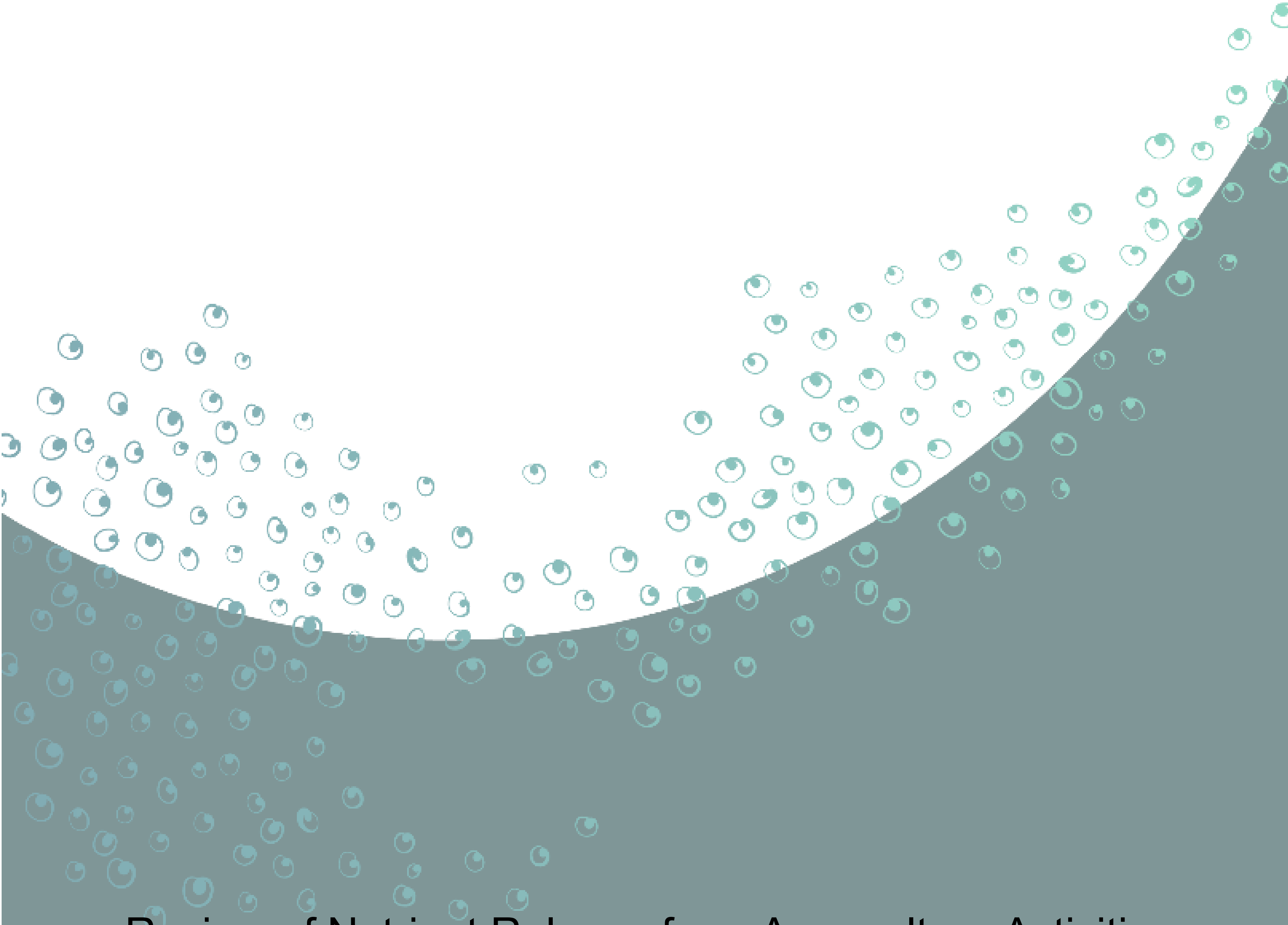

Review of Nutrient Release from Aquaculture Activities

Report for Consultation

Prepared for the Office of the Great Barrier Reef,
Department of Environment and Science

Report for Consultation

This report is open for comments and feedback for 3 months from the date of publishing. All written responses should be emailed to psd.help@des.qld.gov.au.

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Executive Summary

Introduction

Reported point sources are approximately 4% of overall anthropogenic nitrogen loads and 9% of anthropogenic phosphorus loads exported from the Reef catchment based on 2018 data. Approximately 80% of reported point source nutrient loads in the Reef catchment originated from sewage treatment plants (STPs) which service approximately 800,000 people. Pond aquaculture was the second greatest contributor, estimated at 20% of the reported point source nitrogen load or approximately 1% of the total anthropogenic nitrogen load. While these point source nutrient loads appear relatively small when compared to diffuse source loads, they can still have potentially significant local impacts on the receiving environment as they are concentrated at one location.

The key aim of this study was to develop a better understanding of current nutrient management practices used by the prawn and barramundi sectors of the pond aquaculture industry in Queensland. A further aim was to identify opportunities for improved nutrient management, environmental assessment and regulation for aquaculture activities within the Reef catchment, and more broadly across Queensland.

The main farming type in Queensland is pond aquaculture for black tiger prawns (*Penaeus monodon*) and barramundi (*Lates calcarifer*). The aquaculture industry is likely to expand as wild-caught fish become increasingly less available. At the time of this project, there were 14 operating prawn farms situated within the Reef catchment and 5 operating prawn farms outside the Reef catchment on the Logan River in South East Queensland (SEQ). All the farms are situated relatively close to the coast and use saltwater from tidal creeks and rivers. There were 5 barramundi farms releasing to waters within the Reef catchment in north Queensland at the time of this study. These farms use seawater, brackish water or freshwater as their intake water. The major source of nutrient input for intensive aquaculture pond production systems is the high-protein feed.

Potential impacts from aquaculture pond release mainly relate to the release of nutrients and particulate organic matter and impacts occurring in the local receiving waters. Particulate nitrogen and ammonia are the main forms of nitrogen released from aquaculture treatment ponds. A better understanding of potential water quality impacts from aquaculture releases will be gained through the analysis of historical receiving water quality data from operating farms along with an assessment of assimilative capacity of local receiving waters.

Currently, most farmers use settlement ponds as their main treatment system to reduce concentrations and loads of nutrients in release water. Information is lacking on how effective these ponds are although previous research suggests that they have only limited capacity for total nitrogen removal and are somewhat better at removing suspended sediments. There is a willingness to adopt new technologies within the aquaculture industry, but there is a lack of information on available options and concerns about whether these are cost-effective and able to meet licence requirements.

Available release monitoring data for aquaculture farms in the Reef catchment were limited. The facilities were compared based on combining (averaging) all years with a full year of operational data. The annual release volume from aquaculture farms in the Reef catchment with data was estimated at 75 gigalitres (GL). The annual nutrient release loads of farms with data were estimated at approximately 113 tonnes of Total Nitrogen (TN) and 11.4 tonnes of Total Phosphorus (TP). These TN and TP load estimates are 30% and 43% higher, respectively, than the previously reported aquaculture loads for 2018. The data showed that two large farms in the Reef catchment produced half of the reported release volume, and more than 60% of the reported TN load. Four farms produced nearly 80% of the reported TN load.

There is considerable variation in nutrient concentrations within farms, and between farms, for both TN and TP. Some farms can achieve an average TN release concentration of near to, or less than, 1 mg/L, and an average TP concentration at, or below, 0.1 mg/L. These average release concentrations are relatively low compared to other point source activities such as sewage treatment plants. In addition to TN and TP, total suspended solids (TSS), chlorophyll-a and BOD_5 concentrations appear to be important water quality indicators for aquaculture farm releases. These indicators are only measured for some farms and the available data shows that they can be elevated during the growing cycle, at concentrations that could potentially cause an impact on receiving waters.

Most aquaculture farms are required to develop and implement a Receiving Environment Monitoring Program (REMP) to monitor the water quality of local receiving waters and undertake an annual assessment of impacts.

A desktop review was undertaken of REMP reports for 7 aquaculture farms (including 4 prawn farms and 3 barramundi farms). Receiving Environment Monitoring Programs were found to vary significantly between farms in terms of intensity, scale, design and analysis. Some areas for potential improvement were identified. Overall, it was not possible to draw any strong conclusions about the conditions of the environments that receive aquaculture farm releases from the review, given the site-specific nature of most receiving environments and farm production. Visual and tabulated information in the reports showed that water quality within the local receiving estuary downstream of the aquaculture farm release was different for indicators such as TN, chlorophyll-a and DO concentrations compared to further-a-field results.

Further work gathering and assessing industry data on both release water quality and REMPs is recommended to help assess the sustainability (footprint) of current aquaculture releases and help inform the need for potential future studies for the industry. Development and application of a specific aquaculture REMP guideline is also recommended to help improve the suitability and consistency of aquaculture farm REMPs.

Improved nutrient management and treatment options were reviewed in this study. Most of the treatment alternatives discussed rely on biological processes to transform or remove nutrients from the discharged water prior to release. Although there have been many studies related to those processes, none of these are currently used throughout the industry. There are technologies used in other industries that can reduce nutrient levels, however they are designed for higher input concentrations of nutrients and relatively low water volumes compared with aquaculture farm discharge. As such, these technologies are likely to be inefficient or cost prohibitive for aquaculture applications. Enhancing settlement ponds remains an option but research is needed to examine ways to do this. Some knowledge gaps remain in the use of biofloc systems, particularly for the black tiger prawn, to optimise its performance.

Multiple facets of aquaculture nutrient load management and regulation need to be further investigated, as there are currently no solutions to allow for industry-wide expansion of aquaculture in Queensland, and specifically in the Reef catchment. Research, development and full-scale demonstration is needed to determine the applicability of treatment and management approaches to a Queensland context for both barramundi and prawn farms. Priority research and development areas include alternative treatment (such as high-rate algal ponds or sand filtration), wetlands and recirculation systems that can reduce nutrient release loads. Recirculation presents the greatest opportunity to reduce overall nutrient loads but will require significant changes to farm operation and approvals to accommodate event releases. Further work should also be considered on enhancing and augmenting settlement ponds to make them more effective.

More information regarding risk assessment and regulation of aquaculture farms, including improved guidance material and tools, should be developed and provided to support development assessment and operation. Increased guidance on options for nutrient offsetting and information about how offset policy has been implemented for other industries, particularly for activities in the Reef catchment, is recommended.

There are opportunities to review the regulation of aquaculture facilities, such as reviewing Environmentally Relevant Activities (ERAs) under the *Environmental Protection Act 1994*, to allow greater flexibility in operation by industry while maintaining environmental standards and outcomes for the Reef. Planning code modifications could reduce risks associated with production intensity and the scale of operation. The aquaculture Model Operating Conditions and Prawn Farm Policy could be reviewed to improve alignment with certification standards. Any changes would require an active and considered industry consultation program.

A list of 14 draft recommendations is provided in this report and each requires further scoping, prioritisation and resourcing. These cover the following issues: release management; decision support tools and information; receiving environment assessment; stewardship; environmental approvals; and nutrient offsets.

Ongoing communication and collaboration across government, industry and research organisations is essential for implementation of each of these recommendations.

Contents

Glossary

Term	Description
ABFA	Australian Barramundi Farmers Association
ADA	Aquaculture Development Area
AIMS	Australian Institute of Marine Science
Anammox	Anaerobic ammonium oxidation—microbial process in the nitrogen cycle during which nitrite and ammonium ions are converted to diatomic nitrogen and water
ANZECC	Australian and New Zealand Environment and Conservation Council. This organisation no longer exists. The ANZECC water quality guidelines have been superceded by the Australian & New Zealand Guidelines for Fresh & Marine Water Quality
APFA	Australian Prawn Farmers Association
Aquaculture	Farming of aquatic organisms including fish, molluscs, crustaceans (including prawns), and aquatic plants.
ASC	Aquaculture Stewardship Council—global non-profit organisation which establishes protocol for farmed seafood
ASFBC	Australian Sustainably Farmed Barramundi Certification
Assimilative Capacity	The capacity that a waterbody (e.g. estuary) has to receive anthropogenic nutrient inputs such that the water quality levels do not exceed water quality objectives for the waterbody.
BAP	Best Aquaculture Practices—program developed by Global Aquaculture Alliance
BOD_5	Five-day Biochemical Oxygen Demand
Catchments	Geographical areas that drain to a certain location or waterbody
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAF	Department of Agriculture and Fisheries, Queensland Government
DES	Department of Environment and Science, Queensland Government
Diffuse source	Agricultural or urban sources, other than ERAs, that result in runoff and contaminants to the environment, often from an area of land and typically related to rainfall.
DIN	Dissolved inorganic nitrogen—including ammonia (NH_3, NH_4^+), nitrate, and nitrite.
DON	Dissolved organic nitrogen—nitrogen from organic matter (e.g. soil, organic matter decomposition)
EAs	Environmental Authority issued under Queensland Environmental Protection legislation. Also known as a permit or licence. See Environmental Approval
ELI	Environmental Load Index
Environmental Approval	Includes Environmental Authorities, accepted development requirements, permits and licences. See EAs
Environmental Values (EVs)	Environmental values (EVs) for water are the qualities that make it suitable for supporting aquatic ecosystems and human uses. EVs define the human uses of the water to include drinking water, irrigation, aquaculture, recreation, and cultural/spiritual values
EP Act	*Environmental Protection Act 1994*
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
ERAs	Environmentally Relevant Activities including prescribed ERAs (e.g. sewage treatment plants, quarries, abattoirs and aquaculture operations) and (ii) resource ERAs (e.g. mining). Aquaculture is prescribed ERA 1 and Seafood processing is prescribed ERA 27
Facility	Site, farm, or property where one or more ERAs are being undertaken. More than one facility may be listed in an EA.

Term	Description
FCR	Food conversion ratio—measure of livestock production efficiency
FRP	Filterable Reactive Phosphorus
GSA	Global Seafood Alliance
GU	Griffith University
GVP	Gross Value of Production—monetary estimate of the commercial fisheries and aquaculture production
HP	Horsepower
MIP	Major Integrated Project—Wet Tropics Major Integrated Project
MOCs	Model Operating Conditions—standard set of conditions that may be applied to an ERA.
NGO	Non-Governmental Organisation
Nutrient releases	Point source releases that are likely to contain significant quantities or concentrations of nutrients, particularly nitrogen and phosphorus
Offset Policy	Point Source Water Quality Offsets Policy 2019
PASF	Polychaete-assisted sand filter—nutrient treatment system involving filter-feeding animals
Pers. comm.	Personal communication
PL	Postlarvae—in reference to juvenile prawn
Point source	Industrial activities that release water and contaminants to the environment from a specific location. In this report, point sources are ERAs
Pond aquaculture	Land-based aquaculture, specifically relates to prawn or barramundi farms in Queensland
Pond discharge	Water coming from aquaculture production ponds that would flow into a treatment system(s) prior to release
Pond water	Water that is being used by industry in aquaculture ponds as part of the farming process
Prawn Farm Policy	Licensing wastewater releases from existing marine prawn farms in Queensland – Operational policy
QCA	Queensland Competition Authority—independent statutory authority which promotes competition to enhance efficiency and encourage growth in Queensland, currently named the Office of Productivity and Red Tape Reduction
RAS	Recirculating Aquaculture Systems—tank-based systems in which fish are grown at high density, water is recirculated through the tanks and water treatment systems
Reef	Geographical areas related to the Great Barrier Reef Lagoon
Reef legislation	*Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Act 2019* came into effect on 1 June 2021 and sets a ‘no residual impact’ requirement for nutrient and sediment loads that applies to all industries in the Reef catchment
REMP	Receiving Environment Monitoring Program. Monitoring programs often required under EAs with authorised release to water
SEQ	South East Queensland
Settlement Ponds	Treatment unit designed to encourage the sedimentation of particulate material from the water column to reduce total suspended solids but less efficient at removing nutrients. Main treatment unit adopted by pond aquaculture in Queensland
SSTV	Site-specific trigger values
TN	Total nitrogen, includes dissolved and particulate nitrogen
TP	Total phosphorus, includes dissolved and particulate phosphorus
TSS	Total suspended solids
UQ	University of Queensland

Term	Description
Wastewater release	Water that has been used by industry and is released to the environment, typically having undergone some type of wastewater treatment. For aquaculture, may contain nitrogen, phosphorus, and suspended sediment
Water Quality Offsets	Water Quality Offsets—alternative investment options to meet wastewater discharge requirements for Environmentally Relevant Activities—see Section 4.3 Water Quality Offsets
WaTERS	Water Tracking and Electronic Reporting System— database system used to submit water monitoring data electronically to the department of environment and science
Wetlands	Generally referred to in this report as artificial wetlands that are used for the treatment and management of wastewater
WQOs	Water Quality Objectives—set of limits needed to protect the environmental values for a particular water body. May be scheduled under the Environmental Protection Policy for Water and Wetland Biodiversity

1 Introduction

The Food and Agriculture Organisation of the United Nations defines aquaculture as the farming of aquatic organisms including fish, molluscs, crustaceans (including prawns), and aquatic plants through intervention in the rearing process to enhance production. The water source for aquaculture can be either marine, brackish, fresh or even inland saline. The production systems are adapted to each farm's situation and include open ponds, sea-cages, raceways, tanks and indoor fully recirculating aquaculture systems (RAS). The industry in Queensland focuses mainly on prawn and barramundi farming. Most pond aquaculture farms rely on large volumes of intake water, and subsequently, large volumes of water release, which can contain nitrogen, phosphorus, and suspended sediment.

In Australia, aquaculture has grown over the past 20 years to become, in 2019/20, the largest sector of the Australian seafood industry in terms of gross value of production (GVP) (Steven et al., 2021). Although only accounting for 38% of total seafood volume, the GVP for aquaculture increased by 10% on the previous financial year, to a total of $1.6 billion in 2019/20. Pond aquaculture is a significant industry in Queensland, valued at $161 million GVP for the 2019/20 financial year. The industry is a significant contributor to rural employment, both in SEQ and in the Reef catchment from Gladstone to Ingham. The industry in Queensland has seen major proposals for expansion, more intensive farming and increased investment from larger companies. The Queensland Competition Authority (QCA) reviewed aquaculture regulation in Queensland in 2014 and made a series of recommendations to improve investment opportunities and reduce the regulatory burden for industry. As a result, the Queensland Government has identified 8 aquaculture development areas (ADAs) to promote and grow the aquaculture industry. Some other recommendations have not yet been implemented.

There are several regulatory and legislative mechanisms applicable to aquaculture in Queensland. Many of these aim at protecting the environmental values of the receiving environment, for example, the *Environmental Protection Act 1994* (EP Act); the *Environmental Protection Regulation 2019*; and the Environmental Protection Policy for Water and Wetland Biodiversity 2019). Major industries (and point source activities) are regulated as ERAs under the *Environmental Protection Act 1994* and require an EA to operate. An aquaculture facility is defined as ERA 1 in the *Environmental Protection Regulation 2019* as cultivating or holding marine, estuarine or freshwater organisms in an enclosure on land or in waters where release to water is proposed. The EA sets out a range of conditions that need to be met, and in the case of a point source release, would typically require limits on the quality and quantity of the release. These levels are set prior to the commencement of activity when the level of potential risk to the environment is assessed by potential applicants. At this stage, sufficient measures need to be proposed to manage and minimise potential environmental impacts. Once approved, these measures and limits need to be complied with during operation.

Effective water quality management through better land use management practices will be an important part of maintaining and improving the resilience of Reef ecosystems. Diffuse source runoff from agricultural land use is the largest contributor to nutrient and sediment loads exported to the Reef (Reef 2050 Long-Term Sustainability Plan 2021-2025, Commonwealth of Australia 2021). Ramsay et al. (2021) undertook a major study into point source activities in the Reef catchment and determined that in 2017/18, point source activities contributed approximately 4% (approximately 400 tonnes) of the anthropogenic nitrogen load and approximately 9% (approximately 120 tonnes) of the anthropogenic phosphorus load. The main point source activity was identified as STPs which contributed 80% of the total point source nitrogen load. Aquaculture was identified as the next largest contributor with 20% of the total point source nitrogen load. Therefore, based on the data available at the time, aquaculture contributed less than 1% (approximately 0.8%) of anthropogenic nitrogen load to the Reef in 2018. It should be noted that this is a gross, rather than net, estimate and did not include nutrients contained in intake water.

Given point sources are a potential contributor of pollutants to the Reef, the Reef discharge standards for industrial activities under Section 41AA of the *Environmental Protection Regulation 2019* came into effect in mid-2021. Section 41AA specifies that an EA must not be approved if a new or expanding point source activities will have a "residual impact" on the Reef catchments waters. Residual impact relates to dissolved inorganic nitrogen (DIN) and fine sediment loads. Where a residual impact is proposed, offsets are required to counterbalance the impact. However, the 'no residual impact' condition does not account for the DIN and sediment loads in aquaculture farm intake water. Therefore, it is critical to investigate how to address the requirements of this legislation so that the aquaculture industry in Queensland continues to operate and expand where possible.

Continued expansion of aquaculture is a priority for the Queensland Government with the priority development areas in Queensland now identified. Major expansion proposals have also been received from large companies developing in the Reef catchment. This desire for expansion needs to be considered alongside catchment-based load targets in the Reef 2050 Water Quality Improvement Plan and potential local water quality impacts. Preliminary information was obtained for aquaculture facilities as part of the study on point sources in the Reef catchment by Ramsay et al. (2021). However, more information was needed given the nature and complexity of aquaculture activities and releases and the lack of information available. Additional information was necessary to better understand current management of nutrients, explore ways to minimise nutrient release loads, and navigate environmental and legislative constraints.

This project was funded by the Office of the Great Barrier Reef and World Heritage under the Queensland Reef Water Quality Program, with a focus on establishing how nutrient loads exported to the Reef lagoon can be better managed, for example through improved land use practices. The report was prepared for the Queensland Government and therefore focusses on the aspects of aquaculture that is managed by the State, particularly the environmental approvals and compliance aspects.

The key aim of this project was to develop a better understanding of current environmental practices used by the pond aquaculture industry in Queensland to manage nutrient levels in pond water. A further aim was to identify opportunities for improved nutrient management, environmental assessment, and regulation for aquaculture activities within the Reef catchment, and more broadly across Queensland. This work was undertaken collaboratively by the Science and Technology Division of DES and Griffith University, and involved direct engagement with the pond aquaculture industry, industry associations and relevant government departments. As well as obtaining feedback from industry, the project examined release monitoring data that had previously been submitted to DES by the industry and undertook a detailed review of environmental authorities.

This report initially provides a high level overview of the policy and legislative context for aquaculture in Queensland. A major part of the technical review is presented in the next section which examines the pond aquaculture used in Queensland, based on available literature and information obtained directly from the industry. It covers an overview of both prawn and barramundi production, key production parameters, pond nutrient budgets, typical characteristics of pond water, potential impacts of release water and feedback from industry. The next major section provides a detailed review of environmental regulation policy and standards for aquaculture. This covers model operating conditions, the current Prawn Farm Policy, water quality offsets and certification standards. The next section provides a detailed review of Environmental Authorities (EAs) for aquaculture in Queensland, in addition to a review of the available release monitoring data and receiving environment monitoring programs (REMPs). The final section provides an overview of nutrient management and treatment options for pond-aquaculture, including feed management and available pond water treatment and management.

2 Policy and Legislative Context

This section sets a high-level policy and legislative context for aquaculture. It is not intended to be a comprehensive review of all legislative and policy frameworks in Australia, rather relevant extracts of matters that are discussed later in the report. Further detail is provided in Appendix 1.

The National Aquaculture Strategy (Department of Agriculture and Water Resources, 2017) sets out how to achieve the target to double the current value of our aquaculture industry to $2 billion a year by 2027. The National Aquaculture Strategy details the actions government and industry need to take to meet this target. Eight priority areas have been identified to encourage new projects and grow existing businesses. The priorities identified in the strategy are:

- Regulatory framework — removing unnecessary burden on businesses.
- Research, development, and extension — maximising the benefits of innovation.
- Market access — developing and improving access to domestic and international markets.
- Biosecurity — understanding and managing risks to protect Australia's aquaculture.
- Public perception — improving knowledge of aquaculture as a safe and sustainable industry.
- Environmental performance — identifying opportunities to adopt cost-effective strategies.
- Investment — encouraging and promoting investment in our aquaculture industry.
- Training and education — ensuring future employment needs are met.

The Queensland Aquaculture Policy Statement (2016) articulates the Queensland Government's vision, initiatives, and support for land-based and marine non-intensive aquaculture development (which the Statement defines as aquaculture which has low or no environmental impact) in Queensland. The vision "The Queensland Government supports the future development and growth of an ecologically sustainable, diverse and innovative aquaculture industry" is supported by 8 key initiatives. The key initiatives set the direction for the future development and growth of a sustainable, diverse, and innovative aquaculture industry in Queensland. The statement also identifies core strategies to achieve the key initiatives.

The core strategies that are relevant to this project include:

- Reviewing, where necessary, existing legislative and policy arrangements (regulations, operational standards, and conditions of statutory approval) to ensure approval and operational standards are based on measurable ecological impacts.
- Actively pursuing a continuous improvement model, for example, review water quality release standards based on current scientific findings and ensure consistency with the Queensland Governments' Water Quality Guidelines 2009 and the Australian and Queensland Governments' Reef 2050 Water Quality Improvement Plan (Reef Plan).
- Developing assessment criteria for aquaculture development which will ensure that best practice methodologies continue to be adopted.
- Where required, application of offsets to facilitate appropriate developments to ensure consistency with Commonwealth and Queensland State Government laws.
- Continuing to support the voluntary development and uptake of best practice guidelines for aquaculture, for example, uptake of the Pond Construction Guidelines.

A review of Aquaculture Regulation in Queensland by the Queensland Competition Authority (QCA) in 2014 found that investment in Queensland's aquaculture sector had stalled, and concerns had been raised that investment was being discouraged by regulatory risks and costs. The Queensland Government requested that the QCA recommend reforms to reduce the regulatory burden on the industry, although this needed to be balanced with environmental protection, particularly recognising the unique conservation value of the Reef and the pressing need to improve water quality in areas adjacent to the Reef. The QCA recommended the creation of ADAs and a clearer process for regulatory approvals, with a known set of conditions set in a new regulatory code. For marine areas, the most prospective areas were likely to be in the Torres Strait, Gulf of Carpentaria, and other less populated areas with a low possibility of conflict with other users of marine resources. Environmental offsets were also seen as part of the solution, particularly through the Reef Trust initiative.

