations, at certain times *L. majuscula* can rapidly develop into nuisance blooms.

Primarily a benthic organism, *L. majuscula* grows attached to seagrasses, macroalgae, and other substrates that enable it access to light. Blooms appear to originate out of the sediments, where microscopic reproductive cells (hormogonia) may be able to persist. The filaments are approximately 40 µm wide and comprised of cells 1-2 µm thick, which are enclosed in a very distinctive sheath. The common name "mermaid's hair" is due to the macroscopic "hair" or yarn like appearance of the *L. majuscula* filaments, that can grow to lengths of 30 cm or more. During calm sunny periods, gas bubbles from photosynthesis and other metabolic processes get trapped within the filaments, causing them to become buoyant and lift up from the benthos, often ripping up seagrass, or macroalgae that they are growing on. Surface accumulations of this material then can drift with currents allowing dispersion and also causes the deposition of biomass on beaches, creating health, odour and aesthetic problems. Mats can cause localised anoxia as well as increased nutrient addition from decaying material.

(1) Wracks of the seagrass *Syringodium filiforme* with *Lyngbya majuscula* intertwined, washed up on St Pete's Beach, Florida, USA, October 2002. (2) *Lyngbya* blooms on Amity Bank

Lyngbya identified from *Australian locations*

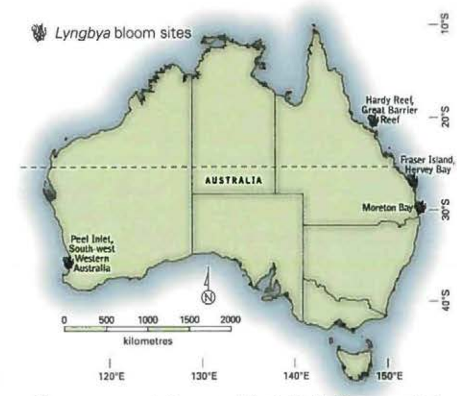
Lyngbya majuscula has historically been found in many regions of tropical and subtropical Australia. However, blooms of the dimensions seen in the last few years have not been quantitatively or scientifically documented previously. Anecdotal evidence suggests that significant blooms may have occurred previously, particularly in Hervey Bay and Moreton Bay. In 2001, significant blooms were recorded in two previously unaffected areas: Peel-Harvey Inlet, Western Australia and Hardy Reef lagoon, off the Whitsunday Islands, Qld.



Lyngbya majuscula growing on corals in Hardy Reef, located on the Great Barrier Reef.

The blooms in Peel-Harvey Inlet occurred in a region that previously experienced blooms of the estuarine cyanobacterium species *Nodularia spumugiena* that generally does not occur at salinities above 27 ppt. In 1994, the Dawesville cut was created to increase the flushing in the basin to decrease the potential for *Nodularia* blooms. The increase in salinity seems to have alleviated the estuarine cyanobacterial bloom problem, but may now be replaced with more marine species such as *L. majuscula.*

In 2001, Hardy Reef, a mid-shelf reef approximately 57 km off Airlie Beach experienced a proliferation of *L. majuscula* growing directly on coral heads as well as on macroalgal outcrops. On some coral heads, particularly on *Acropora* species, the growth of *L. majuscula* grew over the coral causing mortality. Seaplane operators have been visiting Hardy reef on



There are several sites around Australia that have reported significant *Lyngbya majuscula* blooms, Peel Hervey Inlet, Western Australia, Hardy Reef off the Whitsunday Islands and Hervey and Moreton Bays.

a daily basis for 27 years, and had not previously observed blooms of *L. majuscula* in the region. The blooms coincided with the installation of a helicopter platform within the lagoon. This platform provides a roost for hundreds of sea-birds which provide phosphorus-rich guano, that may be facilitating the proliferation of the *L. majuscula.*

Since then, *L. majuscula* blooms have also been observed in other Queensland waters, such as Hinchinbrook Island, Shoalwater Bay, Great Keppel Island.

Lyngbya majuscula deposited on the beach at Hinchinbrook Island.

Lyngbya blooms continue in *northern Deception Bay*

Lyngbya majuscula has been expanding its presence in Moreton Bay over the last several years. Blooms have ecological, economic and human health impacts. *L. majuscula* can contain several toxins that produce a variety of symptoms, including dermatitis, eye, nose and throat irritation, as well as respiratory symptoms, akin to asthma. In Moreton Bay, these effects were originally experienced by commercial fisherman in the Deception Bay area. The fisherman also noticed a drop in fish and crab harvests during the time of these blooms. Subsequently, it has been shown that *L. majuscula* blooms have detrimental effects not only on the biota in and around the bloom, but seagrasses, mangroves, and potentially seagrass macrograzers such as turtles and dugong, which may ingest *L. majuscula* covered seagrass. Additionally, nutrient input through nitrogen fixation and death and decay of the large cyanobacterial biomass (tonnes/per event) may have a significant localised effect on nutrient cycling and trophodynamics. The blooms have persisted in the region with varying intensity. Queensland Parks and Wildlife Services mapped the extent of the 2000 – 2001 bloom. Maximum bloom area reached an estimated 10 km^2 in January 2001. The 2001 – 2002 bloom in Deception Bay was slightly less persistent than the previous year, but covered approximately the same area. In subsequent years intensity has varied with some correlation with dry vs. wet periods.

A *Lyngbya majuscula* bloom in Deception Bay.

The extent of the *Lyngbya majuscula* bloom in northern Deception Bay during the 2001 bloom. *Lyngbya majuscula* extended from Godwin Beach to the mouth of Pumicestone Passage in early January, but had reduced to a very small area by the end of the month

Lyngbya blooms occur in ***eastern Moreton Bay***

Starting in March of 2000, extensive blooms of *Lyngbya majuscula* were observed on the Eastern Banks of Moreton Bay, including Moreton, Amity and Maroom Banks. These areas are very important seagrass feeding areas for both turtle and dugong. In many of these areas 100% of the seagrasses were covered in *L. majuscula* for up to a month or more. In some areas, such as Cooloola and Diabla passages the *L. majuscula* persisted throughout the winter. In both the 2000 – 2001 and 2001 – 2002 seasons, the blooms had bi-modal seasonal peaks. The first was in the spring in October/November, waning by the end of December. The initial phases of these blooms seem to originate from the sediments, although filaments can also persist and be transported in the water column. The early phases of these bloom periods are characterised by a diverse array of cyanobacteria including *L. majuscula*; *Oscillatoria spp. Nostoc sp.* and members of the LPP-group (*Lyngbya*, *Phormidium* and *Plectonema*). Gradually the blooms shift towards a predominance of *L. majuscula*. The second bloom generally occurs from mid-March through April or May and is usually almost exclusively *L. majuscula*. Except for the protected passages mentioned above, the blooms tend to wane and completely dissipate by early to mid June.

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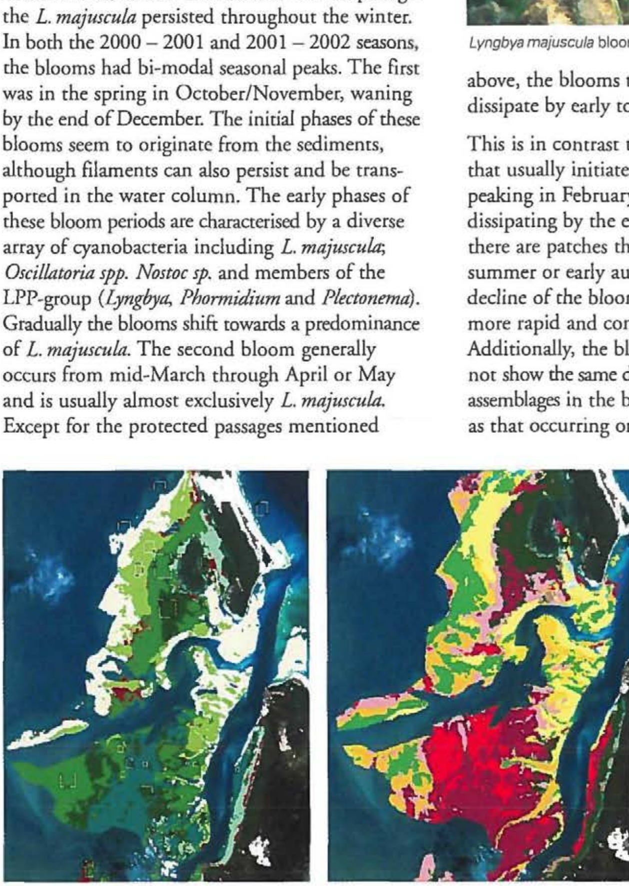
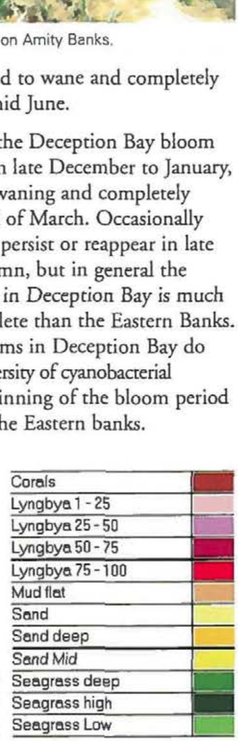
Lyngbya majuscula blooms on Amity Banks.

This is in contrast to the Deception Bay bloom that usually initiates in late December to January, peaking in February, waning and completely dissipating by the end of March. Occasionally there are patches that persist or reappear in late summer or early autumn, but in general the decline of the blooms in Deception Bay is much more rapid and complete than the Eastern Banks. Additionally, the blooms in Deception Bay do not show the same diversity of cyanobacterial assemblages in the beginning of the bloom period as that occurring on the Eastern banks.





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Satellite images of Eastern Moreton Bay before (left) and during (right) the 2000-2001 bloom. *Lyngbya majuscula* cover was thickest on the southern part of the banks south of Amity Point.

Comprehensive studies initiated

In response to the extensive *Lyngbya majuscula* blooms in Deception Bay in 2000, the *Lyngbya* Steering Committee, chaired by the Environmental Protection Agency and with representation from local government, state agencies, industry and community, was established. Local and state governments provided funding to address knowledge gaps, elucidate potential causes and impacts and to trial mitigation techniques for *L. majuscula* blooms. The development of the framework for *Lyngbya* scientific studies followed a staged approach, with a review in between stages. This process recognises that the causes of *L. majuscula* blooms (both at the initiation phase and the bloom phase) are multi-faceted.

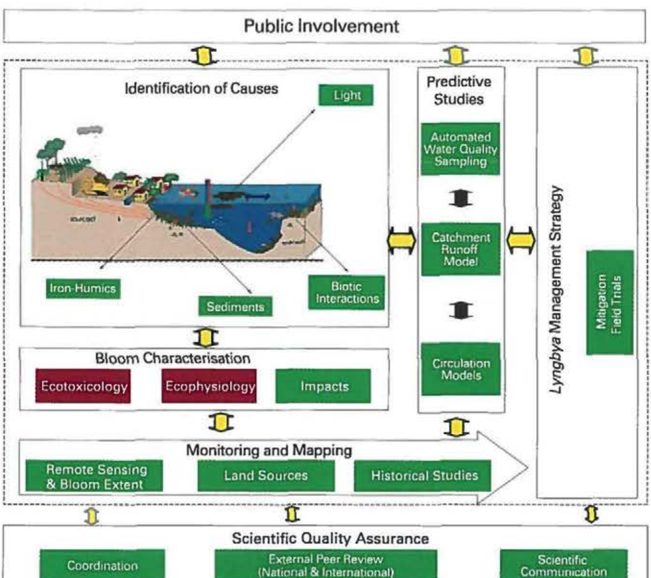
The **Initial Task Framework (2000/01)** concentrated on identification of causes of *L. majuscula* blooms in Deception Bay and included tasks looking at Water Quality Interaction, Biotic Interaction, Sediment Interaction, Light Interaction, Land Sources and Automated Sampling. There was also an Australian Research Council SPIRT project on ecophysiology and ecotoxicology (*Dennison, Waite, Shaw and O'Neil*). The findings of the initial research program have underpinned the developmen of the *Lyngbya* Management Strategy.

The **2001/2002 Task Framework** focused on the determination of causes of *L. majuscula* blooms on the Eastern banks. The task framework also include some biotic impacts studies and a historical study of *L. majuscula* blooms.

The **2002/2003 Task Framework** includes culture techniques of *Lyngbya* to allow for manipulative experiments (bioassays), a contingency monitoring program, and DNA Analyses (sediments). It was recognised that long-term cultures of *Lyngbya* are necessary to run more consistent quantitative bioassay and uptake experiments.

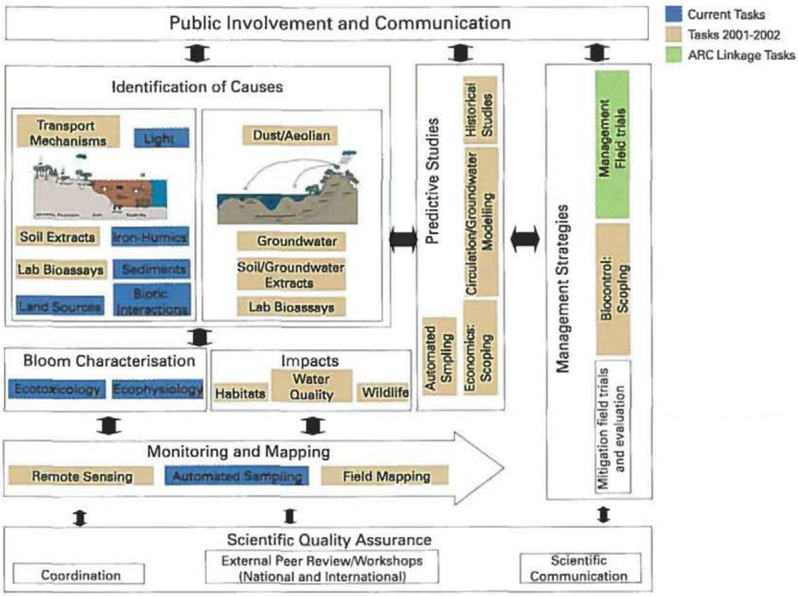
Additionally, an ARC/DPI Forestry Linkage Grant 2001-2004 (*O'Neil, Dennison, Waite and Lukondeh*) focussed on potential links with runoff from pine forests and different potential management practices.

Future directions include developing predictive tools, which can allow short-term and long-term management strategies to address *Lyngbya* blooms ir South East Queensland.

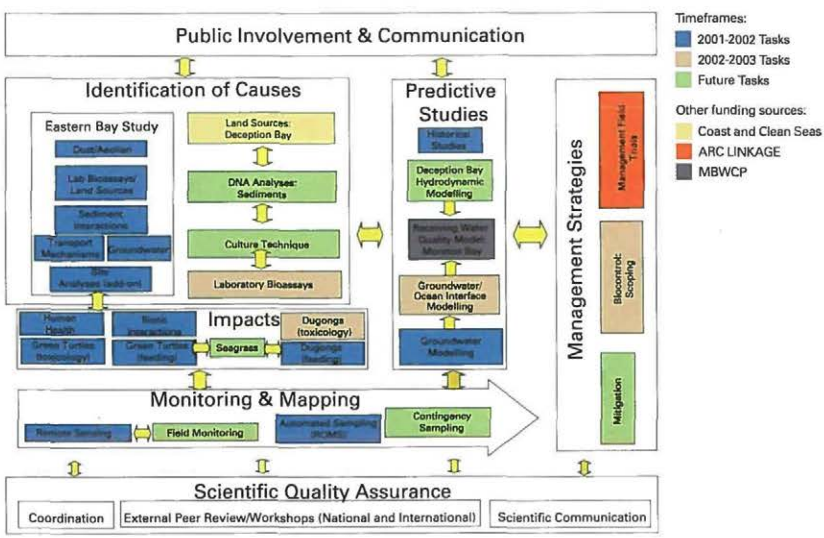


Initial task framework for *Lyngbya* tasks (2000-2001) concentrated on identification of causes of blooms in Deception Bay. Findings of the initial work underpinned the development of a draft management strategy to address *Lyngbya majuscula blooms.*

ARC Linkage tasks
Tasks funded

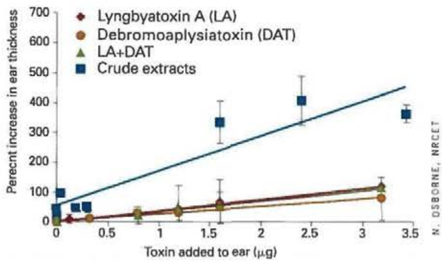


2001-2002 *Lyngbya* task framework focused on the scoping of possible causes of *Lyngbya majuscula* blooms in Eastern Moreton Bay. The framework also included some studies on biotic inputs of *Lyngbya majuscula* as well as historical studies.

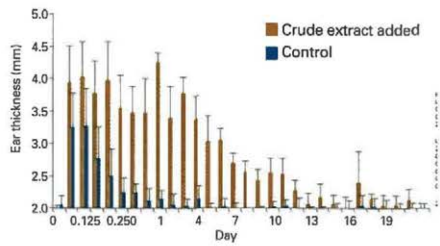


2002-2003 task framework highlights the need for developing culture techniques of *Lyngbya majuscula* and predictive tools for management strategies.

Lyngbya contains ***contact irritants***



Response of mouse ear thickness to the addition of different lyngbyatoxins. Crude extracts produced the largest response increasing ear thickness to about 400%, with lyngbyatoxin A (LA), Debromoaplysiatoxin (DAT) and combined LA and DAT all having a similar response.



Mouse ear thickness over time after being treated with lyngbyatoxin A. Maximum swelling was reached in four days with crude extract and persisted for several days after treatment.

Anecdotal evidence of human health impacts resulting from contact with *L. majuscula*, has been reported from numerous sources including, local fisherman, researchers and local community. Contact with *L. majuscula* has caused dermatitis, respiratory irritation and eye irritations. As such, investigations into the impacts of these toxins have been carried out.

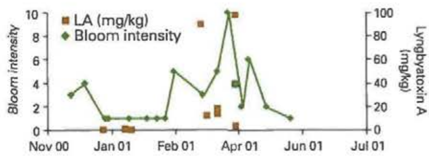
Two toxins, lyngbyatoxin A (LA) and Debromoaplysiatoxin (DAT) were initially investigated as they were previously found in other areas of the world to be the most potent toxins, and to be the cause of contact dermatitis in humans. Studies were conducted to assess the toxicity of toxins extracted from *L. majuscula* using the "mouse-ear swelling test". Pure extracts of lyngbyatoxin A and Debromoaplysiatoxin and crude extracts of *L. majuscula* were applied to mouse ears using dimethyl-sulfoxide as the solvent. Mouse ear thickness was measured using a spring-loaded gauge. Maximum swelling was reached within one day using the pure extract, and increased with increasing amounts of toxin added. DAT, LA and DAT plus LA treatments had similar responses. The crude extract produced the most significant increase in ear thickness (up to 400% of initial thickness), but took up to four days to produce maximum effect. This may suggest a synergistic effect of a cellular compound in the crude extract such as the lipopolycaccharide layer from the cell wall of the cyanobacteria, or as yet indentified compounds that cause toxic or allergic reactions.

Dermatitis following contact with *L. majuscula*.

Lyngbyatoxin levels variable in space and time

As with many toxic cyanobacteria, toxin levels can vary widely within a species. Variation can be a function of genetics, nutrient status, phase of the bloom, environmental conditions or potentially even grazer interactions. *L. majuscula* from other parts of the world have yielded numerous bioactive compounds. Many of these compounds are being researched for pharmaceutical and other applications. Several are known tumour-promoting agents and skin irritants. The two most potent dermatitis producing compounds, lyngbyatoxin A (LA) and debromoaplysiatoxin (DAT) were investigated in South East Queensland.

During the blooms in 1999-2000, the blooms in Moreton Bay showed distinct spatial differences in the type of toxins elucidated despite being genetically identical. *L. majuscula* samples from Deception Bay routinely contained DAT and no detectable LA, whereas the Eastern Bank blooms showed exactly the opposite, with LA present and no DAT.



Concentrations of lyngbyatoxin A varied greatly in the *Lyngbya majuscula* tissues during the course of the 2001 Eastern Banks bloom. The toxin levels appear to increase with bloom intensity.

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Additionally, over the course of the Eastern Banks bloom in 2001, the concentration of LA within the *L. majuscula* tissue (mg/kg) varied widely. There appeared to be a trend towards increased LA concentration during times of greater bloom intensity.

Concentrations of LA and DAT in *Lyngbya majuscula* from Deception Bay and Eastern Moreton Bay.

Month	Year	Lyngbyatoxin A (mg/kg)	Debromoaplysiatoxin (mg/kg)
Northern Deception Bay			
April	1999	0	0.3
February	2000	0	23.6
March	2000	0	28.8
April	2000	0	1.64
January	2001	0	0.8
Eastern Moreton Bay			
February	2000	8.4	0
March	2000	6.8	0
June	2000	5.4	0
January	2001	0.8	0
March	2001	51	0
April	2001	38.3	0

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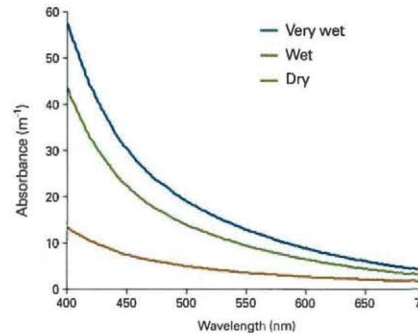
Stained runoff when it rains

When plant tissue decomposes, a complex group of compounds loosely referred to as humic substances are formed. These substances may enter coastal waters by leaching through the soil or by *in situ* decomposition. Water-soluble humic substances impart a "yellow" colour to the water (termed Gilvin). Based on the concentration and composition of these humics, the water colour may range from yellow through to brown and even black. The "yellow" substances absorb strongly in the blue and ultra-violet region of the light spectrum. A spectrophotometric technique (absorption at 440 nm wavelength) was used to assess the interaction of these compounds and light absorption.

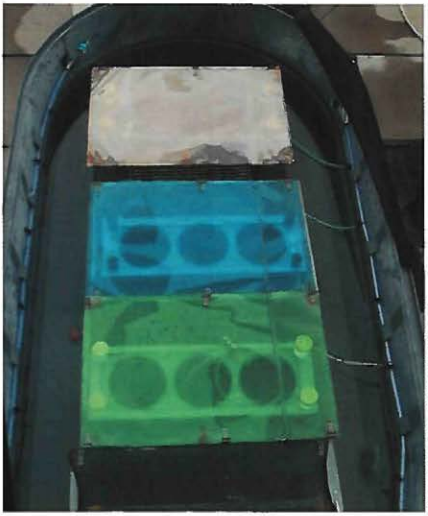


Water absorbance at 440 nm is lower during dry weather and increa in magnitude with increasing rainfall ("wet" vs. "very wet").

Water absorbance spectra and the Gilvin 440 values show that the concentration of water colour greatly depends on the intensity of rainfall and hence soil leaching and humic acid transportation.

Stained water can be seen leaching from a cleared pine plantation.

Light conditions in stained water stimulates *Lyngbya*



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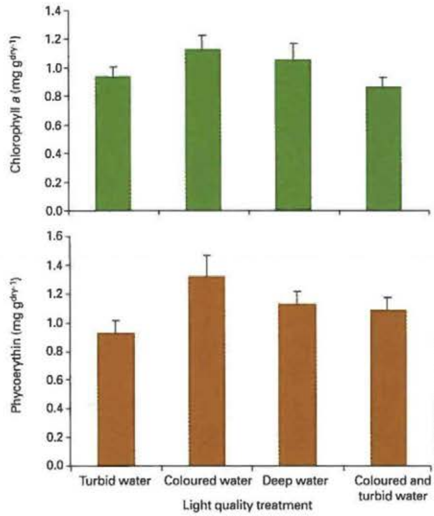
Experimental set-up to investigate the responses of *Lyngbya majuscula* to different light regimes.

Samples of *Lyngbya majuscula* were grown in aquaria simulating different light regimes to represent light quantities recorded in Moreton Bay: 1) coloured water; 2) deep water; 3) shallow turbid water, and 4) turbid and coloured water. Spectral filters were selected to ensure similar quantities of light were received (25-30% surface light) by the *L. majuscula*. After growing for twelve days under these different regimes, both productivity and photosynthetic pigments (chlorophyll *a* and phycoerythrin) were measured.

Primary productivity (^{14}C-bicarbonate incorporation) was significantly elevated in *L. majuscula* samples exposed to the coloured water treatment as compared to all other treatments. Both chlorophyll *a* and phycoerythrin in coloured treatment had elevated concentrations when compared to turbid water and turbid plus coloured water treatments. Similarly the deep water treatment had elevated pigment concentrations when compared to turbid treatments. Most importantly, the coloured water treatment that showed the greatest response in all parameters, is the treatment that was used to represent the water quality found in Northern Deception Bay. These experiments demonstrate that the quality of light not just quantity can significantly affect *L. majuscula* bloom physiology and proliferation.



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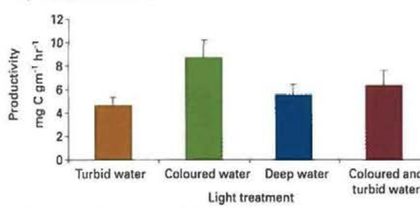
Lyngbya majuscula pigment (chlorophyll *a* and phycoerythrin) concentration following a 12 day incubation under light filters indicates a preference for light quality similar to that imparted by "stained water".



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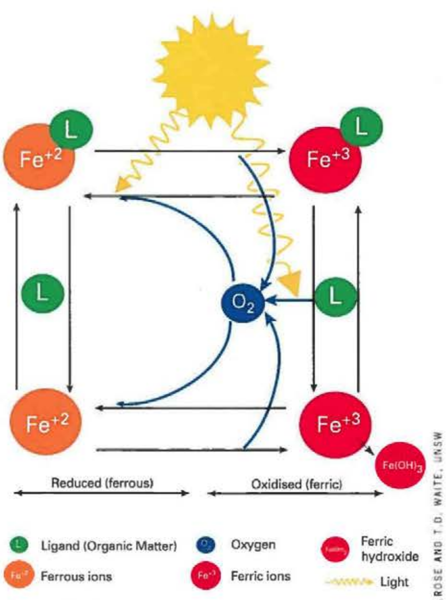
Lyngbya majuscula productivity (carbon incorporation) in response to light quality treatments indicates influence of light availability on bloom potential.

Iron availability for *Lyngbya* dependent on iron transformations

There is strong evidence that the availability of iron (Fe) controls the productivity, species composition and trophic structure of planktonic communities in the open ocean. Even in regions once considered Fe replete, Fe exerts considerable influence on aquatic ecosystems. Various mechanisms of Fe acquisition have been proposed for both eukaryotic and prokaryotic organisms. Fe uptake by many prokaryotes appears to involve solubilisation, chelation and cellular uptake by inducible Fe^{+3} – siderophore-systems. For those organisms that do not produce siderophores (eukaryotes and some cyanobacteria), Fe uptake appears to be highly dependent upon the concentration of "free" Fe^{+3} and Fe^{+2} in the external medium.

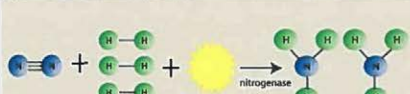


Schematic diagram of transformations that may occur in aqueous system containing iron and a complexing organic ligand (L).

Given that the formation of either highly insoluble Fe oxides or strongly complexed Fe reduces concentration of available Fe^{+2} and Fe^{+3}, non-thermodynamic processes such as light induced redox cycling of Fe are now recognised to be important factors increasing the steady state concentration of available Fe.

Some studies indicate that nitrogen-fixing cyanobacteria can require up to 100 times more Fe than non-nitrogen fixing forms. Therefore cyanobacteria capable of nitrogen fixation would be expected to be particularly susceptible to Fe availability if relying on N_2 fixation for survival.

Fe may undergo transformations in the presence of a single, major organic ligand that forms a light-active complex. Recently, application of a sensitive chemiluminescence based flow injection technique (FeLume) has provided a means for probing these reactions. Field results confirm the significant impact that light has on Fe speciation and the dramatic increases in the steady state concentration of Fe^{+2} in surface waters in response to solar radiation. More recent experiments indicate that *L. majuscula* produces the free radical of oxygen superoxide which it uses to reduce complexed iron to Fe^{+2} for uptake (Rose *et al.* 2005).

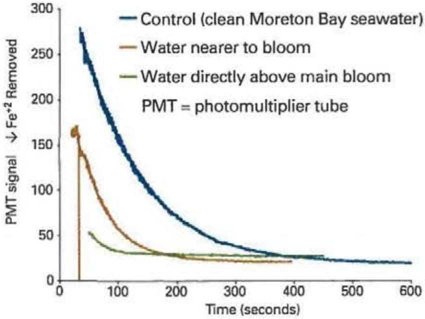


$$N_2 + 3H_2 + \text{Energy} \longrightarrow 2NH_3$$

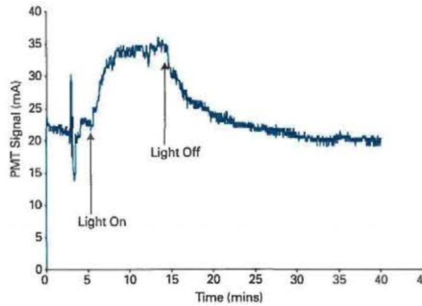
Nitrogen fixing organisms such as *Lyngbya* are able to use atmospheric N_2 for their cellular needs. Nitrogen fixation is catalyzed by the enzyme nitrogenase that requires a large amount of energy to break the stable triple bond of N_2. Three H_2 are combined to form ammonia NH_3 which is used to produce amino acids and proteins.

The process of nitrogen fixation.

Iron oxidation at Deception Bay bloom site



Ferrous iron (Fe^{+2}) was added to water samples to examine the loss of this species from solution.



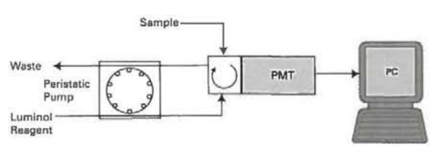
When samples were exposed to light, rapid generation of detectable levels of Fe^{+2} was observed.

In these studies, ferrous iron (Fe^{+2}) was added to Moreton Bay water samples and the loss of this form of iron from solution investigated. Ferrous iron concentrations have been determined using the FeLume system, a chemiluminescence-based flow injection technique designed specifically for Fe^{+2} analysis.

Results reveal a half time for free ferrous iron on the order of two minutes in relatively clear Moreton Bay waters. On addition of ferrous iron (Fe^{+2}) to waters either directly above or near the bloom, much more rapid removal was observed. These results suggest that organic ligands are present in these waters which rapidly bind the ferrous iron and prevent its measurement by the FeLume technique. Such loss is most likely mediated by strong iron-complexing agents. The identity of these agents is unknown, but may be important in uptake of iron by *L. majuscula* or may simply result from the presence of high algal activity and associated high concentrations of extracellular metabolites. Alternatively, these iron-binding agents may be terrestrially-derived and could possibly be key factors in stimulation of *L. majuscula* blooms through their ability to maintain iron in complexed, soluble form.

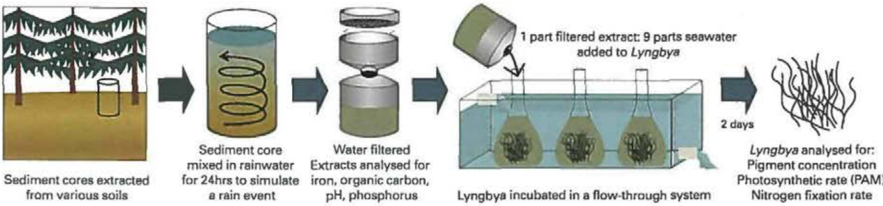
Exposing samples to light resulted in the rapid generation of detectable concentrations of Fe^{+2}, which rapidly reached steady state. When the light was switched off, the Fe^{+2} level decayed to zero within 20 seconds. The key conclusions are therefore:

- High oxidation rates, associated with strong binding of Fe^{+2} by organic material, are also likely linked with a high solubility of iron in the water column. There is, therefore, a higher degree of Fe solubility in the centre of the *L. majuscula* bloom.
- Exposure of samples to light results in the rapid generation of detectable levels of Fe^{+2}, these equally rapidly decay once the light is removed.
- It was not determined whether or not the trends observed were due to high levels of terrestrial-derived organic matter inflowing to the site of the bloom, or whether the organic material was generated at the site, perhaps by *L. majuscula*.



Configuration of the FeLume experimental apparatus for measurement of chemiluminescence.

Soil extracts and bioassays conducted



Methodology of *Lyngbya* bioassays. Soil extracts were taken from various land uses to monitor their effects on *Lyngbya majuscula* pigment concentrations, photosynthesis and nitrogen fixation.