2.1 Legislation

Aquaculture is regulated through a combination of planning, environmental, fisheries, biosecurity and food safety regulations. Various approvals, licences and permits may be required for aquaculture production, depending on the location, the species farmed and the production systems. More information on aquaculture regulation is presented in Figure 1 and at Regulatory Framework for Aquaculture. Further information is also provided in this report in Section 4 and Appendix 1. This report does not involve a detailed review of all legislation and policy for aquaculture as this is outside the scope of the project. It focusses mainly on the aspects that are relevant to point source nutrient releases and management.

To operate an aquaculture facility in Queensland, approval is required under the *Planning Act 2016* for the use of the land. Any development that is an 'accepted development' must be completed in accordance with the Accepted development requirements for material change of use that is aquaculture (DAF, 2020) and does not require a development permit.

For other aquaculture ventures, including marine and land-based farms, activities may be either:

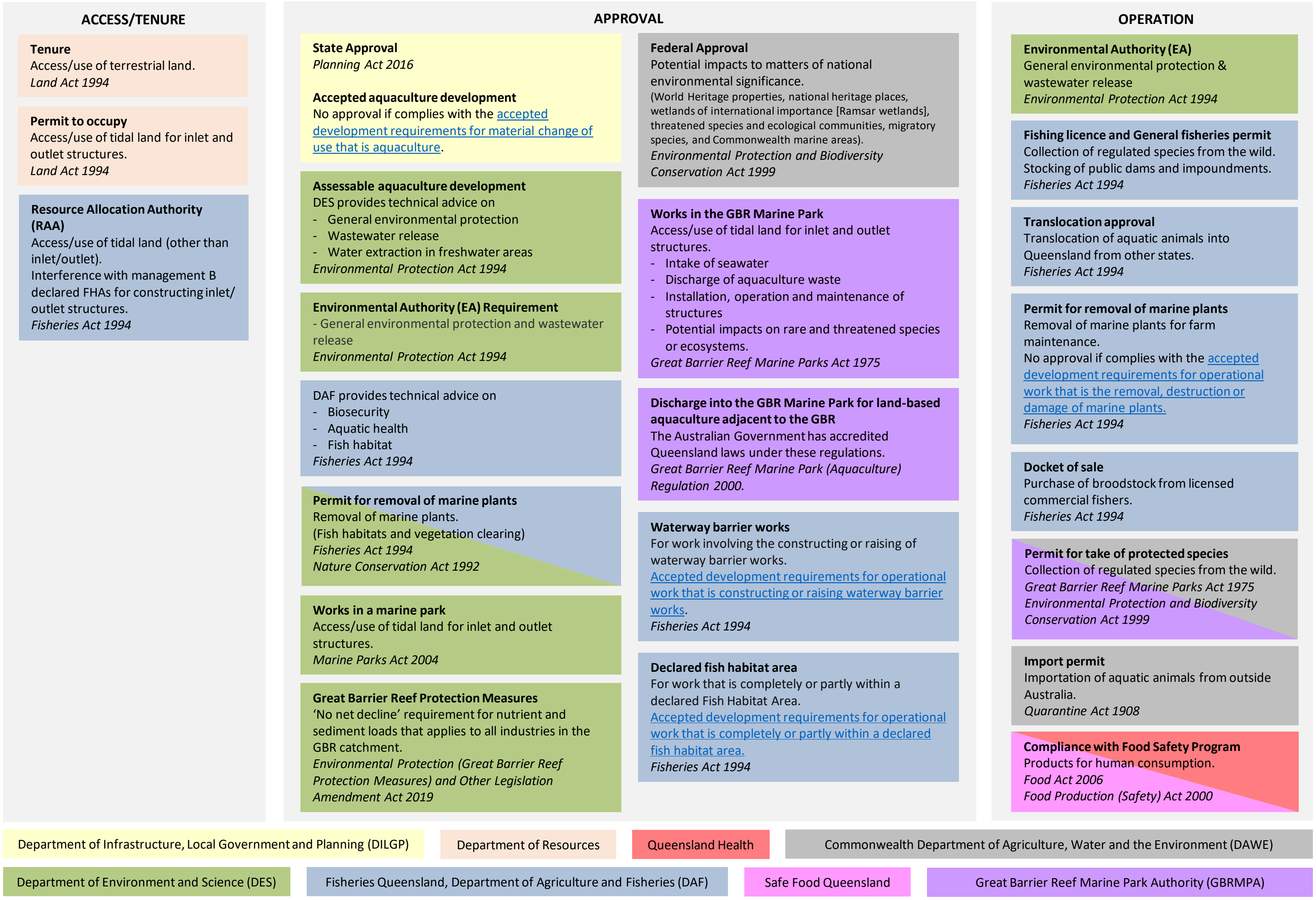
- development-related activities, which require approvals issued under the *Planning Act 2016*.
- non-development activities, which require approvals issued under separate legislation.

In addition to planning approvals, an Environmental Authority (EA) under the *Environmental Protection Act 1994* is required for the operation of the facility, if the activity meets the definition of Environmentally Relevant Activities 1 in Schedule 2 of the *Environmental Protection Regulation 2019*. This ERA includes all types of aquaculture activities that hold or cultivate marine, estuarine, or freshwater organisms on land or in waters that include a release of water from the enclosure to waters. If the activity does not release waste into waters, then it is not an ERA. ERA 1 contains 8 'thresholds' which are assigned different 'aggregate environmental scores' (AES) depending on the fishery and footprint of the facility. The AES is used to calculate application and annual fees.

There are three application pathways to obtain an EA under the EP Act: a standard, variation and site-specific application. In 2012, ERA 1 was assessed and due to the potential release of contaminants including nitrogen, phosphorus and total suspended solids to water, it was considered unsuitable for a standard application, and therefore a site-specific application always applies. In addition, the ERA was listed as a '*concurrence ERA'*. As a concurrence ERA, the application process for the planning approval and EA are linked in the application stage but result in 2 separate permits. The Department of State Development, Infrastructure, Local Government and Planning (DSDILGP) is the single point of lodgement for all development applications that are assessed through the State Assessment and Referral Agency (SARA).The assessment process for the EA includes mandatory consideration of the *standard criteria* (defined in the Dictionary of the EP Act) and the *regulatory requirements* under Chapter 4 of the *Environmental Protection Regulation 2019* (see Appendix 1 for further details). One of the regulatory requirements is Section 41AA of the regulation which came into effect on 1 June 2021 and sets a 'no residual impact' requirement for nutrient and sediment loads that applies to all industries in the Great Barrier Reef catchments. This means that new or expanding facilities cannot increase their nutrient and sediment loads above current licence limits without the use of water quality offsets (see Section 4.3 Water Quality Offsets).

In deciding whether to approve an EA, the administering authority may set conditions on the activity. A condition is a legal requirement which requires the proponent to do, or not do something, or sets limits on what can be done. Failure to comply with a condition is an offence under the EP Act. The DES has set Model Operating Conditions for Aquaculture (MOCs) which outline the minimum set of conditions that may be applied to an aquaculture facility in an EA.

Other approvals may be required, for example under the *Fisheries Act 1994*, the *Nature Conservation Act 1992* and the *Marine Parks Act 2004*, as shown in Figure 1 and published in the Business Queensland portal (see Regulatory Framework for Aquaculture).



ACCESS/TENURE

Tenure
Access/use of terrestrial land.
Land Act 1994

Permit to occupy
Access/use of tidal land for inlet and outlet structures.
Land Act 1994

Resource Allocation Authority (RAA)
Access/use of tidal land (other than inlet/outlet).
Interference with management B declared FHAs for constructing inlet/outlet structures.
Fisheries Act 1994

APPROVAL

State Approval
Planning Act 2016

Accepted aquaculture development
No approval if complies with the accepted development requirements for material change of use that is aquaculture.

Assessable aquaculture development
DES provides technical advice on
- General environmental protection
- Wastewater release
- Water extraction in freshwater areas

Environmental Protection Act 1994

Environmental Authority (EA) Requirement
- General environmental protection and wastewater release

Environmental Protection Act 1994

DAF provides technical advice on
- Biosecurity
- Aquatic health
- Fish habitat

Fisheries Act 1994

Permit for removal of marine plants
Removal of marine plants.
(Fish habitats and vegetation clearing)
Fisheries Act 1994
Nature Conservation Act 1992

Works in a marine park
Access/use of tidal land for inlet and outlet structures.
Marine Parks Act 2004

Great Barrier Reef Protection Measures
'No net decline' requirement for nutrient and sediment loads that applies to all industries in the GBR catchment.
Environmental Protection (Great Barrier Reef Protection Measures) and Other Legislation Amendment Act 2019

Federal Approval
Potential impacts to matters of national environmental significance.
(World Heritage properties, national heritage places, wetlands of international importance [Ramsar wetlands], threatened species and ecological communities, migratory species, and Commonwealth marine areas).
Environmental Protection and Biodiversity Conservation Act 1999

Works in the GBR Marine Park
Access/use of tidal land for inlet and outlet structures.
- Intake of seawater
- Discharge of aquaculture waste
- Installation, operation and maintenance of structures
- Potential impacts on rare and threatened species or ecosystems.

Great Barrier Reef Marine Parks Act 1975

Discharge into the GBR Marine Park for land-based aquaculture adjacent to the GBR
The Australian Government has accredited Queensland laws under these regulations.
Great Barrier Reef Marine Park (Aquaculture) Regulation 2000.

Waterway barrier works
For work involving the constructing or raising of waterway barrier works.
Accepted development requirements for operational work that is constructing or raising waterway barrier works.
Fisheries Act 1994

Declared fish habitat area
For work that is completely or partly within a declared Fish Habitat Area.
Accepted development requirements for operational work that is completely or partly within a declared fish habitat area.
Fisheries Act 1994

OPERATION

Environmental Authority (EA)
General environmental protection & wastewater release
Environmental Protection Act 1994

Fishing licence and General fisheries permit
Collection of regulated species from the wild.
Stocking of public dams and impoundments.
Fisheries Act 1994

Translocation approval
Translocation of aquatic animals into Queensland from other states.
Fisheries Act 1994

Permit for removal of marine plants
Removal of marine plants for farm maintenance.
No approval if complies with the accepted development requirements for operational work that is the removal, destruction or damage of marine plants.
Fisheries Act 1994

Docket of sale
Purchase of broodstock from licensed commercial fishers.
Fisheries Act 1994

Permit for take of protected species
Collection of regulated species from the wild.
Great Barrier Reef Marine Parks Act 1975
Environmental Protection and Biodiversity Conservation Act 1999

Import permit
Importation of aquatic animals from outside Australia.
Quarantine Act 1908

Compliance with Food Safety Program
Products for human consumption.
Food Act 2006
Food Production (Safety) Act 2000

Department of Infrastructure, Local Government and Planning (DILGP)
Department of Resources
Queensland Health
Commonwealth Department of Agriculture, Water and the Environment (DAWE)
Department of Environment and Science (DES)
Fisheries Queensland, Department of Agriculture and Fisheries (DAF)
Safe Food Queensland
Great Barrier Reef Marine Park Authority (GBRMPA)

Figure 1. An overview of the approvals potentially required to establish and operate an aquaculture facility and the matters considered under these approvals. Adapted from Queensland Competition Authority. 2014.

3 Review of Pond Aquaculture in Queensland

Aquaculture production is often described in terms of the intensity of production from extensive through to intensive based on the level of inputs and outputs. However, there are various definitions for these terms used in the literature. The Queensland Aquaculture Policy Statement (2016) defines non-intensive aquaculture as aquaculture with little environmental impact; this definition is not widely used. Primavera (1993) defined the farming systems for prawn production in Thailand based on the stocking density, feed sources and production output. Extensive production was defined by a very low stocking density (1–3 prawns per square meter), relying on natural food items with occasional supplemental feeding, and production of up to 0.8 tonnes per hectare. An intensive production was defined as being stocked at 10–30 prawns per square meter, relying on manufactured feeds, and producing 3–6 tonnes per hectare. A semi-intensive production sits between these two, with natural feed and supplemental feeding relied on for production. In more recent years, there has been a move to further intensify production using raceways and highly controlled production systems to achieve stocking densities of 150 or more prawns per square meter (termed "super-intensive") (Emerenciano et al., 2022). Oddsson (2020) sought to provide a framework to define the intensity of production in terms of input, treatment and output functions that can be applied to the whole aquaculture production. Currently, most pond aquaculture farms which release to waters in Queensland would be defined as intensive using any of these 3 definitions.

3.1 Industry overview

Across Australia, there are a number of different species, farming types and water sources used in aquaculture. These are summarised in Table 1. A comparison of farming practices in Queensland with other states in Australia found that there is little similarity between the species grown, farming type and water source. Unlike other states, the main farming type in Queensland is marine/brackish pond aquaculture centred around producing 2 main species, marine black tiger prawns (*Penaeus monodon*) and barramundi (*Lates calcarifer*). There are also several hatcheries and seafood processing facilities across the state. However, these generally do not involve significant releases to catchment waters and are, therefore, not the focus of this study. Pond aquaculture involves the construction of purpose-built earthen ponds, constructed on lands near estuaries or river systems. They are used for the intensive culture of marine prawns and finfish. Farm operations are located throughout Queensland from SEQ to Far North Queensland, excluding Cape York.

Aquaculture containment structures used in pond aquaculture are shown in Figure 2 and may include intake reservoirs, supply channels, production ponds, release channels and treatment ponds. In general, the process involves pumping water onto the farm where it is then gravity fed to a series of production ponds. Water drains or is discharged from the ponds and enters a treatment pond where suspended sediment settles before water is released back to the receiving environment. Farms may also be able to undertake recirculation where water can be passed back through the farm system, rather than be released to the environment.

Production ponds are generally flat bottomed or slightly sloping to allow for draining and harvesting of the cultured product and to allow full draining for a dry-out period between crops (prawn farming). Pond depths of about 2.0 m are common. Pond sizes can vary, especially between prawn and barramundi farms, and between operations.

While there are some emerging species, their current production volumes are very small. This may change, as all the identified ADAs have noted several species of marine finfish as potential stock. The 2 peak industry bodies for prawn and barramundi aquaculture are the Australian Prawn Farmers Association (APFA) and the Australian Barramundi Farmers Association (ABFA).

Although sometimes described as one of the fastest-growing primary production sectors in Queensland, this may depend on how growth is defined. While production of prawns in Queensland during the past 2 years has seen a marked increase to a record 8,000 tonnes in the 2020/21 financial year (Figure 3. A), generally, there was a much slower rate of increase between 2006/07 to 2018/19. Barramundi production in the state has also grown slowly, but steadily in the past 15 years. However, while production in both sectors has increased during this time, the number of farms in production has declined (Figure 3. B).

Table 1. Examples of fed Aquaculture species and farming methods regulated in states of Australia

State	Species	Farm Method	Water Type
Queensland	Prawns	Pond	Marine
	Barramundi	Pond / Raceway	Marine / Freshwater
South Australia	Tuna, Yellowtail Kingfish	Sea cage	Marine
	Abalone	Subtidal sea cage	Marine
	Prawn	Pond	Marine
	Yabby, Murray Cod, Silver Perch, Barramundi and Trout	Pond	Freshwater
Victoria	Abalone	Pond, Sea cage	Marine
	Atlantic Salmon (caviar), Rainbow Trout	Raceway	Freshwater
	Eel, Golden Perch, Murray Cod, Silver Perch, Yabbies	Pond	Freshwater
	Eel	Tanks	Freshwater
	Barramundi, Murray Cod	RAS*	Freshwater
Western Australia	Barramundi, Abalone, Yellowtail Kingfish, Mussels	Sea Cage	Marine
Northern Territory	Barramundi	Pond	Marine
	Sea Cucumber	Subtidal Sea cage	Marine
Tasmania	Atlantic Salmon, Trout	Sea cage	Marine

* RAS (recirculating aquaculture system)

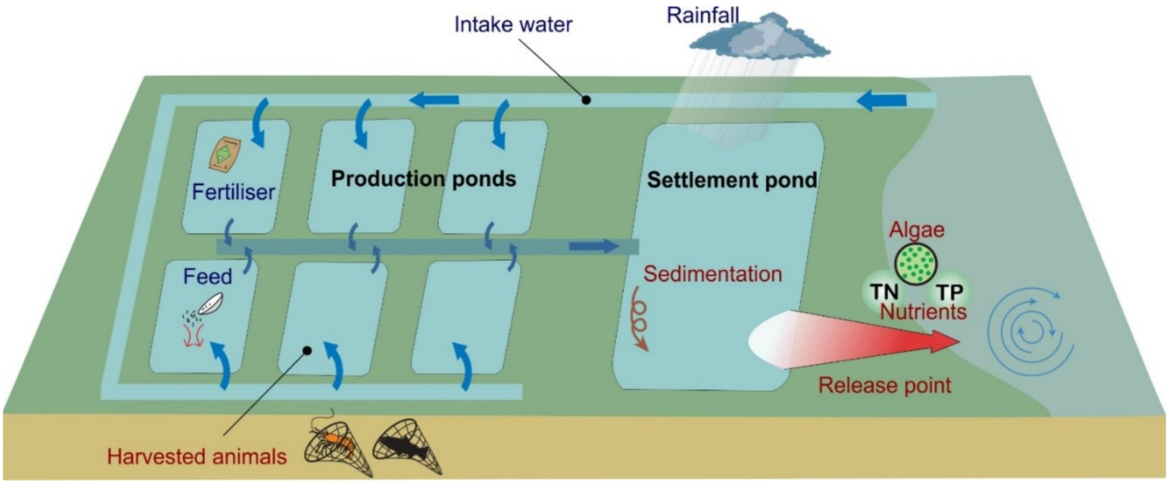


Figure 2. Aquaculture pond conceptual model

Queensland Government has identified 8 ADAs covering more than 9,000 hectares from Gladstone to Ingham (Figure 4). These areas are not exempted from Reef legislation; any new or expanding aquaculture development within the ADAs would still be obligated to meet the 'no residual impact' requirement under Section 41AA of the *Environmental Protection Regulation 2019.* If fully developed, this represents a several-fold increase in the area allocated for pond aquaculture from the 2019–2020 financial year.

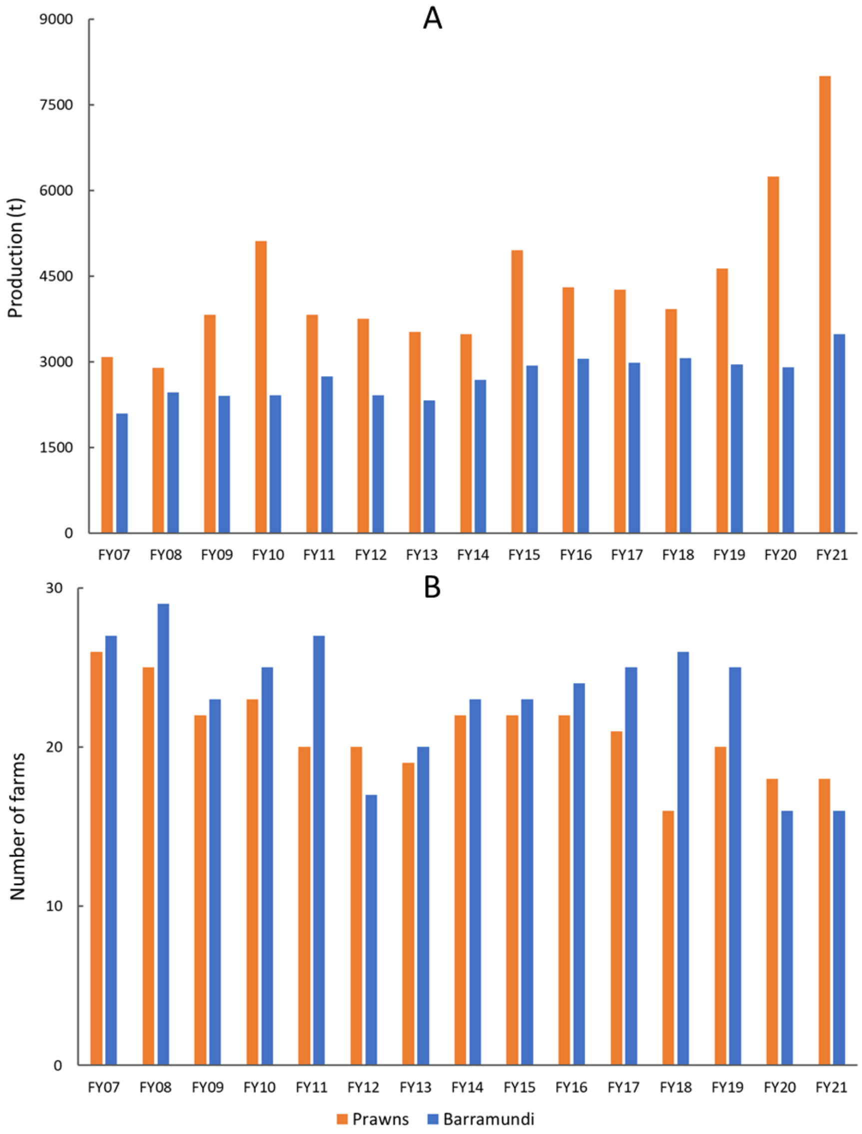


Figure 3. Aquaculture production statistics for prawns and barramundi in Queensland from financial years 2006/7 (FY07) to 2020/21 (FY21). A. Production per year (tonnes), and B. Number of farms. Data sourced from the Ross Lobegeiger report to farmers Aquaculture Production Summary for Queensland 2020-21.

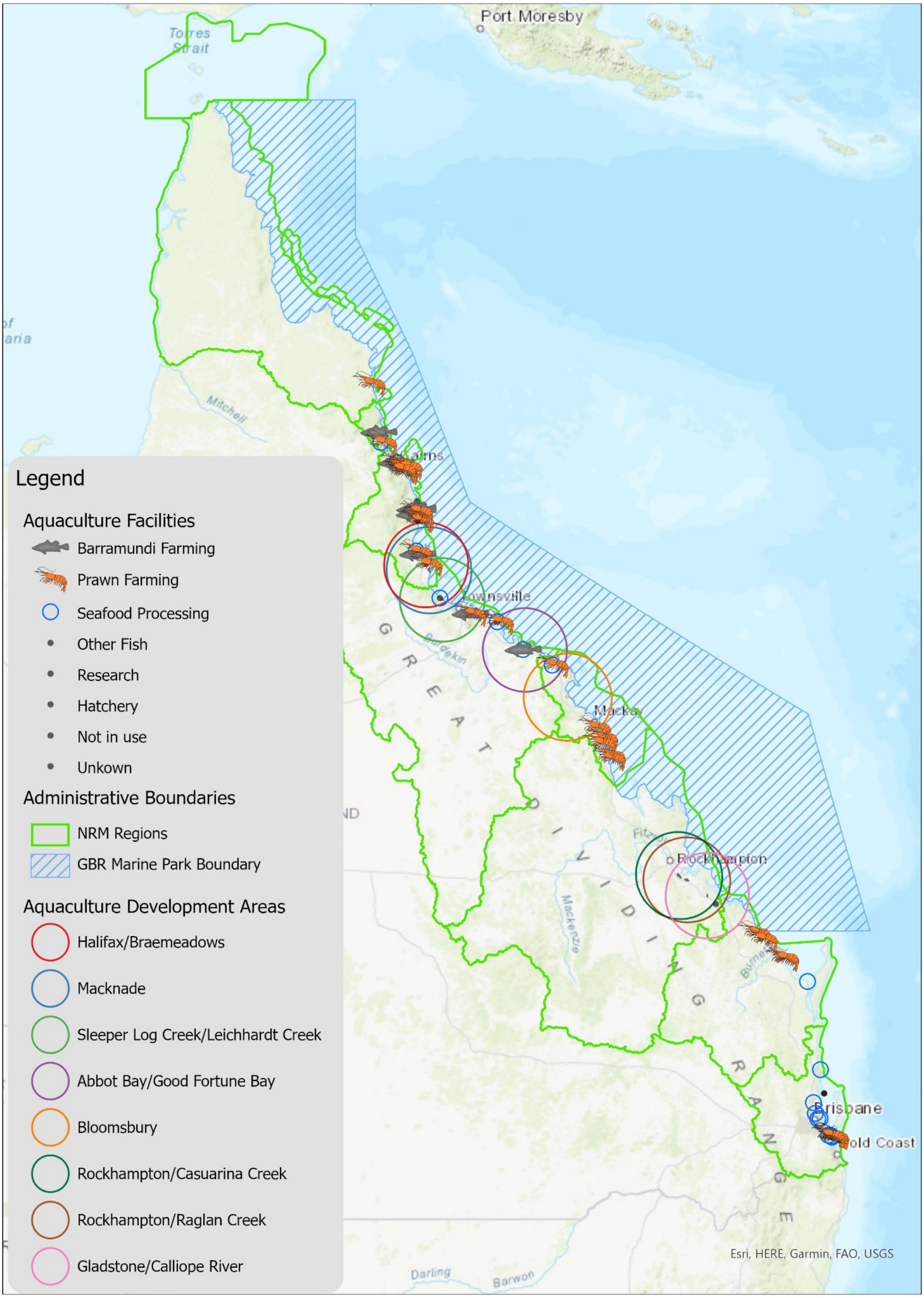


Figure 4. Location of aquaculture farms and seafood processing facilities. Aquaculture Development Areas (ADAs) are shown as a circle of 80 km radius around the actual areas, more information is available from Queensland Government's Business Queensland webpage.

3.1.1 Prawn production in Queensland

The prawn industry in Queensland is comprised of farms from the Logan River to Far North Queensland. In 2021/22 prawn production was 8,727 tonnes, valued at $167.1 million. The majority of this was black tiger prawns (*Penaeus monodon)*, but there was also limited production of banana prawns (*Penaeus merguiensis*). The total prawn production came from 17 farms (DAF, 2022). Most of the farms within Queensland are situated in the Reef catchment from Bundaberg to Mossman. At the time of this project, there were 14 farms, covered by 13 EAs, producing prawns within the Reef catchment in the 2020/21 season. Two larger companies have multiple farm sites, with the remainder all being single entities from larger scale farms to smaller holdings. Five farms were operating outside the Reef catchment on the Logan River in SEQ. All the prawn farms are situated relatively close to the coast and use saltwater from tidal creeks and rivers. The prawn industry is Queensland's largest aquaculture employer, with approximately 598 FTE jobs in 2021/22 (Ross Lobegeiger report to farmers. Aquaculture Production summary for Queensland 2021-22).

Black tiger prawns in Australia, at the time of this project, were typically being grown to a market weight of around 30–40 g or more per animal, as these larger prawns commanded a better price in the market. Traditionally, there is an increased demand for prawns around Easter and Christmas. The Christmas market was met through early stocking (June/July) aiming to supply 20–25 g prawns to the market at this time. Although there were a small number of producers that targeted this market with some of their ponds, most producers concentrated on one crop per year, stocking ponds between August and November to complete harvesting by April/May.

The productivity of prawn farms has also increased significantly since the early 2000s. The industry average at that time was 4.2 tonnes/ha which has increased to an average of 8.1 tonnes/ha in recent years (M. Heidenreich, *pers. comm.*).

3.1.2 Barramundi production in Queensland

The barramundi industry in Queensland produced 3,992 tonnes from 17 farms, with a value of $46.3 million in 2021/22 (DAF, 2022). At the time of this project, there were only 4 farms which released to waters within the Reef catchment. These 4 farms are the largest barramundi producers in Queensland and are owned by 3 companies. These farms are all based in north Queensland. Two farms use seawater either drawn from a tidal river or directly from the sea, one is fully freshwater. The remaining farm is nominally freshwater for most of the year, but subject to season and rainfall, the salinity of intake water can increase to become brackish.

At the time of this project, Barramundi were generally grown to a market size of about 3–4 kg in around 18–24 months using either earthen ponds or fully lined raceways. There is a market for table-size fish, but it appeared that this was not a market that was routinely supplied by these farms. Production is almost continuous with fish being harvested throughout most of the year, but there are peaks in the market around April and December. After harvest, earthen ponds are dried and then cleaned before being restocked. Production has increased from an average of 6.1 tonnes/ha in the early 2000s to an average across the whole pond aquaculture industry of about 22 tonnes/ha in recent years (M. Heidenreich, *pers. comm.*).

3.1.3 Hatcheries

Broodstock for production of young prawns are mostly caught in the wild and are generally only kept until they have finished spawning. Therefore, most hatcheries will only operate for the period required to supply the stocking window for each crop. There are exceptions where hatcheries are maturing and spawning animals, then rearing their larvae. This allows selective breeding to occur.

Fish hatcheries, however, will hold their broodstock animals for an extended period and will produce fingerlings several times each year.

Although water use is relatively high, when compared with water use for pond production it is typically a minor component of the release from a farm. Additionally, because the overall prawn or fish biomass is low, the feed inputs are also low, meaning that nutrient concentrations are low relative to releases from treatment ponds.

3.1.4 Pond aquaculture production parameters in Queensland

Production parameters and farm management practices may change depending on variables such as the species grown, location of the farm, prevailing weather conditions, water source, tide heights, intake location, pond construction, release point/s and receiving environment. However, typical production parameters may be used to generally describe the pond aquaculture of barramundi and black tiger prawns in Queensland. These are summarised in Table 2.

Table 2. Typical production parameters for pond aquaculture facilities discharging to waters within the Great Barrier Reef catchment

Species	Barramundi‡	Prawns*
Production[a]	Intensive	Intensive
Pond types	Earthen Lined raceways	Earthen Rock lined batters Plastic lined batters
Water sources	Freshwater Brackish Saltwater	Brackish Saltwater
Pond size (ha)	0.3 – 1.3	0.8 – 1.3
Average water depth (m)	1.5 – 1.8	1.5
Stocking weight of animals	50 – 200 g	PL 15 – 20 (8 – 10 mg)
Stocking density	0.5 – 1.5 m^{-3}	30 – 70 m^{-2}
Target harvest weight of animals	3 – 4 kg	30 – 40 g
Crop duration (months)	18 – 20	4 – 7
Typical yield per crop (t ha^{-1})	15 – 30	6 – 15
Typical food conversion ratio (FCR)[b]	1.5 †	1.7
FCR range	1.3 – 2.2	1.5 – 2.5
Typical water exchange (% d^{-1})	1.5 – 5	2 – 5
Feeding methods	Broadcast by blower	Broadcast by blower Autofeeders (trials)
Feed monitoring	Visual	Feeding trays
Cropping strategy	Continuous	Seasonal
Aeration type	Paddlewheels Oxygen injection	Paddlewheels Injectors
Aeration supply (HP ha^{-1})	12 – 16	12-24

* Parameters for *P. monodon*. Parameters for the limited production of *P. merguiensis* in Queensland may differ.

‡ Limited information available for raceway production, parameters may differ.

† Source: DAF. (2020)

[a] As defined by Oddsson (2020)

[b] FCR = Food fed (kg as fed) / Total weight of harvested animals (kg wet weight)

3.2 Aquaculture pond nutrient budgets

When assessing nutrient outputs from aquaculture facilities' release water, it is important to understand all nutrient inputs, the nutrient processes and fluxes within production ponds and treatment systems, and nutrient outputs before release (that is, potential nutrient sinks).

Nutrient budgets are a simple mass balance. The contribution of all nutrient sources is totalled and balanced against the total outputs from the system, allowing an assessment of the relative importance of each nutrient source and sink within the production system (Figure 5).

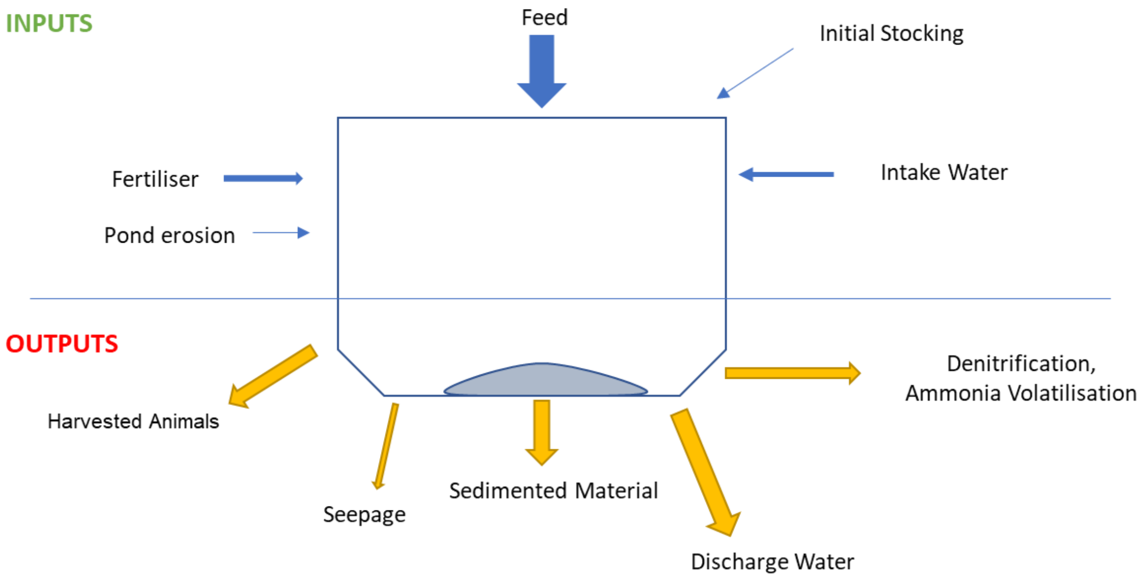


Figure 5. Sources of nutrient input and potential sinks for nutrient output in a typical aquaculture production pond

These budgets have been described for fish and crustaceans (for example, prawns) in both fresh and saltwater pond environments. However, there are no published studies for barramundi, so examples for other fish species are provided. Most commonly, the focus of these studies is nitrogen and phosphorus due to their eutrophication potential in receiving waters. While budgets for solids (soil particles and organic matter) have also been calculated, the relative contributions are highly affected by pond construction, soil type and its erodibility, feed inputs, stocking densities, and the intensity of aeration and circulation within the pond. Sedimented material remaining from previous crops (if not fully removed after harvest) will also impact on the relative contributions of soils as a source of nutrients in the budget. Microalgae, detritus, and bacteria within the pond will contribute to both the settled solids and suspended solids fraction of the budget. However, estimating the proportion of these different sources is complex and depends on multiple factors, such as the state of the algal bloom, the amount of flushing that occurs and the level of soil erosion.

3.2.1 Sources of nitrogen, phosphorus, and total solids in ponds

In pond aquaculture systems, the sources of nutrients entering the system are:

- Water used to fill the system
- Water exchange required throughout the production cycle
- Fertilisers used to promote algal blooms and natural productivity within the pond, particularly early in the production cycle
- Animals initially stocked into the ponds
- Rainfall and runoff entering the pond during the production cycle
- Erosion of the pond soil
- Formulated feeds
- Nitrogen fixation.

Fertilisers are added, particularly early in the production cycle, to promote algal blooms which in turn feed the zooplankton and benthic biota in the pond. Although beneficial as a food source for the stocked animals early in the production cycle, this natural productivity needs to be supplemented with formulated feed. Therefore, feed becomes the dominant source of nitrogen added as the production cycle progresses and the animal biomass increases. Budgets for semi-intensive and intensive production systems have shown that feed contributes between 80 and 97% of the nitrogen input to the pond (Boyd, 1985; Daniels and Boyd, 1989; Acosta-Nassar et al., 1994; Briggs and Funge-Smith, 1994; Martin et al., 1998; Jackson et al., 2003a; Sahu et al., 2012; Adhikari et al., 2014). While fertilisers themselves contribute to the total nutrient pool, in more intensive production this contribution is around 2–5% of the nitrogen input (Briggs and Funge-Smith, 1994; Sahu et al., 2012; Adhikari et al., 2014).

Similarly, the main sources of phosphorus in a pond are feed, fertiliser, pond soils and water. In freshwater ponds with lined walls, Daniels and Boyd (1989) reported that feed added to striped bass (*Morone saxatilis*) ponds contributed about 75% of the phosphorus inputs to the pond with the remainder coming from intake water, rainfall and runoff. Gross et al. (1998) attributed about 97% of the phosphorus input to the feed supplied to channel catfish (*Ictalurus punctatus*) in similar ponds. In earthen brackish water prawn (*P. monodon*) ponds where the erosion of soil and sediments from previous crops was more prevalent, Briggs and Funge-Smith (1994) found that feed contributed only 51%, while erosion of the soil provided 26% of the TP input. The contribution from fertilisers depends on the application rate and their phosphorus content. Sahu et al. (2012) reported a small contribution from phosphorus in fertilisers (around 3%) while Briggs and Funge-Smith (1994) found that the fertiliser applied to prawn ponds contributed about 21% of the TP input.

Nitrogen fixation by heterocystous cyanobacteria may also contribute nitrogen to a pond system (Hargreaves, 1998), particularly in freshwater systems. However, nitrogen fixation does not occur when DIN concentrations are high, as is typical in intensive aquaculture ponds (Boyd, 1985; Lin et al., 2002). Generally, nitrogen fixation is considered a minor input so is not reported in most studies (Hargreaves, 1998).

3.2.2 Potential sinks for nitrogen, phosphorus, and total solids in ponds

Data from studies of the partitioning of total nutrient inputs into the various sinks for nitrogen and phosphorus in aquaculture ponds are outlined in Table 3.

3.2.2.1 Animal biomass

The nutrients supplied to the production animals through consumed feed and pond biota are used for growth and development, and maintenance of metabolic functions. However, not all nutrients are retained by animals and may be lost through faeces and metabolic processes within the animal. Nitrogen is excreted by fish and crustaceans through the gills as ammonia. Urea and phosphate may also be excreted by the kidneys of fish (Lemarie et al., 1998), while in crustaceans, the moults also contribute to nutrient and mineral loss (Sarac et al., 1994). As a result, harvested animals account for only a moderate proportion of the nitrogen input. Although this proportion varies with each study, in prawns it is usually around 20–37% (Briggs and Funge-Smith, 1994; Jackson et al., 2003a; Sahu et al., 2012; Sun and Boyd, 2013; Adhikari et al., 2014; Luu et al., 2018). Similarly, in fish the harvested animals account for 16–36% of nitrogen input (Boyd, 1985; Krom et al., 1985; Krom and Neori, 1989; Acosta-Nassar et al., 1994; Gross et al., 2000; Muendo et al., 2014).

The differences in phosphorus retention by the harvested animals are more marked. The phosphorus content of fish will change through the lifecycle, but the largest variation is between species. Channel catfish have a relatively low level of phosphorus in their body so the proportion of the phosphorus inputs that are retained by the harvested fish is only 15–30% (Boyd, 1985; Gross et al., 1998). Striped bass contain more phosphorus and so retained 42% of the phosphorus input (Daniels and Boyd, 1989). Although there have been no pond nutrient budgets calculated for barramundi, the level of phosphorus in their body is also higher (9–11 g P kg^{-1} live weight), with retention efficiency of phosphorus supplied by the feed between 35 and 55% (Chaimongkol and Boonyaratpalin, 2001; Simon et al., 2019). The retention of phosphorus by prawns is lower than in fish, with values from 6 to 11% of phosphorus inputs being reported for *P. monodon* (Briggs and Funge-Smith, 1994; Sahu et al., 2012) and *P. vannamei* (Sun and Boyd, 2013).

3.2.2.2 Sedimentation

Particulate matter in ponds, subject to the mixing and aeration regimes, will tend to accumulate on the bottom of the pond. This will include inorganic particulate matter (that is, eroded soil), suspended material imported in the intake water and organic matter from uneaten feed, faeces, senescent microalgae and other detritus (Avnimelech et al., 1999). Sedimentation is an important process in the pond system, constantly removing nutrients and other waste from the water column, although the resuspension of this material is possible due to the shallowness of aquaculture ponds, bioturbation and water movement. Rates of sedimentation in prawn ponds are highly variable between studies. Sedimentation rates of 93% of the solids, 63% of the organics and 24–31% of the nitrogen were reported (Briggs and Funge-Smith, 1994; Funge-Smith and Briggs, 1998), while other studies have reported both lower nitrogen sedimentation rates of 14–18% (Jackson et al., 2003a; Chen et al., 2018), and higher rates of 50–52% (Sahu et al., 2012; Adhikari et al., 2014). Similar variability in the rates of nitrogen deposition in fish pond sediments has been observed. No accumulation of nitrogen was found in some studies of channel catfish and striped bass ponds (Boyd, 1985; Daniels and Boyd, 1989). However, Gross et al. (2000) reported almost 23% of the nitrogen input was retained in the sediment of channel catfish ponds, while 67–70% was measured in tilapia ponds (Acosta-Nassar et al., 1994; Green and Boyd, 1995).

While nitrogen may accumulate in pond sediments, the low oxygen conditions in this environment cause ammonia release from the organic matter. Burford and Longmore (2001) measured major fluxes of nitrogen into the water column in prawn ponds. Using this data, Burford and Lorenzen (2004) modelled the benefits of removing sedimented material to reduce ammonia release from the sediment, hence reducing nitrogen discharge from ponds.

Sediments are the main sink for phosphorus in pond systems because suspended soil particles chemically bind dissolved inorganic phosphorus. Liming of ponds, which is a common management practice, encourages the formation of calcium phosphate, increasing the sequestration ability of the soils (Boyd et al., 2006). Sedimentation of phosphorus may be further enhanced by the precipitation of dissolved calcium phosphate at pH 8–8.5. This is reflected in studies of phosphorus budgets. Gross et al. (1998) found sediments accounted for 76% of the phosphorus input in channel catfish ponds, the same proportion as reported by Adhikari et al. (2014) in giant freshwater prawn (*Macrobrachium rosenbergii*) ponds. Similarly, sedimentation accounted for around 84% of the phosphorus in prawn ponds (Briggs and Funge-Smith, 1994; Sun and Boyd, 2013). In the striped bass ponds studied by Daniels and Boyd (1989), only 53% of the phosphorus was deposited in the soils, but the retention of phosphorus in the fish accounted for 42%.

3.2.2.3 Other nutrient removal processes

Nitrogen can also be removed from production ponds through nitrification/denitrification and ammonia volatilisation (Figure 6). Nitrification is the conversion of ammonia to nitrite and ultimately nitrate, by microbes (Bernhard, 2010). However, nitrification is a relatively slow process and will only occur when water residence times are long enough, and organic substrates are sufficient (Burford et al., 2003b). Nitrate is then converted into nitrogen gas (N_2) through anaerobic microbial processes, resulting in nitrogen being lost to the atmosphere. Nitrogen gas is also produced from anaerobic ammonia oxidation or anammox which may contribute to nitrogen loss from the system, but it has been poorly studied in aquaculture ponds (Strous et al., 1999). Nitrogen may also be lost to the atmosphere through ammonia volatilisation, although this process does not appear to result in a major loss of nitrogen from aquaculture ponds (Gross et al., 1999).

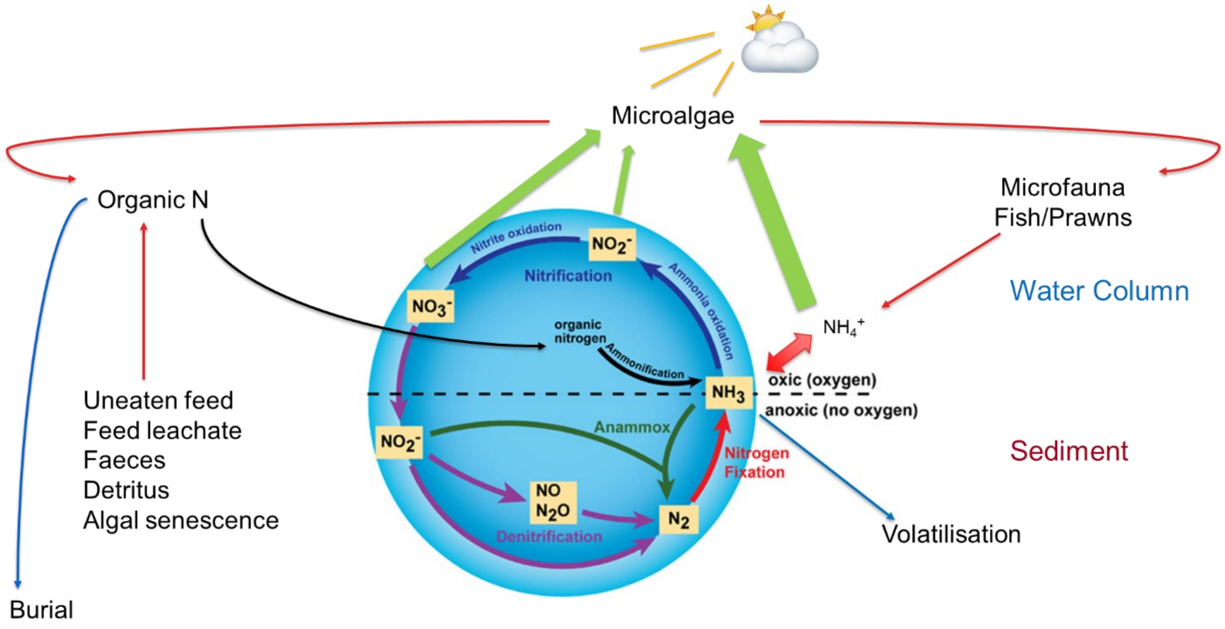


Figure 6. Nitrogen transformation processes within a pond environment. Adapted from: Bernhard A (2010) 'The nitrogen cycle: processes, players and human impact', *Nature Education Knowledge,* 3(10), 25.

Denitrification, anammox and ammonia volatilisation are rarely measured in nutrient budget studies but are recognised as pathways through which nitrogen may be lost from the system. Where any of these processes have been studied, they are generally estimated indirectly as the difference between inputs and the measured outputs from the pond. The percentage removed, based on the differences between inputs and outputs, range from 7.3 to 47% depending on the study (Boyd, 1985; Briggs and Funge-Smith, 1994; Hopkins, 1994; Gross et al., 2000; Chen et al., 2018)

In Australian studies, removal of nitrogen through gaseous exchange was not determined to be a significant loss of nitrogen from prawn pond systems. In a whole-of-farm budget, only 3% of the nitrogen could not be accounted for and was presumed to have been lost through these processes (Jackson et al., 2003a). This was similar to the low denitrification efficiency previously measured in SEQ prawn ponds where the loss was less than 2% (Burford and Longmore, 2001). In a tropical freshwater fish pond, denitrification rates were also low, removing just 1% of the nitrogen input (Acosta-Nassar et al., 1994). Castine (2013) found anammox contributed very little if any to N_2 production from sediment in aquaculture settlement ponds, and overall denitrification and anammox only removed about 2.5% of the nitrogen input.

3.2.3 Pond discharge loads

Nutrients which are not incorporated into any of the sinks outlined above will eventually be discharged from the pond through water exchanges or final draining at harvest. Therefore, the proportion of each nutrient that is discharged will depend on the effectiveness of those sinks in removing nutrients from the water column.

Most pond aquaculture production in Queensland uses some water exchange to manage algal blooms (including controlling harmful algal species), maintain water quality and for animal husbandry. Nitrogen budgets developed for prawn ponds have found that discharge accounted for between 3 and 57% of the nitrogen input (Briggs and Funge-Smith, 1994; Funge-Smith and Briggs, 1998; Jackson et al., 2003a; Sahu et al., 2012; Adhikari et al., 2014; Chen et al., 2018; Luu et al., 2018). Budgets for phosphorus found that the proportion of pond phosphorus that is discharged ranged between 2 and 45% (Briggs and Funge-Smith, 1994; Boyd et al., 2006; Lemonnier and Faninoz, 2006).

There are fewer relevant examples of nutrient budgets for fish species. Nitrogen budgets developed in fish ponds account for a similar range (1–59%) of the nitrogen inputs that are discharged in the water, but phosphorus budgets are even more variable (5–72%), due partly to the wide range of exchange rates that were used in these studies (Boyd, 1985; Daniels and Boyd, 1989; Krom and Neori, 1989; Acosta-Nassar et al., 1994; Gross et al., 1998). Improved management techniques and algal bloom control have resulted in a reduction in water exchange rates used by the pond aquaculture industry in Queensland over time. Reducing water exchange will reduce the total nutrient load discharged from the pond (Hopkins et al., 1993).

Table 3. Summary of percentage of nutrient inputs that are partitioned into various outputs from ponds, based on published nutrient budget studies

				Proportion of output (%)											
	Species	Salinity	Daily Exchange Rate≠	Animal Biomass		Sedimented material		Seepage		Discharge water		$N_2 + NH_3$ processes	Unaccounted		Reference
				N	P	N	P	N	P	N	P	N	N	P	
Fish	*Ictalurus punctatus*	Freshwater	0%	25	30		55	11	8	7	7	57			Boyd (1985)
Fish	*Morone saxatilis*	Brackish	0%	20	42		53			25	47	55			Daniels and Boyd (1989)
Fish	*Sparus aurata*	Seawater	48%	26	21	10	17			59	72		5	-10	Krom and Neori (1989)
Fish	*Oreochromis sp.*	Freshwater	0%	22		67				1		1	9		Acosta-Nassar et al. (1994)
Fish	*Ictalurus punctatus*	Freshwater	0%		19		76				5				Gross et al. (1998)
Prawn	*P. monodon*	Seawater	2-5%	21	6	31	84	0.1	0.02	35	10	13			Briggs and Funge-Smith (1994)
Prawn	*P. monodon*	Seawater	2-5%	18	6	24	84	0.1	0.02	27	10	31			Funge-Smith and Briggs (1998)
Prawn	*P. monodon* & *P. merguiensis*	Seawater	4%	26		14				57		3			Jackson et al. (2003a)
Prawn	*P. monodon*	Brackish	0%	30	11	50	65			7	3		13	22	Sahu et al. (2012)
Prawn	*M. rosenbergii*	Freshwater	0%	37	10	52	76			3	2		9	13	Adhikari et al. (2014)
Prawn	*P. vannamei*	Brackish	NR	35	24	38	57			18	6		10	13	Luu et al. (2018)
Prawn	*P. monodon*	Brackish	NR	27	13	40	57			24	9		9	21	
Prawn	*P. vannamei*	Brackish	44%	24		18				51		7			Chen et al. (2018)
Range of values				18 – 37	6 – 42	10 – 67	17 – 84	0.1 – 11	0.02 – 8	1 – 59	2 – 72	1 – 57	5 – 13	-10 – +22	

≠ Average daily exchange rate as reported. NR = not reported.

$N_2 + NH_3$ Estimated loss of nitrogen through denitrification and ammonia volatilisation

3.3 Nutrient characteristics of aquaculture pond water

In terms of environmental effects, knowing the proportion of nitrogen and phosphorus in particulate versus dissolved forms is significant. Nutrients in release water are typically comprised of particulate, dissolved inorganic and dissolved organic nutrients. The main source of DIN in aquaculture ponds is typically ammonia (NH_3 + NH_4^+). It is primarily derived from excretion by the livestock and remineralised organic matter accumulated in the sediments (Burford and Longmore, 2001; Burford and Williams, 2001).

Microalgae are one of the dominant particulate components of aquaculture ponds and use dissolved inorganic nutrients, such as ammonia and nitrate, as well as urea for growth (Burford and Pearson, 1998; Burford and Glibert, 1999). Ammonia is rapidly utilised by microalgae, but when the assimilative capacity of the microalgal population is exceeded, the ammonia concentration will rise (Figure 7). Microalgal growth may be limited by various factors including pH; temperature; salinity; nutrient availability; and light.

The scale of the bloom varies substantially from day to day and water exchange can be used to control blooms and prevent them from "crashing". For example, nitrogen discharge from a marine fish pond during a period with low chlorophyll levels (after a "microalgal crash") was half that of the same pond when the algae were blooming (Krom and Neori, 1989). At the same time, DIN concentrations increased almost 4-fold over that in the discharge when algae were blooming. Phosphorus discharge displayed a similar pattern, albeit with a smaller magnitude of change. The same study also showed an increase in ammonia at night when the uptake of nitrogen by microalgae would be reduced. These daily and diel variations are not unusual in outdoor ponds and have also been demonstrated in prawn ponds (Burford, 1997; Burford and Glibert, 1999).