Bioassays were carried out to assess the metabolic response of *Lyngbya majuscula* to soil extracts from representative land uses in the Deception Bay and Pumicestone Passage catchments. These included: soils from intact pine forest, cleared pine forest, melaleuca forest, canal development, mangrove forest, coffee rock, Sandstone Pt and Shirley Creek. Soils were treated with rainwater to simulate a rainfall event flushing through soils. *L. majuscula* samples were incubated in the water solution sourced from each of these sites and metabolic responses were monitored. Flushing under low pH (acidic) conditions can facilitate the leaching of trace metals including iron (Fe), providing a transport mechanism, along with organic material that may cause the Fe to stay in solution.

The most acidic extract (lowest pH) was obtained in the cleared pine, intact pine, canal development and melaleuca forest samples (ranging from pH 3.3 – 4.3). The rest of the sites yielded almost neutral values (ranging from pH 5.9 – 6.8) Phosphorus concentrations were significantly higher (6.7 and 9 µM) in the two pine plantation extracts than any other sites (0.05 – 0.3 µM). The amount of Fe in the extracts varied significantly between sites. However, when the proportion of soluble to total Fe is considered, the three forested sites (cleared pine, intact pine and melaleuca) had high proportions of bioavailable Fe. The high proportion of soluble to total Fe in the forested sites was generally matched by high dissolved organic carbon contents.

Chemical parameters of soil extracts taken from numerous locations in the Deception Bay and Pumicestone catchments.

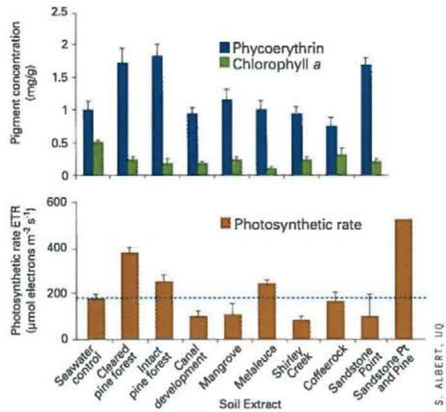
Soil extract	pH	Phosphate (µM)	Dissolved organic carbon ($mg.l^{-1}$)	Soluble Iron ($mg.l^{-1}$)	Total Iron ($mg.l^{-1}$)
Cleared Pine	3.9	6.7	62.9	0.57	1.1
Intact Pine	3.3	9.5	35.8	0.12	1.0
Melaleuca	4.3	0.3	59.1	0.43	2.8
Mangrove	6.1	<0.01	4.1	0.16	3.5
Shirley Creek	5.9	0.2	5.3	0.05	43.0
Marine sands (Sandstone Point)	6.8	0.1	2.1	<0.01	1.0
Canal development	3.7	0.1	4.7	0.15	3.3
Iron rich creek (Shirley Creek)	6.6	<0.01	28.6	0.2	6.1

S. ALBERT, UQ

Pine plantation extracts high in P and Fe stimulate photosynthesis and pigments

Extracts from different land uses varied in both spectral and chemical composition. The photosynthetic yield (using a Pulse Amplitude Modulated-fluorometer) was significantly higher in the two pine treatments than in any of the other extracts. However, an even higher yield was obtained by mixing the extracts from Sandstone Point (marine sands overlying Landsborough sandstone bedrock and high in iron) and acidic, high organic extract from pine forests.

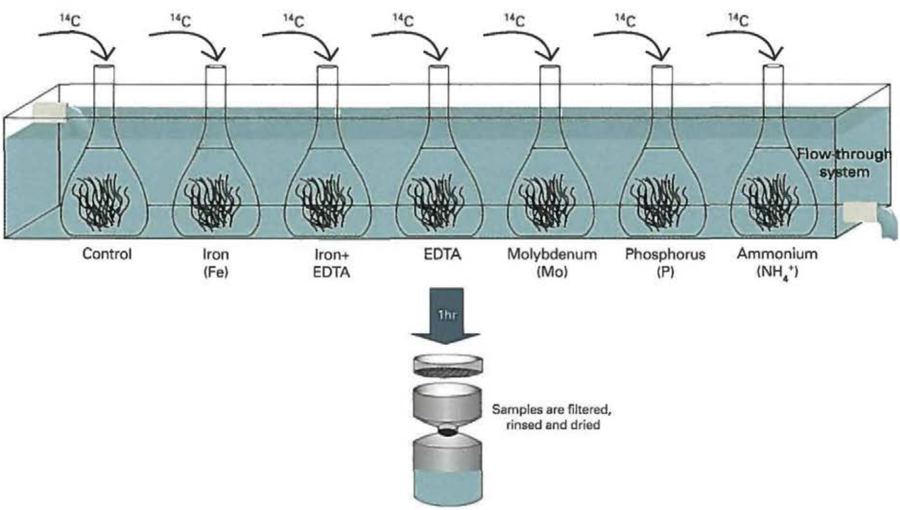
There were no significant differences in chlorophyll *a* content between treatments. There were, however, significant differences in the amount of the photosynthetic pigment, phycoerythrin, in the cleared pine, intact pine and coffee rock extracts. The increase in this particular pigment gives a competitive advantage to *L. majuscula*, as most other marine plants, do not contain this pigment. This may help explain the success of this cyanobacteria over non-phycoerythrin containing phytoplankton, seagrasses and other macrophytes after runoff events.



Soil extracts from cleared and intact pine forests resulted in a significantly increased photosynthetic rate when applied to *Lyngbya majuscula*.

Soil extracts from pine forests stimulated photosynthetic rates in *Lyngbya majuscula*.

Phosphorus and iron additions stimulate *Lyngbya*

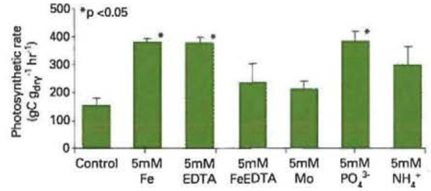


Methodology used to assess the effects of nutrient additions on *Lyngbya majuscula* productivity using radioactive carbon (^{14}C) uptakes.

In an effort to determine which nutrients might be stimulating the growth of *Lyngbya majuscula*, laboratory experiments were conducted using a range of compounds. Various physiological parameters were used to assess the biology of *L. majuscula* including Pulse Amplitude Modulated fluorometery, ^{14}C incorporation and nitrogen fixation. The three treatments that significantly increased the metabolic parameters included phosphorus (P), iron (Fe) and chelators (organics – compounds that keep Fe in solution).

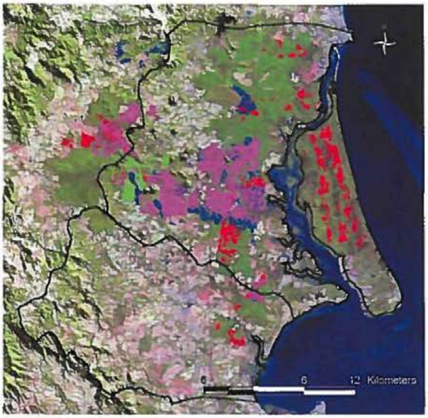
Phosphorus often stimulates nitrogen-fixing organisms, as the energetic nitrogen-acquiring reaction becomes limited by the consumption of energy-containing molecules. Hence, P is always a suspect with blooms of nitrogen fixing organisms.

Fe has been reported in numerous cases to be a limiting micronutrient in open ocean systems. Coastal systems are generally thought to be saturated in Fe, however, it is often in a biologically unavailable form, due to the insolubility of Fe at seawater pH. P and Fe stimulated both nitrogen fixation and productivity when added with a chelator (EDTA). An increase in activity was also observed with EDTA alone, which may be due to the chelation of Fe already in the water, or the removal of other metals such as copper which inhibit cyanobacteria.



The addition of iron, chelator (EDTA) and phosphate significantly increased the photosynthetic rate of *Lyngbya majuscula* indicating that these compounds are important in the growth of *Lyngbya majuscula*.

Recent pine plantation clearing in Pumicestone Passage catchment and Bribie Island



Pumicestone Region Catchment Plantation Clearfelling between 1991 and 1999

- Pumicestone Region Catchment
- September 88 to July 91
- June 95 to September 97
- July 91 to June 95
- September 97 to August 99

The areas shaded in purple show felling from 1991 to 1995 i.e. a 4-year period whereas the other shaded areas cover a 2-year period only. The background image is a 1995 Landsat™ image provided by SLATS. Large areas of pine plantation have been cleared in the last ten years in the Pumicestone Passage and Deception Bay catchment areas.

Pine clearfelling in the Pumicestone Catchment.

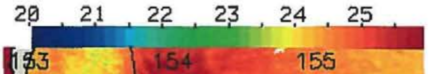
The majority of land in the Pumicestone catchment surrounding the Deception Bay *Lyngbya majuscula* bloom site is pine plantation, covering 39% in 1991. The majority of the plantations are the exotic pine species *Pinus elliotti* and *Pinus caribaea var. hondurensis.* A large area of pine plantation has been cleared (and some subsequently replanted) in the last ten years. In particular, large scale clearing in the mid 1990's followed broad scale bush-fires in the region. There are plans to clear a further 2,300 ha in the future, followed by conversion of this land into rural residential use.

On the mainland, the dominant soils on which the pine plantations occur are sandy surfaced, yellow leached gradationally textured soils and sandy surfaced yellow gradationally textured solids containing ironstone nodules. In their natural state, these soils are not considered to have much capacity to contribute iron (Fe), phosphorus (P) or organics to the system via leaching as they are appreciably weathered and therefore less likely to contribute nutrients. However, in pine plantation areas on Bribie Island, the soil is predominantly sandy Podzols with the possibility of acid peats in low-lying areas. These soils are generally associated with "tea-tree" Melaleuca stained perched shallow water tables containing iron and humics.

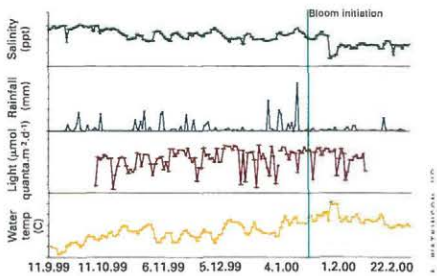
All the soils under pine plantation are fertilised to enhance production, and hence additional phosphorus is potentially present in soil leachates under such plantations. Additionally, acidification of soils under pine plantation is well documented, which may aid in the mobilisation of both Fe and P.

The rapid clear-felling in this timeframe that may have added to acceleration of the flow of P, Fe and organics has ended. Management practices have been trialed to minimise impacts of clear-felling in the future, including litter retention and seasonal timing of harvest.

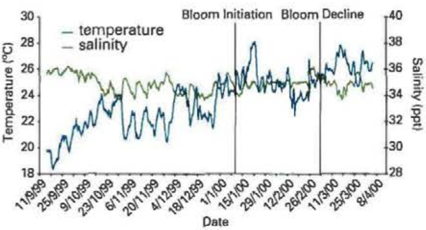
Lyngbya blooms initiated at high temperatures



AVHRR image of sea surface temperature for the Moreton Bay Region (27 October 2001, 1823H). Note the warm areas (>24°C) on Eastern Banks and Deception Bay.



Temperature graphs showing onset of *Lyngbya* blooms at temperatures above 24°C.



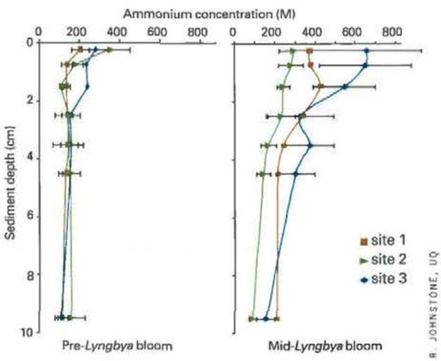
Temperature graphs indicating temperature and salinity levels are dominated by tidal frequencies, a wind driven diurnal frequency and a 5-7 day oscillation.

Blooms of *Lyngbya majuscula* appear to initiate after prolonged periods of high surface light (44.7 mol quanta $m^{-2}d^{-1}$) following a rainfall event with calm weather conditions resulting in high light penetration (mean K_d 0.77m^{-1}) and constant near full strength salinity (34.8 ppt). Although *L. majuscula* can exist at lower temperatures, temperatures about 24°C appear to be required for rapid growth and bloom expansion. Bloom expansion can be quite rapid, expanding 8 km^2 within 2 months.

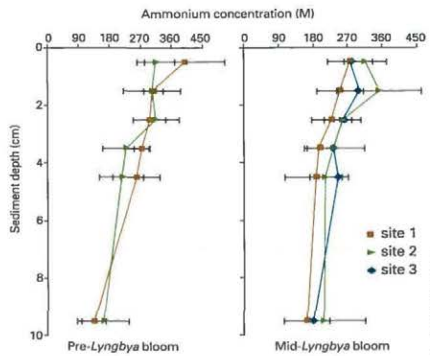
Analysis of temperature and salinity data collected at Deception Bay indicate that temperature and salinity levels are dominated by tidal frequencies, a wind driven diurnal frequency and a 5 – 7 day oscillation. The latter is possibly due to regional wind effects. The bloom area is therefore considered to be subject to frequent changes in water quality associated with water movements from within the Bay, Pumicestone Passage and oceanic sources. Currently two automatic sampling platforms have been deployed: one in Deception Bay and the other on Amity Banks, in Eastern Moreton Bay.

In the future, parameters measured from one or more continuous, real time water quality data collection platforms will allow an improved understanding of key processes across the Bay at a range of spatial and temporal scales. These data, when integrated and combined with the results from scientific tasks, may allow the identification of the key triggers for a bloom. Data from the platforms can be used as part of an "early warning" system on the likely location and occurrence of blooms.

Nutrient enrichment following *Lyngbya* blooms



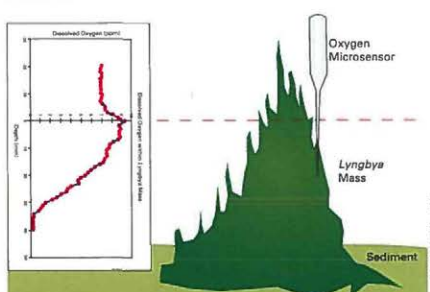
Eastern Banks sites showed a significant increase in subsurface ammonium concentrations between pre bloom and mid bloom samples.



Sites at Deception Bay showed no significant difference in ammonium concentrations between pre and mid bloom samples.

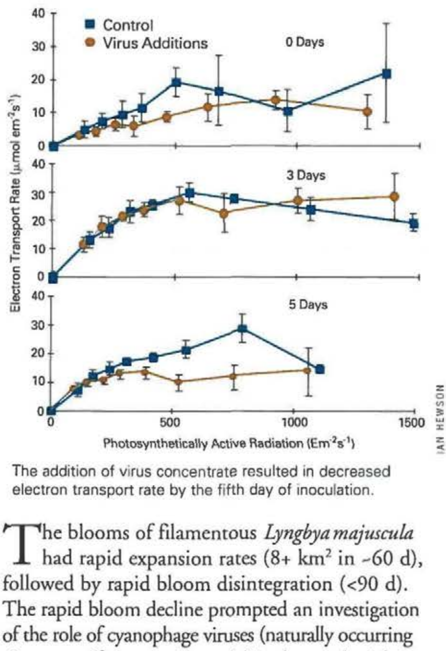
As *Lyngbya majuscula* is predominantly a benthic organism, understanding how this cyanobacterium interacts with the sediment and microbial nutrient dynamics is a key component in understanding how blooms are both established and maintained. Evidence-to-date suggests that *L. majuscula* may exert a strong influence on, and may in turn be strongly affected by pore-water nutrients and influence flux from the sediments, by influencing redox levels particularly on a diurnal basis. Lower oxygen results in the flux of key nutrients such as P, Fe and NH_4 to the overlying water column. Microsensor measurements of oxygen and redox profiles in sediments with and without *L. majuscula* indicate this cyanobacterium has a clear impact on the sediment chemical environment with substantial oxygen generation in the surface layers during the day but also causing localised anoxia especially at night. The possibility that this cyanobacterium alters its environment to provide essential nutrients (nitrogen, phosphorus and iron) from the sediment by creating areas of anoxia, may be important in promotion and maintenance of blooms.

Pore-water profiles indicate that during *L. majuscula* blooms, pore-water nitrogen (N) concentrations increased dramatically, with oxides on N increasing two orders of magnitude. The nutrient depth profile changed as well, with a tendency towards a stronger peaks 'in concentration' in the upper sediment layers. As a N-fixing organism, the observed trends likely reflect the substantial N input resulting from rapid growth and decay of the large *L. majuscula* biomass. An equivalent increase in phosphorus (P) concentration was not observed, highlighting the importance of *L. majuscula's* nitrogen fixing capability, and possibly the need for P to sustain blooms.

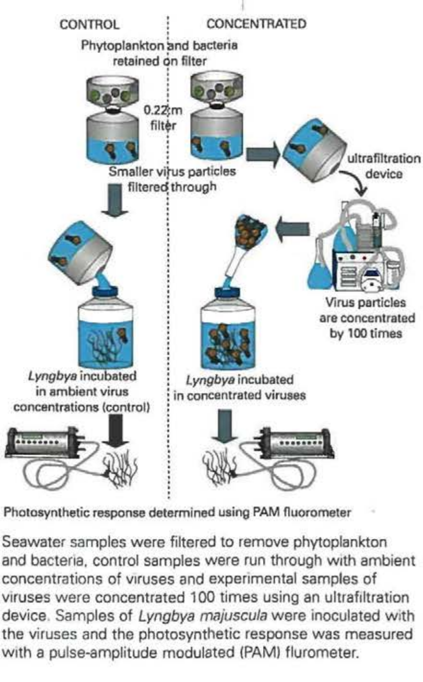


Microsensor measurements of dissolved oxygen through a *Lyngbya majuscula* matrix.

Viruses affect Lyngbya blooms



The addition of virus concentrate resulted in decreased electron transport rate by the fifth day of inoculation.



Photosynthetic response determined using PAM fluorometer

Seawater samples were filtered to remove phytoplankton and bacteria, control samples were run through with ambient concentrations of viruses and experimental samples of viruses were concentrated 100 times using an ultrafiltration device. Samples of *Lyngbya majuscula* were inoculated with the viruses and the photosynthetic response was measured with a pulse-amplitude modulated (PAM) flurometer.

The blooms of filamentous *Lyngbya majuscula* had rapid expansion rates (8+ km^2 in ~60 d), followed by rapid bloom disintegration (<90 d). The rapid bloom decline prompted an investigation of the role of cyanophage viruses (naturally occurring viruses specific to cyanobacteria) in the ecophysiology of *L. majuscula*. Virus-like particles were observed using electron microscopy following ultraviolet irradiation of *L. majuscula* filaments. The UV light causes viruses hidden silently within the genome (latent viruses) to become active. The virus-like particles were similar in morphology to viruses in the genus *Cyanostyloviridae*. The effect of viruses on *L. majuscula* photosynthesis was investigated by a) creating a virus concentrate using tangential-flow ultrafiltration of seawater surrounding *L. majuscula*, b) inoculating *L. majuscula* with the concentrate and c) measuring photosynthetic response using a PAM fluorometer.

Virus concentrate addition resulted in decreased initial fluorescence (F_o), decreased photochemical efficiency (F_v/F_m) and decreased electron transport rate in rapid light curves. Viruses present within *L. majuscula* filaments (temperate viruses) as well as viruses present in the surrounding seawater that infect the cyanobacteria (lytic viruses) may both play an important role in the bloom dynamics of this ecologically important cyanobacterium.

What are Cyanophages?

Cyanophages are viruses that infect cyanobacteria such as *Lyngbya*. Infective cyanophages are extremely abundant in the marine environment. These viruses have a measurable impact on their hosts rate of carbon-fixation and nutrient cycling. Furthermore, cyanophages can control cyanobacterial community structure and diversity.

Faunal assemblages in *Lyngbya* blooms


C. ROELFSEMA, MARINE BOTANY, UQ

Echinoderms such as starfish can be found amongst *Lyngbya majuscula* blooms.

Faunal assemblages in and around *Lyngbya majuscula* blooms are extremely diverse and variable at different sites as well as different phases of the bloom. The faunal community includes organisms of many single classes including those living in and around the macroalgae, seagrass and sediments where *L. majuscula* blooms. It also includes organisms living on and within the cyano-bacterial filaments and organisms capable of moving in and out of the bloom area, either using the bloom as a feeding ground or as habitat.

The diversity of bottom organisms (benthic species richness) decreased at Deception Bay and increased at Eastern Moreton Bay between pre and peak-bloom conditions. Deception Bay was dominated by hermit crabs and snails that were, in contrast, found in very low abundance at Eastern Moreton Banks. The harpacticoid copepod *Metis holothuridae* was present at both sites in pre-bloom conditions, increasing markedly during the peak bloom at both sites.

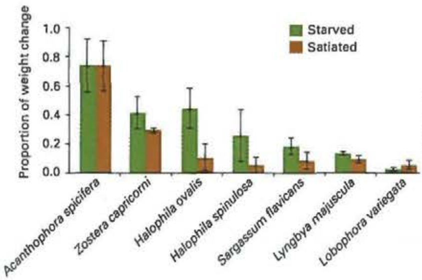
Cyanobacteria in general are not considered particularly good food sources for grazing organisms given their potential toxicity as well as the absence of some essential nutrients. There are, however, organisms that find ways to exploit an abundant food source. Many cyanobacteria have specialised grazers that can either tolerate or detoxify the toxins present in the food source.

A two-pronged approach to research into bloom dynamics was adopted in this study examining the role of "top down" (grazers) vs "bottom up" (nutrient) control of biomass. Several naturally occurring organisms have been suggested as potential "biological mediating agents". The copepod *Metis holothuridae* is able to graze this cyanobacteria but it is a generalist able to graze many things and aids in breakdown and recycling on a local scale. Most are generalists, including the fish *Siganus fuscescens* (black trevally or rabbit-fish); the harpacticoid copepod *Metis holothuridae*; and the molluscs *Haminoea*; *Bursatella* and *Stylocheilus*. Only the latter, *Stylocheilus striatus* is a specialised feeder on *L. majuscula*.

Relative abundance of the haepacticoid copepod *Metis holothuridae*.

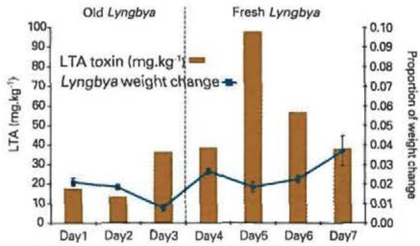
	Deception Bay	Amity Banks
Pre-Bloom	+	++
Bloom	+++	+++

Siganid fish do not preferentially graze *Lyngbya*



A. CAPPER, UQ

Siganus fuscescens has been observed feeding on *Lyngbya majuscula* in the field, but in a feeding trial, the fish preferred algae and seagrass over *Lyngbya majuscula*.



Lyngbyatoxin A levels were plotted together with proportion of *Lyngbya majuscula* weight change to determine if toxin levels affected grazing by *Siganus fuscescens*. There is a weak trend for *Siganus fuscescens* to reduce feeding intensity when toxin levels are high.

The herbivorous fish *Siganus fuscescens* (black trevally or rabbitfish) has been observed feeding on *Lyngbya majuscula* in Moreton Bay and in other parts of the world, and has been suggested as a potential candidate for bio-control of *L. majuscula*. A feeding preference trial was conducted in the laboratory using wild *S. fuscescens* which indicated that *L. majuscula* was not a preferred food source when other choices were available. The fish preferentially consumed the algae *Acanthophora* and the seagrass *Zostera capricorni*. The siganids continued to consume their favoured plant foods under simulated *L. majuscula* bloom conditions in the lab. Over a short period (7 days), both wild and naïve (bred) *S. fuscescens* were deterred from grazing *L. majuscula*.

C. ROELFSEMA, MARINE BOTANY, UQ

Siganus fuscescens (black trevally or rabbitfish).

The high acidity of the *Siganus fuscescens* stomachs (pH 2.44) may be capable of lysing cells of *Lyngbya majuscula*, thereby releasing the toxins. *L. majuscula* has been implicated at the causal agent in food poisoning episodes. This suggests the possibility of bioaccumulation of toxins with implications for human consumption and *Siganid* predators. The commercial *S. fuscescens* catch from Moreton Bay in 1998 was estimated at 131 T, worth $327,000 (DPI 2000). Therefore, understanding if toxins persist in the food web is of concern. Feeding trials were conducted with naïve *S. fuscescens* that were fed on *L. majuscula* with different toxin levels and as the toxin level increased, there was a trend towards reduced feeding intensity. The findings of this study suggest that *S. fuscescens* is not a good candidate for bio-control.

Sea hares graze on *Lyngbya*

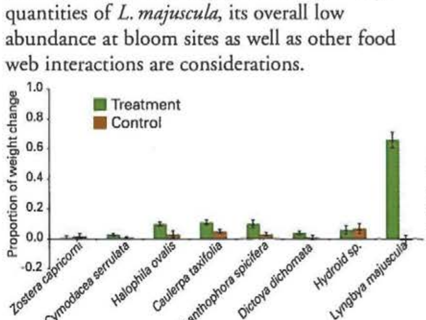
A. CAPPER, UQ

The sea hare, *Stylocheilus striatus*, is a specialised feeder on *Lyngbya majuscula*.

The sea hare, *Stylocheilus striatus* proliferated in aquaria containing *Lyngbya majuscula*. Egg masses of the *S. striatus* were found both on the *L. majuscula* as well as on the sides of aquaria. The *S. striatus* demonstrated a distinct feeding preference for *L. majuscula* even in the presence of other food, although, they will graze filamentous macroalgae including *Bryopsis sp.* and *Giffordia sp.* Feeding trials showed that small *S. striatus* have a rapid growth rate (300 – 800% over 8 days) when feeding on *L. majuscula* alone.

L. majuscula showed a marked decrease in biomass (90% in 12 hours) in the presence of starved *S. striatus* in laboratory experiments. *S. striatus* consume a greater proportion of *L. majuscula* and increase their biomass at warmer temperatures (24 – 26°C) but consume less and lose weight faster at cooler temperatures.

The potential of *S. striatus* as a bio-control agent needs to be addressed cautiously. While these lab results do indicate its ability to consume large quantities of *L. majuscula*, its overall low abundance at bloom sites as well as other food web interactions are considerations.



A. CAPPER, UQ

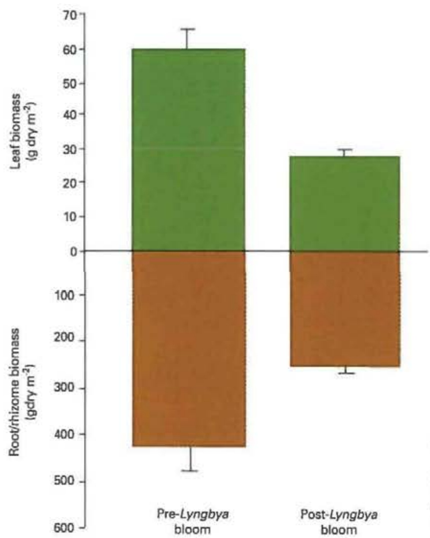
Lyngbya majuscula showed a significant decrease in biomass in the presence of *Stylocheilus striatus*.

Seagrass and mangrove dieback during *Lyngbya* blooms

During blooms, seagrass beds are significantly impacted by *Lyngbya majuscula* coverage through reduction in light availability and by increasing anoxia. When *L. majuscula* detaches from the benthos and floats to the surface, the biomass often deposits on the foreshore beaches. This has been a particular problem in the Pebble Beach and Godwin Beach sections of Northern Deception Bay during late summer months. The rotting material is not only a health risk, due to potential contact toxicity, but also potential aerolisation and hydrogen sulfide production due to the natural decay of the abundant quantities of biomass. In addition to the health concerns, there are also aesthetic and economic concerns for the residents and tourists using these beaches. Shire Councils have had to spend significant resources removing this material with bulldozers and in disposal at land-fills.

The removal of decaying *Lyngbya majuscula* from mangroves using a vacuum pump.

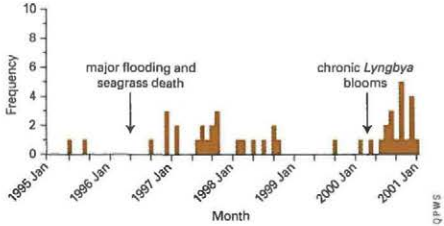
In addition to residential areas, *L. majuscula* blooms affect significant areas of mudflats and mangroves. The ecological impacts are severe, as *L. majuscula* smothers mangrove seedlings and pneumatophores and leads to anaerobic conditions at the sediment surface. Quantitative results are yet to be obtained on the extent of the damage, but it appears that the smothering by *L. majuscula* results in seedling malformation and mortality.



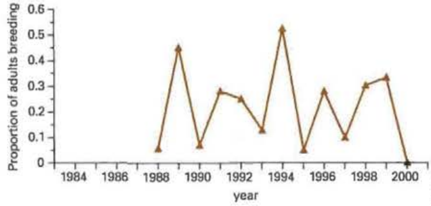
Lyngbya majuscula blooms have significantly impacted on *Syringodium isoetifolium* seagrass beds. Reduced light and increased anoxia resulting from a bloom,cause a reduction in both leaf and root biomass.

Mangroves seedlings flattened by *Lyngbya majuscula*.

Effects on *dugong, turtles and fisheries*



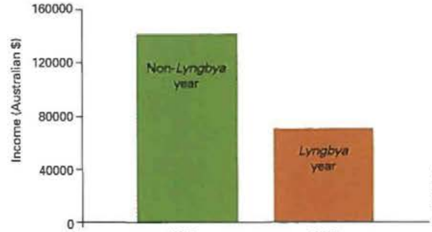
The number of dugong strandings and deaths increased over months following *Lyngbya majuscula* blooms to levels not seen since major flood events.



The proportion of adult female green turtles in Moreton Bay which are breeding was at its lowest percentage in 2000, which coincides with the occurrence of large blooms of *Lyngbya majuscula* on the Eastern Banks.

The occurrence of blooms of *Lyngbya majuscula* on the Eastern Banks in Moreton Bay is correlated with a ten year low measurement of dugong herd size, the highest annual dugong mortality since major flood events, and the lowest percentage of female green turtles preparing for breeding. However more research on the interaction of these macrograzers is needed to confirm causes.

Lyngbyatoxin A has previously been isolated from the flesh of the green turtle *Chelonia mydas* in Madagascar. This toxin has been known to promote tumours *in vivo*, and it has been hypothesised that the occurrence of fibropapilloma in turtles may somehow be linked to the presence of toxins from *L. majuscula*. Studies in the US have linked the occurrence of fibropapilloma in sea turtles to the toxic dinoflagellate *Prorocentrum*. It is clear that research in this area is key to the long term health and viability of both sea turtle and dugong populations in Moreton Bay. Economic consequences of *Lyngbya* blooms include reduced fisheries, tourism loss and local council costs for *Lyngbya* beach clean-up.



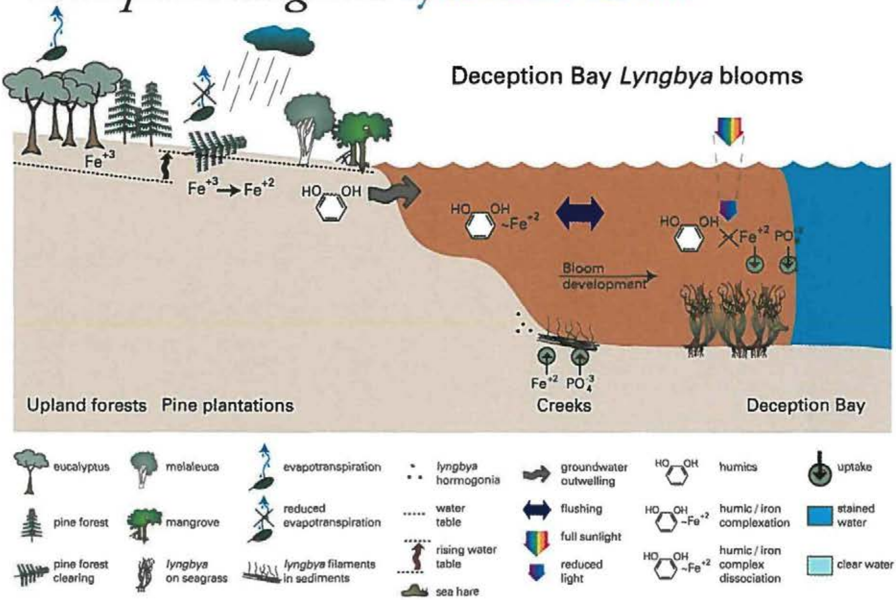
Fisheries income decreased from 1995 to 1997, which corresponds to an increased prevalence of *Lyngbya* blooms.