The other form of nitrogen in ponds is dissolved organic nitrogen (DON). It is derived primarily from feeds and feeding and has been shown to be broken down very slowly by bacteria; the bulk of it cannot be utilised by microalgae, and hence has fewer environmental effects in the short term (Burford, 2001; Burford and Williams, 2001). It may therefore accumulate over the crop cycle, depending on the efficiency of microalgae (Figure 8).

Most of the phosphorus discharged from aquaculture ponds is typically in particulate form, with low concentrations of phosphate. This is because phosphate is rapidly used by microalgae for growth. The concentrations of TN and the proportion of ammonia released from a farm can also vary substantially (Jackson et al., 2003a). The rate of water exchange from individual ponds typically increases over the season as the nutrient loading on the ponds increases (Figure 9), but it is also governed by the health and scale of the microalgal bloom. Therefore, it is impossible to predict the daily exchange rate.

Compared with raw municipal wastewater flowing into a treatment plant, aquaculture production pond release water is much more dilute. Raw municipal wastewater can be characterised as having a low, medium, or high concentration. A typical "low" nutrient concentration for TN is 30 mg/L (of which around 66% is inorganic), and for TP is 6 mg/L (Volcke et al., 2020). In contrast, aquaculture pond release water, whether treated through settlement ponds or not, is typically around 10 times more dilute in TN concentration with a higher proportion present as DON (Castine et al., 2013). Phosphorus concentrations are 30–50 times more dilute in aquaculture ponds than raw municipal wastewater. The high efficiency of nutrient removal in STPs is due, in part, to the high initial concentrations. In 2019, STPs within the Reef catchment where wastewater is released had median concentrations of 3.5 mg/L TN and 0.76 mg/L TP (Ramsay et al., 2020). For TN, this is close to the concentrations of untreated aquaculture pond discharge. The comparison between the 2 leading point source activities illustrates why treatment practices are likely not transferable across industries. Therefore, it is unlikely that the technology used in STPs can be easily adapted to current aquaculture pond discharge, particularly given many pond aquaculture facilities are dealing with marine or brackish water, not freshwater.

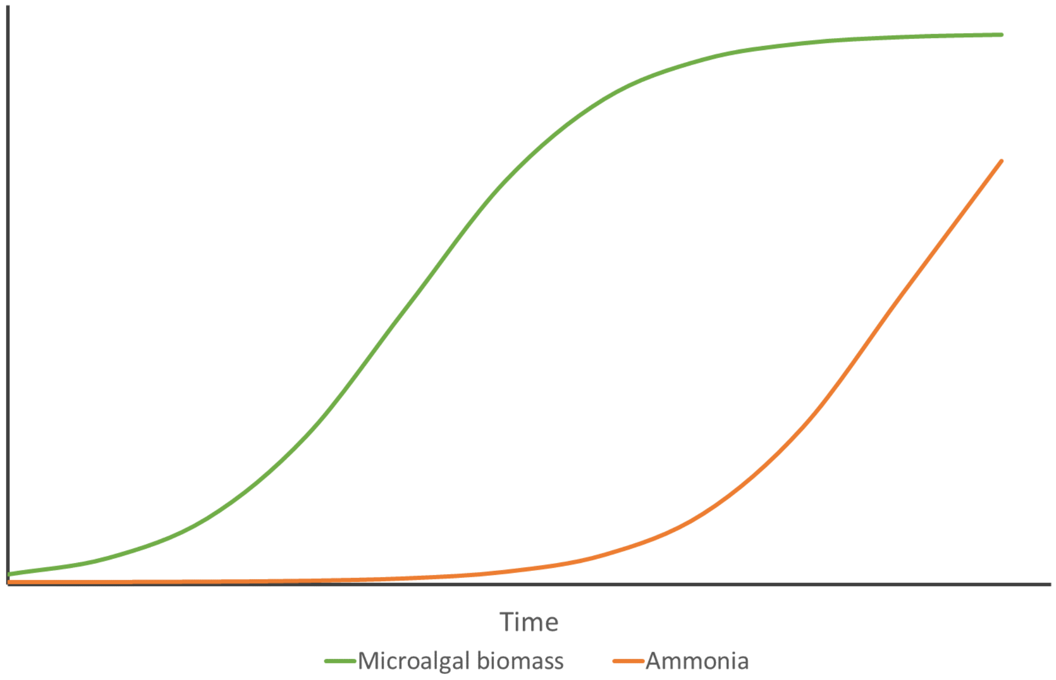


Figure 7. Conceptual figure showing microalgal growth and ammonia levels in pond water over a typical crop cycle.

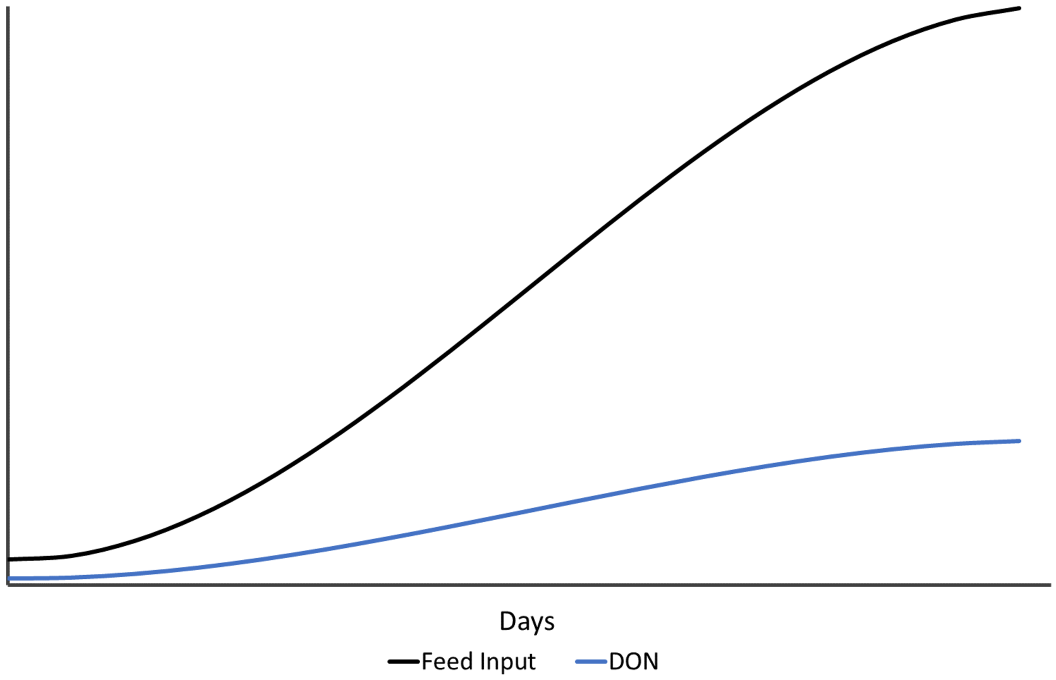


Figure 8. Conceptual figure showing feed input and dissolved organic nitrogen (DON) concentration in pond water over a typical crop cycle.

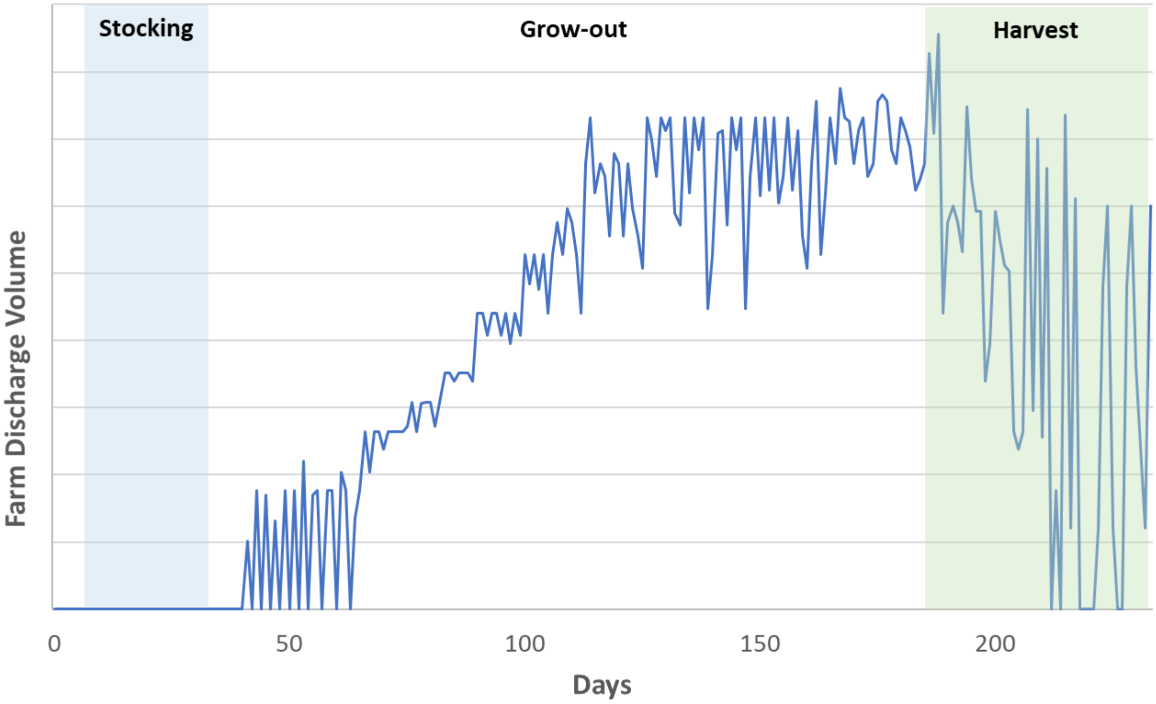


Figure 9. Conceptual figure of the pattern of daily discharge from a prawn farm in Queensland.

3.4 Potential impact of release

While there have been several studies of aquaculture pond nutrients, including nutrient budgets and characteristics of release water, the impacts on the environment are less well studied. This is particularly true for intensive pond aquaculture systems. As outlined previously, aquaculture wastewater has a nutrient load dominated by ammonium (animal excretion, sediment remineralisation), DON (feed and feeding waste) and particulate nutrient (primarily algal in origin). The relative proportion of these compounds contributing to the TN concentrations in wastewater varies depending on environmental conditions, stage of crop and husbandry techniques. Ammonium is very bioavailable and can stimulate primary and microbial production in tidal creeks, estuaries, and coastal areas. In sufficient loads, ammonium can cause algal blooms which have flow-on ecosystem effects, including potential production of toxins, and reduced oxygen levels as blooms crash.

The most comprehensive study of the environmental impacts of aquaculture release water was conducted at 2 north Queensland prawn farms (Burford et al. 2003a). This research was from the late 1990s and early 2000s and was conducted within the Cooperative Research Centre (CRC) for Aquaculture involving the Australian Institute of Marine Science (AIMS), the Commonwealth Scientific and Industrial Research organisation (CSIRO) and the University of Queensland (UQ), with input from the then Queensland Department of Primary Industries and Queensland Environmental Protection Agency. Both farms released into tidal creeks. The study found that many nutrient-related parameters, including nutrient concentrations, and fluxes of nutrients, had similar concentrations (although highly variable) in the downstream tidal creeks compared with the water in the treatment ponds. However, once these creeks flowed into the Reef lagoon, the study found no measurable signal or impact on the system that was studied.

On an annual basis, the upper reaches of one of the creeks identified in the Burford et al. (2003a) study mineralised only a small fraction of the nutrients derived from the prawn farm wastes (Trott et al., 2004). However, release of wastewater containing nitrogen during prawn harvest periods did not cause eutrophication further downstream, likely due to a combination of physical mechanisms (intensive tidal flushing) and biological nutrient transformations by pelagic microbes, and subsequent grazing by microzooplankton and fish.

Particulate nitrogen is primarily algal in origin (Burford and Pearson, 1998). This is because algae bloom in aquaculture ponds where there are sufficiently available nutrients. The release of algae into receiving waters may have a range of effects including providing the seed stock for an algal bloom, crashing and creating low oxygen conditions. The degree to which these impacts occur depends on the degree of dilution that occurs in the receiving environment. The study of the receiving environment (tidal creeks) of the 2 north Queensland prawn farms showed that primary productivity rates in the water column were higher in the 2 km downstream of the farms compared with further downstream (Burford et al. 2003a). This may have been due to either algae released from the farms and/or released ammonium from the farms stimulating primary production of the algal communities in the creeks. As might be expected, sedimentation rates of particulate material were also higher within the 2 km downstream zone, compared with further downstream.

These research findings were also stated as part of a CSIRO submission to the Joint Select Committee on Northern Australia Inquiry into Opportunities for Expanding the Aquaculture Industry in Northern Australia in 2016. There have also been 2 Productivity Commission reviews (2004 and 2016) and the Parliamentary Joint Select Committee inquiry (2016) into aquaculture which at the time accepted these findings (N. Preston, *pers. comm.*).

Although no major impact was observed in these studies, it was found that there was limited overall loss of nitrogen in the ponds, estuary, and sediments. In other words, it could be assumed that most of the nitrogen produced from aquaculture facilities was exported from the overall system (ponds and estuary) via tidal flushing and into the coastal bays and Reef lagoon. Therefore, the available information suggests that aquaculture wastewater that is released to tidal estuaries will be a potential contributor of nutrients to the Reef lagoon, even if overall levels are minor compared to diffuse sources.

Since the studies outlined above were undertaken around 20 years ago, there have been no comprehensive studies of the environmental impacts of pond aquaculture wastewater releases in Australia. The historical studies are limited in their current application due to several factors, including:

- Farming practices have changed, including production intensity, as well as improved efficiencies in production,
- The potential impact of nutrients on the receiving environment will vary with different size creeks/estuaries and relative tidal mixing (hydrodynamics) of the receiving waters, and
- Concentrations of nutrients and other relevant water quality parameters, such as chlorophyll-*a*, as well as nutrient fluxes in the water column and sediment, are highly variable over short time frames, so without frequent measurements, it is difficult to discern differences.

A further potential impact from aquaculture releases may include scouring of the local estuary where large volumes of water are released into small receiving waters. This has been observed with one farm operating in north Queensland. In such cases, targeted monitoring, assessment, and modification to release structures may be required to manage potential impacts.

Our understanding of the potential impact of aquaculture wastewater release could be improved by analysing receiving water data collected by farmers as part of their licence requirements. This would give a more comprehensive picture of impacts, provided there is sufficient data from each farm site.

Additionally, estuarine biogeochemical models could be used, along with this data, as a means of integrating the short-term variability to gain more insights into the potential impacts of aquaculture on estuarine/marine water quality and assess assimilative capacity. Such assessments are potentially time-consuming and resource-intensive, and models need to be validated with real data for each farm location to be meaningful.

Assessment of potential hydrodynamic impacts is also needed for farms with large release volumes releasing to local receiving waters.

3.5 Aquaculture Industry Engagement

As part of the project, Griffith University conducted a survey of the pond aquaculture industry in Queensland, regarding their approaches and the challenges of treating and mitigating nutrients in discharge water (see Appendix 2). This was focused on farms within the Reef catchment. Representatives from the 2 peak industry bodies (ABFA and APFA) were briefed on the aims and scope of the project and were asked to assist in establishing contact with their members. Farmers were contacted directly, and a participant information sheet was developed to provide each farmer with the background and purpose of the project and sent out ahead of the survey. At the time of surveying farmers, it was made clear that farmers should not report on commercially sensitive data as the report would eventually be made widely available.

At an individual farm level, information was sought about: current discharge water treatment systems; planned changes or upgrades to treatment systems; farm size and cropping strategies; plans for expansion or factors limiting expansion; and release regulation conditions and concerns. Through these discussions, further information on the challenges and constraints faced by the industry more broadly was gathered.

Additionally, the survey sought to collect information and opinions from each participant to:

- establish which factors are influencing the growth of the industry more broadly in Queensland
- determine the perceived importance of nutrient management amongst all the issues and challenges facing the industry
- gauge the industry awareness of alternate, new, and emerging nutrient management strategies or technologies.

It should be noted that the survey participants were generally understanding of the projects' goals and the approach taken by the team in conducting the survey. However, there were reservations about the potential ulterior motives for use of the data which is likely to have impacted the amount of data provided.

At the time of the survey, there were 19 farms (covered by 18 EAs) in production that had approvals granted to release to waters within the Reef catchment. A further 4 operational EAs were for a prawn hatchery, a barramundi hatchery and two for emerging aquaculture species. All the farms were contacted either by their associations or the project team, with 14 agreeing to participate in the survey. The survey was conducted through individual discussions with a representative from each farm. As some enterprises cover more than a single farm, a total of 10 individual discussions were held.

All respondents recognised that nutrient loading to the Reef from adjacent catchments is an issue, but there was a commonly expressed concern about whether aquaculture was being unfairly targeted. One respondent summarised this unease as, "End of pipe is always easier to regulate and monitor than diffuse sources, even though the evidence has for decades shown the impacts of diffuse source nutrients and sediments". This has been a common concern within the pond aquaculture industry in Queensland for a number of decades. It seems aquaculture farmers were either not aware or confident of recent effort to regulate and monitor terrestrial farming practices in the Reef catchment. Data sharing is needed to demonstrate if diffuse source loads are decreasing and how they compare with aquaculture loads.

Universally, aquaculture farmers recognised the need for nutrient management but expressed the opinion that uncertainty about the details and implications of the new Section 41AA of the *Environmental Protection Regulation 2019* was a major barrier to industry expansion. Respondents reported that investments had already been delayed through difficulty in receiving feedback on applications and issues from the Queensland Department of Environment and Science (DES), and difficulties with progressing some permit applications. Answers to survey questions revealed there was a lack of clarity around:

- nutrient offsetting provisions within the regulations
- whether there is accounting for incoming nutrient loads from adjacent waterways into farms when determining output loads
- consistency and alignment of state and federal regulatory needs
- whether regulation should be based on nutrient concentrations versus loads and the rationale
- what nutrient parameters should be measured in release waters.

Additionally, farmers questioned the scientific underpinning of the new regulations based on a residual impact being the "presence of fine sediment or dissolved inorganic nitrogen" in terms of whether they are the most environmentally relevant components of discharge.

3.5.1 Farm-level survey responses

The survey revealed that more than 80% of the respondent farms were concerned about the quality of their intake water, particularly during rainfall events. They were also concerned about the impact on intake water quality of other activities within the water source catchments, for example, agriculture, industrial activities and urban development. Two farms have had issues where the nutrient concentrations (particularly TN) in the intake water were often above their release limits. At least 3 farms reported substantial production losses due to the intake water being contaminated with chemicals from surrounding industries or coliforms from domestic septic systems. Monitoring of nutrients in intake water is not an EA condition for most farms, but some farmers had analysed samples for their own information.

About 30% of farms had a current concern about biosecurity from intake water, usually because of proximity to other farms. All farmers recognised biosecurity as a potential risk to their business, particularly given the recent experience of prawn farmers on the Logan River in SEQ with White Spot Syndrome Virus (WSSV). Although farms on the Logan River are outside the Reef area, some farmers in the Logan River region were consulted about the changes in water handling and farming practices that they had adopted in response to the biosecurity threat. The potential intake of harmful algal species and disease agents was an added concern for most farmers, but they have monitoring protocols in place.

All farms aim to limit nutrient inputs through feed management and maximise the conversion of expensive feed into saleable product within production ponds. Some farms mentioned trialling the use of automatic feeding systems to further minimise feed waste and improve feed conversion, which appears to have had some success based on the information provided.

The main method of treating water discharged from production ponds was settlement (86% of respondent farms used settlement ponds) (Figure 10). Settlement ponds were established within the industry, in a large part, due to research done in the 1990s which showed their efficacy in reducing suspended sediments in discharge water. Generally, settlement ponds on prawn farms are dried out over the off-season but the removal of sedimented material is not routinely done. Barramundi farms have the additional complication of producing fish year-round, so the settlement ponds rarely have the chance to be dried out or cleaned. Shortcomings of the settlement pond design and construction have meant that, in the case of some farms, the ponds cannot be cleaned out without a large investment in rectification works.

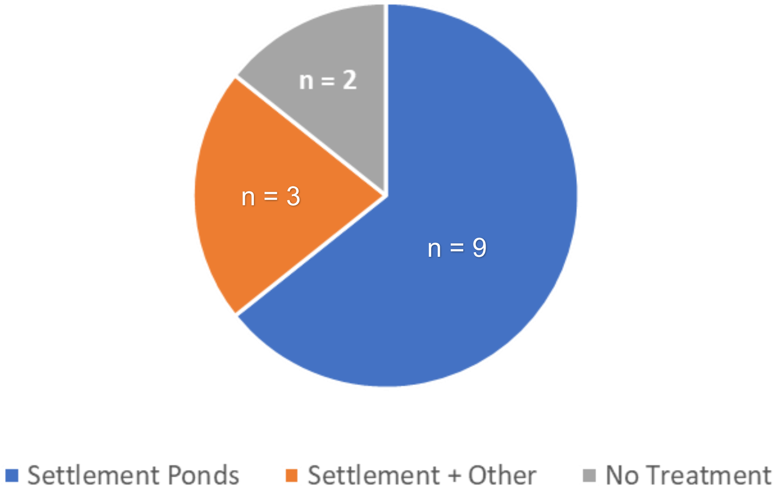


Figure 10. Proportion of farms that responded to the survey which use settlement ponds, settlement ponds followed by another treatment component or do not have a treatment system

Farmers generally do not know how efficient their settlement ponds are because only outlet water is sampled. Some farmers flagged that they have experienced sudden changes in environmental conditions (for example, temperature and salinity) causing the death of established biota within the settlement system which then contributes to the released nutrient load. Some farms use an extra component termed “zig-zags”—narrow, shallow channels which help to remove additional nutrients through algal and plant growth—after the settlement pond. These structures also appear to provide a mechanism to aerate the water prior to release. This may increase the volatilisation of ammonia and promote algal use of dissolved nutrients. However, the efficacy of this feature is unknown.

Some of the surveyed farms (42%) have the infrastructure to recirculate treated water within the farm if required. However, these farms either only recirculate a small volume, or the system is only being used when intake water quality is poor. Three farms are investigating options to increase the amount of water that is recirculated within the farm. However, reservations were expressed about the impact of recirculation on the health of the stock and biosecurity within the farm. There was one example of a farm where recirculation caused production losses due to the spread of pathogenic bacteria through the production ponds. Understandably, poor experiences with recirculation influence further adoption. This is clearly an area where further research would be beneficial to determine if protocols for recirculation can be developed that do not negatively impact on production.

About 40% of the farms that took part in the survey want to expand or intensify production, but in at least 3 cases these plans were on hold due to licence requirements for nutrient release. Some farmers have trialled and continue to trial other treatment methods, which has included the use of macroalgae to utilise dissolved nutrients. However, no fully effective solutions were identified by farmers, despite 60% of the farms either actively looking for improvements or being open to modifying current treatment regimes. This relies on a cost-effective solution being available.

Farmers were asked what the main impediments to changing or modifying their treatment system were. Cost and the unknown cost-effectiveness of nutrient treatment options were the most frequently identified concerns (> 70% of participants) (Figure 11). There is a significant knowledge gap around the cost of different treatment options. Available land area within farms for treatment was also highlighted as a barrier. For farmers to invest in treatment modification, they need confidence that the modifications will lead to predictable and reliable outcomes. Therefore, more research is needed to give options that increase reliability. Even farms that did not have plans for expansion expressed the need for information and clarity about the cost and effectiveness of alternative treatment options in reducing nutrient loads before capital could be raised to invest in change.

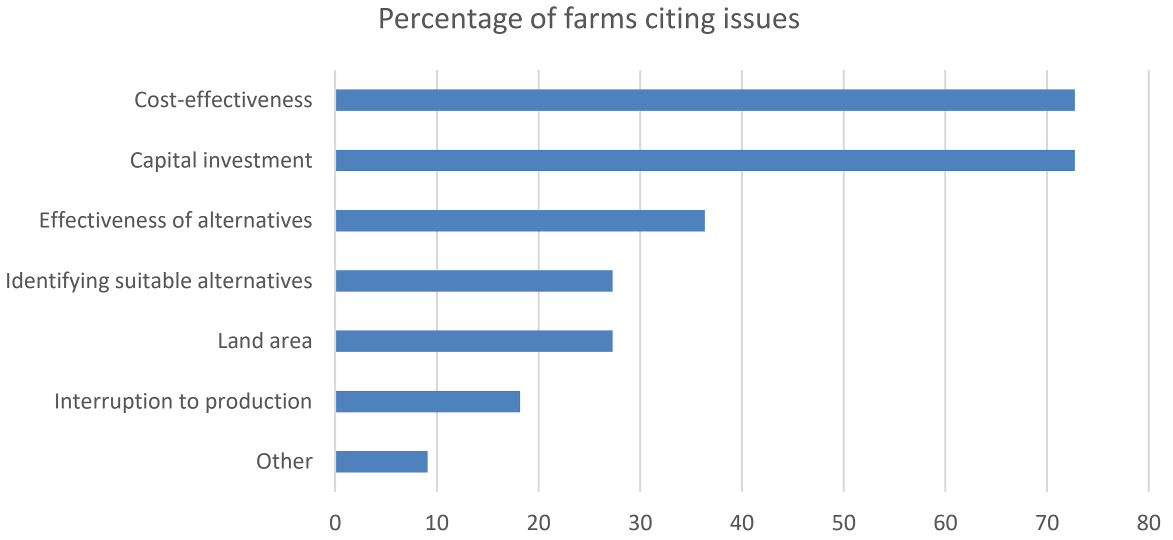


Figure 11. Issues and information gaps identified by survey respondents as the main impediments to changing or modifying treatment systems

The farms currently operating within the Reef catchment were all established more than ten years prior to this study, although some have been redeveloped since then. However, in some cases, the current managers or owners were not involved in the original establishment of the farm, or the EA associated with it. There were questions raised during the survey, by several respondents, as to how or why particular conditions within the EAs and limits on release had been imposed. Whilst there may be some misunderstanding around the process and how EA decisions are made, it is apparent that some communication between DES and the industry would assist farmers in understanding the decision-making process. About 30% of respondent farms expressed a reluctance to apply for amendments to EAs as it was feared that this may result in changes to conditions or limits beyond those requested in the application.