Turtles in Moreton Bay have recently been found with fibropapilloma.

Fibropapilloma Disease

Green sea turtles develop fibropapillomas that appear as lobe-shaped tumours which infect the soft portions of the turtles body. Tumour-promoting toxins such as those produced by *Lyngbya majuscula* have been implicated as a cause of this disease. *L. majuscula* forms dense mats covering seagrass and macroalgae which form the basis of the turtles diet. The disease may therefore be related to the assimilation of tumour-promoting toxins which occurs during digestion.

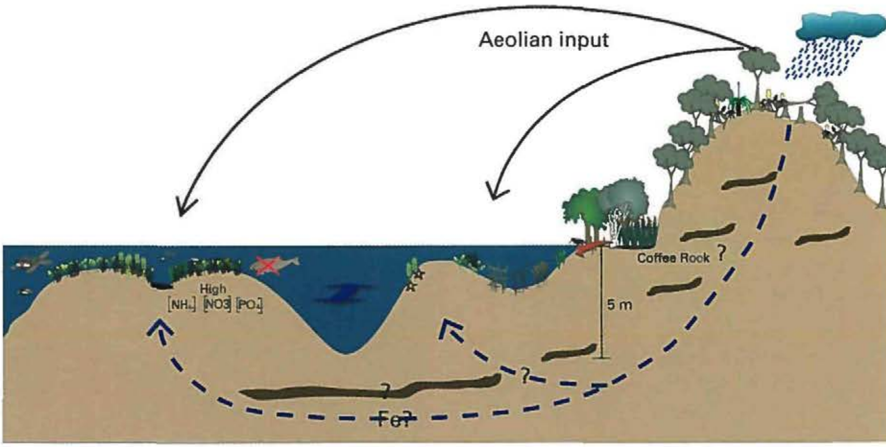
Conceptual diagrams synthesise results



A conceptual diagram was developed summarising the current understanding of the processes leading to formation and delivery of bio-available iron in the Deception Bay and Pumicestone region. Conceptual diagrams are modified as new information is acquired.

Deception Bay

In the early phases of the bloom, *Lyngbya majuscula* cells (hormogonia) appear to develop into filaments in the sediments and grow on the sediment and on seagrass macroalgal substrates. For *Lyngbya majuscula* to proliferate, it requires sources of phosphorus and bioavailable iron (Fe). Nitrogen (N) is sourced from N fixation in the initial stages of a bloom, however, *L. majuscula* is capable of taking up NO_x and NH_3 if available. There are large sources of Fe in the catchment from the Landsborough sandstone, but a transport mechanism is required to deliver bioavailable Fe (dissolved Fe^{+2})to *L. majuscula* bloom sites. Reduced evapotranspiration resulting from large-scale catchment disturbance results in rising water table. Water-saturated soils become anoxic and the chemical reduction of dissolved Fe compounds leads to the formation of Fe^{+2}. Rainfall events carry organic-rich waters, which form complexes with Fe^{+2}. The humic/Fe^{+2} complexes are then flushed into northern Deception Bay. With sufficient light, photolysis (splitting by light) results in the dissociation (separation of the humic Fe^{+2} complexes), thus making Fe^{+2} available for uptake by *L. majuscula* probably by enzymes associated with the surface of *L. majuscula*. These particular sources and transport mechanism may be unique to Deception Bay blooms, however, casual factors may be similar in other areas where *L. majuscula* blooms have been observed.



Potential causes of blooms conceptual diagram for the Eastern Banks *Lyngbya majuscula* blooms, linking possible iron sources from groundwater and aeolian (wind/dust) inputs. Causes of the proliferation and persistence of *Lyngbya majuscula* blooms in the Eastern Banks, require further study.

Eastern Moreton Banks

Lyngbya majuscula blooms were first documented in eastern Moreton Bay in 2000. These blooms have persisted through the winter months. Monitoring of these blooms have been conducted by the Queensland Parks and Wildlife Services and University of Queensland Marine Botany Group since then. Although studies indicating direct "cause and effects" have not been conducted, *Lyngbya* presence on the Eastern Banks and overgrowth on seagrass has been correlated with a ten year low measurement of dugong herd size, the highest annual dugong mortality and the lowest percentage of female turtles preparing for breeding.

ENVIRONMENTAL PROTECTION AGENCY

The Eastern Banks area is a relatively pristine area of Moreton Bay with extensive seagrass meadows.

The Eastern Bay conceptual diagram summarises the various hypotheses on the causes of *Lyngbya majuscula* blooms, e.g. role of groundwater and atmosphere in the transport of the causative factors of the blooms. The proximity of Stradbroke Island and potential groundwater seepage is one potential source of nutrients; there is also potential for aeolian (wind) driven input from Stradbroke Island. Land disturbance or clearing on the island may lead to increased groundwater, surface flow and aeolian transport. However, more studies are needed on the specific causes for blooms on the Eastern banks.

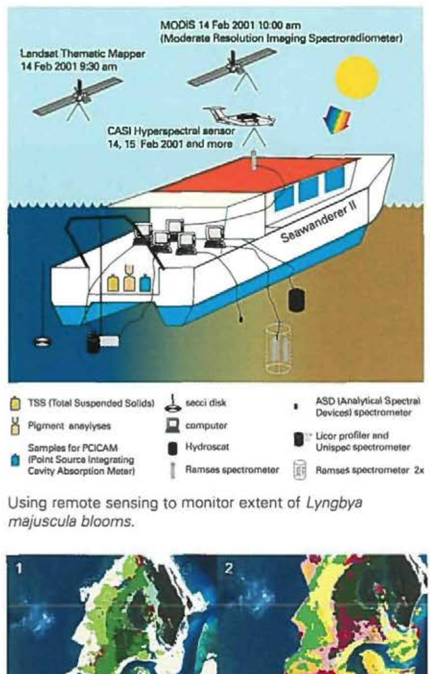
Developing techniques to *track changes*

To study the origins and development of the bloom, an accurate and cost-effective means is required to map bloom extent and its biophysical properties. Mapping these areas using intensive field work can not provide full spatial cover at any one point in time. Algal blooms have been mapped successfully from remotely sensed data in a number of different habitats worldwide.

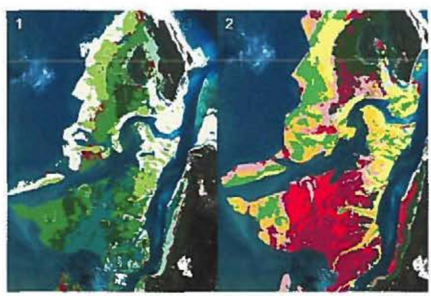
Lyngbya majuscula occurs seasonally in Moreton Bay and vary in duration and timing. For instance, blooms have been mapped over areas that range from 8 km^2 to 80 km^2. *Lyngbya majuscula* does not cover 100% of affected areas. Rather, the cyanobacteria occur as patches that range from several metres to hundreds of metres.

A procedure to monitor the extent of *Lyngbya majuscula* blooms in Moreton Bay is currently being developed. It applies image classification to satellite (Landsat Thematic Mapper) data that are available every 16 days. The images provide the basis for mapping the location of *L. majuscula* by reference to data collected at key sites in the field. The preliminary output maps for Eastern Moreton Bay are considered to be fairly accurate in representing the true distribution observed on the ground during *L. majuscula* blooms. The technique has not been extensively implemented but would prove invaluable for long-term and historical assessment of *L. majuscula* blooms.

The aim of the remote sensing study is to design an operational approach for monitoring the extent and health of *L. majuscula* blooms within Moreton Bay from a combination of field (Queensland Parks and Wildlife Service) and remotely-sensed data before and after bloom events. The overall approach focuses on scaling field data to airborne and satellite imaging data.



Using remote sensing to monitor extent of *Lyngbya majuscula blooms.*

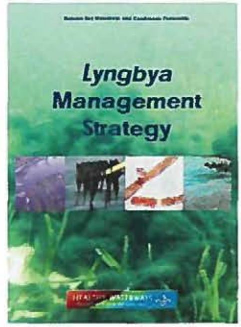


Corals		Sand	
Lyngbya 1 - 25		Sand deep	
Lyngbya 25 - 50		Sand Mid	
Lyngbya 50 - 75		Seagrass deep	
Lyngbya 75 - 100		Seagrass high	
Mud flat		Seagrass Low	

Lyngbya majuscula distribution in Eastern Moreton Bay based on classification of remote sending images based on spectral signatures (1) before and (2) during the 2000 *Lyngbya majuscula* bloom. *Lyngbya majuscula* is represented by shades of red.

Lyngbya management strategies

Vacuums which pump *Lyngbya majuscula* and water from foreshores and mangroves during high tide, to containers where the *Lyngbya majuscula* is filtered out, were used to reduce *L. majuscula* biomass on foreshores.



The *Lyngbya* Management Strategy, a document produced by the cooperative approach involving all levels of government, the community, and industry.

The overall *Lyngbya majuscula* bloom problem in South East Queensland is a multi-faceted problem with ecosystem, human health, economic, social and tourism industry issues. It is likely that no one factor triggers the bloom events, rather a confluence of physical, chemical and biological factors synergistically allowing the perfect environment for the growth of this nuisance cyanobacterium. It is always far easier, and less costly to prevent problems than to clean them up after the fact. As the problem was not created overnight, the problem will not be solved instantaneously. Patience and research are needed to unravel the tangled mess of "Mermaid's Hair". However there are a few recommendations to be made invoking the precautionary principle to reduce nutrient and organic runoff into the waterways.

While it would be easier to prevent blooms, the reality remains that blooms do indeed occur, causing significant impact on those who live, work and recreate in the bloom areas. During and after the blooms in Deception Bay it was imperative that some alleviation of the blight upon the foreshore was initiated. Therefore, mitigation trials were carried out by Queensland Parks and Wildlife Service (QPWS) to assess the feasibility and benefits of *L. majuscula* removal techniques.

The primary objectives were to reduce the impact of *L. majuscula* blooms on seagrass and mangrove communities and to reduce the impact of rotting biomass when washed onshore.

As part of developing management strategies, an ARC Linkage Grant is underway that provides research that may assist in reducing discharges to adjacent water bodies. In response to the challenges presented by the occurrence of blooms in our coastal waters, a cooperative approach, involving all levels of government, the community and industry is identifying and the causes of this complex problem. The *Lyngbya* Management Strategy details the catchment protection actions that aim to reduce the land-based pollutions at their source. It also provides information on the scientific work being conducted on the Eastern Bay blooms, bloom mitigation techniques and stakeholder and community education initiatives.

It is through the adoption of best practice environmental management of our land-based activities, and the achievement of sustainable land management practices, that we can attempt to ameliorate the causative factors associated with *Lyngbya* blooms in Moreton Bay.

CONTRIBUTORS (in alphabetical order)

Eva Abal, Karen Arthur, Col Ahern, Simon Albert, Angela Capper, Lee Carseldine, Malcolm Cox, John Driver, Tony Chiffings, Jack Greenwood, Kylie Hey, Ron Johnstone, J. Kwik, Pippi Lawn, Col Limpus, Ben Longstaff, Tred Lukondeh, Phil Moody, B. Neilan, Peter Oliver, Nick Osborne, Stuart Phinn, Micaela Preda, Shane Pointon, Bernie Powell, Chris Roelfsema, Andrew Rose, Tim Salmon, Julie Savage, Greg Savige, Glen Shaw, Ian Tibbetts, David Waite, Andrew Watkinson, and Miles Yeates.

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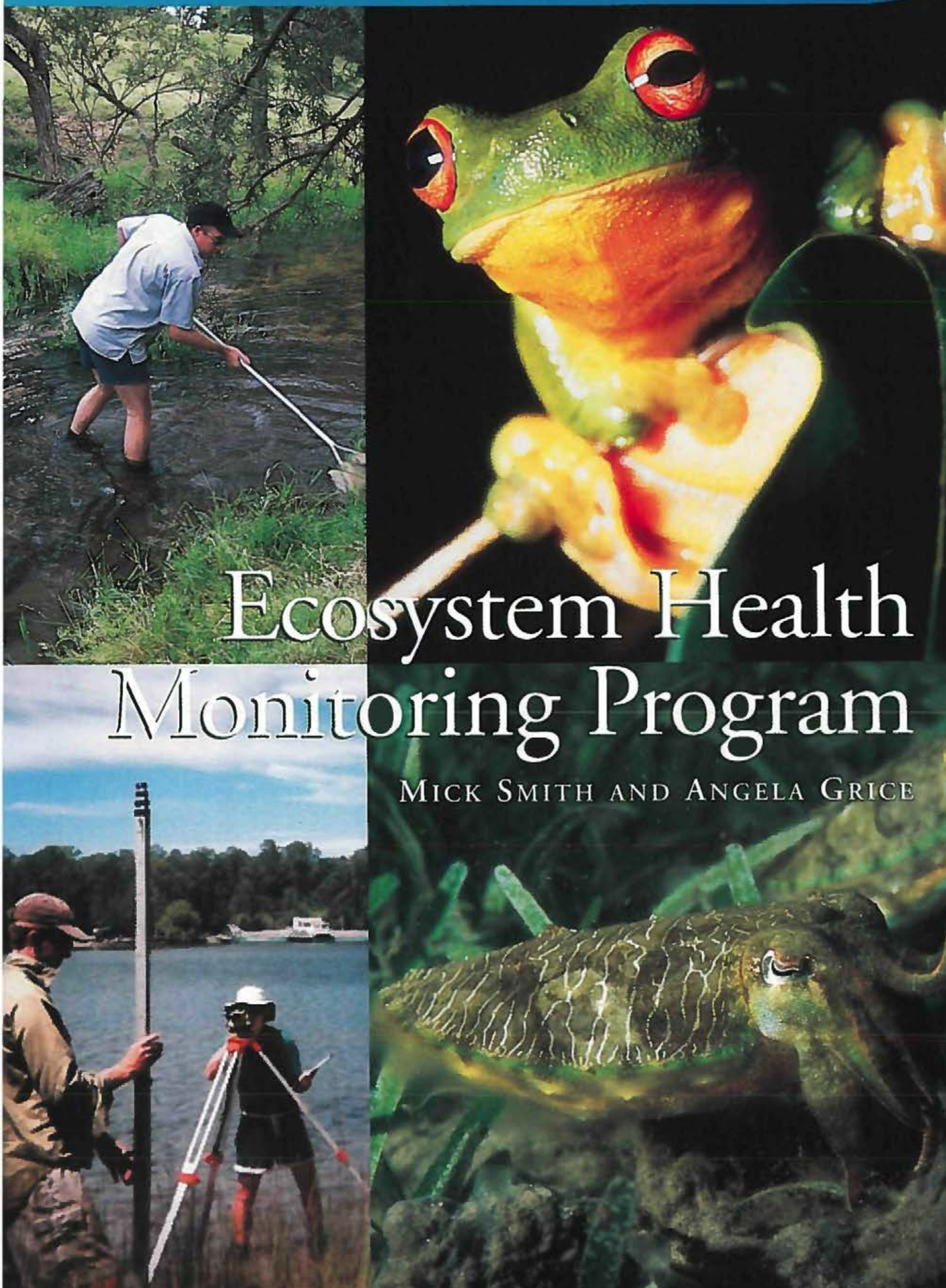
Chapter 7



Ecosystem Health Monitoring Program

MICK SMITH AND ANGELA GRICE

Ecosystem Health Monitoring: An important management tool

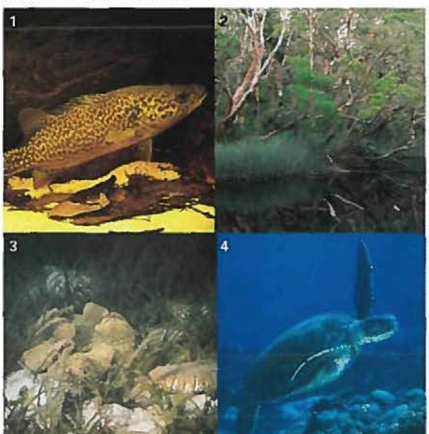
We receive reports on the environment we live in through daily/hourly updates on the weather, daily traffic reports, and regular share market updates. We expect to have information available on a range of topics that shape the world we live in. For environmental indicators, updates are more informative if reported on longer time scales that incorporate natural variability.

In recent decades, we have become more aware of the negative effects that we are having on our environment. This awareness has led to a greater desire to assess the state of our ecosystems, particularly the aquatic environment, which has often been overlooked because impacts are out of sight and hence, out of mind. This heightened concern has in turn led to a need for greater understanding of how our aquatic environments function and how they are affected by our activities.

While in the past we have measured physical and chemical attributes of our aquatic environments, such information is no longer deemed adequate because it does not tell us about the biological or ecological *health* of our environment: that is about the effect that we are having on aquatic plants and animals. As such, state-of-the-art monitoring programs include biological indicators that assess ecological patterns and processes as these provide a direct measure of the effect of human activities on aquatic ecosystems.

An **E**cosystem **H**ealth **M**onitoring **P**rogram (EHMP) is an important tool for both environmental managers and the community. It uses biological, physical and chemical indicators to provide an objective assessment of the health of an ecosystem. Such information can provide early warnings about declines in ecosystem health and is invaluable when evaluating the ecological benefits of management actions such as riparian rehabilitation and improved sewage treatment.

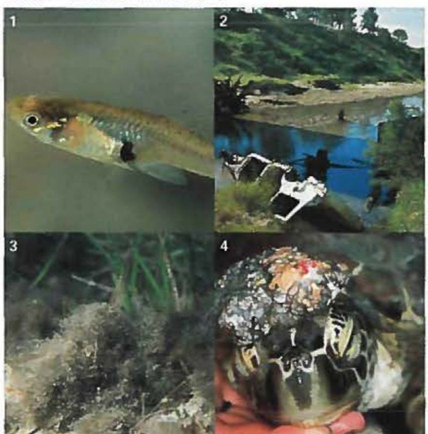
Species and habitats associated with healthy ecosystems in South East Queensland



(1) GUNTHER SCHMIDA (2) ENVIRONMENTAL PROTECTION AGENCY (3+4) CHRIS ROELFSEMA, MARINE BOTANY, UQ

(1) Mary River Cod, (2) Healthy riparian cover, (3) Healthy seagrass beds with diverse fauna and (4) A healthy turtle.

Examples of animals and occurances that typify poor ecosystem health in South East Queensland



(1) DPI FISHERIES (2) HEALTHY WATERWAYS LIBRARY (3) CHRIS ROELFSEMA

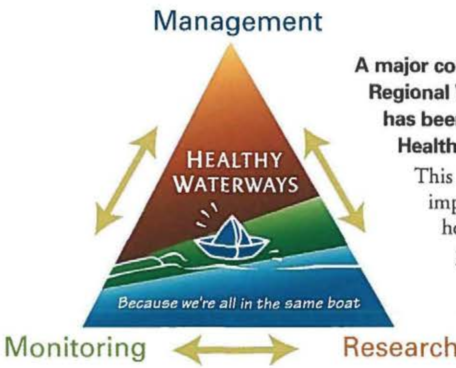
(1) *Gambusia*, an alien (introduced) fish, (2) Poor riparian cover, (3) Unhealthy seagrass beds with *Lyngbya majuscula* and (4) Turtle infected with fibropapilloma.

In the past few years, there has been a great deal of investigation as to what constitutes a healthy ecosystem. One of the more universally accepted definitions (Rapport *et al.*, 1998) states that a healthy ecosystem has three basic attributes:

1. **Vigour –** refers to the rates of processes, such as the productivity or "pulse" of an ecosystem. A strong steady pulse is desirable, whereas a racing pulse or no pulse are signs of major disturbance;
2. **Organisation –** refers to the structure or number of interactions within an ecosystem. Healthy ecosystems have many species and interactions (e.g. a complex food web) whereas heavily disturbed systems are highly simplified and have fewer interactions;
3. **Resilience –** refers to an ecosystem's ability to recover following disturbance. Healthy ecosystems should "bounce back" soon after a disturbance, unhealthy ones may not recover.

What is a healthy ecosystem?

A healthy aquatic ecosystem is one that is stable and sustainable; maintaining its physical complexity, biodiversity and resilience to stress. It has the ability to provide ecosystem services that promote good water quality, wildlife and recreation.



A major component of the South East Queensland Regional Water Quality Management Strategy has been the development of the Ecosystem Health Monitoring Program.

This monitoring program has been implemented to independently evaluate how effective the various environmental protection strategies are in restoring and protecting the ecosystem health of South East Queensland's rivers, estuaries and Moreton Bay.

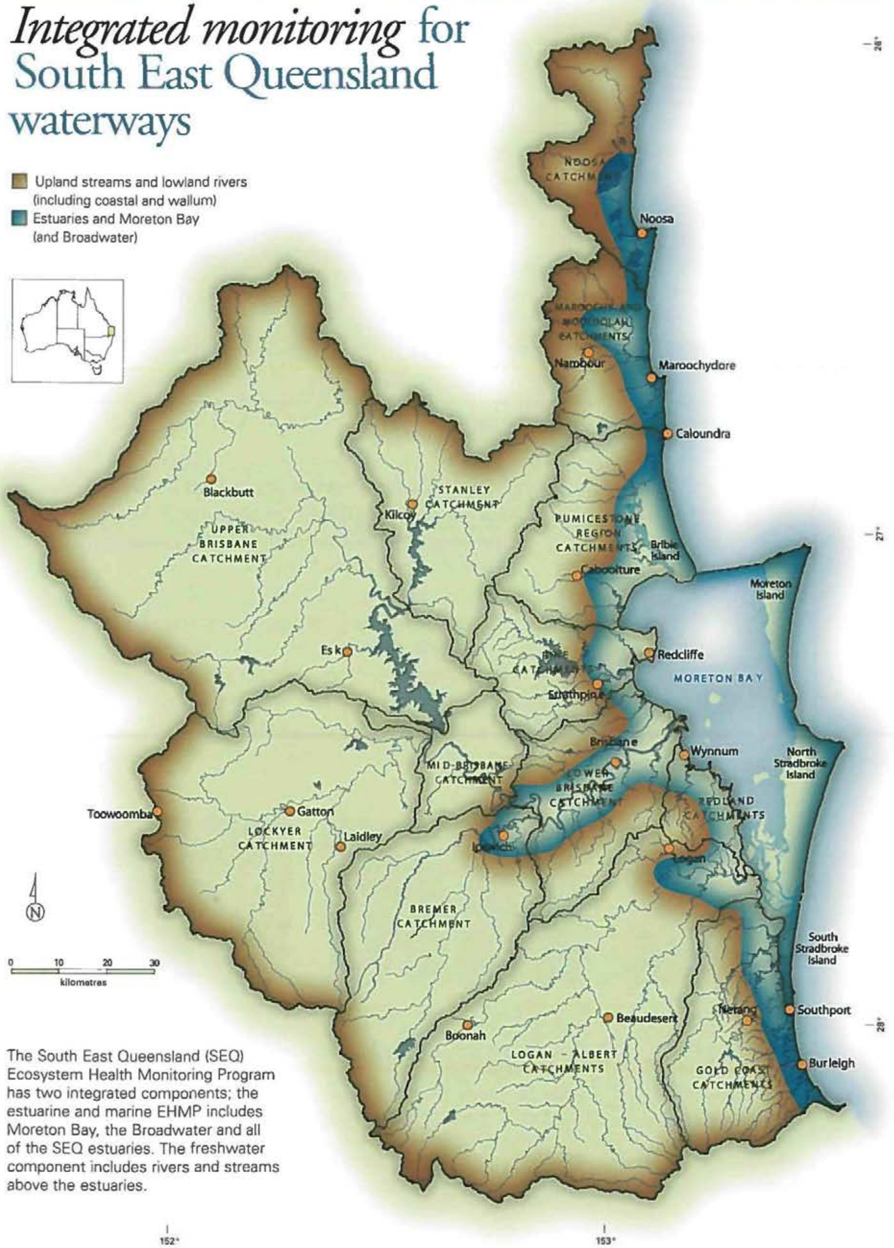

Management
Managers have upgraded sewage treatment plants, installed stormwater quality improvement devices and implemented many of the recommendations made by scientific researchers. In addition, managers have raised other questions that need to be investigated.


Research
Highly acclaimed research has been used to identify the most appropriate tools (indicators) to assess ecosystem health. In addition, this research has pinpointed the most important issues that require prompt management responses to ensure the improved health of our aquatic ecosystems in line with the healthy waterways vision.


Monitoring
The EHMP was implemented in estuarine and marine waters in 2000 and the freshwater component was added to the current program in 2002.

(1,4+5) ENVIRONMENTAL PROTECTION AGENCY
(2) BRISBANE CITY COUNCIL
(3) MICK SMITH, GRIFFITH UNIVERSITY
(6) HEALTHY WATERWAYS LIBRARY

Integrated monitoring for South East Queensland waterways



The South East Queensland (SEQ) Ecosystem Health Monitoring Program has two integrated components; the estuarine and marine EHMP includes Moreton Bay, the Broadwater and all of the SEQ estuaries. The freshwater component includes rivers and streams above the estuaries.

Stakeholders in South East Queensland identified the need for a state-of-the-art monitoring program to assist in the effective management of the region's waterways. In particular, stakeholders required a program that would monitor and assess the effectiveness of the significant investments in environmental protection. It was a high priority for monitoring data collected to be synthesised and communicated to them in a usable form.

The collection of this information and subsequent development and implementation of the monitoring program for fresh, estuarine and marine waterways have been carried out in a staged approach.

Stage 1 focused on establishing strong links between various stakeholders, including Federal, State and Local Government agencies, and a range of industry and community groups. In addition, Stage 1 marshalled teams of scientists who then scoped the necessary scientific investigations.

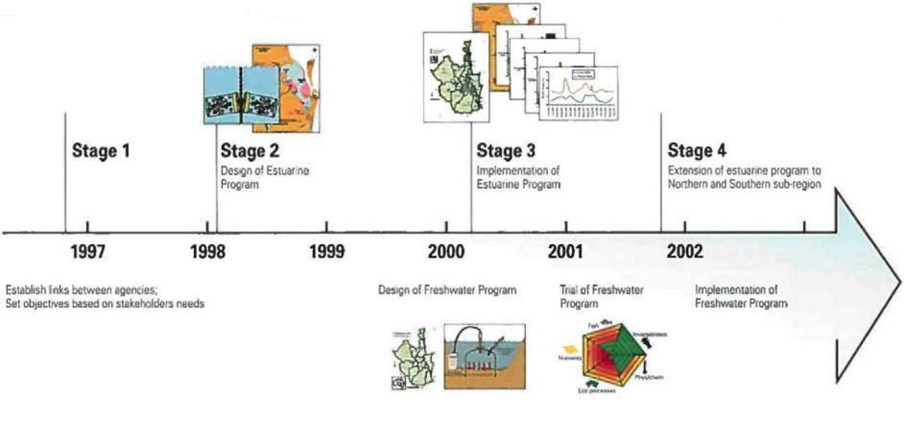
Stage 2 saw the development of the EHMP for river estuaries and Moreton Bay. This focus on marine and estuarine waters was brought about by immediate ecosystem health problems in the Bay (e.g. algal blooms) and the obvious need to plan and implement sewage treatment upgrades.

Six local councils were involved in Stage 2 and the focus was on point sources and their impacts.

In contrast, Stage 3 was much broader, incorporating 19 local councils and addressing regional catchment issues in the rivers above the estuaries. The focus was on diffuse sources of pollution such as sediments and nutrients.

The EHMP for estuarine and marine waters was implemented in January 2000. This program initially included Moreton Bay, as well as the estuarine reaches of the Caboolture, Pine, Brisbane, Bremer and Logan Rivers. This program has now been extended to include the northern subregion (Noosa, Maroochy, Mooloolah and Pumicestone Passage) and the southern sub-region (Nerang, Coomera and Pimpama Rivers and The Broadwater).

The Freshwater EHMP was developed during 2000/2001 under the Design and Implementation of Baseline Monitoring Task. The recommended monitoring program has now been implemented and has led to the establishment of a comprehensive monitoring program for rivers and streams in SEQ.



The design and implementation of the Ecosystem Health Monitoring Program have been undertaken using a staged approach. Both the estuarine/marine and freshwater components are now underway.

Freshwater Monitoring Program developed

When it comes to assessing ecosystem health of freshwaters a wide variety of tools (indicators) are available. This abundance of indicators is a reflection of the complexity of natural systems and an admission that no one indicator can fully summarise the health of an ecosystem. The availability of all these indicators often confounds the assessment of ecosystem health, especially when individuals are strong advocates of their particular indicator. As such, it was necessary to perform an experiment to compare the various indicators and determine which ones were most appropriate for measuring and reporting on stream health in South East Queensland. In 1999 a study team was formed to design and perform this experiment. The team was comprised of freshwater ecologists, natural resource managers, statisticians, water quality experts and community group representatives. They derived a six-step process to identify and test the most appropriate indicators for assessing the health of our rivers and streams.

1 Derive list of potential indicators

Based on experience, local knowledge, expert opinion, and the scientific literature, the team produced a comprehensive list of potential indicators addressing physical, chemical and biological attributes of stream health.

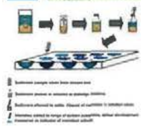
2 Develop conceptual models

Conceptual models (simple schematic diagrams) were developed to highlight the important ecological attributes of streams and show how these are effected by various disturbances. These models were then used to pinpoint the most important attributes of stream health and reduce the list of indicators so only relevant indicators were retained.

3 Classify region into different river types

The study area was divided into different river types on the basis of rainfall, stream size, slope, and altitude. Four broad stream types were identified: Upland, Lowland, South Coastal, and North Coastal (or Wallum). This was an important step that ensured that any comparisons of health were between similar types of streams.

4 Perform pilot studies



Pilot studies (small field and laboratory experiments) were undertaken to assess less-proven indicators. These included techniques to measure aspects of stream health that have not been routinely investigated in biomonitoring programs. Indicators that performed well in the pilot studies were included in the major field trial: those that did not were dropped.

5 Undertake major field trial

MICK SMITH, GRIFFITH UNIVERSITY

In September 2000, four teams of field workers trialed a range of potential indicators at 53 sites in South East Queensland. Results for each indicator were assessed against a known gradient of diffuse disturbance caused by land use (from forested to urbanised catchments). Those indicators that responded strongly to the disturbance gradient were included in the monitoring program while those that responded poorly were omitted.

6 Use results for EHMP

Results showed that five types of indicator responded well to the land use disturbance gradient. Importantly, these groups each tell us something different about the nature of the disturbance. The five types recommended for the EHMP include two indicators of stream processes, two biodiversity measures, and one concerning water quality/chemistry.

Conceptual diagrams used to identify indicators

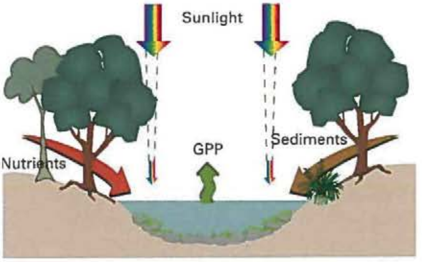
Step 1 Derive list of potential indicators

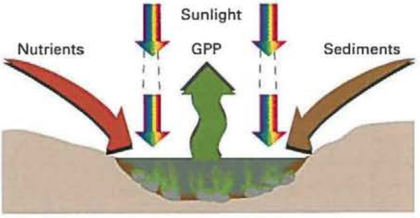
Based on experience, local knowledge, and the scientific literature, the study team assembled an exhaustive list of potential indicators. Initially, the list consisted of more than fifty indicators and included indicators of ecosystem health and human health as well as direct physical measures of disturbance such as flow regulation. Importantly, the list included indicators of both ecological processes and biological patterns to measure vigour and organisation of the ecosystem, respectively.

Potential ecosystem health indicators considered for the freshwater EHMP

Ecosystem processes	Biological patterns
Amino acid composition of algae	Structure and function of fish communities
Benthic metabolism (includes GPP, R_{24})	Structure and function of macrophyte communities
Tracking sewage Nitrogen using $\delta^{15}N$	Structure and function of macroinvertebrate communities
Tracking catchment disturbance using $\delta^{15}N$	Structure of benthic microbial community
Use of $\delta^{13}C$ as a potential surrogate of GPP	Structure and function of diatom community
Tracking trophic structure using $\delta^{13}C$	Fish condition/Fish kills
Change in denitrification potential	Health and presence of "megafauna" (e.g. platypus)
Filamentous algae – nutrient or shade limitation	Presence of exotic species
Chlorophyll *a* – as measure of algal biomass	Asymmetry/high rates of deformities
Depth of O_2 penetration in sediments	Bio-accumulation of pesticides and metals
Water chemistry	**Water chemistry**
Nutrient concentrations	Alkalinity / pH / hardness
Nutrient flux to and from sediments	Dissolved oxygen – snapshot/diel measures
Salinity/conductivity/ionic composition	Water temperature – snapshot/diel measures
Pesticides – snapshot /integrative measures	Turbidity – snapshot/diel measures

Step 2 Develop conceptual models





Conceptual models illustrating how riparian vegetation affects Gross Primary Production (GPP) and the growth of plants/algae in stream ecosystems.