The cost of compliance with EA conditions for monitoring was raised by half of the respondents. This was not simply a monetary cost, although in some cases there were substantial third-party monitoring and assessment costs or high sample analysis costs. There was also a cost in terms of time (especially for smaller and family enterprises) and resources devoted to sample collection, preparation, and reporting. An example was cited where samples were being collected and analysed for both state and federal (EPBC) permits, but the sampling schedules, locations, analyses, and conditions were different for each permit. One respondent queried whether the effort and money that goes into monitoring is disproportionate to the impact that the industry could have when compared to runoff from rain events.

3.5.2 Industry level survey responses

When farmers were asked to identify the main impediments to expansion of the aquaculture industry in Queensland there were several common themes around regulation, consistency, uncertainty and red tape. The responses are summarised in a word map (Figure 12).

Participants in this study were also asked more broadly, for their views on the impediments and challenges that the pond aquaculture industry in Queensland is facing. While there were areas that were common between both the prawn and barramundi industries, each sector also faces some more unique challenges. Since there were more prawn farmers than barramundi farmers the responses were categorised into similar topics.

Figure 12. A word map representation of responses when farmers were asked to identify the main impediments to the expansion of the aquaculture industry in Queensland. Colouration is random and used to assist with reading.

When asked about the major challenges that face the pond aquaculture industry in Queensland, ~75% of the participants that responded to this question cited release regulation (and certainty around how it is applied) as one of the major issues. A similar number were concerned about access to skilled and reliable staff, 50% of respondents mentioned access to broodstock and larvae, and 50% cited biosecurity risks and stock health management. Other common themes included rising costs and reduced return on investment, the overall regulatory burden on farmers from all levels of government, competition from cheap imports and access to the tradespeople required for farm maintenance and development (Figure 13). The competition from cheap imports was viewed not only as a financial risk but also, considering the introduction of WSSV into Australia, as a demonstrated biosecurity risk.

Most participants were aware that the development and expansion of the aquaculture industry is a recognised priority of the Queensland Government, as proposed by the Department of Agriculture and Fisheries (DAF). However, some farmers questioned whether there were sufficient suitable sites when considering intake water quality, suitable release points, access to labour, and access to suitable infrastructure (for example, sufficient electrical power). Several farmers mentioned that production was, at times, constrained by being unable to draw sufficient power from the grid. One respondent questioned whether further investment in the sector would proceed due to the cost of headworks to deliver sufficient power to a site. The proposed ADAs that have been identified by the government may address some of these issues. However, questions were raised about the climatic suitability of these areas for barramundi developments as well as the biosecurity risks from clustering aquaculture enterprises together. This also creates increased environmental pressure on the individual catchments. Some queried whether there would be cooperation between the various departments within government to streamline the application process in these areas.

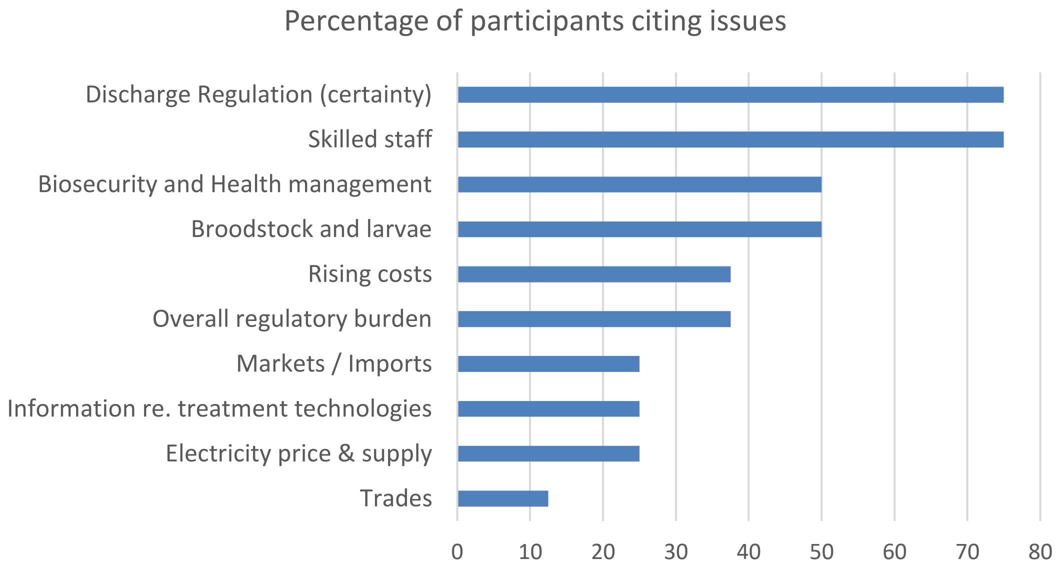


Figure 13. Major challenges more broadly facing the pond aquaculture industry in Queensland, as identified by survey respondents.

A related topic raised by 70% of participants was questioning the impact of aquaculture nutrient release on the receiving environment. They cited research from the late 1990s and early 2000s which was conducted within the CRC for Aquaculture (Australian Institute of Marine Science, CSIRO, University of Queensland), with input from the then Queensland Department of Primary Industries and Queensland Environmental Protection Agency. The research showed that within 2 tidal creeks in the study, the signal and impact of prawn aquaculture wastewater release were measurable for some parameters (Burford et al., 2003a; Trott et al., 2004). However, once these creeks flowed into the Reef lagoon there was no measurable signal or impact (CSIRO submission to the Joint Select Committee on Northern Australia Inquiry into Opportunities for Expanding the Aquaculture Industry in Northern Australia, 2016). There have been 2 Productivity Commission reviews (2004 and 2016) and the Parliamentary Joint Select Committee inquiry (2016) into aquaculture which at the time accepted these findings (N. Preston, pers. comm.).

This research is now 20 years old and was done when the industry average production per hectare was lower, but production practices have also become more efficient. Unfortunately, no further studies have been done to assess whether the level of impact has changed. Data collected as part of the receiving environment monitoring plan (REMP) for farms, however, was not immediately available for this study. Therefore, further work is needed to determine the level of impact of aquaculture in receiving water environments.

Farmers also questioned whether a similar effort to assess discharge/runoff from other, more established industries was also being undertaken with the same level of rigour.

The COVID-19 pandemic and border closures may have added to the staffing situation for some farms, but farmers flagged that this was a pre-existing issue. The higher remuneration offered by other sectors, especially the mining sector, has meant that it has been difficult to attract and retain labour in the industry. The ongoing uncertainty around staffing led one farmer to question whether they would stock their ponds for the next season.

4 Aquaculture Regulation, Policy and Standards under the EP Act

This section discusses several key environmental regulatory policy and standards related to point source releases for aquaculture under the EP Act including the Model Operating Conditions for Aquaculture, the Queensland Prawn Farm Policy for Wastewater Releases, the Nutrient Offset Policy and certification standards. For further information on regulation of wastewater releases is provided in Appendix 3.

4.1 Model Operating Conditions for Aquaculture

4.1.1 Background

The Model Operating Conditions for Aquaculture (MOCs), which were last reviewed in February 2021, provide a framework of conditions that may be applicable to all new EAs for ERA 1, thresholds 1 and 2. The MOCs supply a range of indicators, limit types and limit calculations, but do not generally provide details on specific limit values. As the MOCs are a framework only, modified and/or additional conditions can be applied at the discretion of the administering authority to address risks that are specific to a particular operation or a particular site. Also, if a particular model operating condition is not appropriate for an operation, then it will not form part of the conditions placed on the EA. The applicant can also request the addition, removal, or replacement of conditions to tailor the EA to their operation.

The MOCs for aquaculture also provide guidance on the intent of and how to comply with each condition. These sections provide basic information on the reason for the inclusion of a condition and how operators can achieve compliance.

The applicant must decide on the level of risk associated with their activity and ensure that the measures implemented are appropriate to manage the environmental outcome or requirement set out within each condition of the approval.

4.1.2 Model Operating Condition Review

The MOCs for Aquaculture have been reviewed as part of this project, with a particular focus on the suitability of the conditions relating to wastewater management and releases for application to new and expanding activities in the Reef catchment, and more broadly in Queensland. This specifically relates to Sections 5, 6 and 7 of the MOCs covering model operating conditions, guidance on model operating conditions and definitions, respectively, and those conditions relating to water contained in the General (G) or Water (WT) sections. The MOCs potentially related to wastewater release management are presented in Table 4.

In general, the MOCs for ERA 1 do not provide details on specific limit values as these are often site/project specific and are determined through the assessment process based on the impacts to the receiving environment. Therefore, the MOCs are potentially less relevant to a review of operating standards compared to policies or EAs that specify numerical limits. Furthermore, as discussed above, the administering authority, including at the request of the applicants, may modify or exclude conditions as appropriate. However, the MOCs present a general range of indicators, limit types, limit calculations and definitions that will guide regulation and management of the aquaculture industry. These are discussed more below.

Table 5 presents a list of indicators that are included in the current MOCs for aquaculture releases to water. The indicators have been categorised into those recommended to be monitored daily, weekly or are calculated from monitoring results. In general, the MOCs present an indicative suite of indicators and incorporates the 2 additional cases where: (i) net annual mass loads and (ii) offset loads are considered. The net mass load is for TN and TP and requires monitoring of quantity and quality of intake water. The model conditions specify that this requirement is only for cases where intake water and release water are in the same water body. Offset loads involve management works considered under the current Water Quality Offset Policy and these are used to “increase” the allowance for annual mass loads of TN and TP.

Table 4. Key MOCs that relate to wastewater release management

Condition	Description of condition
G3	Reporting of contravention to administering authority must be via WaTERS (Water Tracking and Electronic Reporting System)
G6	All records must be provided to the administering authority upon request and in the format requested
G14	All monitoring required must be carried out and interpreted by an appropriate qualified person (s)
G18, G19, G20, G21, G22, G23	Receiving environment monitoring program (REMP) implementation, details, submission, and amendment
G26, G27	Annual monitoring report preparation and submission (includes REMP results and annual mass load calculations)
WT1, WT2	Release to water conditions including contaminant monitoring, release location and release limits.
WT3	Reporting to WaTERS annually
WT4, WT5	Annual mass loads for total nitrogen and total phosphorus
WT6, WT7	Maximum release volume during any day and in a year
WT8 to WT12	Accuracy of quantity measurement, no visible slick etc, no erosion or stream bank disturbance, structure maintenance, no impact on groundwater
Additional MOCs – net mass loads	
WT4, WT5, WTNM1-WTNM4	Includes annual mass load calculations and limits for total nitrogen and total phosphorus but incorporates intake nutrients, i.e. net mass loads. Only to be applied if intake is from the same waterway as release.
Additional MOCs – offsets	
WT4, WT5, WTO1-WTO5	Includes annual mass load calculations and limits for total nitrogen and total phosphorus but incorporating annual offset loads.

Table 5. List of indicators recommended for measurement by aquaculture releases in the current MOCs, either daily, weekly or calculated.

Monitored daily	Monitored weekly	Calculated*
pH**	TN (mg/L)**	Annual mass load (kg)
Dissolved oxygen**	Ammonia (mg/L)**	Annual release quantity (ML)
Turbidity**	Oxidised nitrogen (mg/L)**	(financial or calendar year)
Electrical conductivity**	TP (mg/L)**	Yearly long-term mean (mg/L)
Temperature**	FRP (mg/L)**	Annual net mass load (kg) **
Release quantity (daily)	TSS (mg/L)**	Intake mass load (tonnes)**
Intake quantity (daily)**		Annual mass load (offset) (kg) ***
		Offset (kg) ***

* each calculated for total nitrogen and total phosphorus based on financial year unless otherwise stated;
** also monitored for intake when net mass load conditions apply; *** calculated when nutrient offset conditions apply

Several release indicators are listed in the MOCs as shown in Table 5. For each of these, a mean, minimum or maximum limits (or combination thereof) may be applied. The timeframe over which the mean is calculated needs to be inserted in the footnote, for example, 6 weeks. Reference is also made in the footnote to the Queensland Monitoring and Sampling Manual. Also, the footnotes specify that monitoring devices must be calibrated and maintained according to the manufacturer's specification.

Many elements within the MOCs are comprehensive and fit-for-purpose for ERA 1 activities including notification and reporting requirements; many water release conditions; REMP conditions; and some elements of the mass load conditions, net loads and offsets. However, some areas need further policy development including overall water and treatment management, consideration for differences between prawn and barramundi farms, consideration of intensity and scale (smaller and larger facilities), consideration of the effects of rainfall on release volume and loads, application of ebb-tide releases, and the process for developing load limits.

More detail on possible amendments to this document include:

- Reworking the conditions so that they refer to, and integrate with, current and future aquaculture policy and impact assessment guidelines to provide consistency and clarity for applicants and regulatory officers: for example, reference to an updated Prawn Farm Policy, Aquaculture REMP guideline or sustainable load assessment. Some differentiation in requirements for small and large facilities is recommended, such as for release monitoring frequency and indicators given the potential expense involved.
- Key release indicators for farms currently are TN, TP and TSS. Monitoring of speciated nutrients such as ammonia, oxidised nitrogen and filterable reactive phosphorus (FRP) is also included in the MOCs. This is supported for larger facilities in the Reef catchment, or more broadly in Queensland. At this point in time, there is insufficient information to set release limits or know whether release limits are required for speciated nutrients. A good understanding of speciated nutrients could assist with the implementation of reef legislation for point source activity regulation based on DIN.
- The monitoring frequency specified in the MOCs is higher than specified in most EAs currently. This frequency may be better suited to larger facilities. Also, as discussed in this report, higher monitoring frequency is more likely needed for intensive growing periods. This typically corresponds to a 3–4 month growing period for most prawn farms. No monitoring would be required when not releasing. Less frequent monitoring could occur at other times (for example, monthly).
- Release monitoring of indicators BOD_5 and Chlorophyll-a concentrations have historically been required for numerous aquaculture activities but are not included in the MOCs. These indicators are potentially important for assessing risk related to decreases in DO in receiving water. As a minimum, these indicators should be adopted in the MOCs for all facilities involving significant releases to water.
- Monitoring and controlling DO in the release is a key consideration not addressed in the MOCs. In the future, continuous monitoring of DO at the release point could potentially be warranted for larger facilities. However, this would incur additional cost and may only be required in some higher risk circumstances.
- The MOCs make reference to ensuring that the total nutrient load within the receiving waters remains below the threshold for impacts on environmental values. However, procedures for deriving load limit values are not readily available. This is not the purpose of the MOCs but reference can be made to relevant guidance material that assists with this process.
- The use of net loads could be considered in all cases, not just when the intake is in the same waterway, as specified in the current MOCs. However, intake concentrations and volumes would need to be reliably measured or estimated. Also, any net load limit needs to be related back to the assimilative capacity of receiving waters in all cases.
- The use of annual load limits as specified in the MOCs should be revised for use with prawn farm aquaculture given typical variability of farms operation and wastewater loads across the year. Monthly load limits may be more suitable for application given operation is not continuous (peaks March to May) and can also be impacted by rainfall. A different approach, such as used in the current MOCs, may be required for barramundi farms given operations are generally less seasonal.
- Maximum release volume limits and calculations in the MOCs need to consider rainfall. Many approvals currently accommodate higher release volumes due to rainfall.

4.2 Queensland Prawn Farm Policy for Wastewater Releases

4.2.1 Background

The Licensing wastewater releases from existing marine prawn farms in Queensland Operational Policy (Prawn Farm Policy) aims to enhance and protect the environmental values of the water environment, while allowing for ecologically sustainable development through the setting of consistent licensing standards for wastewater release from existing marine prawn farms in Queensland. Two of the key objectives are to define minimum standards for release and impact and to define monitoring programs to measure the performance of each facility. The policy refers to 3 types of existing activities: Category A – no proposed changes; Category B – proposed expansion; and Category C – farms with more stringent standards. The proposed minimum release standards for key indicators are stipulated for each of these categories. A summary of the key elements of the Prawn Farm Policy are described in Table 6.

The Prawn Farm Policy was first approved in May 2001 and has been largely unchanged since that time. The policies, guidelines and regulations considered at the time were related to the Great Barrier Reef Marine Park (Aquaculture) Regulation 2000, *Fisheries Act 1994* and *Environment Protection and Biodiversity Conservation Act 1999*, in addition to the *Environmental Protection Act 1994*. Much of the information presented in the Prawn Farm Policy's 'discharge' (read release) standards is derived from the work undertaken by the Cooperative Research Centre for Aquaculture (CRC) prior to that time. The CRC research was the most current research information at that time that specifically related to Queensland conditions and management practices. Other sources of information included monitoring data provided by existing operations and considered the knowledge of treatment techniques, impacts on the receiving environment and the need for standardisation of reporting at that time.

The Prawn Farm Policy also sets out the recommended monitoring frequency for key indicators in the release. Although TN, TP and TSS concentrations are considered primary indicators for prawn farm releases, chlorophyll-a and DO concentrations are also considered important. Sampling frequency is also proposed for harvesting and excessive rainfall considering the size of the farms. Requirements are also included for receiving environment monitoring. The Policy requires that TN, TP and TSS concentration in the receiving environment are no greater than background, outside of the initial mixing zone.

4.2.2 Prawn Farm Policy Review

The Prawn Farm Policy was specifically aiming to provide greater consistency for wastewater release standards and monitoring across existing marine prawn farms in Queensland. Since 2021, this document has been regularly reviewed but there has been no substantial change in relation to release standards. Since the policy was first introduced, there has been substantial work on scheduled water quality objectives (WQOs) across Queensland waterways and therefore, the "per hectare" load-based release standards are potentially in conflict with these objectives. In addition, there is significant interest from government and industry in intensification and expansion of aquaculture. This policy was not designed for this purpose. Further, no similar standard exists currently for barramundi farms in Queensland.

Table 6. Minimum standards stipulated in the Prawn Farm Policy for wastewater releases from existing farms

Indicator/area	Licences (Category)	Guidance on minimum standards
Drugs and chemicals	A, B & C	"The only drugs and chemical substances allowed to be used in prawn farms are those authorised by the Australian Pesticides and Veterinary Medicines Authority (APVMA), prescribed by a veterinarian or those substances that have been declared "Exempt from Registration" and their use shall be in accordance with the label's requirements. All drugs and chemicals authorised to be used at the facility shall only be discharged* to the receiving environment at a level prescribed or authorised by the administering authority in accordance with ANZECC Guidelines."
Chlorine	A, B & C	Water treated with chlorine must be dechlorinated prior to discharge to a level where the free residual chlorine is less than 0.1 mg/L.
Dissolved oxygen, pH	A, B & C	• Dissolved oxygen – Minimum concentration shall be not less than 90% of the background value or 4 mg/L whichever is greater. • pH – A minimum of 6.5 and a maximum of 9.0. • Both parameters shall be achieved at the time and point of discharge.
Total suspended solids	A & B	• 40 mg/L – mean; and • 75 mg/L – maximum; and • 12 kg/ha/day averaged over the growing season.
Nitrogen	A	• 3.0 mg/L – maximum; and • 1.0 kg/ha/day averaged over the growing season.
Nitrogen	B	• 3.0 mg/L – maximum; and • 0.80 kg/ha/day averaged over the growing season; and applies to the entire farm.
Phosphorus	A, B & C	• 0.40 mg/L – maximum; and • 0.15 kg/ha/day averaged over the growing season.
Receiving environment	A, B & C	Concentrations of suspended solid, total nitrogen and total phosphorus must not exceed background concentrations when measured at a boundary of the initial mixing zone. Background concentrations are to be determined by the operator for acceptance by the administering authority.
Pond grow-out area	A, B & C	Licences will define the current maximum area of grow-out ponds that are authorised.
Discharge volume measurement	A, B & C	All farms shall incorporate a system that can determine discharge volumes to an accuracy of +/- 5%. The operator must be able to certify the required accuracy.

Notes

1. Mean is determined as the average of 6 consecutive samples over the growing season.
2. Minimum levels for nitrogen and phosphorus must reflect the ANZG Guidelines (which superseded the ANZECC Guidelines). Where assessment using the ANZG Guidelines requires a more stringent standard, this more stringent standard must be applied.
3. The levels for total suspended solids, nitrogen and phosphorus are measured as net discharge values, calculated using the following ascending hierarchy;
    - the difference of the discharge water quality the median value derived from AA ambient water quality data where available; or
    - the difference of the discharge water quality and the median value derived from the development of local background water quality; or
    - the difference of the discharge water quality and the intake water quality.
4. Farmer may remove the provision of managing under a net discharge arrangement, however under these circumstances the above parameters shall be measured as total discharge.
5. *The Prawn Farm Policy uses 'discharge' to refer to water exiting the site. In the context of this project, 'release' is the correct term here.

There are several areas of the Policy that are still very relevant to current day prawn farm operation. These include approaches to the management of drugs and chemicals, chlorine and core wastewater indicators. If retained, the policy should be applied across the industry in Queensland to help ensure a consistent approach to regulation. If this is the case, potential areas for revision include:

- Approaches for both new, expanding and intensifying prawn and barramundi farms.
- Updating content to refer to current relevant legislation, policy and guidelines. As a minimum, this should include the Environmental Protection Policy for Water and Wetland Biodiversity, Reef related legislation, Scheduled Environmental Values/Water Quality Objectives, Australian and New Zealand governments Water Quality Guidelines (2018), Queensland Water Quality Guidelines and Point Source Nutrient Offsets Policy.
- Revising and potentially removing the load standards (kg/ha/day) for TN, TP and TSS as these cannot easily be assessed given the limited information on production area. Load standards need to allow for more modern operational configurations currently used by industry and likely needed in the future (for example, including intensification, advanced treatment and recirculation). Furthermore, a more outcome focused approach for setting maximum release loads considering the assimilative capacity of receiving waters is needed.
- Revising concentration standards for TN, TP and TSS based on the most recent operational data and considering different operational regimes such as intensification, different treatment types and recirculation.
- Revising and updating the impact assessment approach, monitoring and standards related to ‘no residual impact’ to background in the receiving waters. This approach is not consistent with the department’s current licensing approach which is based on scheduled or locally relevant water quality objectives. Also, mixing zones are not applicable to nutrients, only toxicants. Nonetheless, an approach for defining an acceptable zone of influence is required.
- Revising and updating the approach related to “net” concentrations to be consistent with MOCs and other current and future policy. There is currently a disconnect between the various approaches specified in these documents regarding the use of “net” concentrations and “net” loads. This approach needs to consider separately both local water quality and broader Reef values.

4.3 Water Quality Offsets

The Point Source Water Quality Offsets Policy 2019 (the Offset Policy) describes how existing or potential EA holders under the *Environmental Protection Act 1994* (EP Act) can offset the water quality impacts of wastewater release to receiving waters. The Offset Policy outlines how water quality offsets (for example, riparian area restoration to reduce diffuse nutrients from erosion, streambank and gully restoration, constructed or remediated wetlands) may be adopted as a voluntary option for managing ERAs, including aquaculture operations, releasing wastewater containing prescribed offset contaminants, including nutrients, into receiving waterways. In addition, under Section 41AA of the *Environmental Protection Regulation 2019*, new or amended approvals involving point source releases must meet a ‘no residual impact’ relating to DIN and fine sediments, if releasing within the Reef catchment. It should be noted that TN and TSS can be used as surrogates for DIN and fine sediments, respectively, under the department’s Guideline on Reef discharge standards for industrial activities.

Therefore, any increase in DIN (or TN) or fine sediments (or TSS) from new or expanded aquaculture farms can be (or must be, in the case of farms in the Reef catchment) offset against catchment actions used to reduce broader contaminant loads to waterways. Nutrient offsetting, with the main focus being on nitrogen, is being trialled in a few jurisdictions in Australia, including Queensland. For example, Urban Utilities—a sewage treatment plant operator—undertook riverbank restoration works in a SEQ river at a cost of $800,000 which was more cost-effective than the alternative of spending $8 million upgrading their STP (wsaa.asn.au). The operational costs were also lower, saving $5 million over the 10-year life of the offset.

Offsets are only to be considered after all reasonable efforts have been investigated to avoid and mitigate the release and it has been found that the proposal will not result in any environmental harm to the receiving water environmental values. Nonetheless, nutrient offsetting provides a critical mechanism for farmers to achieve no residual impact caused by the presence DIN and fine sediment released to the Reef catchment, as required under new Reef regulations for new or expanded operations. Water quality offsets should be fit-for-purpose for the wastewater release, considering the timing and nature of the release, and ensuring there is no local environmental impacts. However, currently, there are limited examples of where water quality offsets have been applied to point source releases in Queensland, especially for aquaculture activities and limited information on the available options and their efficacy.

A further consideration is that there is currently no formal, coordinated nutrient offsetting strategy at a state level. This means that farmers must, on an individual basis, negotiate with the state government to develop and undertake an offset initiative. Additionally, a scientific challenge for nutrient offsetting is establishing the 'equivalency ratio' for determining the comparability of nitrogen from different sources in terms of their ecosystem effects. Equivalency ratios currently in use in Queensland, generally set to one by default, are not based on scientific understanding but are seen as an interim solution until scientific research is completed. Research is currently underway by the Australian Research Council (ARC) Linkage Project (Innovative tools needed for market-based nutrient offsetting, Burford lead Chief Investigator) on this challenge to provide a more scientific foundation for nutrient offsetting. Additionally, projects are underway to examine how nutrient offsetting markets might work, funded by the Queensland Water Modelling Network (QWMN). It is hoped that these projects will help to address some of the challenges associated with nutrient offsetting. However, studies are still needed on developing an offsetting framework that helps assess what type of offset works should occur, the best locations, their efficacy and whether there are benefits for the local water quality of rivers and estuaries.

Although originally designed for offsetting agricultural impacts, Reef credits—or a similar scheme—may have potential application to point source emitting industries such as aquaculture. Reef credits are currently purchased based on amounts of DIN, rather than TN which is currently monitored and regulated for most industries in Queensland including aquaculture.