Conceptual diagrams have been used throughout the study to illustrate our understanding of how healthy aquatic ecosystems function. These simple schematic diagrams are based on current scientific knowledge and show the linkages between major controlling factors (e.g. flow, light, nutrient and sediment inputs) and components of the ecosystem (e.g. fish, macroinvertebrates, algae).

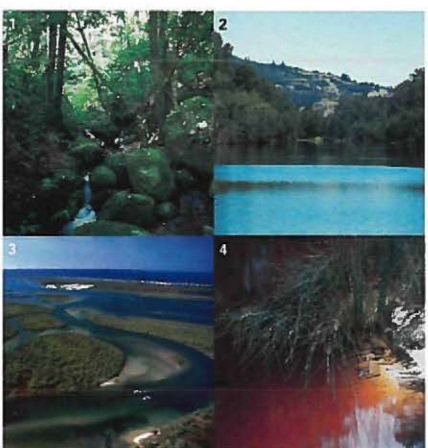
Conceptual diagrams proved invaluable when reducing the list of potential indicators as it enabled researchers to pinpoint those components of the stream that should be measured to assess ecosystem health. For example, stream productivity, a measure of vigour that is critical in maintaining ecological integrity, increases as a result of riparian clearing. As such, one feature of stream health that needs to be measured to assess the effects of riparian clearing is productivity.

Streams classified to identify different types

Step 3 Classify streams into different types

An important step in the development of the freshwater monitoring program was the classification of South East Queensland's waterways. This was done because assessments of health are often comparisons between undisturbed and disturbed streams. As such, it is important to ensure that comparisons are between similar types of stream. Also, it was necessary to identify major stream types to ensure all stream types were included in the major field trial (Step 5).

Each stream was broken down into a series of small segments and a value for rainfall, altitude, slope and stream size was assigned to each segment. These four physical attributes were chosen because they have not been dramatically altered by human activity, and therefore reflect the natural stream types within the region. The preferred classification revealed four river types:



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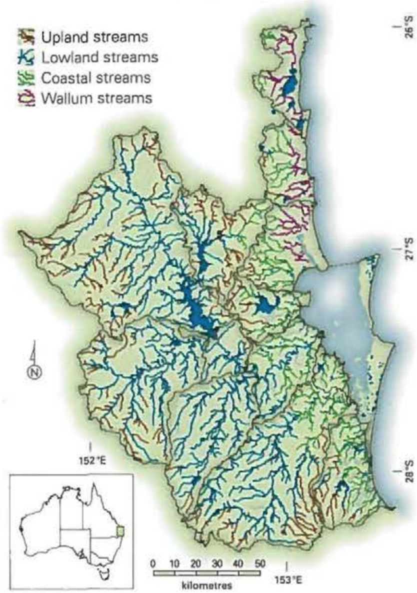
Upland (1), lowland (2), coastal (3) and wallum (4) streams in South East Queensland are distinguished based on physical characteristics.

Upland streams – small, steep streams found in very high rainfall areas at higher altitudes

Lowland streams – larger streams with lower gradients and less rainfall occurring at lower altitudes

Coastal streams – small to moderate sized coastal streams south of the Caboolture River at low altitude receiving high rainfall

Wallum streams – small to moderate sized coastal streams north of the Caboolture River at low altitude receiving high rainfall



Classification of South East Queensland waterways was an important step for the design of the freshwater monitoring program as it allowed physically similar streams to be compared. The waterways were classified according to stream size, altitude, slope and rainfall.

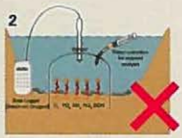
Pilot studies used to develop and assess indicators

Step 4 Testing the merit of novel indicators

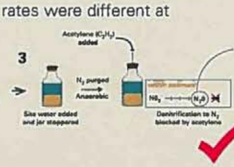
The focus on ecosystem health rather than water quality meant it was necessary to assess the worth of some novel (i.e. less-proven) indicators which offered more direct measures of stream health. A range of novel indicators were subjected to pilot studies (small field and laboratory experiments) to assess their usefulness. Those indicators that responded to ecological disturbance were retained for inclusion in the major field trial (*Step 5*); those that performed poorly were discarded. A brief explanation of what each indicator measures and how it fared in the pilot studies is given below.

Benthic metabolism – Measures the amount of production and respiration (see definitions page 15) that occurs on the stream bed. The pilot study investigated the amount of variability associated with these measures and found that while variability was moderate, the difference between disturbed and undisturbed sites was comparatively large and therefore, this indicator showed promise and should be included in the major field trial.

Nutrient flux – Measures the amount of nitrogen and phosphorus moving between the stream bed and the water column. The pilot study assessed the variability associated with these measures; however, on this occasion variability was very high and unpredictable, and values for disturbed and undisturbed sites were not noticeably different. As such, the indicator was not included in the major field trial.



Denitrification – measures the amount of inorganic nitrogen that is converted to nitrogen gas and thereby removed from the stream. The pilot studies showed that the denitrification rates were different at disturbed and undisturbed sites and thus measurement of denitrification was retained for the major field trial.



Microbes as bioindicators – Ecoplates (standardised 96-well microtitre plates that provide a variety of carbon substrates for microbes to feed on) were used to measure the concentration and diversity of microbes in a sample of stream sediment to see if they were responding to known disturbances. When microbes utilise the carbon, a colour develops. Results showed some promise although a full-scale field trial was not justified. Instead, a second, larger pilot study was undertaken to confirm the worth of this indicator; however, this revealed that further work was required before this indicator could be used routinely.

Fish as bioindicators – Fish communities were measured to see if they are responding to disturbance. A small pilot study was combined with a large desktop investigation to see if fish were responding to known disturbances. Results were highly encouraging and fish were included in the major field trial as potential bioindicators.

Amino acid composition of aquatic plants – The amino acid composition of aquatic plants is determined by their nutrient environment, and hence, can be used to measure an integrated nutrient "history" at a site over time. This composition was assessed in both field and laboratory trials; however, little pattern could be determined in either, and thus, this indicator was omitted from the major field trial.

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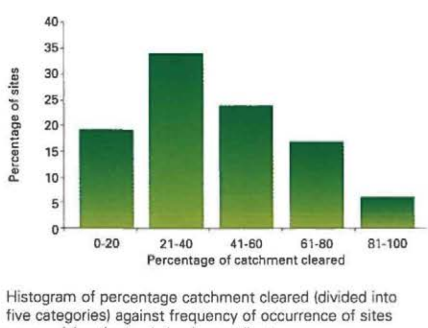
Major field trial of potential indicators at 53 sites

Step 5 Undertake major field trial to compare indicators

To be able to assess which indicators were most suitable for South East Queensland it was necessary to establish a gradient of disturbance against which the response of each indicator could be judged. Since European settlement, the major form of disturbance to streams in the region has been land clearing for agriculture and urbanisation. In keeping with the Stage 3 focus on diffuse sources of pollution, *land use* was chosen as the disturbance against which indicators would be evaluated.

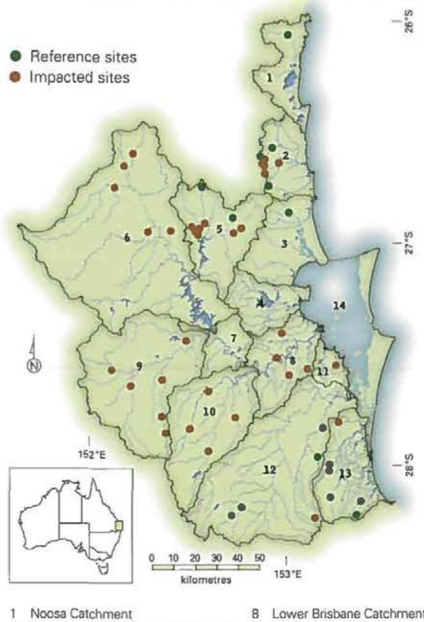
In spring 2000, a major field experiment was undertaken at 53 sites across South East Queensland. Sites were stratified according to the four river types given by the classification, but more importantly, they were chosen to provide the land use gradient. Some sites were minimally disturbed, a large number of sites were moderately disturbed, and a few sites were heavily disturbed.

Potential indicators were trialed at all field sites over a three-week period. During this time the same operators were used to ensure consistency in the methods, and the same sites were used to ensure that no additional spatial variability was included.



Histogram of percentage catchment cleared (divided into five categories) against frequency of occurrence of sites summarising the land clearing gradient.

Importantly, there were no major rainfall events during sampling which meant that conditions in the stream remained stable and any differences in assessments of stream health could be attributed to the indicator rather than operator differences, spatial variation or a change in environmental conditions.



1 Noosa Catchment
2 Maroochy and Mooloolah Catchments
3 Pumicestone Region Catchment
4 Pine Catchment
5 Stanley Catchment
6 Upper Brisbane Catchment
7 Mid-Brisbane Catchment
8 Lower Brisbane Catchment
9 Lockyer Catchment
10 Bremer Catchment
11 Redlands Catchments
12 Logan–Albert Catchment
13 Gold Coast Catchment
14 Moreton Bay

Location of freshwater EHMP trial sites throughout the study area. The sites included minimally disturbed reference sites which formed the basis for comparison with moderately to heavily disturbed sites.

Five indicator groups respond to disturbance gradient

Step 6 **Use results to make recommendations for EHMP**

Results of the field experiment were used to decide which indicators should be included in an Ecosystem Health Monitoring Program for rivers and streams in South East Queensland. Those indicators that responded significantly to the land use disturbance gradient were included in the monitoring program: those that did not were omitted. Apart from considering the scale at which the indicator was responding, it was necessary to take into account the level of training necessary to apply the indicator because the monitoring program had to be suitable for catchment and community groups, as well as Local and State government agencies.

Five types of indicators responded strongly to the disturbance gradient and were recommended for the monitoring program. These indicators are:

1. **Fish**
2. **Macroinvertebrates**
3. **Ecosystem processes**
4. **Algal bioassays**
5. **Physical and chemical indicators**

Details of the five indicator groups including what they measure and what they tell us can be found in the following pages.

Apart from measuring the response of various indicators, a large number of environmental variables (e.g. substrate diversity, riparian cover) were also measured during field work. These variables were seen as additional 'descriptors' of the diffuse disturbance gradient and each was assigned to one of six categories: land use, flow, water chemistry, channel integrity, instream habitat and riparian.

By assigning descriptors to these categories, scientists could make direct comparisons between indicators and pinpoint the type of disturbance to which each indicator was responding.

This process not only allowed researchers to pinpoint which indicators respond to which disturbance, but it also allowed them to infer the type and scale of management action that would be required to address the problem. This was possible because some descriptors reflect catchment-scale disturbance, some reflect local or reach-scale disturbance, and some reflect a combination of these two scales.

Catchment-scale descriptors	
Land use e.g. % cleared land	**Flow related variables** e.g. maximum velocity
Descriptors acting at both scales	
Water chemistry e.g. Total Nitrogen	**Channel integrity** e.g. bank stability
Reach-scale descriptors	
In-stream habitat e.g. substrate diversity	**Riparian condition** e.g. % riparian cover

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Percent catchment cleared is a catchment-scale descriptor of disturbance.

Fish: A high diversity of native fish indicates good stream condition

Their mobility, longevity and position near the top of the food chain mean that fish can reflect disturbances at a range of scales and indicate the net effects of disturbances to the aquatic ecosystem. Fish communities were sampled using electrofishing and seine netting, with all native animals captured being subsequently released unharmed. Fish responded strongly to deleterious changes to in-stream habitat, riparian condition, channel integrity, and the presence of downstream barriers. Three fish indices were recommended for the Ecosystem Health Monitoring Program.

1. **Native species richness –** The number of native species is a commonly used measure of the general health of aquatic ecosystems because species richness declines with increasing environmental stress. A computer model based on data from a large number of minimally disturbed sites was used to predict the *total number of native fish species* expected at a healthy site. This number was then compared with the number actually collected to give a ratio that reflects the ecological condition of the fish community at a site.

2. **Fish assemblage – Observed/Expected –** Unlike the native species richness model, the second model predicts *which native fish species* are likely (i.e. probability >50%) to be found in a healthy stream (also based on data from minimally disturbed sites). By comparing the fish community expected (i.e. predicted by the model) with the community observed, a score reflecting the health of the fish community is derived. An Observed/Expected score close to 1 is indicative of a healthy site, whereas a score less than 1 means a site contains fewer species than expected: the lower the score, the greater the disturbance/impact.

3. **Percent alien individuals –** The presence and relative abundance of alien (introduced) species of fish also reflects the general condition of the aquatic ecosystem and may represent both a symptom and a cause of declines in stream health. The relative abundance of alien species is expected to increase with increasing environmental stress due to their tolerance for degraded water quality and habitat conditions. It is suggested that some alien species out-compete native species for food and shelter and feed on their eggs.

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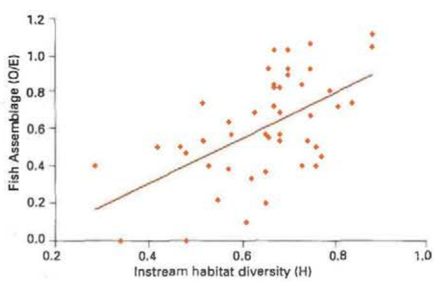
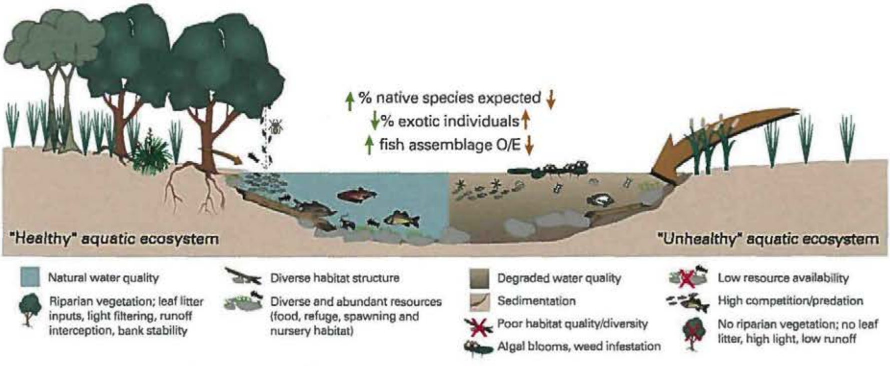
Electrofishing: Nets are set upstream and downstream of a site to confine all fish within a section of a stream. A backpack electroshocker, which has a probe carrying an electric current is used to stun fish within close proximity of the sampler. The stunned fish are then collected with a scoop net, identified and released unharmed back into the waterway.



Plot of fish assemblage (Observed/Expected) against in-stream habitat diversity. Fewer fish are found in streams with reduced habitat diversity.



Changes of physical and biological characteristics of the aquatic environment and their effect on fish assemblages. Healthy systems contain a diverse range of habitats and resources supporting a high diversity of fish species, age classes and trophic levels. With increasing disturbance a decrease in the suitability of habitat and resources leads to a reduction in native species, an increase in exotic fish and an overall low structural and functional diversity.

Alien fish in South East Queensland

Alien fish species were found at 60% of sites sampled and were more abundant overall than native fish. The most common introduced species was the mosquitofish *(Gambusia holbrooki)* which was found at all sites where exotics were present. The mosquitofish, which is native to rivers flowing into the Gulf of Mexico, was first introduced to control mosquito larvae; however, it is unlikely that they are more effective at removing mosquito larvae than other small, insectivorous native species.

The mosquitofish *(Gambusia holbrooki)* is the most common introduced fish.

Tilapias are members of the Cichlid family of fish and are native to eastern Africa. Releases by aquarists have seen one species of tilapia, the Mozambique Mouth Brooder *(Oreochromis mossambicus)*, establish breeding populations in the Brisbane River. This species is abundant in other parts of Australia and can become the dominant fish in freshwater environments due to its omnivorous feeding strategies, tolerance for poor ecological condition, and highly effective reproductive strategies.

Introduced tilapia (*Oreochromis mossambicus*) has established breeding populations in the Brisbane River.

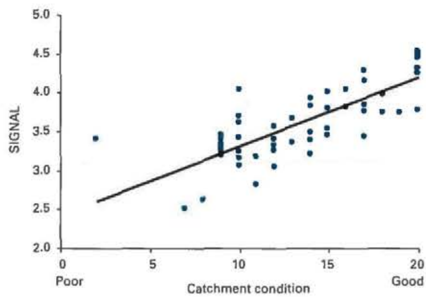
The common carp (*Cyprinus carpio*) is one of the world's most widely distributed freshwater fish. In South East Queensland they are most commonly encountered in the Logan-Albert River and Brisbane River tributaries. They are hardy, tolerating low dissolved oxygen concentrations and high salinities. They are thought to contribute to increased turbidity by their feeding behaviour that sees them suck up sediment and plants then spit out the non-food particles. In addition, they are prolific breeders, capable of spawning more that once a year and producing more that one million eggs per kg of body weight.

Introduced common carp *(Cyprinus carpio)* may contribute to increased turbidity by their feeding behaviour.

Gambusia, tilapia and common carp are all declared noxious species in Queensland because they are pests to native aquatic communities. It is prohibited to place or release them into our waterways and penalties of up to $150,000 apply.
In addition, it is illegal to release captured fish back into a waterway.

Macroinvertebrates: respond to catchment scale disturbance

Invertebrate communities were sampled using a D-framed pond net. All animals collected in a 10 m sweep were emptied into a sorting tray where they were picked out using forceps. The aim of live-picking was to maximise the number of families collected. Animals were preserved in alcohol for later identification in the laboratory under a dissecting microscope.



SIGNAL score (score based on known sensitivity to pollutants) plotted against catchment condition. SIGNAL score increases with improved catchment condition.

The stonefly nymph is sensitive to disturbance and therefore was used as an indicator of stream health.

Aquatic invertebrates (insects, crustaceans, snails, etc.) are ideally suited for biological monitoring because they are common, widespread and easily sampled. Like fish, they provide an integrated measure of stream condition because their presence indicates that the stream is healthy enough to support their food, water quality and habitat requirements, and that it has maintained this condition over recent weeks or months. Invertebrates have been shown to be sensitive to changes in sedimentation, flow regime, and catchment land-use with three indices recommended for the EHMP.

1. **Invertebrate family richness –** As with fish, this "first cut" measure is based on the premise that a healthy site will have greater diversity (i.e. greater family richness) than an unhealthy site because only a few tolerant families can withstand degraded habitats and poor water quality. This index responded most strongly to catchment-scale variables such as the percentage of land cleared in a catchment.
2. **PET richness –** Three orders of aquatic insects, the **P**lecoptera (stoneflies), **E**phemeroptera (mayflies) and **T**richoptera (caddisflies); (i.e. PET taxa) are most sensitive to disturbance. The total number of families belonging to these orders is used as another measure of stream health with undisturbed sites having greater numbers of PET animals than degraded sites.
3. **SIGNAL score –** Commonly encountered invertebrate families have been allocated a score based on their known sensitivity to pollutants. Scores range from 1 (most tolerant) to 10 (most sensitive to pollution). The SIGNAL (Stream Invertebrate Grade Number Average Level) score is calculated by averaging the signal values of all invertebrate families found at a site. The higher the SIGNAL score, the better the condition of the site.

Ecosystem processes: the pulse of the stream

Gross Primary Production (GPP) and Respiration (R_{24}) are vital processes concerned with the production and consumption of carbon in an ecosystem. Measure of GPP and R_{24} reflect the amount of plant and algal growth in a stream. Healthy forest streams typically have low rates of production and respiration because the riparian vegetation reduces the input of sediment and nutrients and shades the water column so that production is light-limited (see conceptual model on page 38). In contrast, at a highly impacted site, excess light and nutrients can result in high production. Following this, the stream can become choked with living and dead plants resulting in high rates of respiration. Three measures of ecosystem processes were included in the freshwater Ecosystem Health Monitoring Program.

1, 2. Gross Primary Production and Respiration – Both production and respiration can be determined by measuring the amount of dissolved oxygen produced or consumed by aquatic plants and algae. Transparent plastic domes are placed on the stream bed and oxygen probes inserted into the domes to measure oxygen concentrations. Using the photosynthetic equation, the amount of carbon being produced or consumed is calculated based on the oxygen produced or consumed.

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Dissolved oxygen probe inserted in transparent plastic dome to measure GPP and R_{24} of a cobble on the stream bed.

Production and respiration are influenced by water temperature and availability of light and nutrients, and therefore provide a direct measure of stream health because they integrate the effects of these variables.

3. Carbon signature of plants – Carbon (C) can occur as several different isotopes, and in aquatic plants, the ratio of these isotopes is influenced by a number of factors, including the rate of production. Unlike direct measures of plant production, the carbon isotope signature $\delta^{13}C$ value (i.e. ratio of the isotopes ^{13}C to ^{12}C) may provide an integrated estimate of productivity over time.

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Elodea, an introduced aquatic plant. The carbon isotope signature of aquatic plants is used to reveal the rate of productivity prior to sampling.

Production (or Gross Primary Production) is a measure of the amount of carbon that is *produced* in the stream. This carbon is formed via photosynthesis in algae and aquatic plants.

Respiration is the measure of the opposite process, being the amount of carbon *consumed* by algae and plants in the stream, as well as the measure of organic matter decomposition (or the conversion of carbon to CO_2).

Algal bioassays: measures of nutrient assimilation

The availability of light and nutrients are important factors in determining the health of a stream. When streams are cleared of bankside vegetation, and light does not limit plant growth, in-stream productivity is likely to increase dramatically causing the "pulse" of the stream to race. Under these conditions the availability of nutrients is of critical importance. Increased nutrient concentrations associated with agricultural runoff may lead to excessive algal growth; however, this depends on which algal species are present and varies from stream to stream.

An algal bioassay is a measure of the amount of algae being produced by the stream and which nutrients are limiting algal production. Bioassays were preferred over the direct measure of nutrient concentrations because they provide a better measure of stream health by integrating light availability, nutrient environment and type of algae. In addition, they integrate conditions over time rather than providing a "snapshot" of water chemistry, which is difficult to relate to ecosystem health. Two measures of nutrient assimilation were recommended for the freshwater Ecosystem Health Monitoring Program.

1. **Algal bioassay –** By comparing the concentration of algae on the four pots (see below) it is possible to determine how much algae is being produced and whether production is nutrient limited. Samples collected during the major field trial revealed that nitrogen (N) is the primary limiting nutrient for streams in South East Queensland, with phosphorus (P) acting in a co-limiting role (i.e. more algal growth when both are present).

2. **Using $\delta^{15}N$ to investigate nutrient assimilation –** N occurs in several different isotopic forms and changes in the N "signature" of aquatic plants can be caused by catchment disturbance. Elevated ^{15}N values occur in freshwater streams that have been subjected to disturbances of the N-cycle caused by catchment clearing. The ratio of ^{15}N to ^{14}N ($\delta^{15}N$) in large aquatic plants and filamentous algae can be used to identify changes to the natural cycling of N due to both point source and diffuse sources and reveals the nutrient "history" of a stream.

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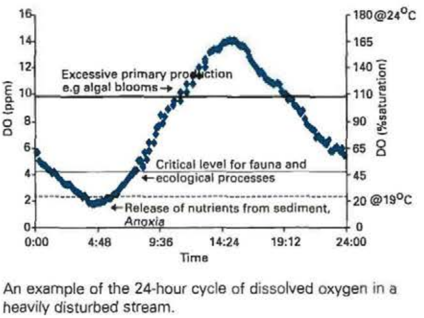
Algae bioassay technique: Wooden tray with four small, plastic pots filled with 4 different nutrient treatments (no nutrients, N, P, and N + P) and covered with fine mesh were deployed in-stream. After 21 days, the trays were collected, the mesh removed and chlorophyll *a* concentrations (algal biomass) measured.

Physical and chemical indicators: 24-hour measurements are more informative

In the past, water quality monitoring has relied heavily on physical and chemical parameters because they are readily quantifiable. Even though there has been a recent shift towards monitoring biological and ecological conditions, physical and chemical measures are an important component of a monitoring program as they aid in the interpretation of more direct measures of stream health. Four physical and chemical indices were recommended for the freshwater EHMP.

Dissolved oxygen and water temperature – The concentrations of Dissolved Oxygen (DO) and water temperature are critically important to stream animals and plants. A decrease in DO will have deleterious effects on many animals, particularly fish, while both increases and decreases in water temperature can limit reproduction and survival of aquatic organisms. Similarly, wide temperature extremes (daily range) can be harmful for fish and other animals. Spot measurements of both DO and temperature can be misleading because both change dramatically throughout the day. As such, 24-hour measurements of both DO and temperature are used because they include the minimum, maximum and daily range and provide a superior profile of the water chemistry conditions being experienced by the biota.



An example of the 24-hour cycle of dissolved oxygen in a heavily disturbed stream.

pH – measures the concentration of hydrogen ions in the water. It is based on a scale from 1 to 14 where 1 is highly acidic, 7 is neutral and 14 is highly alkaline. Extreme pH values are known to have adverse effects on the ionic balance and respiratory efficiency of fish and invertebrates. In South East Queensland, measurements of pH are important for two reasons. First, naturally low-pH "Wallum" streams are associated with heathland vegetation in the Sunshine Coast region are unique, sensitive systems. Second, because of the presence of acid-sulfate soils, which are common in low-lying coastal areas. These soils contain naturally high levels of iron sulfide, which is harmless in its natural state; however, when exposed to air and saturated with water, it oxidises producing sulfuric acid. When this acid enters local streams it can have devastating ecological consequences and is often the cause of major fish kills.

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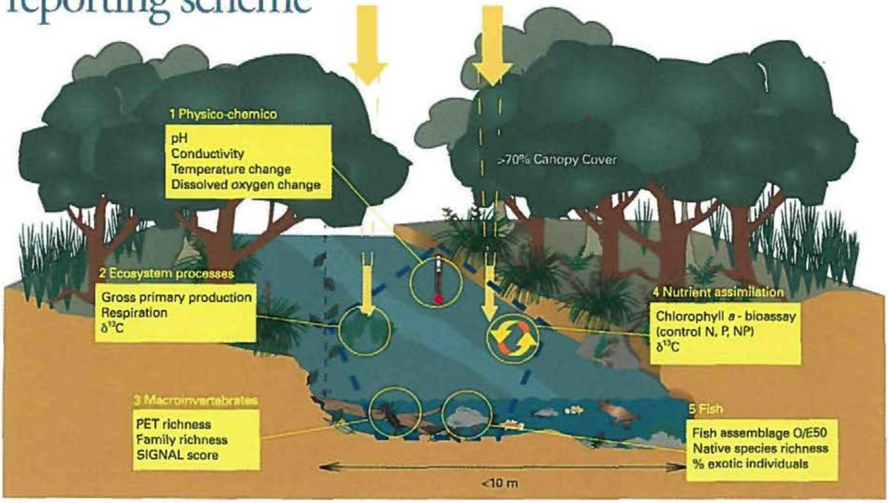
A typical wallum stream has tea-coloured water and low pH.

Conductivity – is a surrogate of salinity and measures concentration of salts present in the water. Elevated salinity levels are known to have deleterious effects on algae, aquatic invertebrates and fish populations, as well as causing the loss of riparian vegetation and algae. While salinity is not a major issue in South East Queensland, conductivity has been included in the EHMP to track possible changes due to rising saline groundwater in some catchments.

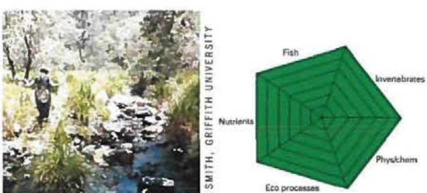
Data integration through EcoH plot reporting scheme



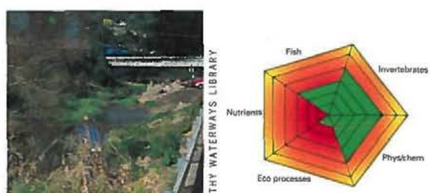
The conceptual model developed for the freshwater EHMP includes indicators of physical and chemical parameters, ecosystem processes, macroinvertebrates, algal bioassays and fish.

No one indicator can adequately summarise the health of an ecosystem. The freshwater EHMP uses five indicator groups to provide a complete picture of ecological condition. These indicators were chosen following a rigorous study that compared a wide variety of indicators and selected those most suitable for streams in South East Queensland.

All five indicator groups are considered to be equally important, and as such, pentagons are used to report on these five facets of stream health. These pentagons reflect **Eco**system **H**ealth at a site and have been named EcoHplots. Each EcoHplot consists of five wedges, one for each indicator grou Each pentagon is coloured orange/red. The result for each indicator group is depicted by the amoun of green in each wedge – the better the score the larger the green wedge, such that a healthy site is represented by an all green EcoHplot whereas a heavily disturbed site would be orange/red. As different indicators were shown to respond to different disturbances, individual wedges can be used to diagnose the likely cause of a disturbance.



Undisturbed site on Back Creek near Canungra, all wedges of the EcoH plot are green indicating a healthy "reference" condition.



Disturbed site on Petrie Creek in Nambour with poor scores for fish, nutrients and ecosystem processes (orange wedges).

Bay and estuarine monitoring program implemented

The Ecosystem Health Monitoring Program for Moreton Bay and estuaries (EHMP) commenced in January 2000. This program is based on a conceptual model that integrates our current understanding of the waterways in the Moreton region with community-derived environmental values. The model focuses on assessing the responses of the ecosystem to natural and human impacts. The water quality and biological information collected by EHMP allows us to evaluate the ecosystem and community benefits of investments in environmental protection (such as improved sewage treatment, stormwater management and catchment management).

Key processes

The addition of excess nutrients into the waterways affects key ecosystem processes such as primary productivity and nitrogen and phosphorus cycling. How excessive nutrient loads affect the waterways is assessed using water quality and chemical indicators. The incorporation of nitrogen from sewage waste-water into aquatic food webs is being assessed using stable isotope signatures of macroalgae and mangroves.

Human Impacts

The zones where human activities have a negative impact on the waterways are difficult to ascertain without biological indicators that can detect subtle and often sub-lethal impacts. In many cases the link to human activity is not well established, yet various biological indicator species can be used to infer ecosystem health. The presence of the toxic cyanobacterium, *Lyngbya majuscula*, various dinoflagellates, tumours on green turtles and dugong numbers are examples of biological measures that are used to indicate ecosystem problems.

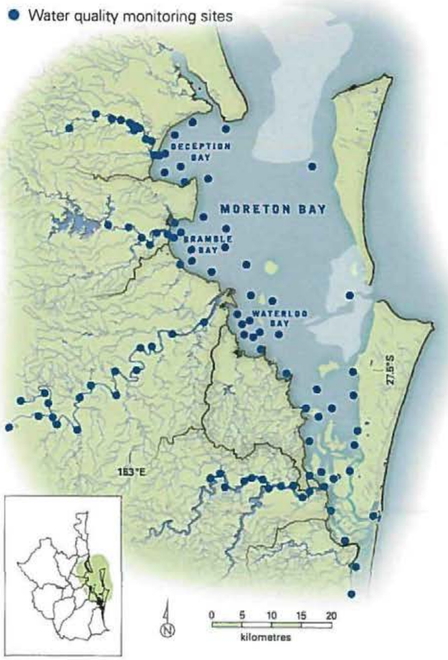
Critical Habitats

Seagrass meadows and mangroves are critical habitats in Moreton Bay. Seagrasses provide food for dugongs and sea turtles, as well as habitat for numerous fish, shellfish and prawns. The distribution of seagrass meadows, mangroves, and the depth which seagrasses grow are important ecosystem health indicators being monitored. Since the link between water clarity and seagrass depth range has been well established, light attenuation (via secchi disc depth) is also monitored.

Conceptual model for the Moreton region, depicting the key processes occurring, human impacts present and critical habitats existing in the region.

Monitoring focussed on *western Bay and river estuaries*

The EHMP for marine and estuarine waters is structured into three main tasks, each with a defined spatial and temporal scale.



Water quality monitoring sites in Moreton Bay and estuaries. Monitoring is carried out at 150 sites every month and focuses on detecting seasonal changes in water quality conditions.

Monthly widespread monitoring

Water quality monitoring is carried out monthly at 150 sites, from Noosa River south to the Gold Coast. Approximately 100 of these sites are in the major river estuaries, and 50 sites are in Moreton Bay. Sites are more concentrated in the river estuaries and western Bay to obtain a higher degree of spatial precision in these sensitive and degraded regions.

Monthly monitoring focuses on detecting the seasonal changes in water quality conditions that occur throughout the year. All sites are surveyed within a 10-day period. Sampling is carried out on the ebbing tide to maintain a consistent sampling regime between surveys, and to reduce the effects of tidal dilution in the rivers.