4.4 Certification Standards

As aquaculture has grown worldwide, there has been an increased focus on the environmental challenges caused by this expansion. Since much of the growth had been in less developed countries where this expansion was not regulated, concern grew around the impact on natural habitats, particularly mangroves, as well as inappropriate site selection, wastewater impacts and societal impacts. During the late 1990s, a number of environmental organisations were highlighting these impacts and scientific publications emerged which were highly critical of the pond aquaculture industry. In response, the aquaculture sector developed codes of practice to begin addressing some of these concerns (Boyd, 2003; Lee and Connelly, 2006; Jobling, 2008).

The Global Seafood Alliance (GSA, formerly known as Global Aquaculture Alliance), an international non-governmental organisation (NGO) representing the world's seafood and aquaculture industry, took its code of practice a step further and developed the Best Aquaculture Practices (BAP) certification program. Initially, this program was focused on shrimp (prawn) farming, but the scope was soon expanded to cover other species, and the entire supply chain, including feed manufacturing, seafood processing and retail. The standards for this program are continuously reviewed by a committee consisting of members from environmental and conservation NGOs, industry representatives, regulatory bodies and academics. Aquaculture farms, seafood processing facilities, hatcheries, and feed producers can apply to be certified. The steps toward BAP certification include audits by ISO-accredited independent third-party certification bodies to ensure compliance with the program's requirements.

In 2004, the World Wildlife Fund for Nature started discussions with multiple global stakeholders around aquaculture particularly focused on the salmon farming industry. These discussions resulted in the development of standards for 12 species and the creation of the Aquaculture Stewardship Council (ASC) in 2010. As the manager of international standards and certification programs, ASC has also developed their system to review and revise these standards. As of December 2022, there are 11 ASC standards covering 17 species.

The BAP program now certifies all steps of the production chain including, hatcheries, production, feed milling and processing plants for salmonids, finfish, molluscs and crustaceans (including prawns). The ASC has developed a feed standard to cover feed milling and the materials used for feed manufacture, and farm standards for the production of various species. Both the ASC and BAP standards have elements addressing environmental values, animal health and welfare, social responsibility, and traceability of product and feeds through the supply chain. The BAP Farm Standard (Version 3.0, March 2021) is the certification standard against which aquaculture facilities producing non-salmonid finfish and crustaceans are audited. The ASC has developed a certification standard for tropical marine finfish and another for shrimp farms. Although ASC and BAP are the 2 largest certification bodies there are a number of voluntary schemes that have been introduced by non-government organisations and private companies which may apply to regional production or individual farms (Naylor et al., 2021). The Friend of the Sea, sustainable aquaculture certification is another example of certification schemes that have been developed. This program has a certification for sustainable marine aquaculture and one for sustainably farmed crustaceans.

The time and effort involved in preparing for yearly audits to maintain certifications is a significant cost. However, farmers' access to the market is increasingly dependent on such certification programs. At the time of our industry survey, prawn farms that sought certification were using either BAP, ASC or both. Barramundi farms used the BAP certification and/or the Australian Sustainably Farmed Barramundi Certification Program (ASFBC). The ASFBC Program was developed by the Australian Barramundi Farmers Association to set minimum standards for sustainability while simultaneously recognising best practice approaches. Only 3 of the respondent farms were not using either the BAP or ASFBC certifications.

The ASC and BAP certifications relevant to barramundi and black tiger prawns have sections that deal with the conservation of local coastal/estuarine/river habitat, biodiversity and wildlife protection, and water quality impact on local aquatic ecosystems. Pond sediment management and release water are also audited. The BAP Farm Standard (Version 3.0, March 2021) which applies to both barramundi and prawns, and the ASC Tropical Marine Finfish Standard (Version 1.0, December 2019), both use concentrations of selected nutrients (see Table 7) and physico-chemical parameters such as pH and dissolved oxygen (DO), as criteria against which the release is assessed.

Table 7. Aquaculture certification assessment criteria for release water from aquaculture farms

		BAP Farm Standard		ASC Tropical Marine Finfish	
Indicator	**Units**	**Criteria***	**Min.Frequency / Conditions**	**Criteria**	**Min. Frequency / Conditions**
pH		6.0-9.5	Monthly		
Total suspended solids	mg/L	< 50	Quarterly	≤ 30 average and < 50	Monthly (2h after feeding)
Soluble phosphorus	mg/L	< 0.5	Monthly		
Total phosphorus	mg/L	---	Quarterly		
Total ammonia nitrogen	mg/L	< 5	Monthly	≤ 1 average and < 1.5	Monthly (2h after feeding)
Nitrate-N	mg/L	---	Quarterly		
Biological oxygen demand	mg/L			≤ 30 average and < 50	Monthly (2h after feeding)
BOD_5	mg/L	< 50	Quarterly		
Dissolved oxygen	mg/L	> 5	Monthly	> 2	95% of weekly samples
Dissolved oxygen	% Saturation			≥ 70	Twice Daily (6am and 3pm)
Chloride	mg/L	No discharge > 800 mg/L chloride into freshwater	Monthly		

* for each variable measured monthly, at least 10 of the values obtained during a 12-month period shall comply with the criteria, provided the 12-month average of the monthly data remains below the BAP limit for each variable. For variables measured quarterly, only one non-compliance is permitted for each variable during a 12-month/4 quarter period, provided the average of the quarterly data remains below the BAP limit for each variable.

The ASC Shrimp Standard (Version 1.2, October 2022) specifies annual nitrogen and phosphorus release load limits per tonne of prawns. The current maximum annual release loads of nitrogen and phosphorus from *P. monodon* production are 32.4 kg N per tonne of prawns and 5.4 kg P per tonne of prawns. The load limits are calculated based on the weight of feed applied, or measured release concentrations of TN and TP and depend on the type of farm operation. According to the ASC Shrimp Standard, all production pond discharge must pass through a treatment system and the final concentration of settleable solids flowing from the treatment system must be < 3.3 mg/L. Settleable solids are defined as the volume of solids that settles to the bottom of an Imhoff cone in one hour. Additionally, the percentage change in diurnal DO relative to DO at saturation in the receiving waters (for the water's specific salinity and temperature, measured at a point at least 200 m downstream of release) must be ≤ 65%.

The BAP standards are designed to manage what their committee identified and considered to be the most important environmental impacts of aquaculture farming worldwide. This includes farms operating in countries where aquaculture development is unregulated or the regulations would not encourage the adoption of better environmental practices. The BAP release, management and compliance options mandate that farms shall comply with specific water quality criteria (see Table 7) or applicable regulations if they are equivalent or more rigorous than local or federal law (BAP Farm Standard 3.0, Clause 3.3.1).

This is often the case in Queensland, where EA nutrient release limits are generally more stringent than BAP's water quality criteria. Even in cases where a failure to comply with an EA condition, defined by BAP as a critical non-conformity, could lead to a temporary suspension of the certification, BAP standards provide different options that allow farmers to avoid a critical non-conformity under specific scenarios. If a farm is unable to comply with its EA limits, it may still maintain its certification where any of the following applies:

- A farm can demonstrate that water quality does not deteriorate between the edge of the mixing zone down current and outside of the mixing zone up current.
- A farm can demonstrate that intake water quality exceeds limits.
- A farm can demonstrate water reuse, only occasional exchange, and no intentional release, such that less than 1% of the farm volume is exchanged daily on an annual basis.
- A farm conducts a third-party Environmental Impact Assessment with a favourable assessment of the assimilative capacity of the receiving environment and an Environmental Management Plan in place.
- A farm operates a freshwater system such that the release is exclusively used for irrigation.
- The flexibility of the selected BAP standard criteria shown above is likely the reason why some farms have been able to maintain their certification despite documented EA non-compliances. BAP load limits are not specifically scheduled in the BAP standards as they vary widely across production systems (finfish and crustaceans), the intensity of production, and receiving environment characteristics. However, unlike common EA conditions, BAP standard criteria assess nutrient load per unit of production, the Environmental Loading Index (ELI). This approach is identical to the ASC load calculation method, where depending on the type of farm, the nutrient loads are calculated by the weight of feed applied or by release concentrations of TN and TP. The BAP standards also specifies the TN and TP concentrations to use in net load calculations in the absence of direct measurements of release and source water concentrations. The ELI, or a similar metric, is not currently employed in Queensland's regulatory framework as the focus of nutrient management is on the absolute outputs of aquaculture farms. Nevertheless, it may prove to be a useful tool to benchmark farms and promote higher production outputs under better nutrient release management.

Barramundi producers in Australia, through a project co-funded by industry and the then Queensland Department of Environment and Resource Management, have had a certification scheme developed specifically for their industry, the Australian Sustainably Farmed Barramundi Certification Program (ASFBC). This certification program aims to achieve benefits beyond compliance and strives for continual improvement. It is administered by the ABFA and all producers, as part of this program, are independently audited every 2 years against criteria addressing economic, social and environmental sustainability. The certification also has elements assessing product quality and food safety, animal husbandry, and fish health. Farm water release is audited against compliance with the EA conditions and impact monitoring of the receiving environment. An annual return and ecoefficiency benchmark report are required every year.

The standards (levels) and indicator types used for accreditation vary between the BAP and ASC standards but some common approaches are used that could be incorporated into EAs to provide more consistency. These could include TSS (< 50 mg/L) and DO (> 5 mg/L or ≥ 65% saturation)—the ASC Tropical Marine Finfish Standard condition for DO requires pond measurement rather than release monitoring of DO (≥ 70% saturation)—which are more stringent than most current Queensland EA limit criteria. The BOD_5 standard is < 50 mg/L which is significantly higher than the 20 mg/L BOD_5 limit that appears in some EAs. There is no standard for TN or TP concentrations with either scheme and the nutrient concentration indicators with a standard are total ammonia nitrogen (< 5 mg/L maximum for BAP and < 1.5 mg/L maximum for ASC) and soluble phosphorus (< 0.5 mg/L maximum for BAP). However, annual nutrient loads are calculated based on the weight of feed applied or release concentrations of TN and TP, divided by the tonnes of product. ASC sets loads limits for prawn (32.4 kg N per tonne of prawns and 5.4 kg P per tonne of prawns). Under certain conditions, monitoring of intake quality is also required with these accreditation programs.

5 Review of Environmental Authorities (EA) and Release Data

5.1 Review for other Australian States and Territories aquaculture approvals

As previously discussed in Section 3, the Aquaculture industry in Queensland is often not comparable to farms located in other jurisdictions of Australia, except for a few farms located in the Northern Territory and northern New South Wales. As a result, there are limited relevant examples of aquaculture farms in Australia. Of 15 aquaculture EAs in New South Wales, one prawn farm was selected along with a barramundi farm in the Northern Territory. The relevant EA release conditions for these 2 farms are summarised in Table 8.

Table 8. Summary of EA conditions of examples of two farms outside Queensland.

Species	State	Reporting Frequency	Max Daily Volume (ML)	Max TN (mg/L)	Max TP (mg/L)	Max TSS (mg/L)	Min DO (mg/L)	Max BOD (mg/L)	Monitoring Frequency
Prawn	NSW	Annual	41.9	10	1	90	4	20	Monthly during discharge
Barramundi	NT	Annual		3	0.39	Ambient Turbidity	Ambient	3	Weekly during discharge

For the prawn farm in New South Wales, the operator is required to monitor wastewater quality monthly and to monitor intake water volume. Non-compliance is defined as any exceedance of the values listed in Table 8. Additional sampling is also required weekly during the pond drain-down, including the last 5% of release volume.

Environmental Authorities (EAs), or their equivalent, are required for pond aquaculture in both NSW and NT. It should be noted that EAs in New South Wales and the Northern Territory are granted with an expiry date leading to a periodic review. Similarly, EAs may require additional plans to be submitted, for example, an “Environmental Management Plan” or a “Water Quality Monitoring Plan”. Aquaculture farming is also a listed waste activity in the Northern Territory whose emissions are categorised as “Animal effluent and residues”. A barramundi farm in the Northern Territory is required to monitor water quality at least once during release, or at least weekly if the release is longer than a week. The water quality characteristics listed in Table 8 are based on the site-specific trigger values (SSTVs) calculated in accordance with the ANZECC 2000 methodology, as per a condition of the EA. These values are derived from the 80th percentile of reference data comprising at least 2-years’ worth of monthly monitoring data from the river adjoining the farm (where samples were collected in the absence of any release from the farm). Non-compliance is defined as an exceedance of a trigger value (SSTVs or the ambient water quality of the adjoining river) at the compliance point on 3 consecutive sampling occasions, or an exceedance of greater than or equal to 3 times the trigger value (SSTVs or the ambient water quality of the adjoining river) at the compliance point on a single sampling occasion. The values shown in Table 8 are calculated by tripling the SSTVs defined for the farm to obtain the maximum limit of each indicator.

In general, the nutrient release limits for nitrogen and phosphorus for the prawn farm example in New South Wales are much less stringent than the limits imposed on most prawn farms in Queensland. The barramundi farm example in Northern Territory has comparable limits to other barramundi farms located in Queensland, however, this farm relied on a very large treatment pond system of 1.4 times the area of production to treat and completely recirculate the farm wastewater. This farm has been able to operate without releasing wastewater, further details are described in Section 6.2.3. Differences in limits between states may be at least partially attributable to the proximity of Queensland aquaculture activities to sites of state, national and international value such as the Reef and Moreton Bay.

5.2 EA Review for Queensland

To understand the current operating conditions for aquaculture facilities, a review of the current EAs was undertaken. Due to the changes over time in legislation, policy and assessment process, a review of the individual EA assessments was not undertaken.

Land based aquaculture under ERA 1 includes cultivating or holding crustaceans in enclosures (ponds) that are on land over 100m^2 (ERA 1.1); or cultivating or holding marine, estuarine or freshwater organisms, other than crustaceans, in enclosures (ponds) that are on over 100m^2. There is a third threshold for conducting the activity on enclosures that are in waters, regardless of the size of enclosures (ERA 1.2). Aquaculture farms can also have other ERAs under the EA, for example prawn farms may also include an onsite processing facility, and therefore include Seafood Processing (ERA 27) as a secondary activity on the EA. A few other facilities that are not aquaculture farms operate exclusively under ERA 27, for example, seafood retailers and aquaculture feed producers. Table 9 below lists the number of facilities per ERA.

Table 9. Aquaculture activity classifications and the number of facilities within the Reef catchment.

Activity Classification	Activity	Number of Facilities (Reef Catchment)	Number of Facilities (SEQ Catchment)	Total
1.1(a)	1-(1a) Aquaculture >100m2	10	5	**15**
1.1(b)	1-(1b) Aquaculture >10ha but <100ha land	16	4	**20**
1.1(c)	1-(1c) Aquaculture >100ha land	2		**2**
1.2(a)	1-(2a) Aquaculture >100m2 but <10ha land	1	2	**3**
1.2(b)	1-(2b) Aquaculture >10ha but <100ha land	6		**6**
27	27-Seafood processing >500t/year	2	5	**7**
Total		**37**	**16**	**53**

The Public Register listed 48 Environmental Authorities (EAs) involving pond aquaculture in the state of Queensland at the time of the review in November 2021. This number refers to granted EAs—for both operational and non-operational sites—and excludes EAs which are not effective, suspended, surrendered, expired and/or cancelled. There are 33 aquaculture EAs located within the Reef catchment and 15 located in the SEQ region. It should also be noted that some EAs include several activities and facilities and that these may not always be located together.

Based on the approval information, Table 10 shows the number of aquaculture facilities within each Region, how many facilities are authorised to release to water and the number of facilities that are required to develop and carry out environmental monitoring programs as part of their approval conditions. Across the 53 aquaculture facilities, there were 73 aquaculture activities spread across 7 NRM regions and 17 sub-catchments. Most aquaculture activities in the Reef catchment involving release to water are either prawn (ERA 1.1) or barramundi (ERA 1.2) farms. Approximately 75% of all aquaculture facilities (40 facilities) are required to carry out receiving environment monitoring. Intake water quality monitoring is a requirement more frequently found in EAs of facilities located in the SEQ region with 6 facilities listed having this requirement as opposed to only 3 in the Reef catchment.

Table 10. Number of aquaculture facilities (including farms and seafood processing facilities) and activities that are authorised to release to water in their approvals for different regions within the Reef and SEQ catchments.

Regions	Catchment	Number of Facilities	Number of Activities	Number of EAs	Release to Water	Environmental Monitoring	Intake Quality Monitoring
Reef	Wet Tropics	21	27	17	21	15	
	Burnett-Mary	5	6	5	5	4	1
	Mackay Whitsundays	5	6	5	5	4	1
	Burdekin	4	10	4	4	4	
	Cape York	1	1	1	1	1	1
	Fitzroy	1	1	1	1	1	
Subtotal		***37***	***51***	***33***	***37***	***29***	***3***
SEQ	SE Qld	16	22	15	16	11	6
Total		***53***	***73***	***48***	***53***	***40***	***9***

Of the 53 Queensland facilities, 22 facilities (relating to 18 EAs and including one seafood processing facility) in the Reef catchment and 14 facilities in SEQ (relating to 13 EAs and including 5 seafood processing facilities) are currently operating. While some farms operate a hatchery alongside the farm, as far as it could be determined, there are only 3 operating prawn or barramundi hatcheries under a standalone EA. Where the hatchery is on the same site as a farm, the water from the hatchery is often incorporated into the whole farm release.

All operating farms have been reviewed in detail regarding wastewater release conditions. Standalone seafood processing facilities were excluded from this review as their EA conditions do not authorise continuous release of wastewater as compared to aquaculture farms. A summary of the most common release limits and limit values is shown below in Table 11.

Table 11. Aquaculture release concentration limits from Environmental Authorities for operating farms in Queensland. Seafood processing facilities are excluded.

Catchment	Farm Type	ERA Code	TN (mg/L)		TP (mg/L)		TSS (mg/L)		Chlorophyll-a (µg/L)		BOD_5 (mg/L)	DO (mg/L)	Free residual Chlorine (mg/L)
			Average[†]	Maximum[‡]	Average[†]	Maximum[‡]	Average[†]	Maximum[‡]	Average[†]	Maximum[‡]	Maximum	Minimum	Maximum
Reef	Barramundi	1.2(b)	1.5	3.5	0.1	0.25	15	25				80%⌂	
	Barramundi	1.2(b)	2.5	3	0.2	0.3	25	100	25	100		4	0.1
	Barramundi	1.2(b)	1	3		0.4	40	75				4	
	Barramundi	1.2(b)	0.6	0.8	0.05	0.08	15	25	30	50		4	
	Prawn	1.1(a)	2.5	5	0.25	0.6	25	100	50	100	20	4	
	Prawn	1.1(b)	2.5	5			90	120	120	200	20	2	
	Prawn	1.1(b)	2.5	4	0.4	60⊐	70	200	20	200		3.5	
	Prawn	1.1(b)	2	5	0.2	0.6	25	100	50	100	20	4	
	Prawn	1.1(b)	1	4	0.2	0.8	25	100				4	
	Prawn	1.1(b)	1	4	0.2	0.8	25	100	25	100		4	
	Prawn	1.1(c)	2.5	4	0.4	0.6	70	200	20	200		3.5	
	Prawn	1.1(c)	1.2	3.8	0.11	0.28	30	100				5	
	Prawn	1.1(b)	2.5	3.5	0.35	0.45	65	100	15	200		4	
	Prawn	1.1(b)	2.5	3.5	0.35	0.45	65	100	15	100		4	
	Prawn	1.1(b)	0.8	3	0.1	0.3	20	100	20	100		4	
	Prawn	1.1(b)		3		0.4	40	75				4	
	Prawn	1.1(b)	0.8	2	0.16	0.4	25	100	15	100		4	
	Hatchery	1.1(a)	2.5	5	0.4	0.6	70	200	50	200		3.5	
	Hatchery	1.1(a)	2.5	5	0.25	0.6	50	100	80	180	20	4	
	Hatchery	1.1(b)	2	5	0.2	0.6	50	100					
	Hatchery	1.2(b)	2.5	5	0.25	0.6	25	100			20	4	
SEQ	Prawn	1.1(b)		3 (+0.65)»		0.3 (+0.16)»	30	50				4*	0.01
	Prawn	1.1(b)		3 (+0.65)»		0.3 (+0.16)»	30	50				4	0.01
	Prawn	1.1(b)		3 (+0.37)»		0.3 (+0.07)»	30	50				4*	0.01
	Prawn	1.1(b)		3		0.3	30	50				4*	0.01
	Prawn	1.1(a)											
	Hatchery	1.1(a)		1		0.5	20	100				4	0.04
	Cobia	1.2(b)		3 (+0.2)»		0.3 (+0.04)»	30	50				4*	0.01
	Research	1.1(a)	0.8	1	0.4	0.5	40	50	20	40		4	

[†] includes 80th percentiles; [‡] includes 95th percentiles; ⌂ 80% in EA unclear whether it refers to saturation or percentage of mg/L at intake; » Ambient TN/TP as calculated from the long-term median results obtained from department ambient water quality monitoring near the facility mentioned in the respective EA; * or 90% of the background value whichever the greater; ⊐ this is believed to be a typographical error made during creation of the EA

The most common release limit types for aquaculture EAs are for TN, TP and TSS concentrations. Generally, these limits can be grouped into averages (or 80th percentiles) and maximums (or 95th percentiles). The majority of facilities had minimum DO concentration limits. Fourteen facilities currently operating in the Reef catchment also had release limits for chlorophyll-a concentration. Five facilities operating in the Reef catchment had BOD_5 maximum limits. No commercial facilities operating in the SEQ catchment had monitoring requirements or limits for BOD_5 or chlorophyll-a. Other than one recently issued EA, monitoring of dissolved inorganic nutrients such as ammonia, nitrate and filterable reactive phosphorus, in the release is not required. Free residual chlorine was required to be monitored at 6 operating SEQ facilities but only for one facility in the Reef catchment.

Each of the abovementioned nutrient and water quality release indicators can have direct relevance to the potential health of the local receiving environment. Elevated nutrient levels may result in increased algal biomass, resulting in blooms or other water quality issues. Chlorophyll-a is an important indicator for the abundance of algae. Hypoxic events may result from low DO levels in released water, high BOD_5 concentrations or a mixture of the two, as well as from abundant algae. Chlorine is generally used as a cleaning agent and to cull harmful bacteria or undesirable fish. Elevated chlorine levels in the release may have pernicious impacts on water quality in the receiving environment.

For facilities in the Reef catchment, the average TN release limits ranged from 0.6 to 2.5 mg/L, while maximum TN limits ranged from 0.8 to 5 mg/L. The average TP release limits ranged from 0.05 to 0.4 mg/L, with maximum TP limits ranging from 0.08 to 0.8 mg/L—except for one EA which had a maximum TP limit of 60 mg/L which is believed to be a typographical error in the document. These limits are lower than most other point source activities in Queensland, including leading practice STPs in the Reef catchment (that is, median limits of 5 mg/L TN and 2 mg/L TP, for example (Ramsey et al. 2020) Therefore, STPs typically have higher concentrations post-treatment (typically tertiary treatment) compared with aquaculture facilities post-treatment (typically settlement ponds). This is potentially relevant as it provides an indication of the levels of nutrient removal that is currently adopted by other industries for treatment of wastewater, highlighting the different baselines between STPs and aquaculture. This comparison underscores why treatment practices are unlikely to be transferrable across industries.

Although there is a similar structure to EA conditions for Reef and SEQ catchment facilities, there are some notable differences, including greater variability in nutrient limits and include average nutrient and chlorophyll-a concentration limits in the Reef catchment. In SEQ, maximum nutrient limits account for ambient concentrations, generally have more stringent maximum TSS limits and typically include a limit for chlorine.

These differences are not necessarily driven by the environmental risk in each catchment. Instead, these are more likely due to different regulatory approaches used historically in each region. At over 15 years old, the average age of the EAs in the SEQ catchment is more than double those in the Reef catchment. Prawn aquaculture was initially established in the Logan area but was affected by the outbreak of the White Spot Syndrome Virus (WSSV) in 2016. Some EA conditions were updated as farms were redeveloped or modified.

Most EAs of farms located in the Logan River area include values derived from long-term ambient monitoring data of the waters located near the intake area of each farm (Table 12). These EAs stipulate that the farmer may elect to use the ambient values to increase the release limits as defined in the EA and/or calculate the daily net load of the contaminants. Alternatively, the farmer may choose to regularly monitor inlet water quality, provided they monitor all quality characteristics stated in the EA and advise the administering authority of this election.

Table 12. Ambient water quality stated in Environmental Authorities of farms in the Logan River area for use in determining release nutrient load and concentration limits. Values are medians in mg/L.

Catchment	Farm Type	Total Nitrogen	Total Phosphorus	Total Suspended Solids
SEQ	Prawn	0.2	0.04	null
	Prawn	0.65	0.16	15
	Prawn	0.37	0.07	10
	Prawn	0.65	0.16	15
	Hatchery	0.37	0.07	10
	Cobia	0.2	0.04	5

Table 13 further illustrates the differences in regulatory approaches to managing aquaculture wastewater. In the Reef catchment, there is a clear focus on limiting the volume of wastewater release. Nutrient loads are therefore limited by concentration limits and release volumes. By contrast, the farms in the SEQ catchment are regulated by limiting nutrient loads without imposing any restrictions on release volume. The conditions are identical for all farms operating in the Logan River area, and overall, are more consistent with the Prawn Farm Policy than those in the Reef catchment.

Table 13. Aquaculture Volume and Load limits from Environmental Authorities for operating facilities in Queensland.