Annual snapshot

An intensive annual survey is conducted to quantify the long-term changes to ecosystem health, and includes monitoring of:

- The extent and impact of nitrogen sewage plumes using nitrogen stable isotope ratios of macroalgae and mangroves (300 sites)
- Seagrass depth range (13 sites carried out twice yearly)
- Phytoplankton growth bioassays (15 sites carried out twice yearly).

Intensive monitoring

The intensive monitoring task focuses on evaluating specific aspects of ecosystem health in order to study ecological processes and/or specific regions in more detail. These tasks have so far included:

- Intensive study of Waterloo Bay
- Contingency monitoring for the upgrade of Luggage Point Wastewater Treatment Plant
- Phytoplankton growth responses and nutrient uptake
- Seasonal variability in the extent and impact of nitrogen sewage plumes
- Noosa Loads and Impacts Study
- Ground-truthing for a remote sensing project in Deception Bay
- Changes to seagrass distribution and benthic habitats in Moreton Bay since 1997.

River estuaries differ in water quality

Major differences in water quality and ecosystem health exist between the river estuaries of South East Queensland (SEQ). Examples of these differences can be illustrated by comparing some of their water quality characteristics. Some of these differences can be attributed to natural factors such as hydrodynamics (wave, wind and tide) and catchment type. However, human pressures such as population size, land use of the surrounding catchment and wastewater inputs are major factors affecting water quality and ecosystem health. The most degraded river estuaries in SEQ – Brisbane and Bremer Rivers – support over 1 million people, drain highly modified catchments, and have high levels of wastewater inputs. In contrast, the near-pristine Noosa River supports only 36,000 people, is primarily bordered by national parks, and has no major point source discharges into the river.

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The Nerang River has relatively low levels of chlorophyll *a*, nitrate and turbidity.

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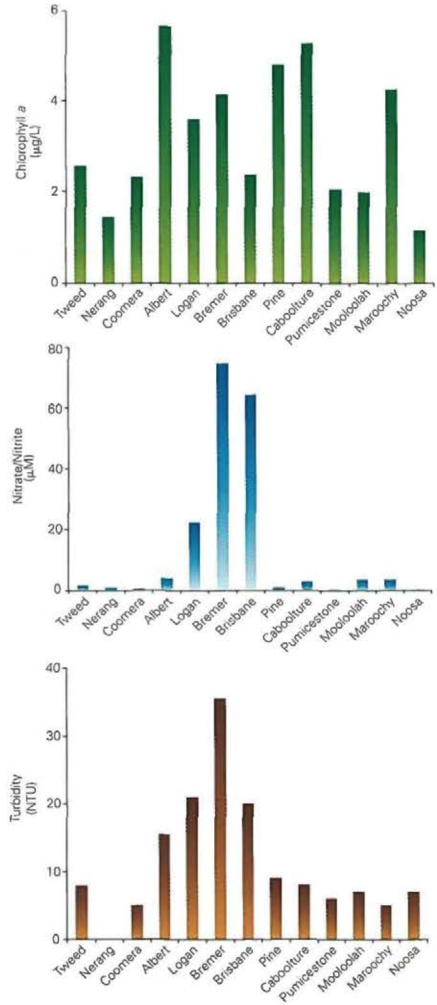
The Brisbane River has poor water quality with higher levels of chlorophyll *a*, nitrate and turbidity.

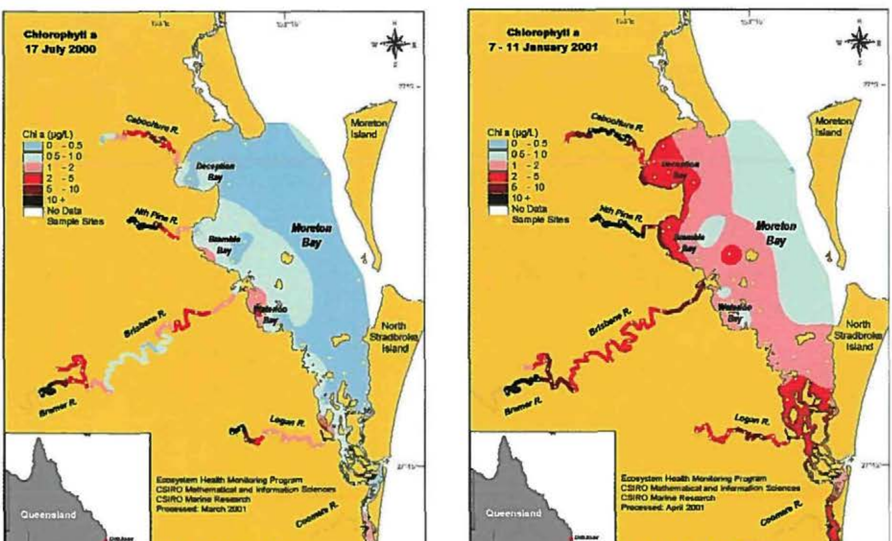


Water quality, measured as chlorophyll *a*, nitrate and turbidity levels, differs across the various river estuaries in South East Queensland, with Brisbane, Bremer and Logan Rivers being more degraded and Noosa River the best.

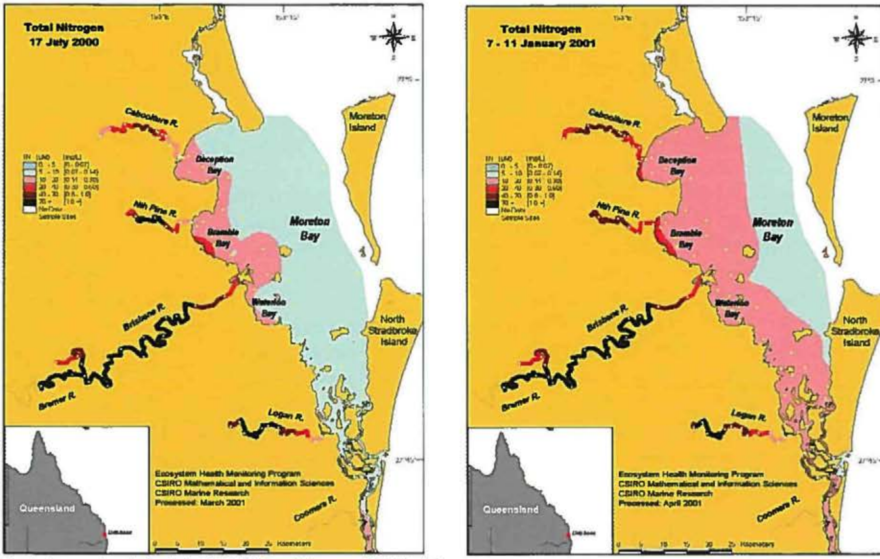
Strong temporal (wet vs dry) and *spatial* (east-west) *gradients* in Moreton Bay

Monthly monitoring since January 2000 has shown that the water quality of Moreton Bay and its river estuaries exhibit both strong spatial and temporal gradients. Spatially, the water quality changes across a west to east gradient with nutrient- and sediment-loaded rivers flowing into, and impacting on, the western embayments of Moreton Bay. The Brisbane, Bremer and Logan Rivers consistently contain high nutrient and sediment concentrations throughout the year. Water quality conditions improve from the western embayments across Moreton Bay to the ocean-flushed, near pristine waters of Eastern Moreton Bay.

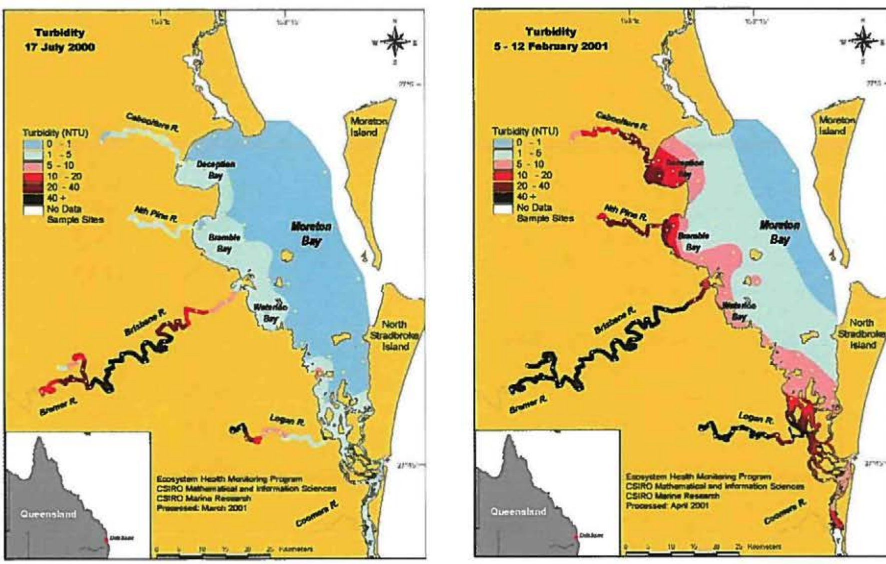
The extent of the sediment and nutrient plumes emanating from the river estuaries vary quite markedly throughout the year. During summer (December to February), rainfall events increase the flow of the river estuaries, and nutrient and sediment plumes extend across the western region. The prevalence of algal blooms in the western embayments, such as Bramble and Deception Bays in particular, also increases in response to the nutrient inputs. In contrast, during the winter months (June to August) the sediments and nutrients are more confined in the river estuaries, and the plumes that emanate from the river mouths are much reduced.



Chlorophyll *a* levels measured in July 2000 (left) and January 2001 (right).



Total nitrogen levels for July 2000 (left) and January 2001 (right).



Turbidity levels for July 2000 (left) and February 2001 (right).

Salinity, temperature and light affect nitrogen stable isotope values

Surveys of sewage plumes in Moreton Bay using $\delta^{15}N$ signatures of the macroalgae *Catenella nipae* have been carried out in September 1997, March 1998 and June 2000. Results in 1997 and 1998 revealed large plumes extending from the Pine and Brisbane Rivers into Bramble and Waterloo Bays. In contrast, in winter 2000 the plumes were largely confined to the river estuaries. This apparent reduction in sewage plume extent between these surveys could be due to:

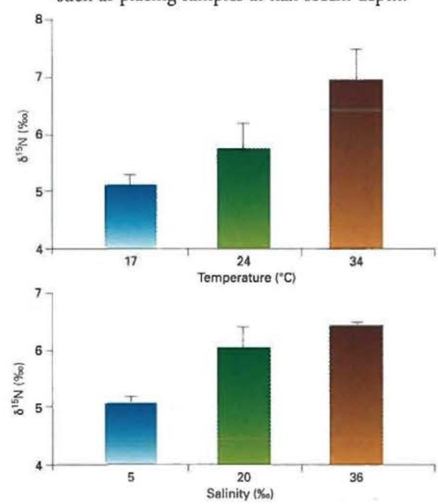
- Lower rainfall in winter reducing the flow of water from the rivers into the Bay,
- Seasonal variation such as temperature and salinity affecting $\delta^{15}N$ signatures of macroalgae,
- Different water circulation patterns at these sampling times, and/or
- Reduced sewage nitrogen inputs into Moreton Bay.

Controlled experiments to investigate the potential variability of $\delta^{15}N$ values in macroalgae as a function of salinity, temperature and light availability were carried out in 2000. These experiments revealed that all of these environmental factors have some influence on the $\delta^{15}N$ values of macroalgae.

However, these results highlight the importance of considering the influence of these and other environmental factors when designing surveys, and interpreting results, to examine the extent of sewage plumes using this technique.

Key findings of this study revealed that:

- Salinity can account for differences in $\delta^{15}N$ signatures up to 2‰ in macroalgae. Low salinity (i.e. <20‰) can reduce the $\delta^{15}N$ signatures of macroalgae. This indicates that $\delta^{15}N$ values recorded in the upper reaches of the river estuaries may be conservative due to the salinity influence. Periods of high rainfall may also lead to reduced plumes being recorded due to freshwater runoff.
- Temperature can account for differences in $\delta^{15}N$ signatures up to 2‰ in macroalgae. Decreased temperature in winter months may lower the $\delta^{15}N$ signatures recorded in river plumes. These results indicate that the reduced sewage plume in Moreton Bay in winter 2000 compared with summer may be due in part to the lower ambient water temperature. However, the winter plume still demonstrated highly elevated $\delta^{15}N$ signatures within the rivers which indicates that nitrogen is still incorporated into plant tissues.
- Light availability can account for differences in $\delta^{15}N$ signatures up to 2‰ in macroalgae. Macroalgae receiving maximum light availability at the surface possess higher $\delta^{15}N$ signatures than macroalgae placed at the same site but at depths of 0.5 m or greater. Thus it is very important that light availability at different sites is standardised, such as placing samples at half secchi depth.

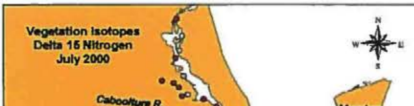


Salinity and temperature have an effect on stable nitrogen isotope values. Lower salinity reduces the $\delta^{15}N$ signature of the macroalgae and lower temperature reduces the ability of the macroalgae to utilise nitrogen from the water column.

Mangroves impacted by sewage derived nitrogen

Annual sampling of the $\delta^{15}N$ signature of the Grey Mangrove, *Avicennnia marina*, is being used as a monitoring tool to investigate the long-term accumulation of sewage-derived nitrogen in mangrove communities. Standardised samples of mangrove leaves are collected from vegetated areas of Moreton Bay and the river estuaries for this analysis. In general, low $\delta^{15}N$ signatures (e.g. 0-4 ‰) indicate little to no incorporation of sewage-derived nitrogen into the plant tissues, whereas higher $\delta^{15}N$ signatures (approaching 10‰ or above) indicate considerable incorporation of sewage-derived nitrogen from the local environment.

The June 2000 samples showed marked differences in $\delta^{15}N$ signatures of mangroves collected from the different regions. Consistently low $\delta^{15}N$ signatures (0-4‰) occurred in mangroves from Eastern Moreton Bay. This can be explained by the negligible to low influence of sewage-derived nitrogen in this region. In contrast, the $\delta^{15}N$ values were elevated in mangroves near the river mouths indicating an influence of sewage-derived nitrogen. At almost all sites adjacent to sewage treatment plant discharges in the Caboolture, Brisbane, Logan and Pine Rivers, $\delta^{15}N$ signatures were greater than 9‰, reflecting a similar $\delta^{15}N$ signature of treated sewage. Similarly, mangrove $\delta^{15}N$ signatures were elevated in Bramble Bay near the mouths of Cabbage Tree Creek, Nundah Creek and Kedron Brook.



The $\delta^{15}N$ signature of the grey mangrove, *Avicennia marina*, is used to investigate the long-term integration of sewage derived nitrogen. Low values (0-4‰) were found in mangroves from eastern Moreton Bay, and higher values (>9‰) were found in trees surrounding river mouths in western Moreton Bay.

HEALTHY WATERWAYS LIBRARY

Leaves from mangrove trees throughout South East Queensland are collected and analysed for $\delta^{15}N$ signature.

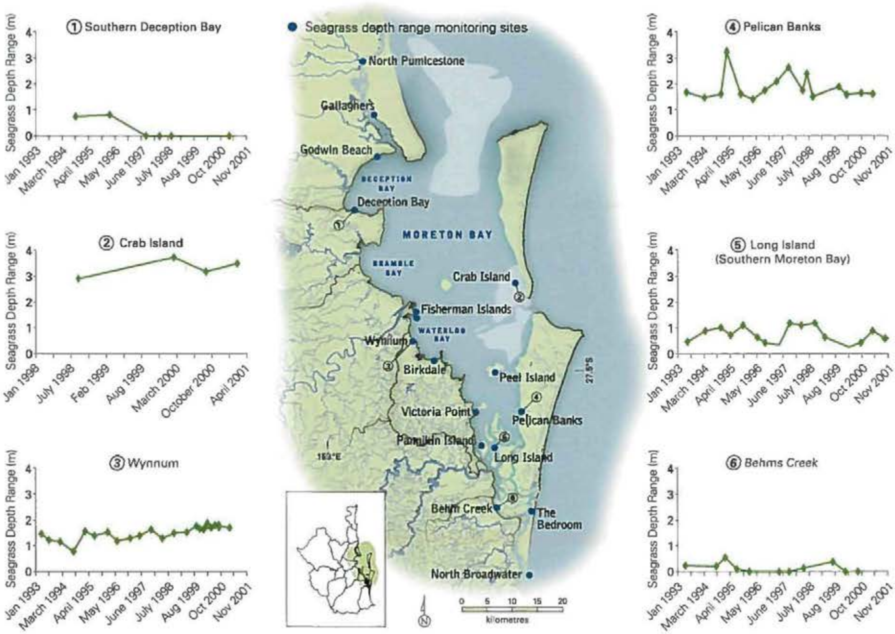
Seagrass depth range trends reveal *ongoing seagrass loss*

Extensive seagrass beds cover almost 25,000 hectares of the shallow waters of Eastern, Central and Southern Moreton Bay. These beds form critical habitats for fish, crustaceans and other invertebrates, and feeding grounds for dugongs and turtles.

However, comparison of the depth ranges of the widely distributed seagrass *Zostera capricorni*, shows that seagrasses in Southern Moreton Bay grow at shallower depths (<1 m depth) and are less stable than in Central and Eastern Moreton Bay (up to 3 m depth). Areas where seagrass meadows have been lost or are threatened correlate closely with degraded water quality.

Seagrasses are important because they:

- *Provide a vital food source for dugongs and green turtles*
- Provide nursery grounds and habitats for commercially important species, including prawns
- Provide habitat for many juvenile fish and invertebrates such as sea cucumbers and shellfish
- Assimilate and recycle nutrients within the ecosystem
- Trap sediments and stabilise the sea bed.



There has been a reduction in depth range at sites in Southern Deception Bay, Behm's Creek and Long Island. The Long Island site appears to be unstable, with seagrass beds disappearing, then recovering followed by a reduction in depth range.

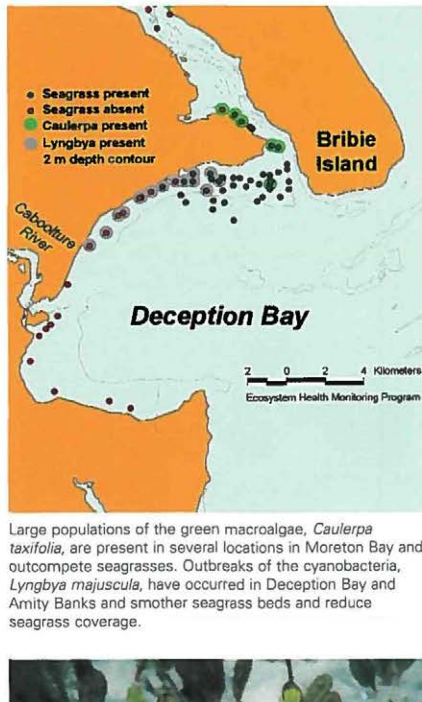
Benthic surveys indicate *seagrasses are sensitive to Lyngbya and Caulerpa*

Outbreaks of the toxic cyanobacteria, *Lyngbya majuscula*, have occurred in Moreton Bay over the past few years, particularly at northern Deception Bay and Amity Banks (Eastern Moreton Bay). Smothering of the seagrass beds by dense *Lyngbya* in Deception Bay appears to have impacted on the seagrass communities in these areas, by reducing the extent of seagrass distribution and percentage cover of seagrasses when compared to 1997 data.

In addition, several locations in Moreton Bay have large populations of a potentially nuisance green macroalgae, *Caulerpa taxifolia*. This macroalgae can proliferate in a diverse range of tropical marine habitats. There is current speculation that *Caulerpa* in Moreton Bay could potentially outcompete seagrasses in localised areas (Pillen *et al.*, 1998). This is of concern as *Caulerpa* does not provide a food source or stabilise the sediment as seagrasses do. Monitoring of over 400 sites around Moreton Bay in 2001 recorded extensive beds of *Caulerpa taxifolia* at:

- Pelican Banks (between northern Macleay Island and North Stradbroke Island)
- Fisherman Islands (near the mouth of the Brisbane River)
- Northern Deception Bay (near Godwin Beach and the southern entrance to Pumicestone Passage), and
- Victoria Point.

At this stage, it is not known whether the distribution and abundance of *Caulerpa* is increasing in Moreton Bay, although field observations indicate that it is. Its occurrence is being monitored as part of the seagrass monitoring task of the Ecosystem Health Monitoring Program.



Large populations of the green macroalgae, *Caulerpa taxifolia*, are present in several locations in Moreton Bay and outcompete seagrasses. Outbreaks of the cyanobacteria, *Lyngbya majuscula*, have occurred in Deception Bay and Amity Banks and smother seagrass beds and reduce seagrass coverage.

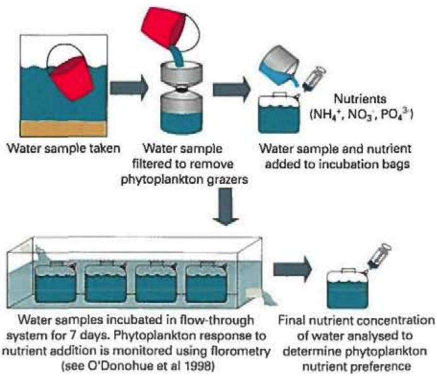
CHRIS ROELFSEMA, MARINE BIOLOGY, UQ

Caulerpa taxifolia is a nuisance algae that has been found in numerous areas of Moreton Bay.

Phytoplankton bioassays indicate *uptake preference for ammonia, nitrate and phosphorus*

Phytoplankton communities in Moreton Bay and its river estuaries are affected by water quality conditions. Light and nutrient availability influence their physiology, productivity and community structure. Temperature is also a major environmental factor that affects the growth and productivity of phytoplankton communities.

Depending on the levels of suspended matter (turbidity) and nutrients in the water column, the growth of phytoplankton populations can be regulated either by light or nutrients.



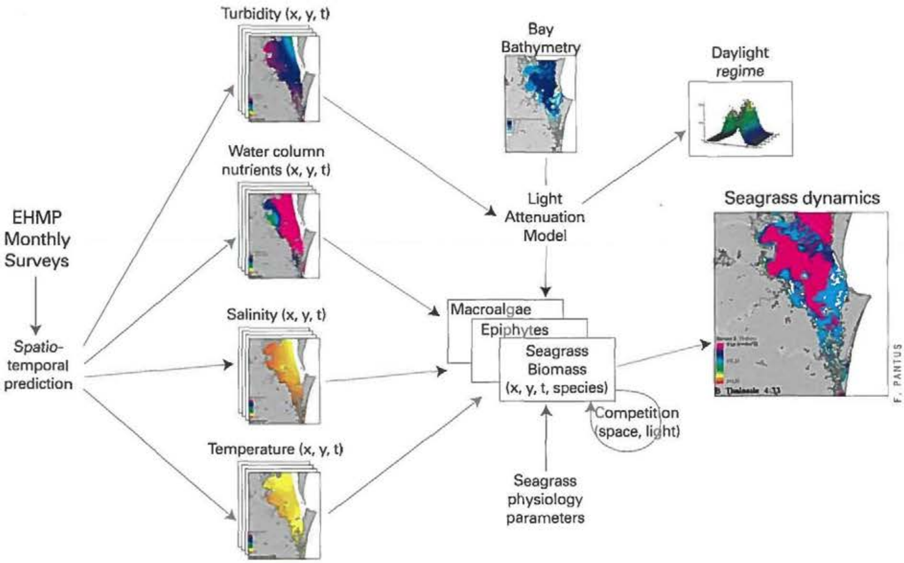
Phytoplankton bioassay technique for determining phytoplankton nutrient preference. Site water containing natural phytoplankton populations are enriched with a suite of nutrients, and their growth response (biomass measured using fluorometry) and nutrient preference (as nutrient loss from the sample) are determined over 7 days.

Major findings regarding the phytoplankton are:

- Phytoplankton growth responses are substantially lower in the Bay than in the river estuaries
- Nitrogen is the major nutrient stimulating phytoplankton growth in Moreton Bay and its rivers.
- Growth of phytoplankton in Caboolture and Pine Rivers is not limited by light availability. These communities possess a high capacity to assimilate nutrients in the water column resulting in elevated levels of phytoplankton
- Despite high levels of nutrients in the Bremer, Brisbane and Logan Rivers, phytoplankton from some parts of these rivers cannot assimilate nutrients as their growth is primarily restricted by light (high turbidity).
- The phytoplankton growth responses throughout the Bay are far greater in summer due to increased light and ambient water temperatures.

In eastern Moreton Bay, phytoplankton growth is nutrient-limited.

Ecosystem models provide tool for synthesising monitoring data



A dynamic model predicting seagrass distribution in Moreton Bay. Monthly water quality data is linked with environmental parameters to predict spatial distribution of seagrass biomass.

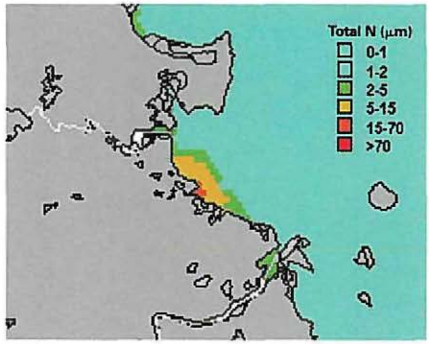
A demonstration version of a dynamic model to predict seagrass distribution in Moreton Bay has been developed. This model aims to predict where seagrass is likely to occur, based on the water quality conditions of the area. The model is created by combining spatial and temporal interpolated monthly water quality data of Moreton Bay and linking environmental drivers like available light and water column nutrients, temperature and salinity to predicted spatial distribution of seagrass biomass.

This seagrass model is useful as it integrates environmental data and biological knowledge into expected ecosystem responses. Resource managers can predict the likely recovery or loss of seagrass meadows to improvements or deteriorations in water quality across Moreton Bay using this approach.

Bad news: new nutrient inputs identified; *flood effects and Lyngbya*

Nutrient inputs from Cabbage Tree Creek

Static modelling of the water quality data has revealed a prominent nutrient source coming from Cabbage Tree Creek, which is probably contributing to the eutrophication problems in Bramble Bay. Some of the highest nitrogen and phosphorus concentrations of the entire Moreton Bay occurred at the mouth of Cabbage Tree Creek and extended into central Bramble Bay (total nitrogen up to 40 µM; total phosphorus up to 10 µM). This nutrient loading also correlated with the occurrence of phytoplankton blooms.



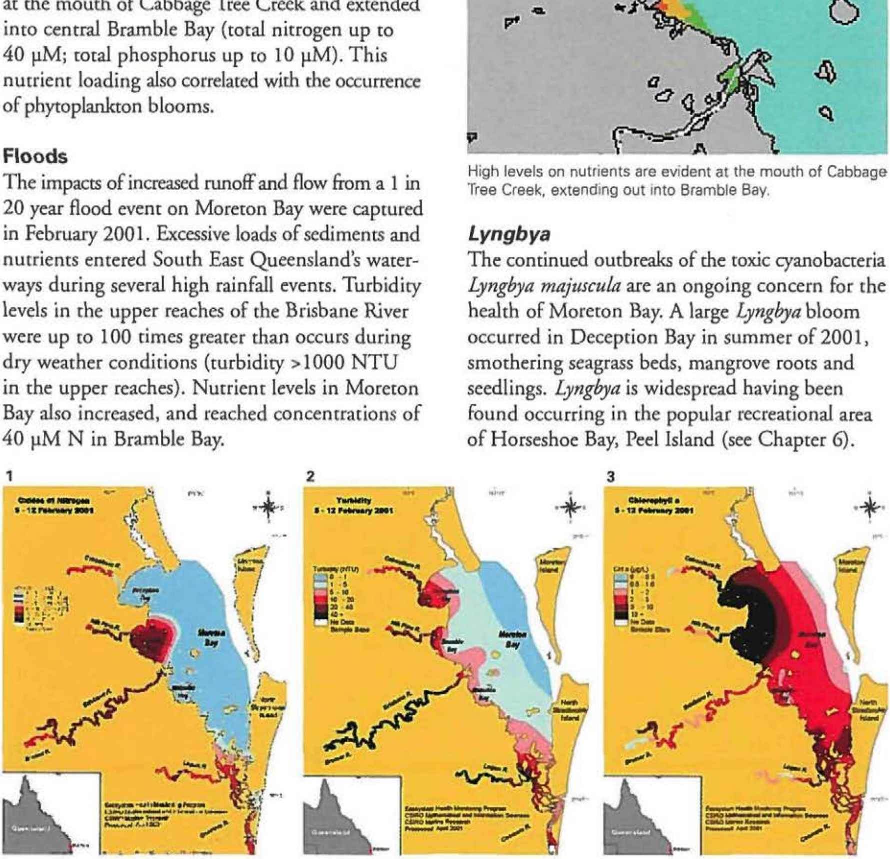
High levels on nutrients are evident at the mouth of Cabbage Tree Creek, extending out into Bramble Bay.

Floods

The impacts of increased runoff and flow from a 1 in 20 year flood event on Moreton Bay were captured in February 2001. Excessive loads of sediments and nutrients entered South East Queensland's waterways during several high rainfall events. Turbidity levels in the upper reaches of the Brisbane River were up to 100 times greater than occurs during dry weather conditions (turbidity >1000 NTU in the upper reaches). Nutrient levels in Moreton Bay also increased, and reached concentrations of 40 µM N in Bramble Bay.

Lyngbya

The continued outbreaks of the toxic cyanobacteria *Lyngbya majuscula* are an ongoing concern for the health of Moreton Bay. A large *Lyngbya* bloom occurred in Deception Bay in summer of 2001, smothering seagrass beds, mangrove roots and seedlings. *Lyngbya* is widespread having been found occurring in the popular recreational area of Horseshoe Bay, Peel Island (see Chapter 6).



Excessive loads of nitrate and suspended solids entered the waterways after heavy rainfall in February 2001 (1,2).
The additional nutrient inputs caused phytoplankton to proliferate across Moreton Bay (3).

Good news: Improvements in turbidity and dissolved oxygen; *sewage plumes decreasing*

Brisbane River turbidity

Brisbane River is the most turbid river estuary in South East Queensland, and exports more sediment into Moreton Bay than any other river. Long term water quality monitoring by Queensland Environmental Protection Agency (Waterways Scientific Services) over the past 10 years has revealed a progressive reduction in turbidity levels in the Brisbane River. Statistical analysis of these data has shown an overall progressive reduction in turbidity by approximately 6-11% each year since 1994. In addition, the lowest turbidity readings for the entire monitoring period were recorded in August 2001. These improvements could be due to a combination of factors:

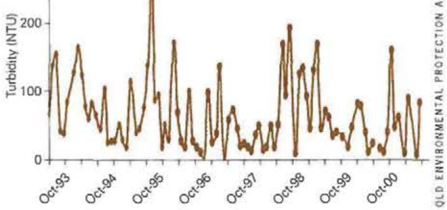
- Long term seasonal differences (e.g. El Niño/ La Niña) driving rainfall patterns which influence runoff and subsequent sediment loading in the estuary
- Calm and dry conditions in winter 2001 enabling substantial settlement of suspended particles from the water column
- Improved management of our catchment and waterways.

Caboolture River dissolved oxygen

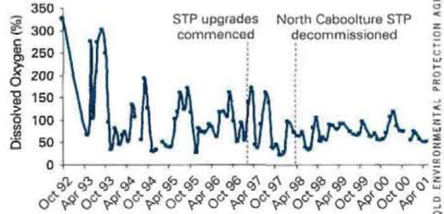
Levels of dissolved oxygen in the Caboolture River estuary have improved, particularly since the upgrade of the Caboolture South Sewage Treatment Plant (1997) and decommissioning of the Caboolture North Sewage Treatment Plant (1999). Dissolved oxygen levels in the river estuary appear to have stabilised, indicating a reduction in the occurrence and intensity of algal blooms. In addition, no sewage plume has been recorded emanating from Caboolture River into Deception Bay.

Sewage plumes

The extent of sewage plumes into Waterloo Bay measured by the nitrogen stable isotope ratios, or $\delta^{15}N$, of macroalgae (*Catenella nipae*) was reduced throughout 2000-2001 compared to 1997-1998. This can be attributed to the upgrades of Capalaba and Thorneside Sewage Treatment Plants that discharge into Tingalpa Creek. A small sewage plume still emanates from Tingalpa Creek into Waterloo Bay.



Statistical analysis of turbidity data over 10 years has revealed a progressive reduction in turbidity levels in the Brisbane River.

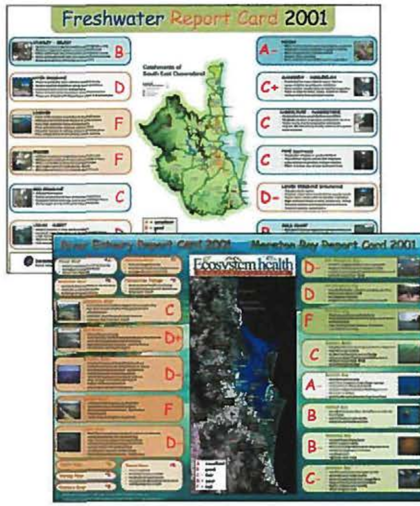


Sewage treatment plant upgrades coincided with improvements in dissolved oxygen levels in the Caboolture River.

Monitoring results communicated through *annual report cards*

Since 1998, an Annual Report Card of Ecosystem Health has been presented to stakeholders and the community that evaluates improvements or declines in the estuarine and marine waterways of South East Queensland. In 2001, the first report card for freshwaters was also presented using scientific data from the Design and Implementation of Baseline Monitoring for Freshwaters task.

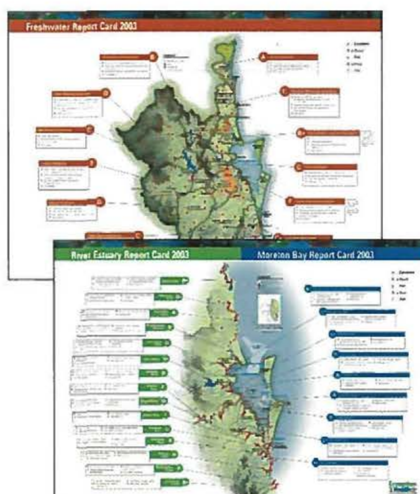
Generation of these report cards is based upon the integration of a range of physical, chemical and biological indicators of ecosystem health, rating major waterways of South East Queensland from A (near pristine) through to F (highly impacted or failed). Water quality and biological indicators, such as macroinvertebrate species, algal blooms, seagrass distribution and the extent of nitrogen sewage plumes, were used to make meaningful assessments of ecosystem health.



2001 Annual Report Card.

ENVIRONMENTAL PROTECTION AGENCY

Freshwater and Marine EHMP teams at the launch of the 2001 Annual Report Card. Clockwise from top left, Prof Stuart Bunn, Mr Michael Smith, Dr Angela Grice, Mr Paul Maxwell, Mr Ivan Holland, Prof Paul Greenfield and Assoc Prof Bill Dennison.



2003 Annual Report Card.

Newsletter and website provide regular updates

Ecosystem Health Monitoring Program newsletters.

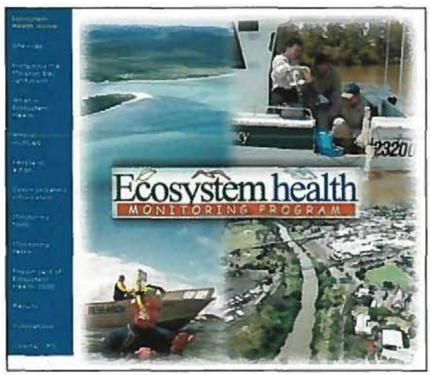
A key component of the Ecosystem Health Monitoring Program is the effective communication of monitoring activities and scientific results. Up to date, interpreted water quality and biological information is readily available for use by council and industry partners, environmental managers, scientists and the community.

Information on ecosystem health is presented via:

- Quarterly newsletters
- Website
- Annual report cards
- Annual technical reports
- Scientific journal papers
- Regular meetings and
- Presentations.

Quarterly newsletters provide regular updates on recent activities and findings of the monitoring program, and are distributed to 2000 people involved in waterways management and research in South East Queensland. Some of the topics that have been covered so far include: impacts of a summer flood event, continued seagrass loss in Southern Moreton Bay, Annual Report Cards of Ecosystem Health, and biological processing of nutrients in river estuaries and Moreton Bay.

Information on the Ecosystem Health Monitoring Program is also available on the internet, via the Healthy Waterways website. This includes more detailed information on the actual program (e.g. who is involved, monitoring tools and experimental design), as well as mapped and interpreted results that are updated every month.



Ecosystem Health Monitoring Program website.

Ecosystem Health Monitoring Program Website address: www.healthywaterways.org

All raw data are stored in the Ecosystem Health Monitoring Program database (Microsoft Access). Raw data are available on request.

CONTRIBUTORS (in alphabetical order)

Angela Arthington, Stuart Bunn, Satish Choy, Joanne Clapcott, William Dennison, Christina Dwyer, Christy Fellows, Angela Grice, Bronwyn Harch, Courtney Henderson, Ivan Holland, Adrian Jones, Mark Kennard, Ben Longstaff, Paul Lutz, Steve Mackay, Chris Marshall, Paul Maxwell, Andrew Moss, Francis Pantus, Michael Smith, Andrew Storey, Tom Taranto, Peter Toscas, James Udy, Nicola Udy, William Venables, Dan Wruck.

REFERENCES AND FURTHER READING

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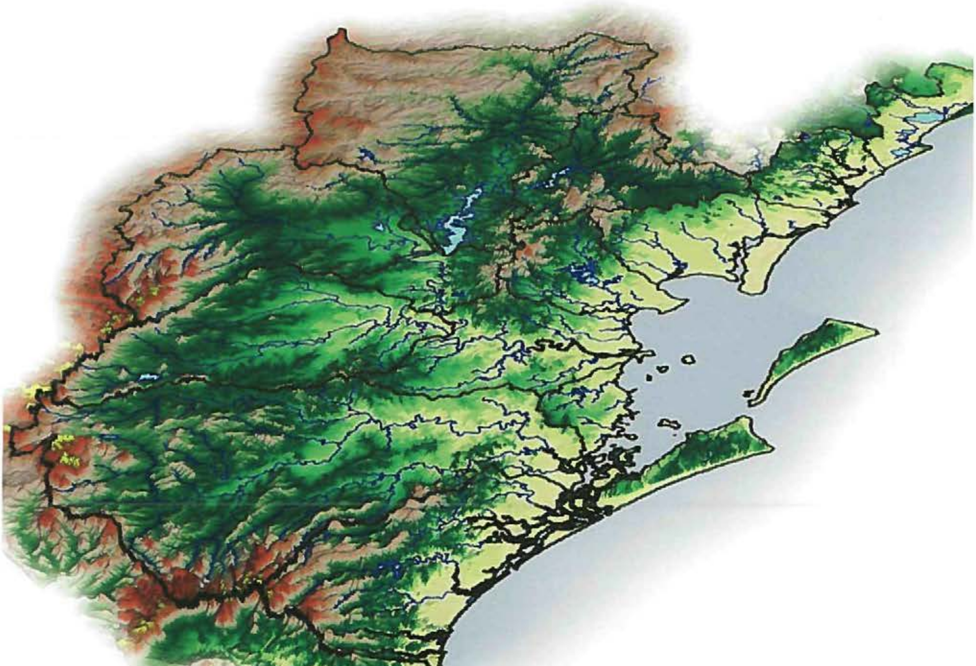
Chapter 8



Integration

ROB VERTESSY AND TONY MCALISTER

A new predictive capability for stakeholders

Research projects supported by the South East Queensland Regional Water Quality Management Strategy have yielded significant insights into the impacts of land management actions on the water quality of the coastal and catchment waterways. Decision support tools have been developed to capture such knowledge and make it readily available to stakeholders. At the beginning of Stage 3 of the SEQ Study, stakeholders from the region met to specify their needs for a regional water quality model.

Through a series of consultation workshops, stakeholders defined the need for:

- A tool which predicts the generation of daily or monthly loads of total suspended solids (TSS), total phosphorus (TP) and total nitrogen (TN) from subcatchments across the South East Queensland region and the delivery of these pollutants to coastal waters;
- A tool with strong spatial representation, enabling both local and regional assessments of catchment management impacts on water quality;
- An integrated database that contains as map layers, field observations and model results;
- Sophisticated data visualisation capabilities to permit effective display of model results in map and chart forms; and

Training workshops are being held to provide stakeholders with the capacity to use and interpret the EMSS.

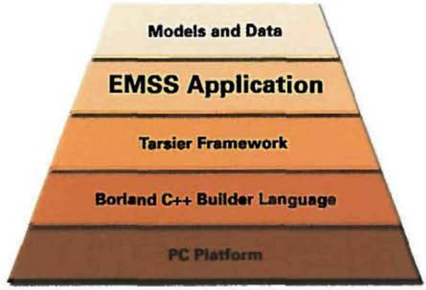
- Most importantly, a user interface that allows stakeholders with varying levels of computer proficiency to interact with the model.

After the consultation workshops, a project was commissioned to build an Environmental Management Support System (EMSS) that satisfied these needs for the whole South East Queensland region. The EMSS has since been built and has met these specifications. Training workshops have been held to equip stakeholders with the capacity to use and interpret the tool. Local and catchment-scale EMSS models are now being developed.

Stakeholder input was sought to develop the specifications of a relevant decision support tool.

A framework for *linking models*

The EMSS was built using an innovative catchment model development environment called *Tarsier*. This provides catchment model developers with various support tools like databases, data visualisation routines and analysts (such as statistical analysis tools). By providing such a modelling 'backbone', *Tarsier* allows model developers to concentrate on the writing of algorithms, saving considerable software development time. More importantly however, *Tarsier* provides a powerful framework for linking models that simulate different things.

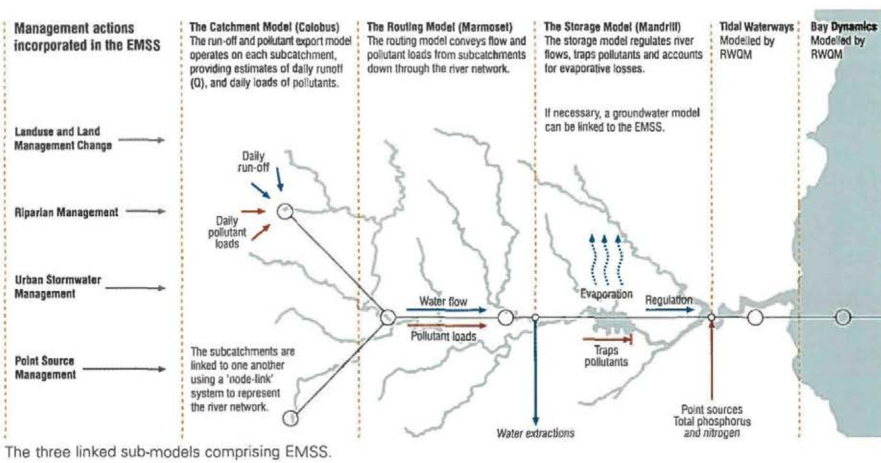


CRC CATCHMENT HYDROLOGY

Tarsier is an innovative catchment model development environment used in the EMSS.

The current version of the SEQ Region EMSS is composed of three linked sub-models. A runoff and pollutant export model (*Colobus*) operates on each subcatchment, providing estimates of daily runoff (Q), and daily loads of total suspended sediment (TSS), total phosphorus (TP) and total nitrogen (TN). The subcatchments are linked to one another using a 'node-link' system to represent the river network. Flow and pollutant loads from subcatchments are conveyed through the river network using a routing model (*Marmoset*). As many of the rivers in the region are regulated by storages, a storage model *(Mandrill)* has been included in the EMSS. This model regulates river flows, traps pollutants, and accounts for evaporative losses on the eight largest dams in the SEQ region. Provision has been made in the EMSS to add point source pollutants to any subcatchment and for water to be extracted from any point in the river network. Daily flows and pollutant loads predicted by the EMSS are written to data files that can be input to estuarine and coastal zone water quality models developed by other researchers in the strategy.

The EMSS is structured so that additional models can be inserted into the system with minimal effort. Future models that may be added include economic and ecological models, as well as alternatives to the current rainfall/runoff, routing and dam storage models.



CRC CATCHMENT HYDROLOGY

The three linked sub-models comprising EMSS.

Applying the EMSS across the region

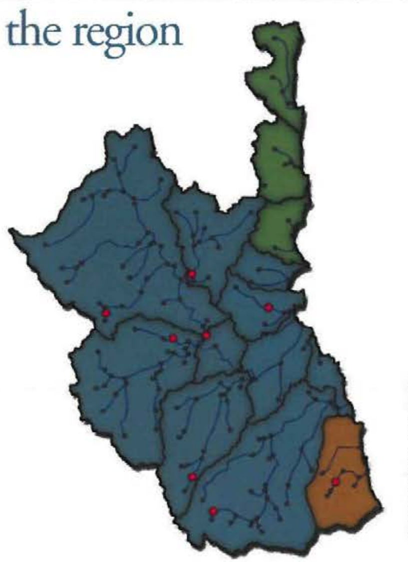
In the EMSS, the South East Queensland region is represented as 14 catchments, broken down into 176 subcatchments. These vary in size between 20 and 200 km², and are connected by a river network that is 2070 km long. The EMSS currently represents the eight largest dam storages, and a further ten dams will be added in future releases of the decision support tool.

The subcatchment map and river network were derived automatically from a digital elevation model, using tools residing in *Tarsier*. The nominal average size of the subcatchments was user-defined as 100 km². However, the ultimate area of each subcatchment was governed by the local terrain shape and the proximity of subcatchment outlets to flow gauging stations. Wherever an outlet was located near one of these stations, the final outlet position was 'snapped' to overlay the gauging station co-ordinate. This was done to enable direct comparison of observed and predicted flows in the EMSS.

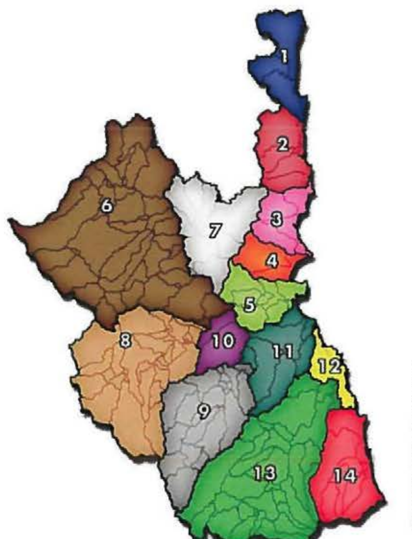
EMSS has 11 different types of land uses: conservation areas, managed forests, plantations, natural bush, grazing, broad-acre agriculture, intensive agriculture, rural residential, suburban, dense urban and future urban.

Catchment areas as used in EMSS.

Catchment number	Catchment name	Area (km²)
1	Noosa	831
2	Maroochy Mooloolah	848
3	Pumicestone North	595
4	Pumicestone South	475
5	Pine Rivers	816
6	Upper Brisbane	5438
7	Somerset Stanley	1527
8	Lockyer	2996
9	Bremer	2022
10	Mid Brisbane	518
11	Lower Brisbane	1171
12	Redlands	354
13	Logan Albert	3779
14	Gold Coast	1302
	Total	22672



The EMSS node-link system representing the river network. Present dam locations are depicted as red dots.



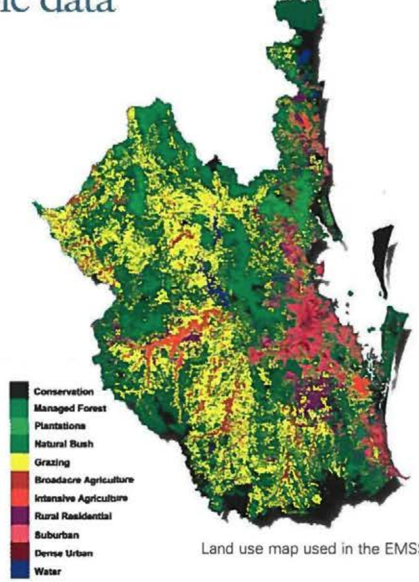
The 14 catchments in SEQ as represented in the Regional EMSS

A model based on available data

Stakeholders of the SEQ region insisted that the EMSS should be based on readily available input data. As a consequence, the data layers used in EMSS include data input layers that are available anywhere in Australia.

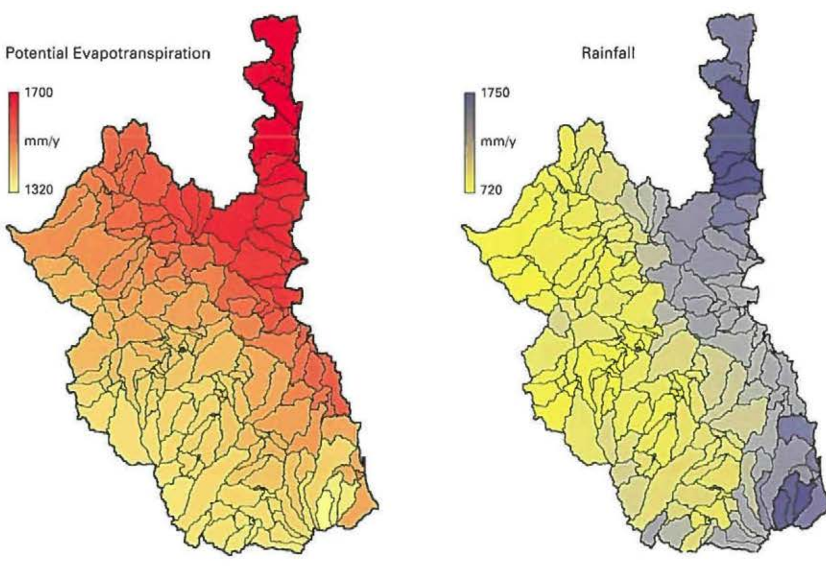
The data layers used in the EMSS include:

- A digital elevation model (sourced from Queensland Department of Natural Resources and Mines) derived from 25 m contour data
- A 25 m pixel land use map (based on the SLATS coverage, sourced from Queensland Department of Natural Resources and Mines)
- A 5 km grid of daily rainfalls (derived from the SILO data base, sourced from Queensland Department of Natural Resources and Mines)
- A 10 km grid of average monthly potential evapotranspiration (derived from the Climatic Atlas of Australia, sourced from the Bureau of Meteorology)



CRC CATCHMENT HYDROLOGY

Land use map used in the EMSS.



CRC CATCHMENT HYDROLOGY

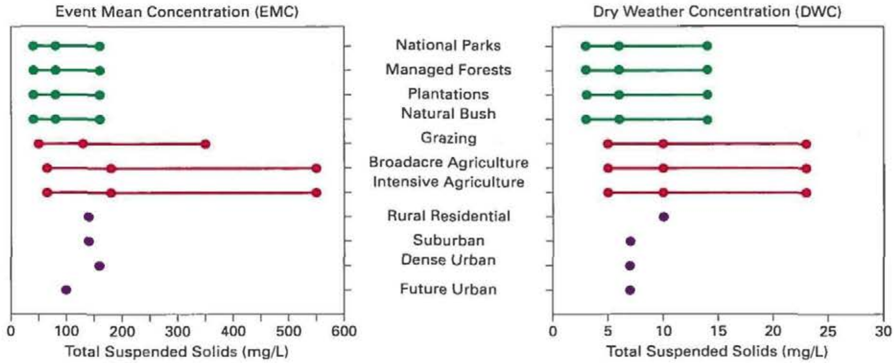
Evapotranspiration and rainfall and maps, showing average values for all subcatchments in the region.

A new database of *pollutant concentrations*

One of the most important inputs to the EMSS is the pollutant concentration database. This is a table of values that is accessed by the model to convert predicted daily runoff volumes into daily pollutant loads. For each of the three pollutants (Total Suspended Solids, Total Phosphorus and Total Nitrogen), and each of the eleven land uses represented in the model, the EMSS needs 'representative' *pollutant concentration values for both storm event* and dry weather conditions. We refer to these as the 'Event Mean Concentration' (EMC) and 'Dry Weather Concentration' (DWC) values, respectively.

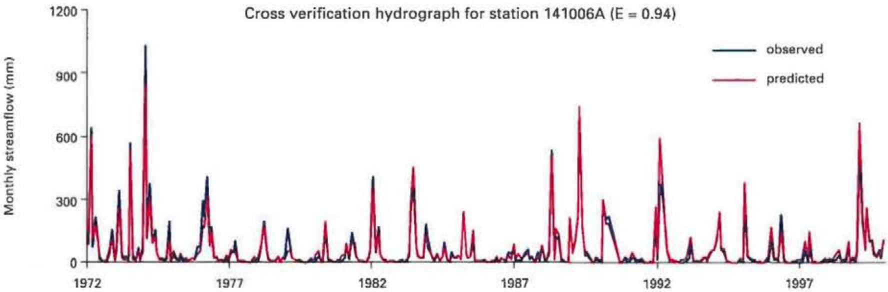
Various agencies and community groups have conducted water quality monitoring programs in the SEQ region. Over the years, they have compiled a large body of data, but little synthesis of that information had been attempted until recently. The EMSS development project was complemented by a 'data mining' project involving the collation of all water quality data gathered in the region and the derivation of a pollutant concentration database for use in the EMSS. The new database includes estimates of the lower (10th percentile), median (50th percentile) and upper (90th percentile) EMC and DWC values for TSS, TP and TN, for each of the pollutants and land uses represented in the EMSS.

Event Mean Concentrations (EMC's) and Dry Weather Concentrations (DWC) values for the Total Suspended Solids (TSS) pollutant are graphed, indicating the lower, median and upper values for each land use. The EMC values are about 10 times higher than the DWC values because most pollutant generation takes place during storm events. EMC and DWC values vary significantly amongst land use groups. Within each subcatchment, the EMSS selects a representative EMC and DWC value for each pollutant and land use from the tabulated range of values. This choice is made by referring to erosion hazard maps that have been compiled for the region (See Chapter 4). Subcatchments with low erosion hazard get low EMC and DWC values and vice-versa for subcatchments with high erosion hazard. In this way, the EMSS accounts for some of the spatial variability in pollutant generation that can be attributed to variations in soil type and rainfall intensity, factors otherwise ignored by the model. In the case of the four urban land uses, the median EMC and DWC values are selected.



Representative pollutant concentration values, the Event Mean Concentration (EMC) and Dry Weather Concentration (DWC) are derived for each land use in the EMSS.

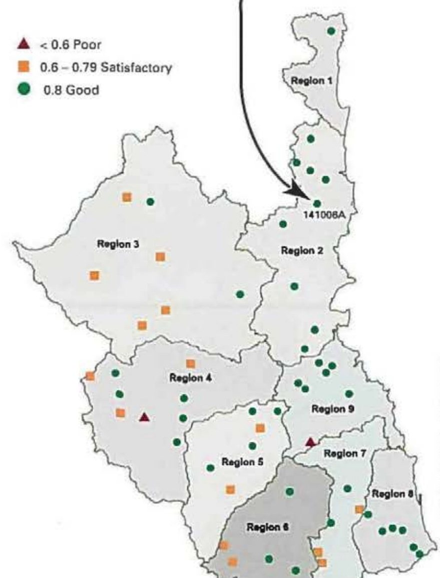
Verification of the *EMSS flow predictions*



For the EMSS to yield reliable estimates of pollutant loads, it is essential that the flow predictions from the model are accurate. Getting this right was a two-step process.

The first step was to calibrate the runoff generation component of the *Colobus* model of the EMSS to gauged subcatchments. The Queensland Department of Natural Resources and Mines has collected flow data for about 200 gauging stations in the region. The data for 58 of these stations, draining subcatchments of between 10 and 1500 km^2 area, was used to calibrate the *Colobus* model. These gauged subcatchments covered about 35% of the region. After calibration, *Colobus* predictions of monthly runoff were cross-validated, using data held back from the calibration process. The cross-validation exercise showed 'good' model fits for 39 subcatchments, 'satisfactory' fits for 15 subcatchments, and 'poor' fits for 4 subcatchments.

The second step was to set model parameters for the rest of the (ungauged) region. In the field of hydrology, this parameter estimation process is referred to as 'regionalisation'. As is commonly done in this process, groups of subcatchments that shared similar hydrologic responses were identified. Nine such regions were identified and all subcatchments within each region were ascribed a common set of model input parameters.



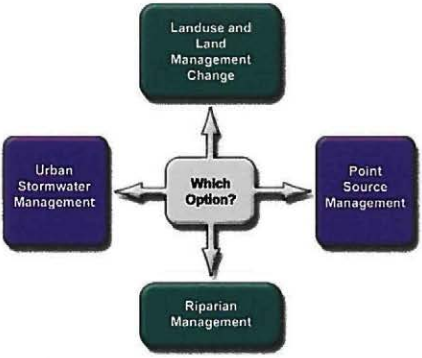
Estimates of flow in EMSS were calibrated against data from gauging stations in SEQ.

CRC CATCHMENT HYDROLOGY

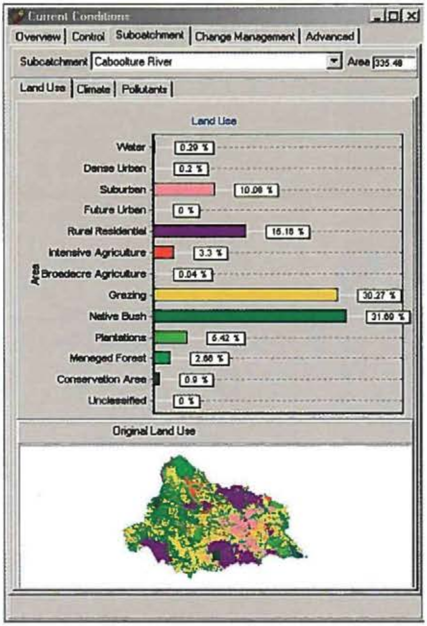
Representing management actions in the EMSS

One of the main purposes of the EMSS is to evaluate the relative efficacy of various catchment management actions aimed at the improvement of water quality. The EMSS represents four main management actions, these being (i) land use change and diffuse land management practices, (ii) riparian vegetation establishment, (iii) diffuse urban stormwater management, and (iv) point source pollutant management. These actions may be implemented in any of the 176 subcatchments represented in the EMSS. The efficacy of such actions will vary from place to place and also in time, with relatively less benefit for large runoff events.

Wetlands have been constructed in urban areas to aid stormwater management.



The various catchment management actions.



A land use histogram generated with EMSS.

The six largest of 33 point sources of Total Phosphorus and Total Nitrogen in the SEQ region.

Source name	Catchment	Total N ($t\ y^{-1}$)	Total P ($t\ y^{-1}$)
Brisbane City Council	Lower Brisbane	1258	357
Brisbane City Council	Lower Brisbane	567	149
Gold Coast City Council	Gold Coast	236	53
Logan City Council	Logan-Albert	166	49
Brisbane City Council	Lower Brisbane	153	54
Ipswich Water	Bremer	74	36

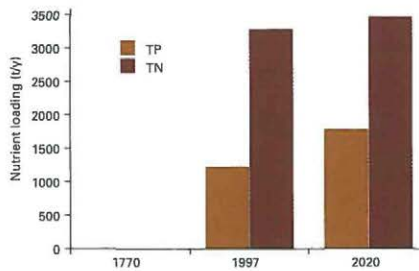
Looking back and into the future: *Scenario analysis*

The current release of the EMSS is distributed with three pre-run scenarios. The main difference between these is the land use, being based respectively on *Pre-Settlement* (1770), *Current* (1997) and *Future* (2020) conditions. By examining these, users of the EMSS can gain an appreciation of how much we have changed our catchments since European settlement, and see how much further change is likely to occur with future development.

To enable inter-comparisons, all three scenarios use an 11-year sequence of daily climate data spanning the period January 1, 1990 to December 31, 2000. The *Current* and *Future* scenarios use the same network of eight storage reservoirs and flow releases (no storages are used in the *Pre-Settlement* scenario). The *Current* scenario uses point source pollutant inputs of TP and TN that were listed in the National Pollutant Inventory for 1999/2000 (1233 and 3280 t/y, respectively). The *Future* scenario uses the same list of point sources, though the volumes are increased according to projections described in the Stage 2 Point Source Loads Study of SEQRWQMS (1791 and 3478 t/y, respectively).

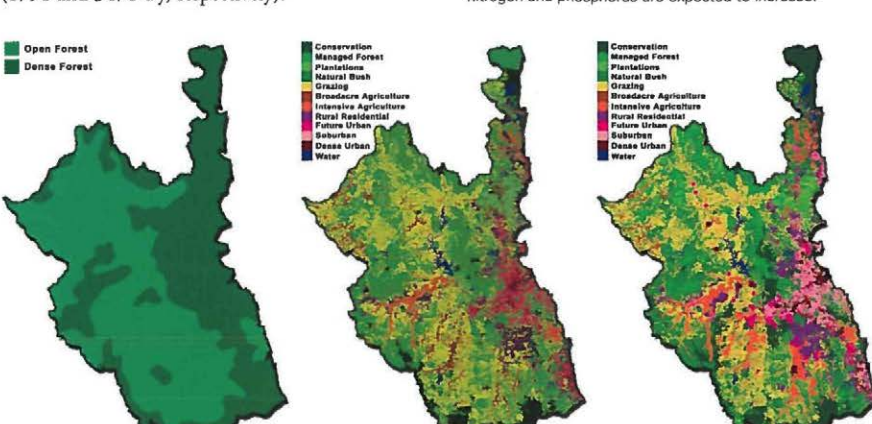
HEALTHY WATERWAYS LIBRARY

Wivenhoe Dam in the Brisbane River catchment is the largest dam in South East Queensland.



WBM

Pollutant inputs from wastewater treatment plants such as nitrogen and phosphorus are expected to increase.



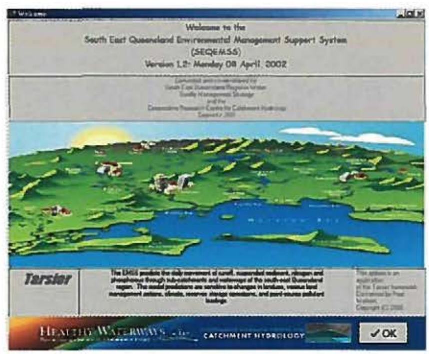
CRC CATCHMENT HYDROLOGY

Land use scenarios for Pre-settlement, circa 1770 (left); Current, circa 1997 (middle); Future, circa 2020 (right).

Stakeholder participation: Vital!

Stakeholder participation has been a vital factor in development of the EMSS. It was the stakeholders who specified what kind of water quality modelling capability was required for the SEQ region. Following the definition of that need, the same group directed the EMSS development team periodically in the design of the decision support tool. The consequence of this participation is that the stakeholders now have a decision support tool that suits them and they can enjoy some sense of collective ownership. The EMSS is *their* modelling system.

However, that participation must continue if the EMSS is to take hold and contribute effectively to the catchment management process. Stakeholders will continue to drive how the EMSS is refined, developed and applied. The EMSS can and should contribute to group-based debate on what catchment management actions are best for different parts of the SEQ region. The software is well suited to application in a workshop setting where stakeholders can propose alternate catchment management scenarios. These scenarios can be set up, run and compared using the sophisticated data visualisation capabilities of the EMSS. In a one-day workshop it is possible to run, compare and debate the merits of five to ten alternate scenarios. The advantage of posing and evaluating such scenarios in a group workshop setting is that stakeholders from various backgrounds can develop a collective appreciation of catchment function and response to management.



The Environmental Management Support System (EMSS), a decision-support tool for the stakeholders.

Stakeholders are trained in the use of EMSS at workshops held throughout South East Queensland.

Future Development of the EMSS

The first phase in the development and dissemination of the EMSS has been completed, but there is still much work to be done before it will attain its potential. Current EMSS activities is focusing on the development of catchment-scale EMSS models, improved sub-model calibration, the training of users, the development of new sub-models and the design of new monitoring programs.

Future EMSS development priorities

Improved calibration of the sub-models

As noted earlier, only preliminary calibrations of the EMSS sub-models have been conducted. Although the EMSS is already yielding credible results, errors in the sub-model predictions could be reduced with more effort given to the calibration process. To some extent, improved calibration will rely on the capture of better flow and pollutant load data.

Training of users

About 60 stakeholders in the SEQ region have been trained in the use of the EMSS. There is a plan to run several training workshops, including in-depth training sessions for consultants wishing to apply the EMSS to new areas. Efforts will be focused on stakeholder capacity building in five different catchment areas within the SEQ region.

New sub- model development

The EMSS should not be regarded as a static model. In fact, it was designed specifically to grow as new or improved scientific knowledge relevant to catchment management emerges. We anticipate adding economic and ecological models to the EMSS in the near future. These will allow stakeholders to determine the consequences of catchment pollutant exports and the cost of remedying such problems.