Catchment	Farm Type	ERA Code	Release Volume (ML)		Total Nitrogen Load (kg)		Total Phosphorus Load (kg)		Total Suspended Solids Load (kg)	
			Daily	Annual	Daily	Annual	Daily	Annual	Daily	Annual
Reef	Barramundi	1.2(b)	3.6							
	Barramundi	1.2(b)	24.37							
	Barramundi	1.2(b)	188	26120						
	Barramundi	1.2(b)				2800		525		
	Prawn	1.1(a)	6							
	Prawn	1.1(b)	19	7000						
	Prawn†	1.1(b)	34							
	Prawn	1.1(b)	35							
	Prawn	1.1(b)	45							
	Prawn	1.1(b)	53	13961						
	Prawn	1.1(b)	65	11000	64		12		955	
	Prawn	1.1(b)	89	26828						
	Prawn	1.1(b)	98							
	Prawn	1.1(b)	120							
	Prawn	1.1(b)	195							
	Prawn	1.1(c)	135	38325						
	Prawn	1.1(c)	236			33872		2968		
	Hatchery	1.1(a)	0.2							
	Hatchery	1.1(a)	6.2							
	Hatchery	1.1(b)	0.01							
	Hatchery	1.2(b)	0.35							
SEQ	Prawn	1.1(a)			15	3150				
	Prawn	1.1(b)			9.9	2100	2.2	462		
	Prawn	1.1(b)			10	2100	1	210	120	25200
	Prawn	1.1(b)			11.75	2468	2.35	493.5	282	59220
	Prawn	1.1(b)			12	2520	1	210	120	25200
	Hatchery	1.1(a)								
	Cobia	1.2(b)			7	1470	1.4	294	168	35280
	Research	1.1(a)								
	Research	1.2(a)								

† – estimated based on the EA condition: 'The quantity of contaminants released during any day from W1 must average no more than 5% over the crop plus 1 harvest'

In general, some EA conditions could be modified to provide more clarity around the requirements for the site and improve the enforceability of the conditions. Some EAs do not currently provide a definition or sufficient information in relation to limit types, to allow assessment and reporting. Many items are necessary for accurate assessment, for example, calculations of median, mean or percentile limits require the time period over which calculations are to be performed to be defined, along with the minimum number of samples required or explicit monitoring frequency. Some EAs have limits that are highly complex or may not be practical. For example, limits based on a "Y% of receiving waters value or a static value" or a "background value + X%", involve the need for data manipulation and are more complicated to apply appropriately. With these limits, there is a risk that monitoring and assessing compliance with the EA limits would not be possible if the EA does not explicitly require for monitoring and reporting on the "receiving waters" or "background" levels. All of these types of issues should be clarified and addressed in aquaculture EAs.

There is also large variability between EAs in terms of how release volume is restricted, including allowing release under all circumstances with a single volume restriction (not considering rainfall), restricting releases to periods of outgoing tide only, having no volume restrictions during rainfall and having release volume linked to production area (see Table 14). In instances where the authorised release volumes are linked to rainfall captured in ponds, rainfall is usually not listed as a monitoring indicator for the site. In addition, the calculation of the release volume considering rainfall is not clearly stated, which may result in different calculation methods being used.

Table 14. Aquaculture release volume and monitoring frequency requirements within Environmental Authorities for operating facilities in Queensland.

Catchment	Farm Type	Release Type	TN/TP Monitoring Frequency
Reef	Barramundi	All weather	Monthly (during discharge)
	Barramundi	Tidal	Monthly (during discharge)
	Barramundi	All weather, no volume restriction during rainfall	Monthly (during discharge)
	Barramundi	Tidal	Twice monthly (during discharge)
	Prawn	All weather, no volume restriction during rainfall	Monthly
	Prawn	All weather	Monthly
	Prawn	All weather, no volume restriction during rainfall	Monthly
	Prawn	All weather	Monthly (during discharge)
	Prawn	Tidal	Monthly (during discharge)
	Prawn	Tidal	Monthly (during discharge)
	Prawn	Tidal	Monthly (during discharge)
	Prawn	Tidal	Monthly (during discharge)
	Prawn	All weather	Monthly (during discharge)
	Prawn	All weather	Monthly (during discharge)
	Prawn	Tidal	Monthly (during discharge)
	Prawn	All weather, no volume restriction during rainfall	Quarterly (during growing season)
	Prawn	Tidal, no volume restriction during rainfall	Weekly
SEQ	Prawn	All weather	Not specified
	Prawn	Tidal	Twice monthly (during discharge)
	Prawn	Tidal	Twice monthly (during discharge)
	Prawn	Tidal	Twice monthly (during discharge)
	Prawn	All weather	Twice monthly (during discharge)
	Cobia	All weather	Twice monthly (during discharge)
	Research	Tidal	Monthly (during discharge)
	Research	Tidal	Monthly (during discharge)

A Productivity Commission Research Paper (2004) stated that unnecessarily prescriptive or inflexible EA conditions may cause some aquaculture farmers to be over-regulated with its associated costs, while others may be under-regulated leading to environmental outcomes below standard. The Research Paper found aquaculture regulation to be more effective if the EA conditions account for: variability of management and production practices; the intake and receiving environment water quality; and release wastewater quality outcomes. Refocusing aquaculture regulation on outcomes, where necessary, would also increase the longevity of the EA conditions and could promote the development and adoption of innovative treatment solutions. More recently, a Commonwealth report found that the current environmental standards in Queensland (related to Reef regulation) were not supported by the body of research that is available (House Standing Committee on Agriculture and Water Resources, 2022).

In general, the EAs reviewed in the Reef catchment are intended for farms that do not involve recirculation of water. Alternative EA conditions would be required to allow for recirculation, and these could be developed with a more outcome focused approach, supplemented with conditions for nutrient management, such as using monthly or annual loads or volumes rather than stringent maximum limits.

The most common sampling frequency presented in Table 14 for nutrients is “monthly (during discharge)”, otherwise known as throughout the growing period. Although this is consistent with the current Queensland Prawn Farm Policy, this frequency does not appear adequate given the observed variability of data and dynamic production environments, particularly for prawn farms. Monitoring and licensing need to reflect the cycle of production and growing season. Prawn farms are often operated over a season of less than 8 months and annual loads are not relevant to such operation. A higher frequency of water sampling, such as fortnightly (weekly for larger facilities), is recommended for peak growing periods for both prawn and barramundi farms. Conversely, frequent sampling may not be required in the first 4–6 weeks of operation when animals are small and feeding rates are low, as there is little pond discharge and low nutrient concentrations.

When comparing the current EA release limits for prawn farms to the minimum standards specified in the Queensland Prawn Farm Policy, some maximum TN and TSS EA limits are above the minimum standard for these limits. In terms of the minimum standards for maximum release loads (kg/ha/day) for TN, TP and TSS over the growing season, it is not possible to draw any conclusions now as there is no readily available information on the farm production area. Further information on production area and release monitoring data is needed to allow an assessment against the other Prawn Farm Policy standards.

5.3 EA Release Monitoring Data

Release data has been provided to DES for 10 separate aquaculture facilities in the Reef catchment, including 7 prawn farms and 3 barramundi farms. No monitoring data were available for facilities outside of the Reef catchment. The data covered varying periods between 2013 to 2021 but the amount of monitoring release data was often limited to only a few years. Data was not available for all, or even the majority, of the facilities for any one year. Data was particularly limited for barramundi farms. Due to these limitations, the available data was combined (averaged), rather than looking at individual years, to permit a comparison of all facilities. In addition, approval-related information was used to estimate release volumes and nutrient loads for 2 additional barramundi farms and one prawn farm using the method adopted by Ramsay et al. (2021), which used mean or 80th percentile concentration limits and either annual release volume limits or daily release volume limits multiplied by 365 days. This is likely to be an overestimate, particularly for the prawn farms that may only operate for as few as 8 months in a year.

It should be acknowledged that this analysis and summary data are based on the data provided with no ability to check the validity of the data. Additionally, there is a further level of uncertainty to the conclusions drawn from this analysis given the limited data that are currently available.

Based on the information provided, the annual release volumes and TN loads are presented in Figure 14 and Figure 15, respectively. Facilities that had loads estimated from EAs accounted for only 6% of the total calculated TN load. The figures show that 2 farms produce half of the wastewater volume and more than 60% of the TN load for the farms in the Reef catchment which provided data. Four farms produce nearly 80% of the TN load for Reef catchment farms which provided data.

The combined annual volume of wastewater released from prawn farms in the Reef catchment which provided data was 75 GL per year, a similar magnitude to the volume of wastewater released from coastal STPs in the Reef catchment (66 GL for 2018), which are the major nutrient point source emitter. These high release volumes are consistent with single throughput, non-recirculated systems.

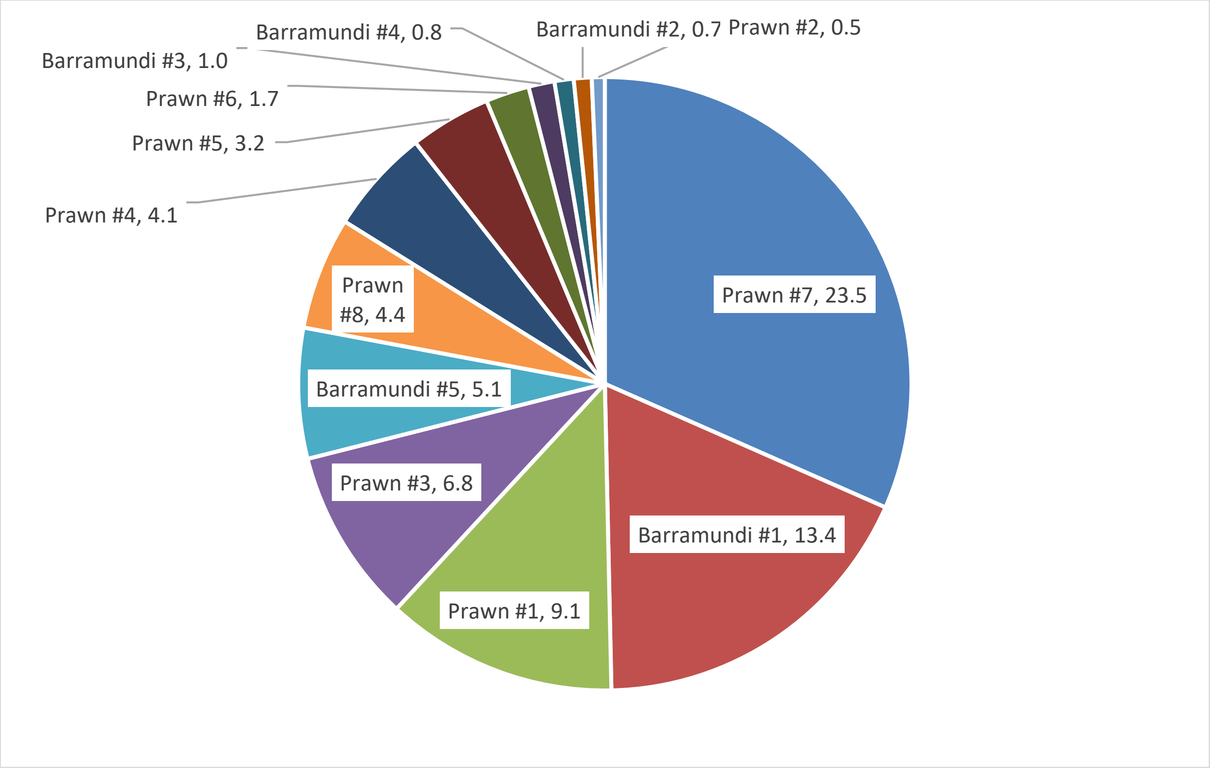


Figure 14. The proportion of annual release volume for individual aquaculture farms in the Reef catchment based on all available full financial year data. Numbers for each prawn and barramundi farm have been allocated as shown. Labels show the volume (GL) released from each farm.

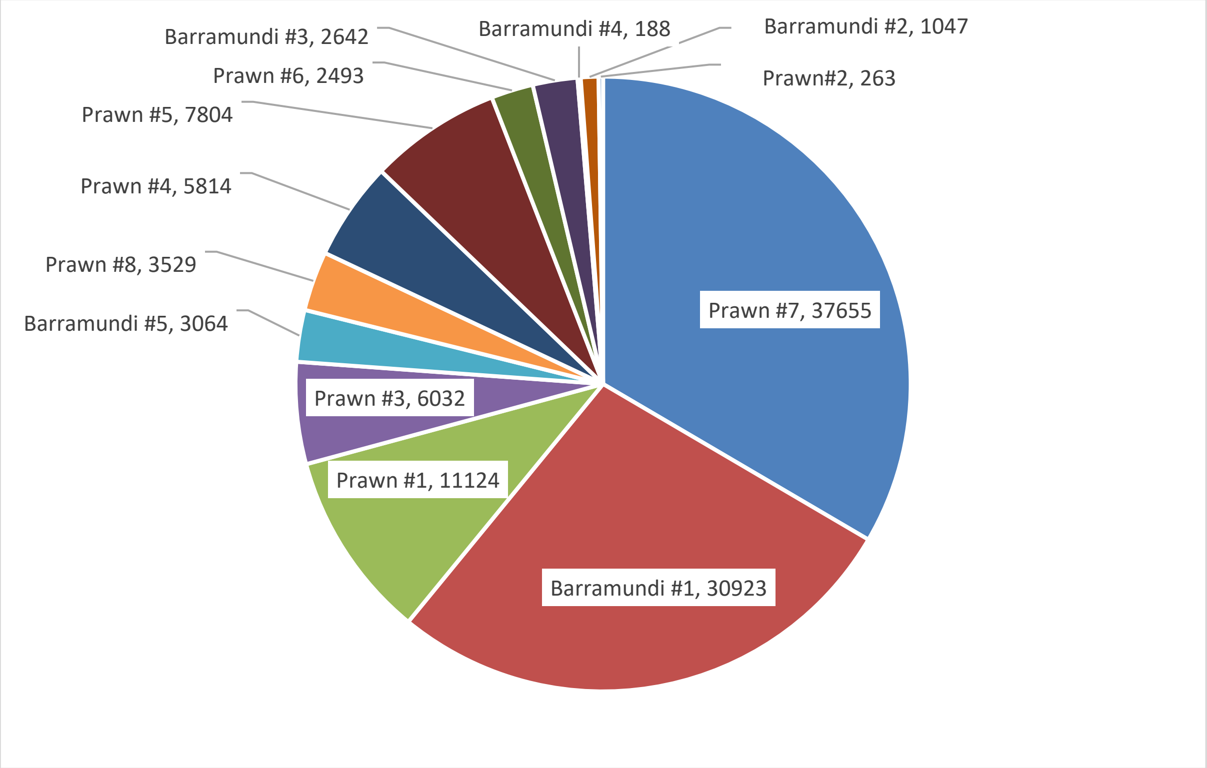


Figure 15. The proportion of annual TN load release from individual aquaculture farms in the Reef catchment based on all available full financial year data. Numbers for each prawn and barramundi farm have been allocated as shown. Labels show TN load (kg) released from each farm.

Average annual nutrient concentrations and loads are presented in Table 15. The annual TN load was approximately 113 tonnes per year, which is approximately one-third of the nitrogen loads reported by Ramsay et al. (2021) for STPs in the Reef catchment in 2018. The annual TP load was estimated at 11.4 tonnes per year, which is approximately one-seventh of the phosphorus loads reported by Ramsay et al. (2021) for STPs in 2018. From a Reef perspective, these results suggest that the management of nitrogen in aquaculture discharges is more important than the management of phosphorus, keeping in mind that aquaculture is a small contributor of anthropogenic nutrients in the Reef catchment.

Table 15. Estimated nutrient concentrations and annual loads for aquaculture farms in the Reef catchment based on all available full financial year release data.

Farm	Average TN Conc (mg/L)	Average TP Conc (mg/L)	Annual TN Load (kg/year)	Annual TP Load (kg/year)
Prawn #7	1.60	0.182	37655	4273
Barramundi #1	2.31	0.236	30923	3165
Prawn #1	1.22	0.159	11124	1445
Prawn #5	2.45	0.179	7804	570
Prawn #3	0.89	0.063	6032	429
Prawn #4	1.42	0.013	5814	53
Prawn #8*	0.8	0.16	3529	706
Barramundi #5*	0.6	0.05	3064	255
Barramundi #3	2.60	0.111	2642	113
Prawn #6	1.46	0.103	2493	176
Barramundi #2	1.49	0.122	1047	85
Prawn #2	0.52	0.169	263	86
Barramundi #4*	0.25	0.02	188	15
Total			**112576**	**11372**

* data for these facilities have been estimated based on approval and application information.

A comparison of overall nutrient concentrations for each species is shown in Figure 16 and Figure 17. In general, the average nitrogen concentration released from barramundi farms (2.25 mg/L) appear to be slightly higher than prawn farms (1.51 mg/L). However, there was not sufficient data to undertake a statistical analysis, so any reported differences should only be considered as preliminary findings. Similarly, the average phosphorus concentration from barramundi farms (0.17 mg/L) is higher than prawn farms (0.12 mg/L).

The average nutrient concentrations released from individual aquaculture farms are presented in Figure 18 and Figure 19. There is considerable variation in nutrient concentrations within farm, and between farms, for both nitrogen and phosphorus for both species. This is likely to be due to differences in management practices and age of crop. Some farms can achieve an average TN concentration of near to, or less than, 1 mg/L and an average TP concentration at, or below, 0.1 mg/L, although it is not clear how this relates to the intensity of production. The available monitoring data for nutrients in wastewater releases from both prawn and barramundi farms in the Reef catchment indicates that, like the release limits, the concentrations are relatively low compared to other point sources, generally considerably less than 4 mg/L TN and considerably less than 0.4 mg/L TP.

The average TN concentrations and volumes for wastewater release water from Prawn #1 and Barramundi #1 over the course of a financial year are presented as examples in Figure 20 and Figure 21, respectively. This shows the monthly average for all the years of data (either 5 or 6 years). These plots show the potential difference in nutrient concentrations and volumes of wastewater release as a result of different modes of operation of prawn and barramundi farms.

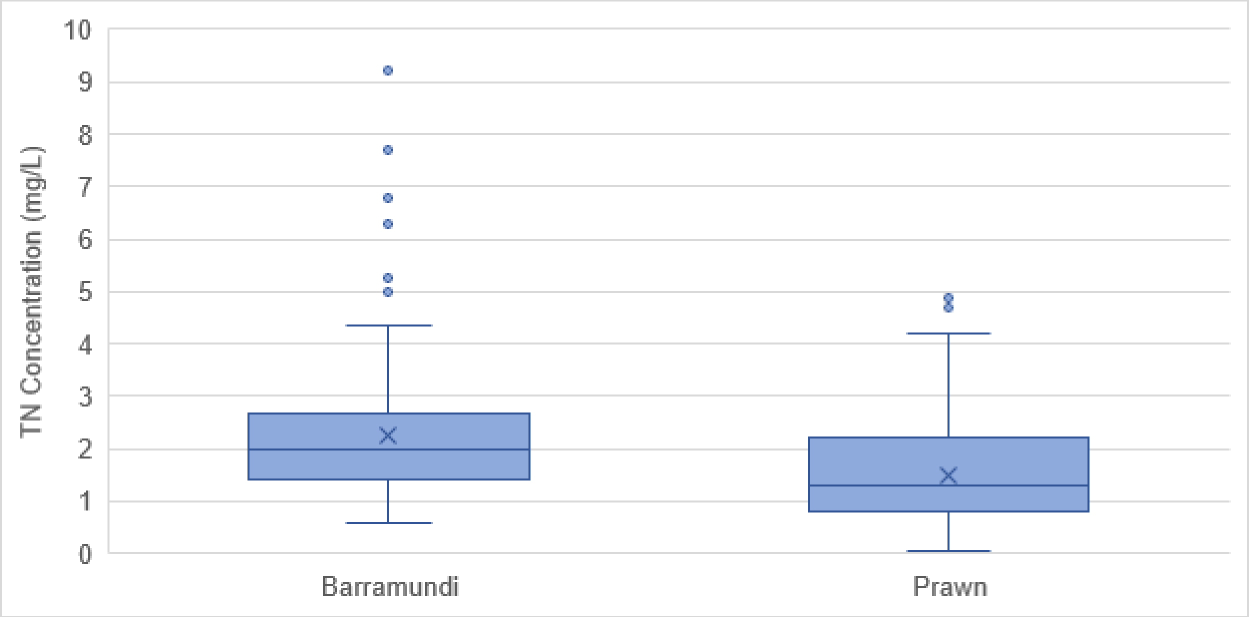


Figure 16. Comparison of TN concentrations (mg/L) in wastewater release water from barramundi and prawn farms in the Reef catchment using all available data (3 barramundi farms and 7 prawn farms) – "x" marks the average values; lower and upper bounds of the box indicate 20th and 80th percentiles; and the middle line of the box indicates median value.

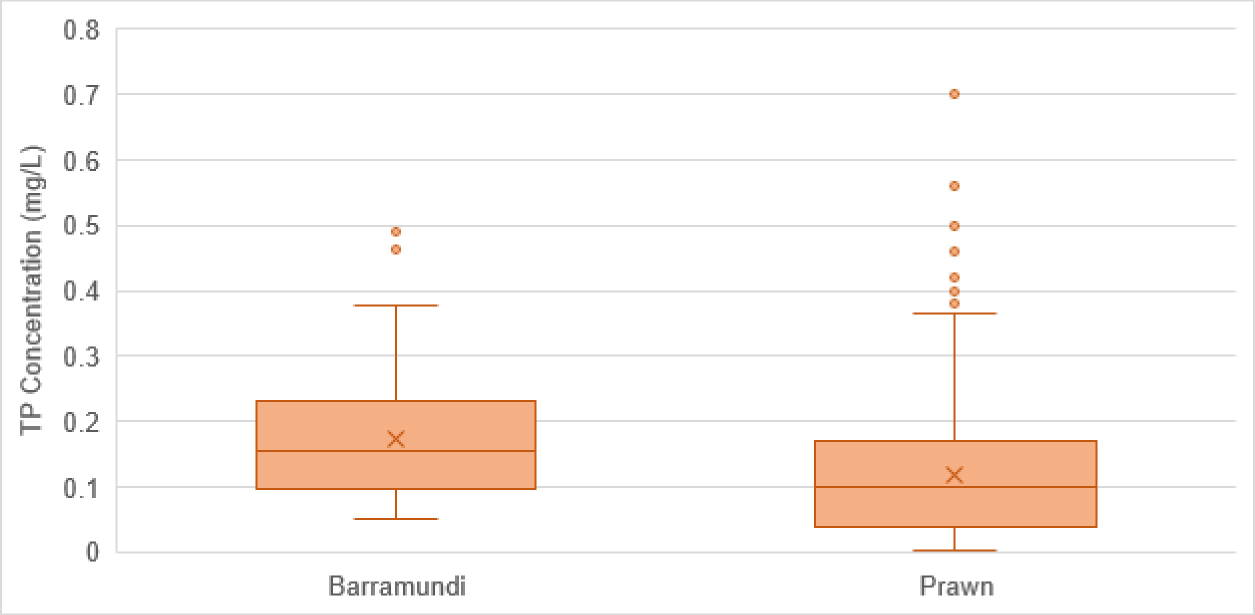


Figure 17. Comparison of TP concentrations (mg/L) in wastewater release water from barramundi and prawn farms in the Reef catchment using all available data (3 barramundi farms and 7 prawn farms) – "x" marks the average values; lower and upper bounds of the box indicate 20th and 80th percentiles; and the middle line of the box indicates median value.

The average TN concentrations and volumes for wastewater release water from Prawn #1 and Barramundi #1 over the course of a financial year are presented as examples in Figure 20 and Figure 21, respectively. This shows the monthly average for all the years of data (either 5 or 6 years). These plots show the potential difference in nutrient concentrations and volumes of wastewater release as a result of different modes of operation of prawn and barramundi farms.

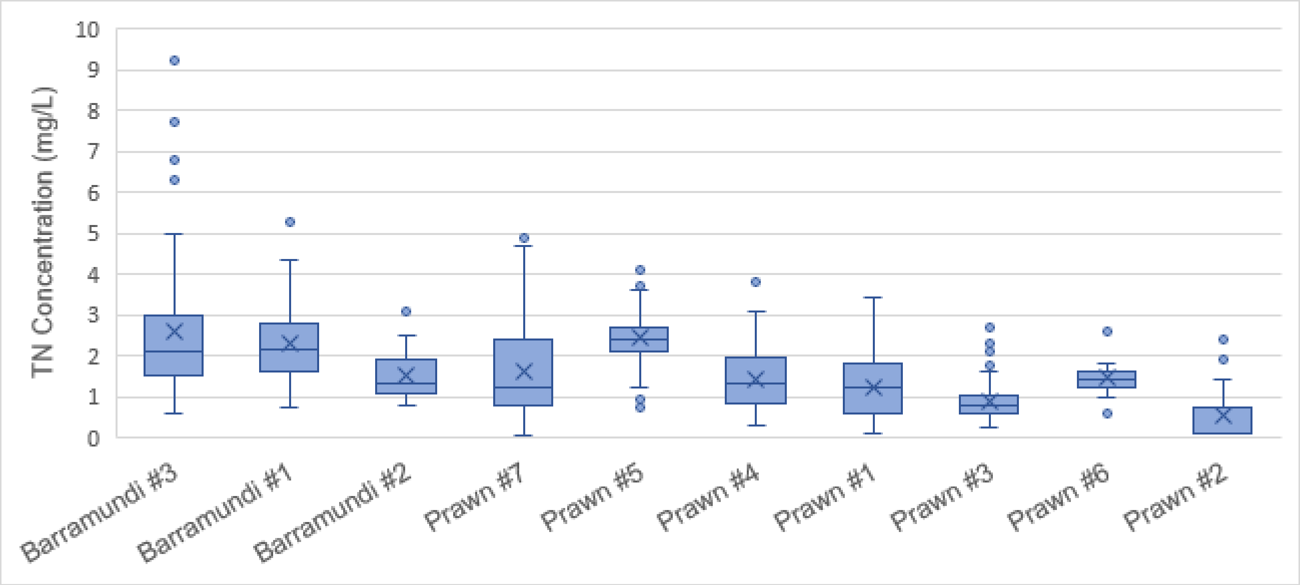


Figure 18. Comparison of TN concentrations (mg/L) in wastewater release water for individual aquaculture farms in the Reef catchment using all available data – "x" marks the average value; lower and upper bounds of the box indicate 20th and 80th percentiles; and the middle line of the box indicates median value.