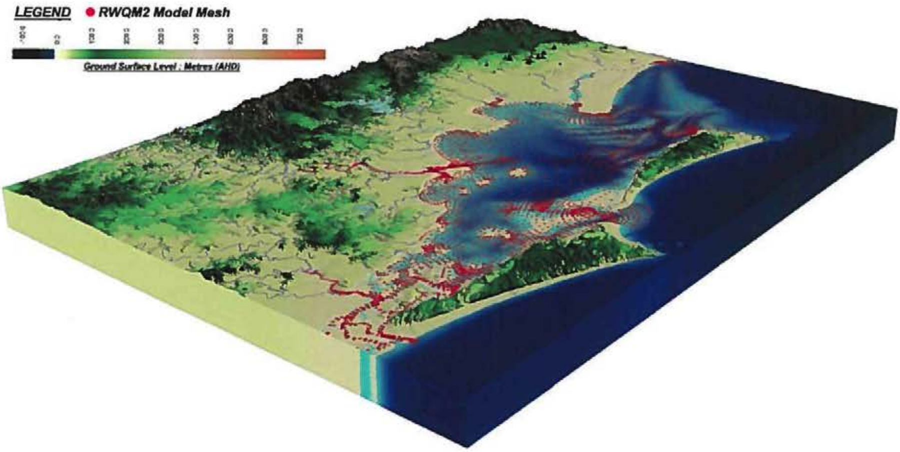
Design of new monitoring programs

The EMSS depends on good input data, but even more so on good flow and pollutant load data for testing. There is a need to collect more pollutant load data to test the EMSS, as the Total Suspended Solids, Total Phosphorus and Total Nitrogen data that we have is sparse both in a spatial and temporal sense. The EMSS can help catchment managers develop better and more cost effective flow and load monitoring programs.

An example of a catchment-scale EMSS, developed for the Gold Coast catchment.

Stream gauging stations in South East Queensland are critical sources of calibration data for EMSS.

An improved predictive capability through upgraded Water Quality Modelling tools

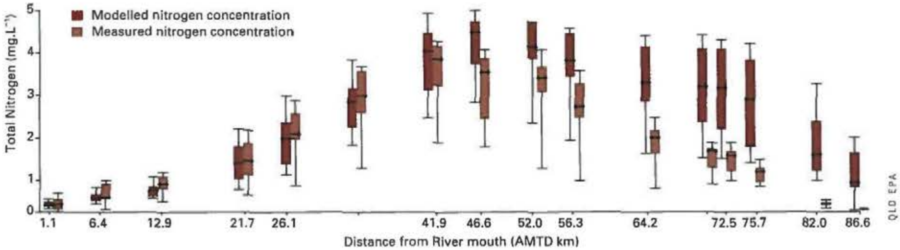


The Receiving Water Quality Model has been shown to be accurate and robust in its predictive capability to simulate water quality in Moreton Bay.

Water quality models for the Moreton Bay area were developed originally for the South East Queensland Regional Water Quality Management Strategy (Stage 2), based on the Resource Management Associates (RMA) finite element modelling platform, initially using the US Environmental Protection Agency Enhanced Stream Water Quality Model (USEPA QUAL2E) water quality algorithms. These algorithms were enhanced significantly based on input provided to the Study by specialists from CSIRO and results from Stage 2 South East Queensland Regional Water Quality Management Strategy (SEQRWQMS) Scientific Tasks. Initial calibrations achieved by these revised models were however, at best, approximate.

Since this earlier modelling effort, considerable work has been undertaken on the model by staff of the Queensland Environmental Protection Agency (EPA), Cooperative Research Centre for Coastal Zone, Estuary and Waterway Management, WBM, and the University of Queensland to revise the water quality algorithms, and especially to remove the "*bugs and errors*" that were present in the code. The end result of this work was a model that has been shown (see following pages) to be accurate and robust in its predictive capability. The initially 'bay focused' Stage 2 model was also upgraded by the EPA to include the relevant estuaries that serve as 'conduits' for much of the catchment and point source derived pollutant loads to the Bay. It is realised that the model schematisation of these estuaries may be the subject of future improvements to enable unique estuarine hydrodynamic processes to be simulated more accurately (especially with respect to the effect of longitudinal salinity gradients on estuarine residence times).

Integrated modelling achieved by linking EMSS to the RWQM



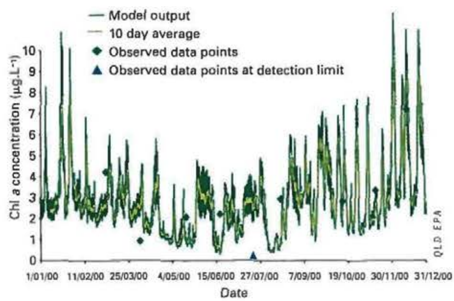
Example of Receiving Water Quality Model Calibration – Brisbane River.

It is a well accepted water quality modelling paradigm that your model is only as good as the load data applied to it. In this regard, in parallel with the internal upgrades being applied to the Moreton Bay Receiving Water Quality Model (RWQM), significant improvements were undertaken with respect to the point and diffuse source loads being applied to the model. Earlier, Stage 2 modelling had used the AQUALM model of the catchment to define diffuse source loads. In Stage 3 of the Study, the more comprehensive and robust EMSS model was available and used in this regard.

Consequently, the South East Queensland Regional Water Quality Management Strategy developed the required interfaces between the RWQM and EMSS to apply improved diffuse source loadings to the model. As well, this approach enabled:

- Better representations of catchment hydrology.
- Better representations of the effects of the various large water supply storages in the catchment (e.g. Wivenhoe and Somerset Dams) on flow and pollutant exports from the catchment.
- Better representation of existing and future catchment land uses, and their effects on catchment runoff loads.

In addition, receiving water quality data sets for the area that were being collected separately by Queensland Environmental Protection Agency staff became available to the Modelling Team for model calibration. This, coupled with the better model schematisation and improved catchment derived loads, has enabled significantly improved model calibration results.



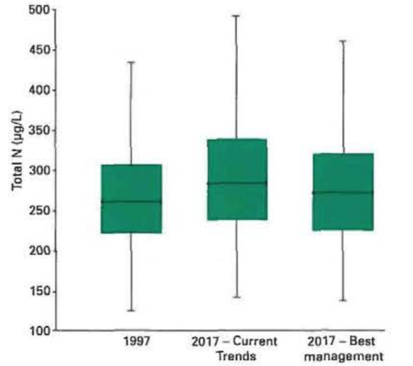
Example of Receiving Water Quality model calibration – Moreton Bay.

Integrated models provided predictions for *various management scenarios*

Integrated models provided predictions for various management scenarios. To help set funding priorities, modelling applications and scientific data acquisition were synthesised to address a number of key water quality and catchment management questions. In this regard, the close interface between the separate catchment (EMSS) and receiving water (RWQM) models was of considerable value.

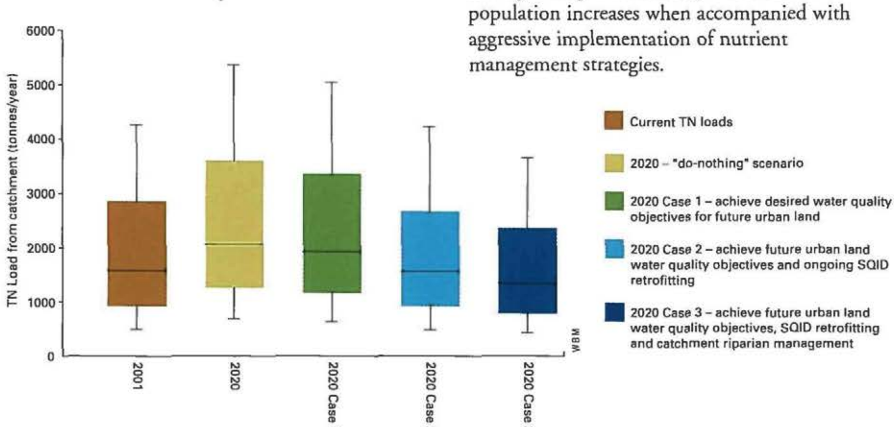
A wide range of scenarios was able to be rigorously assessed including:

- The effects on bay and estuaries water quality of existing and future land use scenarios.
- The relative benefits of stormwater quality improvement device applications in the urban areas within the catchment of Moreton Bay and other waterways.
- The potential effectiveness of various catchment based measures such as riparian and stream rehabilitation.



Predicted total nitrogen (TN) concentrations in 1997 and two scenarios for 2017; current trends and best management.

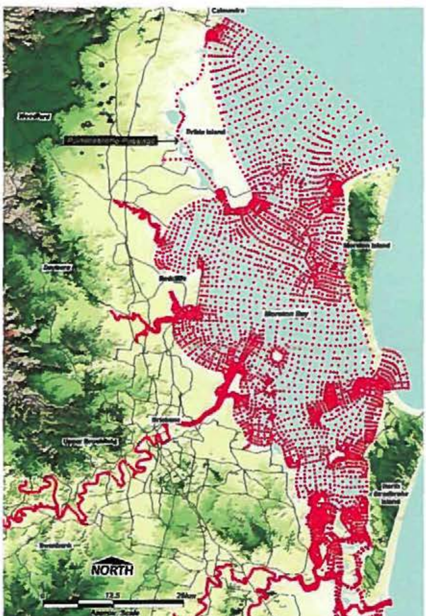
These assessments showed that, with sufficient funding and Government (Federal, State and Local) support, loads from the Moreton Bay catchment could be managed. It was also shown that, with increases in the resident population and urban land uses, water quality levels can be managed despite the anticipated catchment population increases when accompanied with aggressive implementation of nutrient management strategies.



Predicted total nitrogen (TN) load from catchment sources to Moreton Bay.

Receiving Water Quality Modelling – development continues

The Receiving Water Quality Model (RWQM) and Environmental Management Support System (EMSS) are valuable tools. They can help us develop not just a detailed understanding of water quality processes in the area but also predictive capacity. However, as discussed earlier, the models are only as good as the data used in their simulations. There are a number of areas that require further attention so that modelling reliability and accuracy continue to improve.



Mesh of the Moreton Bay Receiving Water Quality Model, showing the representation of the Bay as a network of one-dimensional and two-dimensional elements, with a spatial resolution ranging from 330 m – 2000 m. The model includes hydrodynamic, transport and water quality components.

These areas are as follows:

- Non-point source loads to the RWQM were derived from the EMSS that, while rigorous in the schematisation and approach to simulation of catchment loads, is based on very little locally specific (SEQ) data. There is a significant need for additional data collection activities from the various land uses within the catchment to enable these predictions to be verified or refined (if necessary) in the future.
- The effects of the significant number of large water supply storages in the catchment on stream flows and especially pollutant export from upstream catchment areas need further investigation. Once again, the EMSS has significant theoretical capacity in this regard, however 'hard' data against which to calibrate and verify model performance is lacking.
- The effects of in stream processing of catchment sourced sediments and nutrients, and of other in stream effects (e.g. bed and bank erosion under high flows) are poorly understood in the SEQ region.
- Extension of the RWQM to enable the improved hydrodynamic simulation of certain areas connected to Moreton Bay (e.g. Pumicestone Passage).
- Inclusion in RWQM schematisation of other contaminants and toxicants that could be affecting local environmental and waterway health.
- Enhancement of the sediment module contained within the RWQM2.
- Upgrading of the presently 2-dimensional (vertical) model schematisation to a fully 3-dimensional scheme, in some areas.

Finally, RWQM use would be assisted by an improved interface to enable easier stakeholder use and encourage wider application of the model by researchers.

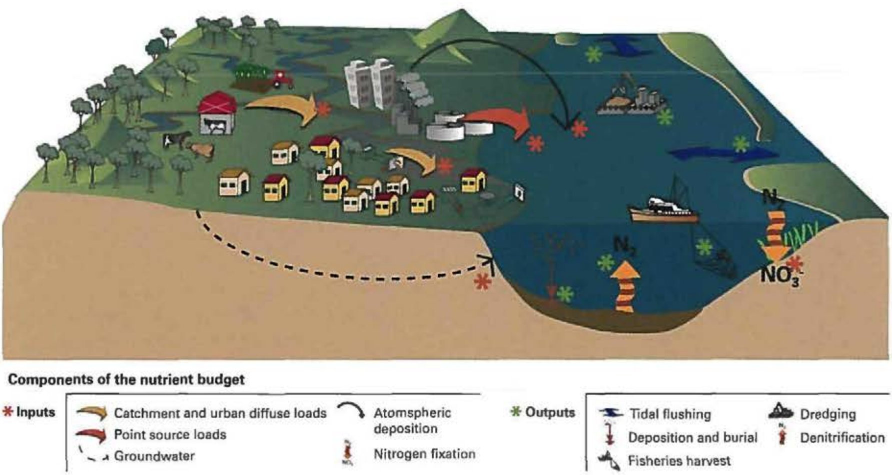
Understanding ecosystem function through *sediment and nutrient budgets*

The cost to local government, industry and state agencies to implement a broad range of point and diffuse source pollution controls will be considerable. Accordingly, the requirement for an understanding of the broad-scale contributions of various point and diffuse source pollutant (sediment and nutrients) sources within the catchment was identified, and addressed. The understanding allows the prioritisation of point source and catchment-based management actions, and hence identifies the most valuable long-term benefits of these investments in terms of the ecosystem health of waterways.

From a research perspective, quantification of sediment and nutrient budgets provides an element of understanding the function of the specific catchments and waterways of South East Queensland. By attempting to balance sediment and nutrient budgets, key uncertainties with respect to the various sources of pollutants in the area are highlighted, enabling prioritisation of further research gaps.

A study considered land use types (and areas), pollutant wash-off rates from the various land uses in the catchment, rainfall patterns (both spatial and temporal) and the efficacy of the range of potential management actions (e.g. Stormwater Quality Improvement Devices, riparian rehabilitation).

Previously, researchers investigating the issue of the relative magnitudes of loads and the significance of catchment processes in the Moreton Bay region have used a number of differing approaches. In this regard, there has been some confusion with respect to the 'correct' answer to this important issue. The South East Queensland Regional Water Quality Management Strategy had previously encountered the anomalies arising from using differing approaches to assess nutrient budgets. Consequently, the available data were re-assessed, and this sometimes contentious issue was resolved.



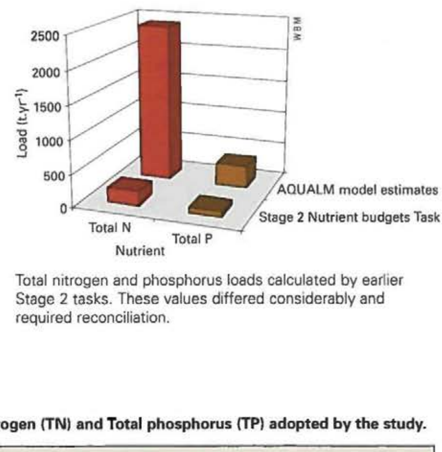
Components of the nutrient budget including both inputs and outputs.

Earlier budget estimates derived for *diffuse P and N were equivocal*

Stage 2 of the Moreton Bay Study indicated a discrepancy in non-point source estimates. The Nutrient Budgets and Diffuse Loads tasks in Stage 2 differed in their estimates of diffuse/stormwater loads from the Moreton Bay catchment. This issue was resolved by reassessing catchment-derived diffuse source loadings of pollutants to Moreton Bay using well recognised and reliable Australian pollutant export data. Relevant data on areal pollutant loading rates for relevant land uses were collated and reviewed. An independent check of the adopted data was conducted using the NEXSYS expert system.

Current data on land uses for the catchment were also accessed. The land use data and areal pollutant loading rates were then combined in a spreadsheet to provide relevant, initial diffuse load estimates. Revised AQUALM modelling was also conducted, using updated land use data and Event Mean and Dry Weather Concentration data. Total predicted pollutant loads to Moreton Bay were then extracted from the model.

This exercise demonstrated that the diffuse source pollutant export assessments of the Moreton Bay region conducted in Stage 2 Diffuse Loads task were relatively accurate. Subsequent EMSS modelling enabled annual catchment derived pollutant loads to be predicted, based on a 15-year data sequence extending from 1985 to 1999.



Total nitrogen and phosphorus loads calculated by earlier Stage 2 tasks. These values differed considerably and required reconciliation.

Areal Loading Rates of Total suspended solids (TSS), Total nitrogen (TN) and Total phosphorus (TP) adopted by the study.

Land Use	Loading Rate ($kg.ha^{-1}.yr^{-1}$)		
	TSS	TN	TP
Native Bushland and National Park	120	0.7	0.038
Managed Forest	150	1.0	0.150
Forest Plantations	150	1.0	0.150
Grazing	300	1.5	0.200
Broadacre Agriculture	400	3.0	0.400
Intensive Agriculture	600	4.0	0.600
Suburban	471	8.5	1.200
High Density Urban	855	12.6	3.100

WBM

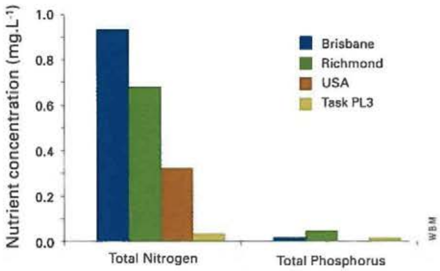
Resolution of the *atmospheric nutrient inputs*

Discrepancies in estimates of atmospheric loading of nutrients to Moreton Bay between Stage 2 Tasks have also been resolved. All relevant atmospheric sources of nitrogen were considered, along with estimations of phosphorus emissions and subsequent deposition, confirming the importance of atmospheric loads.

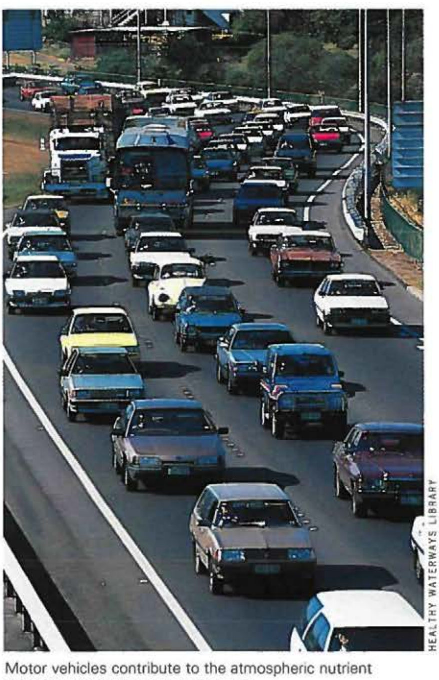
The discrepancy arose between model outputs (which were based on limited available data) and atmospheric loading rates that were extrapolated for Moreton Bay, based on measured rainfall and concentration results recorded in the Richmond River Catchment of northern NSW. The results of this later study were applied to Moreton Bay, as it was considered that Moreton Bay was a coastal area with similar climate and land use characteristics.

A review of available international rainwater quality and atmospheric deposition data, supported by limited additional field data collection, indicated that previous model outputs significantly under-estimated atmospheric deposition and that atmospheric loads calculated from data collected in the Richmond River catchment provided a suitable estimate of loads to Moreton Bay. In this regard, the deposition rates to Moreton Bay proposed by the former study were recommended for adoption for nutrient budgeting.

There remains a need for the collection of air and rainwater quality data. This data collection will provide sufficient evidence to allow a scientific decision to be made regarding the "correct" atmospheric loads to Moreton Bay. Not only do atmospheric inputs contribute a significant fraction of total nutrient inputs, this fraction is likely to increase as other point and diffuse sources are controlled, further emphasising the need to monitor atmospheric nutrient inputs.



Rainwater quality in the Brisbane River catchment based on data from preliminary measured values for Brisbane, USA, Richmond River catchment, northern New South Wales, AQUALM predicted loads for Brisbane.
(Meybeck, 1982; Eyre and McKee, 1999; Omerod, 1998)



Motor vehicles contribute to the atmospheric nutrient deposition loads into our waterways.

Revised nutrient budgets generated for Moreton Bay

The nutrient budgeting work of Eyre and McKee *(1999)* modified estimates of catchment and atmospheric loading that were made by the earlier Tasks PL2 and PL3, as discussed above, to achieve apparently balanced budgets. Key issues in regard to these earlier 'balanced' budgets are as follows:

- The phosphorus budget contained a 'missing' input of 250t/yr; and
- The nitrogen budget contained a 'missing' input of 1700t/yr

Given the agreement with the revised atmospheric deposition rates proposed by Eyre and McKee *(1999)*, and also that all other inputs and outputs to the nutrient budget developed by Eyre and McKee *(1999)* are considered satisfactory, it is apparent that the only potential source for the 'missing' nutrient loads is diffuse source runoff. It is also evident that the differences between the diffuse loading rates of Eyre and McKee and those identified in recent studies (using the EMSS) are of the same order as the 'missing' nutrient loads.

In this regard, a revised nutrient budget was generated for Moreton Bay, incorporating the adjusted diffuse source loads. This results in a more comprehensively balanced budget, without the need to specify 'missing' inputs.

Nutrient Budgets	**Pollutant Load (tonnes/year)**		
	Total Suspended Solids	**Total Nitrogen**	**Total Phosphorus**
Eyre and McKee (1999)	–	222	85
Revised	190,000	1930	334

WBM

Revised nitrogen budget for Moreton Bay and catchment (in tonnes/year).

Inputs		**Ouputs**	
Point Sources	3383	Denitrification	-1765
Non point sources	1930	Dredging	-187
Atmosphere	1410	Burial	-31
Groundwater	120	Fisheries harvest	approx 300
Nitrogen fixation	694	Pumicestone Passage	-160
		Ocean exchange	-5239
Total	**7537**		**-7082**
Difference	455		

Revised phosphorus budget for Moreton Bay and catchment (in tonnes/year)

Inputs		**Ouputs**	
Point Sources	1182	Dredging	-309
Non point sources	334	Burial	-36
Atmosphere	95	Fisheries harvest	-6
Groundwater	2	Pumicestone Passage	-71
		Ocean exchange	-1192
Total	**1613**		**-1614**
Difference	-1		

WBM

Dominant components of the phosphorus and nitrogen budgets

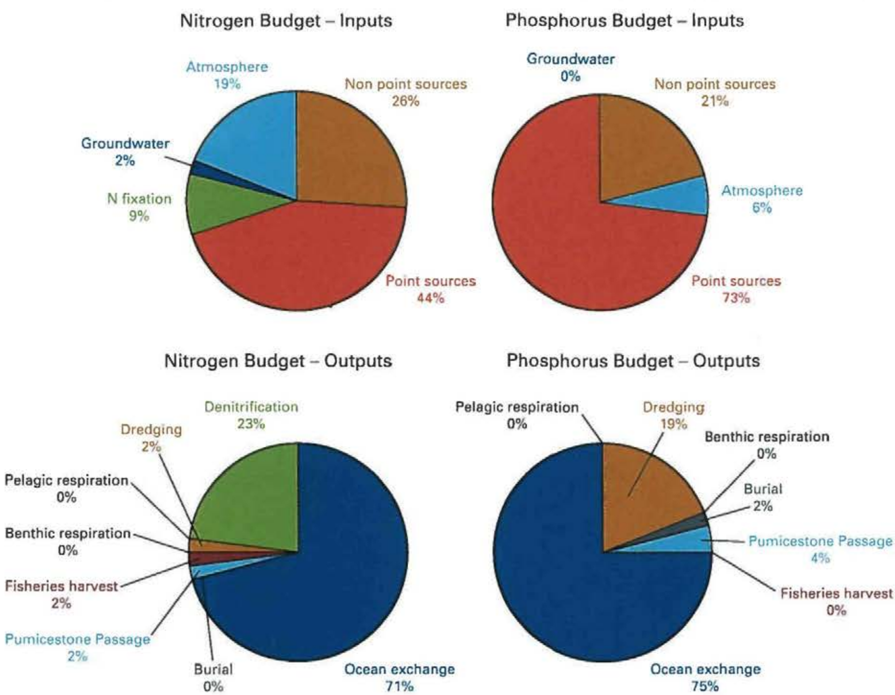
Based on the revised nutrient budget, the following dominant components of the nutrient budget of Moreton Bay can be identified.

Nitrogen

- Point source loads contribute almost half the incident nitrogen load to the Bay, followed in importance by non-point sources (catchment stormwater) and atmospheric deposition loads.
- Denitrification contributes to a significant loss of nitrogen from the system.

Phosphorus

- Point source loads contribute almost three quarters of the incident phosphorus load to the Bay, followed in importance by non-point sources (catchment stormwater) loading. Other sources of P input are minor.

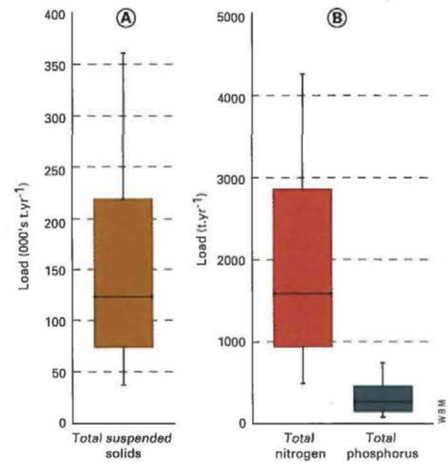


Pie graphs illustrating components of the nutrient budgets and their relative contributions as percent of total loads.

Annual sediment and nutrient budgets are highly variable

One of the other key findings of recent investigations in the study area is the highly dynamic and changeable nature of both the sediment and nutrient budgets of Moreton Bay. This dynamism is particularly important in terms of the catchment-derived loadings of sediments and nutrients, which are heavily influenced by incident rainfall patterns and intensities.

In this regard, it is important to realise that the nutrient budgets presented on the previous page, are based on the average of a 15-year catchment model simulation, extending from 1985 to 1999. In any one year, the loading values for sediment and nutrients can change quite considerably.



Total suspended solids (A) and Total nitrogen and Total phosphorus (B) pollutant export result for the Moreton Bay catchment using 2001 Land Use Case, revised loading data (page 186) and 15-year rainfall patterns.

Average, maximum and minimum pollutant export results for the Moreton Bay catchment using 2001 Land Use case, revised loading data (page 188) and 15-year rainfall patterns.

	Annual Loads (tonnes/yr)		
Descriptor	**Total Suspended Solids**	**Total Nitrogen**	**Total Phosphorus**
Average	157,427	1,930	334
Maximum	360,679	4,259	745
Minimum	37,894	497	85

WBM

Not all subcatchments are equal: *spatial differences in pollutant loads exist*

A useful feature of the Environmental Management Support System (EMSS) is that it can be used to identify 'hot spots' of pollutant generation across the South East Queensland region. Maps were produced to show predicted mean annual sediment load export from each subcatchments over the period 1990 to 2001. Using EMSS, similar maps of any other period of interest can be generated. The large variability amongst subcatchments is due to variations in rainfall, land use and erosion hazard indices. Maps of Total Nitrogen (TN) and Total Phosphorus (TP) can also be produced. These are useful to demonstrate that highly-urbanised areas are the dominant 'hot spots', due to the importance of point source inputs of these pollutants. Clearly defined 'hot spots' are useful for catchment managers because they can assist in focusing limited financial resources to management actions that can provide the most benefit. However, it is also necessary to gain an understanding of the temporal variation in pollutant generation, because the efficacy of any treatment measure will often depend on the size and frequency of polluting events. EMSS can be used to determine the probability that a particular daily pollutant load will be exceeded. Subcatchments with different rainfall and land use characteristics can be compared and this will result in very different temporal patterns of sediment generation.

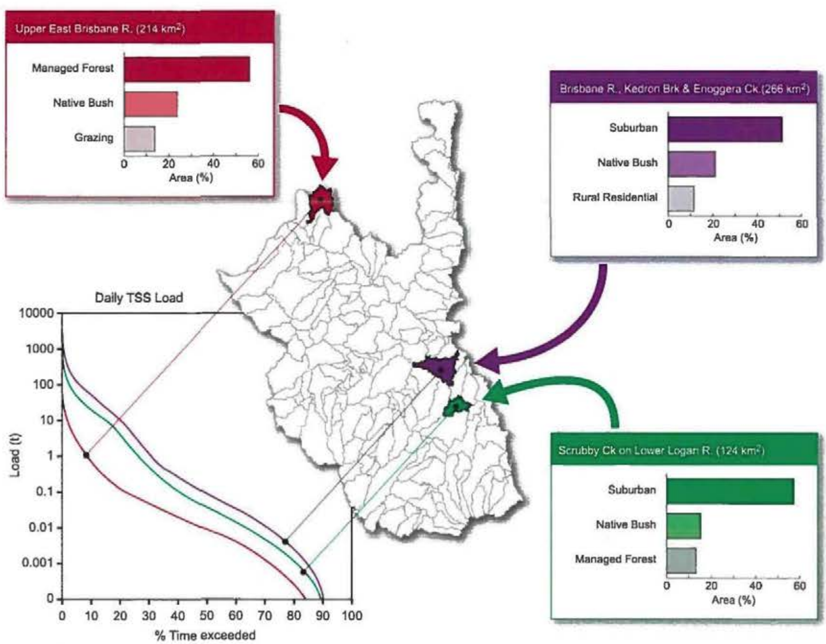


Illustration of catchment/land use/pollutant load relationship.

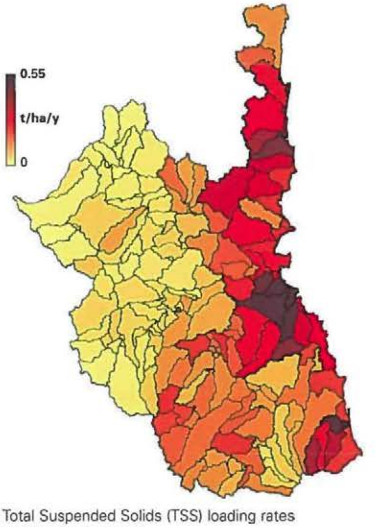
Key assumptions underpin the *EMSS pollutant load predictions*

The EMSS estimates daily loads of Total Suspended Solids (TSS), Total Nitrogen (TN), and Total Phosphorus (TP) by multiplying the daily runoff from each subcatchment by an assumed concentration for each pollutant. Determining the appropriate pollutant concentration for each sub-catchment is a two-step process, involving interrogation of a pollutant concentration database and various maps of erosion hazard potential.

Datasets exist for the pollutants considered by the EMSS (TSS, TN and TP). Different ranges are assumed for storm events (Event Mean Concentration values) and inter-storm periods (Dry Weather Concentration values). Only median values are used for the urban areas. These datasets were compiled from a detailed desktop study that examined local water quality data gathered by Brisbane City Council (for urban areas) and the Queensland Department of Natural Resources and Mines (for rural areas), as well as various water quality studies conducted throughout Australia and other parts of the world.

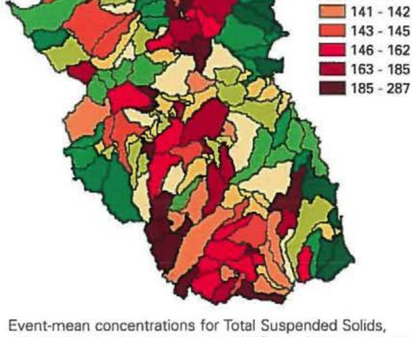
There is a wide range of pollutant concentrations for each land use because of the spatial variability between catchments, differences in land management and climate variability. Selecting the appropriate concentration from this range of values was a key aspect of developing the EMSS.

In the EMSS, the actual pollutant concentration assumed for a particular land use within each sub-catchment depends on the erosion hazard potential. The EMSS refers to gridded maps of erosion hazard index, obtained from the SedNet model. These maps are based on a composite prediction of *hillslope* erosion hazard (in turn derived from maps of terrain slope, hillslope length, soil erodibility, rainfall erosivity and land cover) and *gully* erosion hazard (based on aerial photo analysis of gully networks in the region). For subcatchments with high erosion hazard, the EMSS adopts EMC and DWC values closer to the upper limit of the range, and vice-versa for subcatchments with low erosion hazard indices. Different maps are used for different land uses and the other pollutants.



WBM

Areal Total Suspended Solids (TSS) loading rates in South East Queensland.

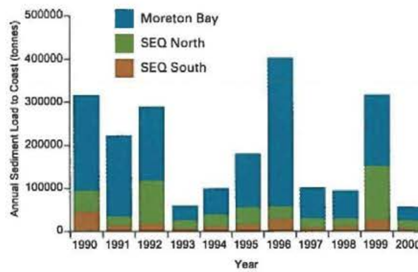


Event-mean concentrations for Total Suspended Solids, adjusted by erosion hazard potential for each sub-catchment.

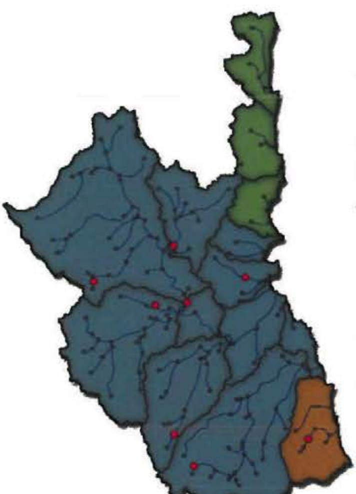
CRC CATCHMENT HYDROLOGY

Pollutant generation does not equal pollutant delivery; not everything makes it to the Bay

Not all of the pollutants that are generated from catchments make it to the coastal waters. In fact, the further away a catchment is from the coast, the less likely that the pollutants generated from it will complete their coastward journey. Some of the load is trapped in dams (there are 21 of these in the SEQ region), while some is locked up in channel and floodplain storages. For the *Current Conditions* scenario described in this book, the EMSS predicts that about 27% of the annual TSS load generated from the catchments draining Moreton Bay is trapped by dams. During large flood events, channel storages get mobilised (adding to the river load derived from catchments). Further load is added to the river from bank erosion during such large events. When flows breach the channel banks, some of the river load is deposited on floodplains. Though the current version of the EMSS (Version 1.1) accounts for pollutant trapping by dams, it does not yet represent channel and floodplain storage dynamics, nor bank erosion. These are vital geomorphic processes which will be represented in the next version of the EMSS software. For now, the EMSS will tend to overestimate pollutant delivery to the ocean.



Annual variabity in sediment delivery to the coast.



SEQ North

- No significant dam storages
- Mean annual generation of sediment = 42,000 t
- Mean annual delivery of sediment to coast = 42,000 t

Moreton Bay

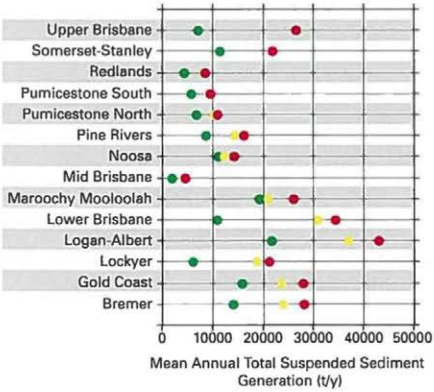
- Seven major storages
- Mean annual generation of sediment = 186,000 t
- Mean annual delivery of sediment to coast = 135,000 t

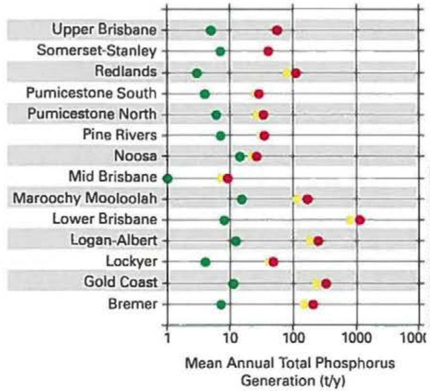
SEQ South

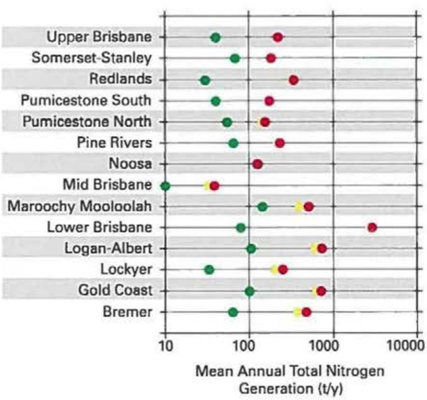
- One major storage
- Mean annual generation of sediment = 24,000 t
- Mean annual delivery of sediment to coast = 18,000 t

Note: Figures above are for the *Current Conditions* scenario (1997 land use, 1990-2000 climate series).

Changing pollutant generation in the SEQ region







Predicted changes in pollutant loads for South East Queensland Catchment (Green, 1770; Yellow 2000; Red 2020).

Pollutant generation from catchments of the SEQ region has increased significantly since European settlement. On average across the region, mean annual TSS generation has increased by about 80% since European settlement. More significant increases in total nitrogen (TN) and total phosphorus (TP) have occurred, with mean annual TP and TN generation increasing by about 1700 and 660%. Approximately half of this increase is due to point source loadings. Based on the predicted 2020 land use pattern, further increases in TSS, TP and TN generation are expected. On average, mean annual TSS generation will increase by about 10%, while mean annual TP and TN generation are expected to increase by about 40% and 10%, respectively. The largest changes are predicted to occur in the coastal catchments where significant urbanisation is planned, and in the Logan-Albert catchment, where considerable intensification of agriculture is likely.

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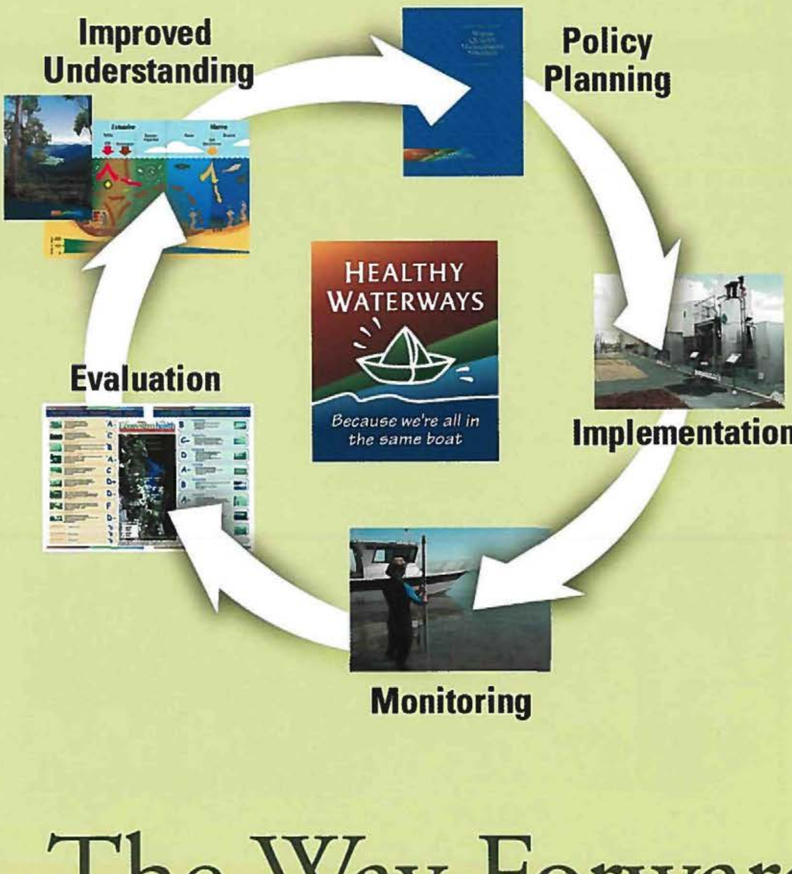
Chapter 9



The Way Forward

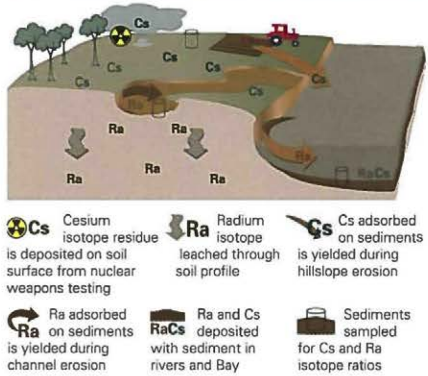
Eva G. Abal, Stuart E. Bunn, William C. Dennison
Paul F. Greenfield and Diane Tarte

Some key issues for *global science applications*

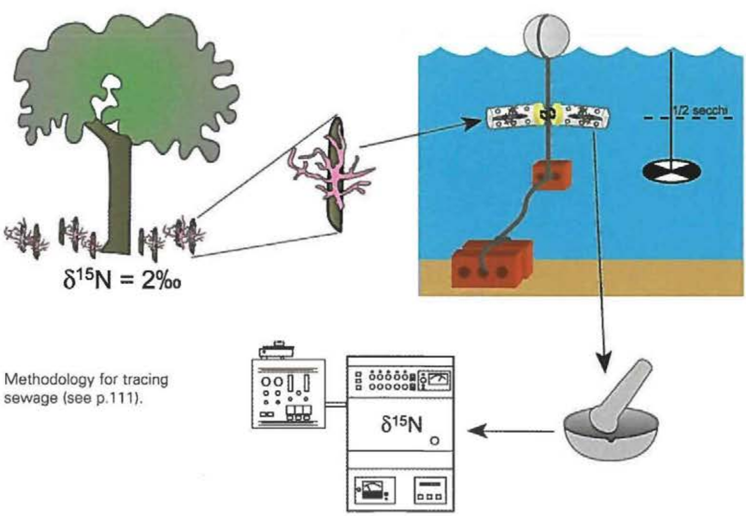
We have selected four key lessons, among the many, of a successful science application process. A catchment-to-coast management program involves many more features. Some of the key lessons that we have selected relate to the activities that took place in Stage 3 of the ongoing Healthy Waterways Partnership.

1 Tracers for source identification

The use of tracers, in particular, isotopic tracers, was a key forensic scientific tool in the study. The stable isotopic tracer ^{15}N was used both in catchment and marine depictions of nutrient flows and sources. Radioisotopic tracers such as cesium and radium tracers were used with great success in soil studies to understand the process of the delivery of sediments to the rivers and eventually Moreton Bay. The key lesson from this is that model results and concentration maps in themselves were not sufficient to convince stakeholders of the direct relationships between sources and fate of pollutants. The interpretation of tracers provided information that could be easily understood and accepted (see pp. 73 and 111).



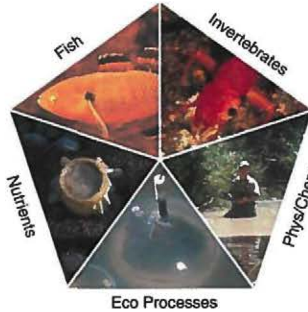
Tracing of errosion processes using isotopes (see p.73).

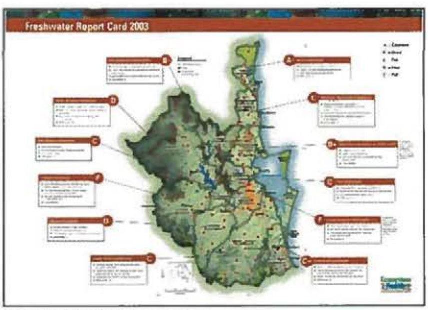


Methodology for tracing sewage (see p.111).

2 Scientifically rigorous environmental report cards

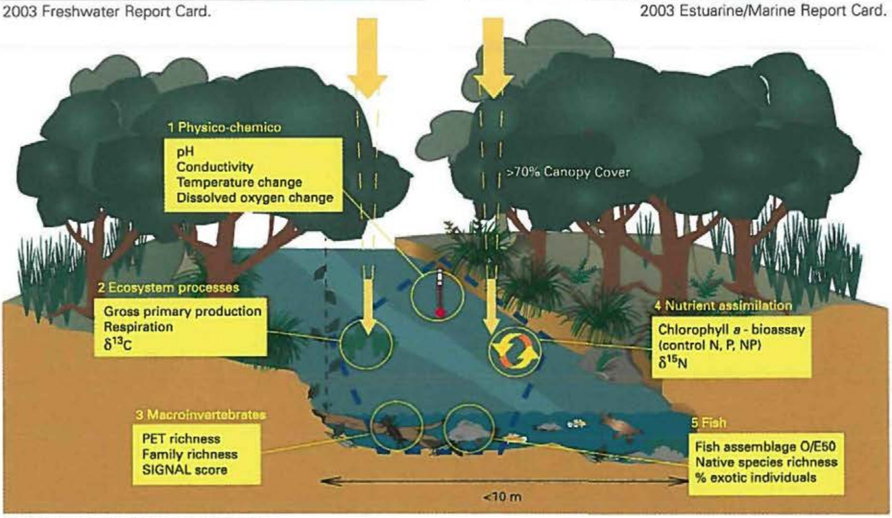
Research identified various measures of water quality, bioindicators and ecosystem features that are useful indicators of ecosystem health. Significant additional research and statistical and spatial analyses were needed to develop these into indices that were used for an annual, scientifically rigorous Ecosystem Health Report Card. The Report Card's release is now a major public event with extensive media coverage. It also provides important feedback to stakeholders on the effectiveness of their significant investments in environmental protection and improvements.





2003 Freshwater Report Card.

2003 Estuarine/Marine Report Card.



EHMP Freshwater Conceptual Diagram.

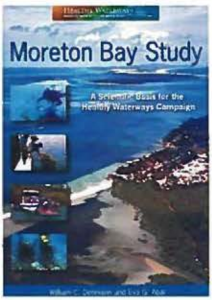
3 Science involvement in cultural celebration

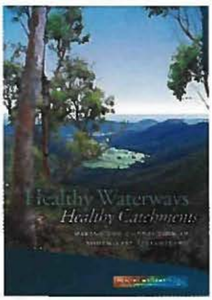
As a result of increased community interest in waterways, the city of Brisbane holds a major annual cultural event called River*festival*, underpinned by environmental messages and attracting over 500,000 people each year. A festival highlight is the 3-day International River*symposium*, which brings together scientists and river management practitioners from across Australia and around the world. A feature of the Symposium is the AUD$150,000 International and $50,000 National Thiess River*prize*, awarded for best practice river management. Healthy Waterways is a consistent presence at the Symposium, which provides a platform to showcase the Partnership's research, acts as an interface between science and management, stimulates interaction with delegates from all over the globe and increases awareness of Healthy Waterways science, planning and communications programs.

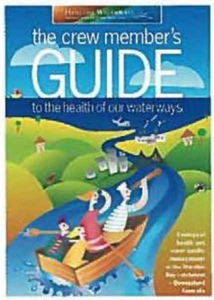
ALL PHOTOS: MAJOR BRISBANE FESTIVALS PTY LTD – RIVERFESTIVAL

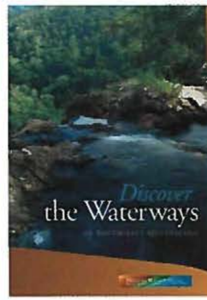
4 Science rigour and communication including conceptual diagrams

This book, previous books, newsletters, websites, public presentations, videos and other communication products heavily relied on the use of scientifically-based conceptual diagrams. These diagrams sought to identify and depict the major processes, biota and threats or impacts in the catchments and associated waterways. They provide an effective means to communicate often complex scientific findings and their implications to a broad range of stakeholders. Scientific credibility for these conceptual diagrams was obtained through peer review and revision so that scientists were able to agree on the key messages being depicted and therefore, communicated to the wider community.

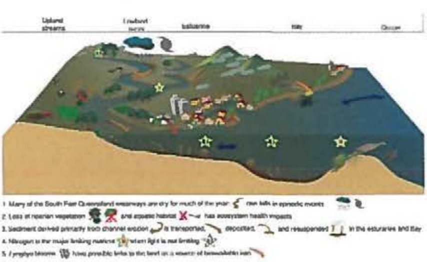




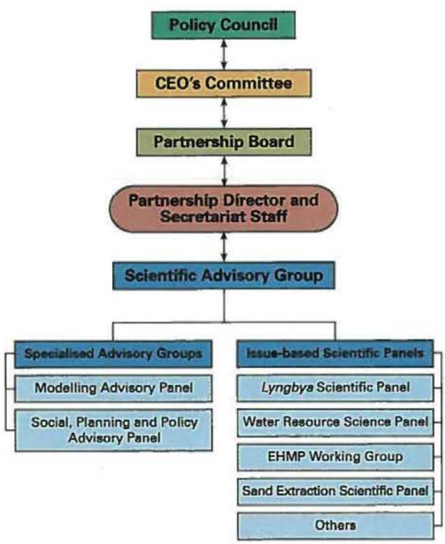




Stage 2 Conceptual Model for the Moreton region depicting the major processes and impacts on the estuarine and marine sections.



Stage 3 Conceptual Model for South East Queensland catchments and waterways.

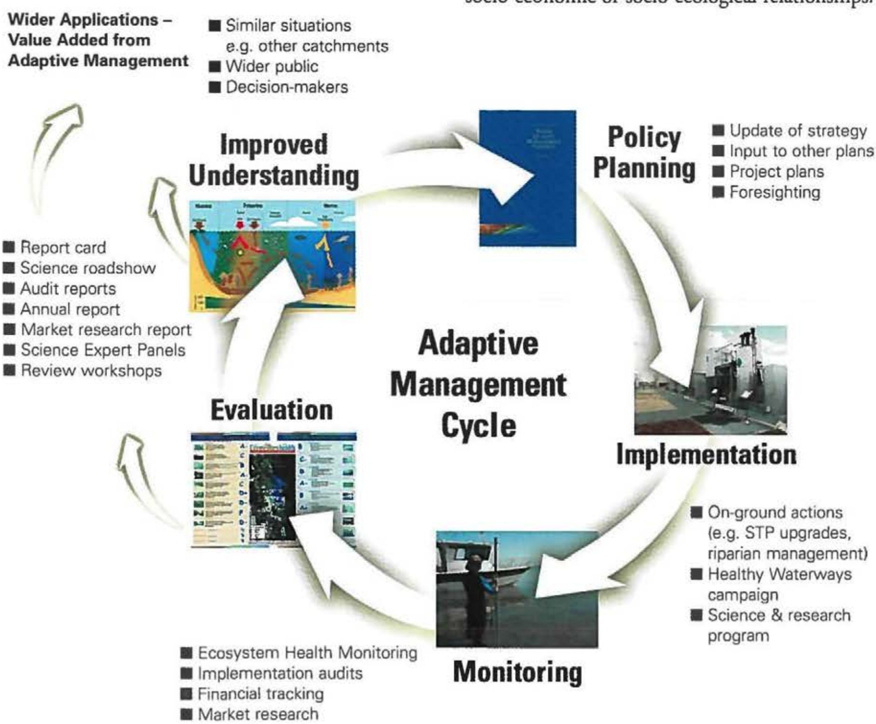


Links between the Partnership Scientific Advisory Group and the policy-setting and decision making components of the Partnership.

A new partnership *using an adaptive management framework*

The Moreton Bay Waterways and Catchments Partnership (the Partnership) evolved from the efforts to develop and implement the South East Queensland Regional Water Quality Management Strategy (the Water Quality Strategy) and to develop an integrated management framework for the Brisbane River. The Partnership operates through a wide variety of consultative, participatory, advisory, planning, decision-making and regulatory processes to achieve the Healthy Waterways vision. Some 72 agreed actions of the Water Quality Strategy are now being implemented.

The Adaptive Management Framework, one of the operating philosophies of the Partnership, can be described as on-going knowledge acquisition, monitoring and evaluation leading to continuous improvement in the identification and implementation of management. The approach recognises that action can seldom be postponed until we have "enough" information to fully understand the situation. This leads to improved understanding of the means for dealing with resource management issues, as well as providing the flexibility necessary for dealing with changing socio-economic or socio-ecological relationships.



Applicability of the adaptive management framework in the Moreton Bay Waterways and Catchments Partnership.

Integration of science and management: assisting in natural resource planning and target-setting

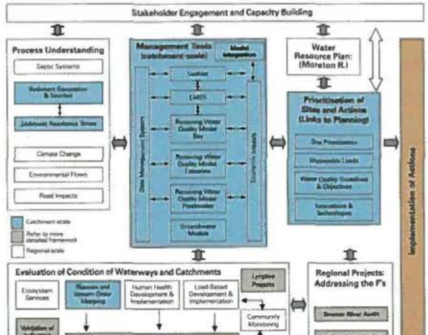
With today's increasing emphasis on regional natural resource management, there is a strong need to deliver to resource managers an enhanced capacity to make decisions on appropriate management actions. The adaptive management approach is based on the recognition that we often need to act on the basis of an imperfect understanding of the systems within which management action occurs. However, unless there is targeted research to expand the knowledge base for management as well as appropriate decision support tools for stakeholders, the outcomes of the adaptive management process will improve only slowly, if at all. Thus, the Partnership is firmly committed to continually improving the knowledge base and the development of decision support tools to assist stakeholders to achieve natural resource management outcomes.

Decision support tools such as the Environmental Management Support System (EMSS) and Receiving Water Quality Model for the estuaries and Moreton Bay (RWQM) are useful not only in evaluating the relative efficacy of various management actions aimed at the improvement of water quality, but can also assist stakeholders in determining sustainable loads and setting environmental targets for waterways. Development of a user-friendly interface to decision support tools also ensures that research outcomes are extended to stakeholders in the most effective form.

The new Healthy Waterways website was launched in April 2003 and provides information for stakeholders, the community and educators on a range of regional and local issues.

The Healthy Waterways campaign provides an essential portal to communicating the understanding of environmental issues to the stakeholders. Healthy Waterways currently enjoys around 50% "brand" recognition in the South East Queensland general community.

The Partnership framework illustrates a unique integrated approach to water quality management whereby scientific research, community participation, and development of management actions are done collaboratively. The Partnership believes that improved understanding and availability of appropriate decision support tools for management of land and water resources result in effective prioritisation of initiatives targeted towards achieving the ***Healthy Waterways vision***. Integral to the success of Healthy Waterways is communicating that from the upper catchments to the coasts, everyone "is in the same boat". After all, it is only when we have **healthy catchments** that we can have **healthy waterways.**



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Glossary

Acid Sulphate Soils – Waterlogged soils containing minerals that are converted into acid when exposed to air and lead to water quality problems in receiving water bodies

Adaptive Management – Framework of on-going knowledge acquisition, monitoring, and evaluation leading to continuous improvement in the identification and implementation of management; one of the operating philosophies of the Moreton Bay Waterways and Catchments Partnership

Adsorbed – Bound to sediment particles in an exchangeable form, referring to, for example, nutrients

Aerobic – In the presence of oxygen e.g. aerobic decomposition of organic matter leads to the production of carbon dioxide (CO_2) (see Anaerobic)

Allochthonous – Inputs of energy or nutrients that are derived from outside of the system (e.g. leaf litter from riparian zones entering streams)

Ambient – Background environmental condition

Ammonium – Reduced form of nitrogen (NH_4^+) and an important nutrient for plants (see Nitrogen, Nitrate, Nitrite)

Anaeorobic – In the absence of oxygen. e.g. anaerobic decomposition of organic matter leads to the production of methane (CH_4) (see Aerobic)

Anthropogenic – Resulting from human activities

Autotrophic – Capable of converting carbon dioxide, water and nutrients into organic molecules that are the building blocks of life (see Heterotrophic)

Bacteria – A primitive group of ubiquitous, microscopic, single-celled organisms lacking a nucleus

Baseflow – Flow of water entering stream channels from groundwater sources

Benthic – Pertaining to the seafloor or river bottom (see Pelagic)

Benthic microalgae – (BMA) microscopic plants which inhabit the sediment surface or interstitial water, mostly diatoms and dinoflagellates

Bioassays – A controlled experimental treatment used to test the response of a biological indicator to additions of nutrients or pollutants

Biodiversity – Variety of different species present in an area

Biomass – The amount of plant and/or animal material (usually per unit area)

Biota – All living organisms; plants and animals

Catchment – The area of land which collects and transfers rainwater into a waterway

Chlorophyll – Major pigment that captures light for photosynthesis, found in cells of plants and bacteria

Conceptual diagram – A diagram depicting the most current understanding of the major ecosystem functions and processes (biological, physical, and chemical components) of a particular location

Cyanobacteria – Primitive, photosynthetic bacteria occurring as a single cell or in filaments, some of which are often capable of nitrogen fixation (often referred to as blue-green algae)

Channel Erosion – Wearing away of the land, chiefly by rain and running water; occurs in gullies and along stream banks, especially where riparian vegetation is degraded (see Hillslope Erosion)

Denitrification – Conversion, carried out by anaerobic bacteria, of the biologically available, oxidised form of nitrogen (NO_3^-) to the biologically unavailable nitrogen gas (N_2) (see Nitrification)

Detritus – Fragments of dead and decomposing plants and animals

Diatoms – A group of unicellular, pelagic and benthic microalgae, which are characterised by the presence of an intricate silica skeleton

Diffuse loads – Non-point sources of pollution such as sediment or nutrients from catchment runoff, groundwater inputs or atmospheric fall-out

Dinoflagellate – A group of unicellular algae, characterised by two flagellae. Some are autotrophic, while others are heterotrophic. Responsible for "red tides"

Dry Weather Concentration – DWC, representative pollutant concentration values for dry weather conditions; determined for each of the three pollutants (total suspended solids, total nitrogen, and total phosphorus) and each of the eleven land uses in EMSS (see EMC)

Ecosystem – The physical and chemical environment and the plants and animals that live in it

EMSS – Environmental Management Support System, a decision support tool which predicts the generation of daily or monthly loads of sediment and nutrients from subcatchments and the delivery of these pollutants to the receiving waters; initially developed for the South East Queensland region

Episodic – An infrequent and often unpredictable event or a series of events (e.g. rainfall, storms)

Estuary – Zone of mixing of fresh and salt water in the lower reaches of a river

Event Mean Concentrations – EMC, representative pollutant concentration values for storm events; determined for each of the three pollutants (total suspended solids, total nitrogen, and total phosphorus) and each of the eleven land uses in EMSS (see DWC)

Flushing – Exchange of water from one location to another (see Residence Time)

Habitat – The physical and chemical environment in which a plant or animal lives

Headwaters – Source and upstream waters of a stream

Heterotrophic – Not capable of photosynthesis and instead, acquires carbon by ingestion of organic molecules (see Autotrophic)

Hillslope Erosion – Wearing away of the land, chiefly by rain and running water: (also referred to as sheet erosion) occurs on soil surfaces that may be covered with vegetation, but is more prevalent on bare soil (see Channel Erosion)

Hydrodynamics – The movement of water and the interactions of the body of water with its boundaries

Interstitial – The spaces and water between particles of sand or gravel in the bottom of a water body

Intertidal – The area along the coast below the high tide and above the low tide

Invertebrates – Animals without backbones

Lowland streams – Includes many urban streams and small tributaries of lowland rivers; characterised by intermittent flow, gentle gradients which created moderate to slow-flowing streams which often recede to a series of pools

Lyngbya majuscula – Filamentous, toxic cyanobacteria

MBWCP – Moreton Bay Waterways and Catchments Partnership, the combined Brisbane River Management Group (BRMG) and the South East Queensland Regional Water Quality Management Strategy (SEQRWQMS)

Macroalgae – Large multicellular plants that include green algae, red algae and brown algae. Algae belong to one of the two subkingdom of plants characterised by the absence of specialised tissues or organs

Mangroves – Trees which inhabit the intertidal zone on sheltered coastlines. Their lower trunk and roots are periodically flooded with the tides

Monitoring – Continual measurements in order to determine changes in the environment

Nitrate – The most abundant oxidised form of nitrogen (NO_3^-), an important nutrient (see Ammonium, Nitrogen, Nitrite)

Nitrification – The conversion, carried out by aerobic bacteria, of the reduced form of nitrogen, ammonium (NH_4^+), to the oxidised forms, nitrite (NO_2^-) and nitrate (NO_3^-)

Nitrite – A less-abundant oxidised form of nitrogen (NO_2^-) (see Ammonium, Nitrogen, Nitrate)

Nitrogen – An essential nutrient for all organisms, forming a component of amino acids, protein and genetic materia (see Ammonium, Nitrate, Nitrite)

Nitrogen fixation – The conversion of nitrogen gas (N_2), which is biologically unavailable to most organisms, to ammonia (NH_3), a process carried out by a select group of bacteria and cyanobacteria (see Denitrification)

Non-point source – A source of, for example nutrients and sediment, not restricted to one discharge location (see also Diffuse Source)

Nutrient budget – A mass-balance budget, which defines all the input, output and storage of nutrients in a specified region; provides insights into the controls on biogeochemical and ecological processes and is helpful in predicting the effects of future changes in these systems

Nutrient flux – The transfer of nutrients between sediments and the water column

Nutrients – Essential elements required by an organism for growth

NRM – Natural resource managment

Pelagic – Pertaining to the water column (see Benthic)

Phosphorus – An essential nutrient for all organisms forming a component of, for example, Adenosine Triphosphate and phospholipids

Photosynthesis – The process carried out by plants and some bacteria, in which light energy is harvested by pigments (mostly chlorophyll) and utilised to convert carbon dioxide and water into organic molecules and oxygen

Phytoplankton – Microscopic, planktonic plants which are either single-celled or form simple chains

Point source – A single point of discharge of, for example, nutrients and sediments (see Non-point Source, Diffuse Source)

Productivity – The rate at which biomass (of plants or animals) is produced

Redfield Ratio – Atomic ratio of nutrient content in aquatic plants and seawater (carbon:nitrogen:phosphorus)

Residence time – Average length of time that water, or compounds dissolved or suspended in the water, remains in a certain location (see Flushing)

Re-suspension – Process in which sediment particles are brought back into suspension in the water column by waves, tides, wind or by disturbance from animals burrowing or feeding

Riparian vegetation – Vegetation living or located on a riverbank

Runoff – *Flow of water into a stream: usually from a* rainfall event where rate of accumulation exceeds losses from infiltration and evapo-transpiration

Runoff coefficient – The percentage of precipitation/rain that appears as runoff

Salinity – Salt content of water, often expressed in parts per thousand or milligrams per litre

Seagrass – Marine flowering plants, which are generally rooted in the sediments

Secchi disc – A plate-sized black and white disc which is lowered into the water column until it is no longer visible from the surface. Provides a measure of light penetration into the water column and the depth at which sufficient light is available for aquatic plant growth

Sediment – Inorganic and organic particulate matter on the bottom or in the water column of rivers, lakes, estuaries and oceans.Much is often derived from soil eroded from the land, though there can also be a significant organic component derived from terrestrial vegetation or from plankton settling from the water column

SEQRWQMS – South East Queensland Regional Water Quality Management Strategy

Sewage effluent – Household and industrial wastewater that has been treated to reduce solids, organic and nutrient content

STP – Sewage treatment plant

Stable isotopes – Naturally occurring and non-radioactive isotopes of common elements, such as carbon (^{12}C:^{13}C) and nitrogen (^{14}N:^{15}N). Useful tracers in the study of ecosystem processes and in the detection of sewage nitrogen

Stratification (vertical) – Physical layering of the water column resulting from density differences primarily due to temperature or salinity differences

Taxa – General taxonomic term for a sub-group of organisms (e.g. species, genus, family, etc.)

Tonnes – A unit of weight equalling 1000 kg

Toxicant – A substance that can harm living organisms

Turbidity – Measure of the clarity of water

Upland streams – Streams located on the higher ground of a region, in contrast to a valley, plain or other low-lying land

Vertebrates – Animals with backbones

Virus – A large ubiquitous group of microogranisms, *composed of a protein sheath surrounding a* nucleic acid core and capable of infecting all animals, plants and bacteria; characterised by total dependence on living cells for reproduction

Virus-like particles – VLP's, viruses that have not been cultured to identify hosts

Waterway – Any creek, stream, river, estuary or bay

Zooplankton – Microscopic animals which live in the water column and feed on phytoplankton and bacteria (includes protists, animals and larvae of animals)

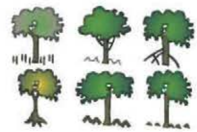
Symbol Glossary

Biota

Terrestrial vegetation

Freshwater vegetation

Mangroves



In-stream habitat

Seagrass

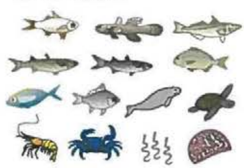
Macroalgae

Lyngbya

Microscopic biota

Freshwater fauna

Marine fauna



Birds

Land use

Agriculture

Forestry

Grazing

Urban

Modifications

Rock wall | Dam | Canal estate

Inputs

Sewage treatment plant | Stormwater drain | Point source | Diffuse sediments and nutrients | Iron runoff

Processes

Tidal flushing | Sediment resuspension and deposition | Limitation | Reduction in light | Loss of

Bank erosion | Gully erosion | Deposition

Physical Environment

Rain | Cyclone | Dry creek bed | Suspended sediment

This book is a comprehensive record of Stage 3 of the Healthy Waterways Campaign – the scientific research and planning, community consultation and consumer education activities of the Moreton Bay Waterways and Catchments Partnership. It is the fourth in a series of publications which seek to inform general and more targeted audiences of the work of the Partnership and follows on from its predecessors:

- 'Discover the Waterways of South-East Queensland: a crew member's guide', published in 2001;
- 'Moreton Bay Study: A Scientific Basis for the Healthy Waterways Campaign', which presented the scientific findings of Stage 2, published in 1999; and:
- 'The Crew members Guide to the Health of Our Waterways', published in 1988.

'Healthy Waterways – Healthy Catchments: Making the connection in South East Queensland, Australia' is aimed at secondary school and university students, researchers, scientists, planners, industry, government, environmental and catchment organisations, natural resource managers and policy makers, plus informed and interested members of the wider community.

The book has been produced to further assist the achievement of the Healthy Waterways Vision:

By 2020, our waterways and catchments will be healthy ecosystems supporting the livelihoods and lifestyles of people in South East Queensland and will be managed through collaboration between community, government and industry.

HEALTHY WATERWAYS
Because we're all in the same boat

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