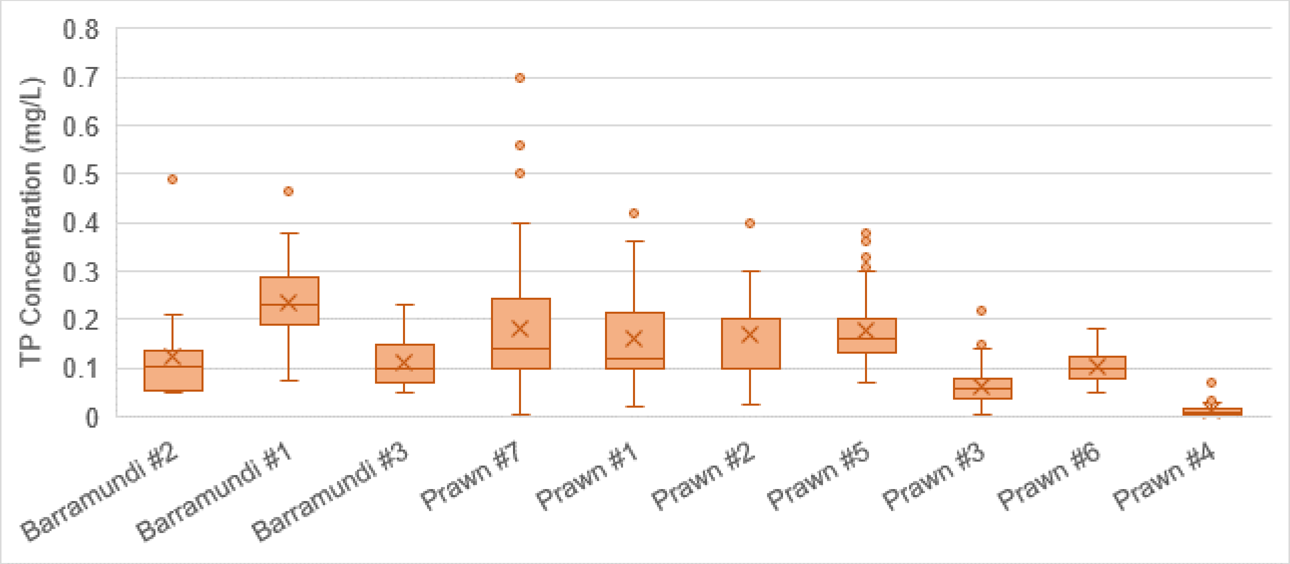


Figure 19. Comparison of TP concentrations (mg/L) in wastewater release water for individual aquaculture farms in the Reef catchment using all available data – "x" marks the average value; lower and upper bounds of the box indicate 20th and 80th percentiles; and the middle line of the box indicates median value.

Figure 20 shows farm release data from Prawn #1 which generally operates from September to May. It shows that peak release volumes and TN concentrations were from December to May. There is significant variation in the average TN concentrations over this time. The TN and discharge volumes appear to be correlated and this supports the theory that release volumes are increased to manage increasing nutrient loads and prevent poor water quality that could negatively impact prawns. The limited available data from other prawn farm operations suggest that peak TN concentrations and volumes may differ depending on when the growing period commences and ends, for example, to meet local domestic demand at Christmas and therefore peak concentrations and volumes are prior to January.

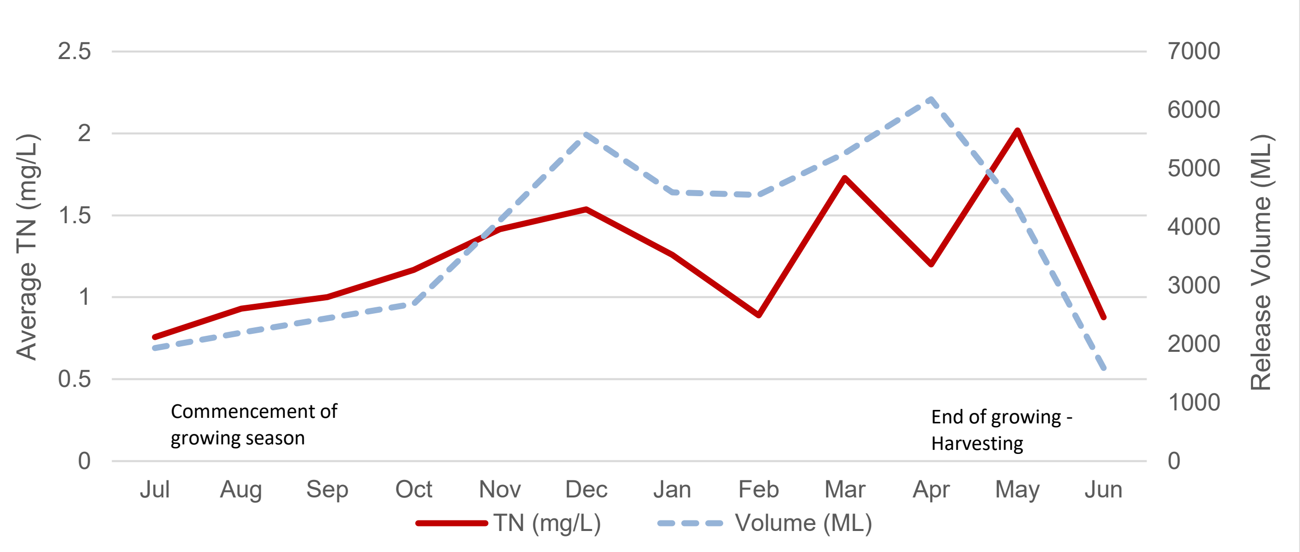


Figure 20. Monthly TN concentrations (red line, mg/L) and volumes (blue dotted line, ML) for a prawn farm discharge averaged over 5 years of operation.

Figure 21 shows the farm release volume data for Barramundi #1 is relatively constant over the year, with slightly higher release volumes in the spring/summer months. This is consistent with the fact that Barramundi farms typically operate over a 2-year cycle. In comparison, the average TN concentrations were higher in the summer months (January/February) with winter concentrations about half of these levels.

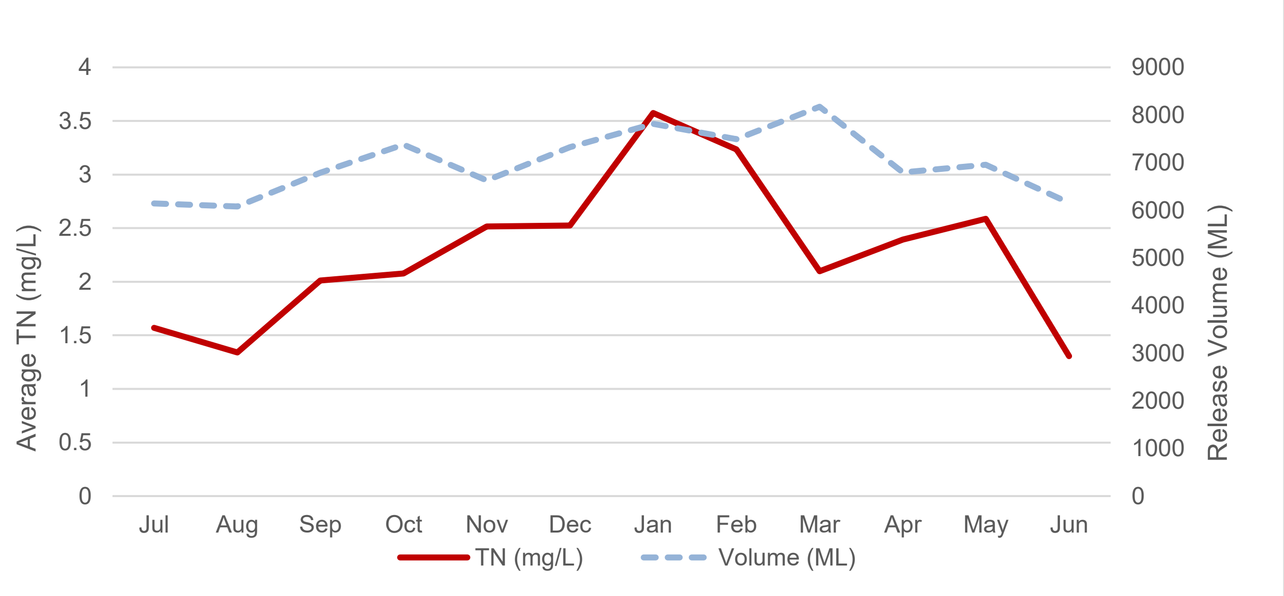


Figure 21. Monthly TN concentrations (red line, mg/L) and volumes (blue dotted line, ML) for a barramundi farm release averaged over 6 years of operation.

The monthly TSS and chlorophyll-a concentrations for release water from Prawn #1 and Barramundi #1 are presented in Figure 22 and Figure 23, respectively. Chlorophyll-a is potentially a useful measure given that algal blooms are promoted in ponds to manage dissolved nutrients, prevent growth of problematic benthic algae, and shade animals. It is also an important ecosystem parameter. From the information available, chlorophyll-a concentrations often correlate with TSS concentrations, particularly in summer months. This is not surprising as algae are often the dominant form of TSS. From the raw results (not shown in Figure 22 and Figure 23), the highest chlorophyll-a concentration recorded for Prawn #1 was 150 µg/L, and for Barramundi #1 was 182 µg/L. Chlorophyll-a concentrations are known to vary rapidly, so it is difficult to generalise from these results. Additionally, the reliability of these results will depend on the method used for chlorophyll-a analysis and the sampling and processing protocols. It requires a higher level of technical input from sampling to analysis compared to TN, TP and TSS. No information was available at the time of this review on the sampling and analysis method used by aquaculture farmers.

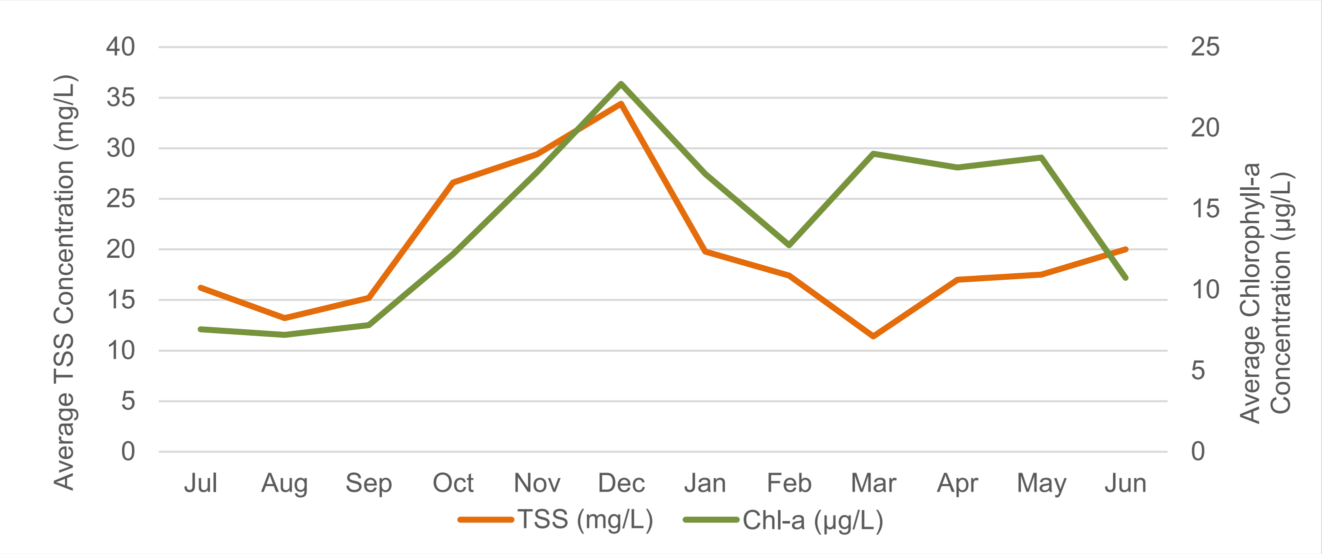


Figure 22. Monthly TSS (orange line, mg/L) and chlorophyll-a (green line, µg/L) concentrations for Prawn #1 release averaged over 5 years of operation.

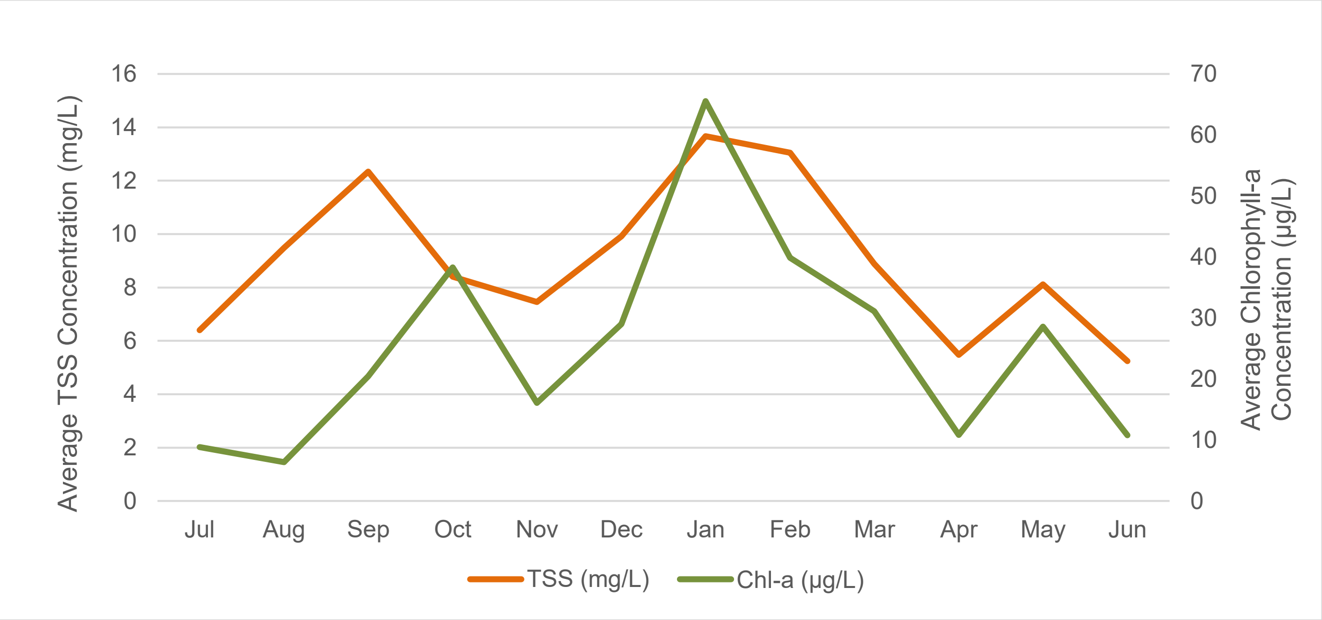


Figure 23. Monthly TSS (orange line, mg/L) and chlorophyll-a (green line, µg/L) concentrations for Barramundi #1 release averaged over 6 years of operation.

A small number of facilities are also required to monitor the BOD_5 in the wastewater release. A review of the available data showed values in the order of 2–24 mg/L BOD_5. High BOD is a potential risk to receiving waters, depending on the mixing and dilution, due to the drawdown of oxygen. In addition, ammonia inputs can also result in oxygen drawdown when consumed by aerobic bacteria or algae (due to respiration). A small number of facilities are required to monitor ammonia; concentrations as high as 3 mg/L, even 6 mg/L, have been observed, but this is typically during harvesting. Given the high algal concentrations sometimes present (based on chlorophyll-a concentrations), there is a potential risk of DO drawdown in the receiving environment during night-time when respiration occurs. This depends on the wastewater concentrations and the level of mixing with receiving waters. This potential environmental impact is not assessed as part of most aquaculture EAs or REMPs but should be included for higher risk situations, for example where large releases occur to poorly flushed receiving waters.

5.4 Receiving Environment Monitoring Program (REMP) Assessment

Most aquaculture farms are required to develop and implement a Receiving Environment Monitoring Program (REMP). The details of the REMP are either specified in a separate report (Design Report) or as part of monitoring specified in the EA. The REMP Design Report is generally developed at the commencement of the activity as set out in the conditions when the EA is first approved. The broad requirements for the design report are usually detailed in the EA conditions and would typically cover a requirement to monitor water quality of the receiving waters and undertake an assessment on an annual basis. Monitoring locations could include downstream (impact), upstream and control (or reference) monitoring locations. Often it is a requirement of the EA to prepare a report analysing the data on an annual basis (Annual Report). The Annual Report does not generally need to be submitted to the department but can be requested.

In general, there are numerous considerations and challenges in designing and undertaking a suitable and robust REMP. These include site selection and access (for example, private/remote access, dealing with tide, wet weather, crocodile hazards, etc), timing/frequency of sampling, field and laboratory methods, quality assurance/control, minimising cost, data analysis, and differentiating impacts of release from other catchment sources and rain events. Recommended approaches to manage some of these challenges are discussed in more detail in the department’s Receiving Environment Monitoring Program Guideline 2015. Many of the aquaculture farm REMPs were developed and implemented prior to the publication of this guideline. Furthermore, the REMP guideline is generic and although provides useful guidance, it is not specifically designed for dealing with aquaculture releases. It is recommended that an aquaculture focused REMP guideline be developed and used to improve the suitability and consistency of aquaculture farm REMPs. Relevant EA requirements should be updated as necessary.

As part of this project, REMP annual reports were obtained for 7 farms, including 4 prawn farms and 3 barramundi farms, covering different years between 2017 and 2021. In general, limited or no electronic monitoring data was available except for a couple of farms that currently report to WaTERS. A desktop review was undertaken of each of these reports. The programs were found to vary significantly between farms in terms of the scale, design, and analysis. The following overall observations were made:

- The monitoring scope ranged from reporting on just intake and release water through to monitoring up to 12 receiving monitoring points. In general, 1–3 downstream monitoring sites were monitored. In one case, the closest downstream monitoring location was approximately 3 km downstream of the release.
- Monitoring sites were generally categorised as either impact sites (potentially impacted by farm release) or control sites (believed not impacted by farm release). Some reports referred to monitoring locations as upstream (and even downstream) in estuaries and were incorrectly considered as control sites. Generally, control sites were used to compare to impact sites.
- The number of sample events undertaken per year ranged significantly from 3 through to 12 times in the year. Some reports only looked at one or 2 years of data. One report looked at a full 7 years of data. Data was often pooled together over all the years of data that was available to do comparisons. In some cases, analysis was undertaken by grouping impact sites rather than looking at individual impact sites.
- In general, there was limited use of water quality objectives for assessment of REMP results, except for the most recent REMPs. The methodology used to compare impact and control sites was not based on the recommended Queensland Water Quality Guideline approach (which recommends deriving 80th percentiles of reference site and comparing to the 50th percentile of test sites). Other statistical methods were generally adopted to do assessment.
- Most assessments did not consider different water types (as recommended in the Queensland Water Quality Guidelines for assessment physical and chemical water quality). Different water types typically have very different water quality, example mid estuary versus enclosed coastal.
- Biological indicators, such as macroinvertebrates and mangroves, were assessed in some reports, as this was often a requirement of the EA. It was not clear if and how the selected biological indicators might be influenced by farm releases, particularly nutrients. In most cases, there were no guidelines available for these indicators. A similar comment could be made for sediment sampling.

- Most reports did not include the long-term data set or trend assessment, most likely given the requirement to report annually. None of the reports included monitoring prior to operation. Therefore, it was not possible to assess if water quality had changed over time or after commencing operation.
- None of the REMPs considered the timing and magnitude of the farm releases over the REMP period when assessing data. This would be particularly important when assessing releases that are not consistent or continuous, such as occurs with most prawn farms.

Given the large variability in methods and approaches, it was not possible to draw any strong conclusions about the conditions of receiving environments that receive aquaculture farm releases. However, from reviewing the available REMP reports, the visual and tabulated information showed that the water quality within the local receiving estuary downstream of the farm release was different for indicators such as TN, chlorophyll-a and DO concentrations. The degree and extent of influence seemed to depend on the size of the estuary and distance from the release point. Assessing the spatial extent of this influence against water quality objectives would require access to the raw monitoring data and a more detailed/in-depth and consistent analysis considering relevant water quality guideline assessment approaches. However, the assessment would be limited by the available data, the monitoring locations and sampling frequency, which may need to be reviewed.

6 Nutrient Management and Treatment

6.1 Feeds and feeding management for nutrient reduction

6.1.1 Feeds

Feed is a major contributor to the cost of production in semi-intensive and intensive aquaculture systems. While farm costs and feed commodity prices have been increasing, the farm gate prices for prawns and barramundi have not kept pace with these increases, meaning that margins have diminished, driving a push for intensification and other production efficiencies (Emerenciano et al., 2022). Beyond the financial cost, uneaten feed and waste products produced by the animals are also the main source of nutrients in the pond system. Therefore, there are dual incentives for improvements in feed and feeding within the aquaculture industry: financial savings and environmental benefits.

Carnivorous fish, like barramundi, have evolved to utilise a diet that is relatively high in protein and low in carbohydrates (Buddington et al., 1997), utilising excess dietary protein as an energy source. The waste products of protein catabolism (ammonia and urea) are excreted by the fish resulting in 40–60% of the nitrogen ingested from food being excreted within 24 hours (Ip and Chew, 2010). Undigested protein in faeces and uneaten food contribute to the organic nitrogen load in the pond. Similarly, penaeid prawns also have a high dietary protein requirement. Penaeids have a limited capacity to store lipids and carbohydrates (Dall and Smith, 1986), so protein metabolism is very important to these animals. The ammonia from protein catabolism is excreted through the gills, with the rate increasing at about 2 hours after feeding, returning to the basal rate around 5–6 hours after feeding (Rosas et al., 2001). Prawns also excrete nitrogen in faeces (Burford and Williams, 2001). Dietary protein requirements for barramundi are reported to be 40–65% crude protein (Glencross et al., 2013), while the optimal protein level for *P. monodon* is 35–40% when grown in seawater with an algal bloom (Burford et al., 2004a).

Phosphorus is an essential element for life. While it is a relatively abundant element, it can be limiting in aquatic environments due to the low solubility of phosphates and transformation into insoluble forms (Smil, 2000). Fish and crustaceans have a requirement for phosphorus which must be met through their diet (Shiau, 1998; Hardy and Gatlin III, 2002). The dietary phosphorus requirement for barramundi is around 0.65% (Boonyaratpalin and Williams, 1990; Boonyaratpalin, 1991), while for penaeids it may depend on the species, with a reported dietary requirement for *P. monodon* being 0.74% (Peñaflorida, 1999).

A reduction in nutrient waste may be achieved through species-specific optimisation of dietary requirements and using feed materials that offer improved digestibility and increased bioavailability (Hardy and Gatlin III, 2002). The food conversion ratio (FCR) is a simple measure of the efficiency with which a feed is converted into animal biomass over the culture period. In a pond situation, it is the amount of feed input relative to the amount of harvested biomass. Theoretically, improving the FCR will reduce the nutrient input required to produce each tonne of fish or prawns. Research into both the nutritional requirements of many cultured species and the array of materials used for feed production has provided the basis for improved feeds and reduced FCRs over time (Hardy and Gatlin III, 2002). However, the gains that can be made in reducing nutrient waste through nutrition will ultimately be limited by the physiology of the animals. There have been significant improvements in the utilisation of phosphorus in fish through an understanding of metabolic requirements and the availability of phosphorus in the feed used to meet these levels, but nitrogen is more problematic (Hardy and Gatlin III, 2002). This is because there is a limit to the reduction in protein that can be achieved before fish or prawn growth is affected.

6.1.2 Feeding management

The feeding behaviour of terrestrial farm animals is relatively easy to monitor but farming in an aquatic environment makes it more difficult to monitor food consumption and adjust feeding rate.

Some fish species will feed on floating pellets, while others prefer to feed below the surface. Hierarchical behaviour is common, where some animals will dominate feeding, making it more difficult to monitor and control the effectiveness of feeding than in a terrestrial environment. Multiple daily feedings may overcome some of this issue (Davis and Hardy, 2022), but monitoring of the feeding responses is important in ensuring that all the fish can meet their growth potential. Camera systems have been used to monitor feeding in offshore salmon cages

(Aquaculture North America). These systems allow less dominant fish to consume pellets sinking through the water column, but are not currently suited to shallow, turbid pond environments. Therefore, although barramundi can be reluctant to feed on the surface if the water is too clear (Barlow et al., 1996), floating feeds are preferred in pond culture as the surface feeding response can be monitored by the feeder, so overfeeding can be reduced.

Prawns require a sinking pellet and rely on chemical cues to detect food rather than visual stimuli. While fish like barramundi will swallow pellets whole, prawns are messy eaters, consuming food more slowly, grinding particles from the pellet with their mouthparts and then scraping them into the mouth (Smith and Tabrett, 2013; Peixoto et al., 2020). This process leads to an amount of feed wastage through particle loss and nutrient leaching. Monitoring feed intake in prawns is more difficult and has relied upon manual methods like feed trays (into which a small amount of feed is placed, and feed consumption can be monitored), and the knowledge and experience of the feeder to adjust feeding rates for subsequent feeds. Despite these difficulties, feeding efficiency has improved in prawn farming resulting in reduced feed wastage.

Another important factor in reducing feed wastage from commercial pelleted feed is to present a pellet to the animal that is:

- durable;
- Has integrity without excessive fines;
- Water stable to reduce leaching of nutrients; and
- Has the physical characteristics required for the target animal.

Feed management is another important factor that aims to maximise the utilisation of the feed and its' conversion into saleable animal product. Managing feeding is therefore an important part of both cost-effective use of feed and reducing nutrient input to the ponds.

Automatic feeding systems and decision support tools are emerging developments that may be useful in reducing FCR's, and thereby reducing nutrient waste in ponds. However, these are generally still developmental. Passive acoustic feeding systems are available for fish, but while some have been trialled in Australian barramundi ponds, they have not yet been adopted by the industry. Similar technology has been used in the development of these acoustic feeders for prawns, based on the audible noise that prawns make when eating (Smith and Tabrett, 2013). This technology has shown improved growth rates and yield of another prawn species (*P. vannamei*) commonly cultured in commercial production (Bador et al., 2013; Reis et al., 2020), and can potentially reduce feed wastage and improve FCR. Some farms are trialling the use of these systems in Queensland, with anecdotal results showing a significant reduction in FCR to around 1.2 from a range of 1.5–2.5 (see Table 2).

6.2 Aquaculture Pond Water Treatment

There are a range of different approaches used to treat pond water prior to release into the natural environment. These range from well-established methods used in Australia and internationally, to methods still being evaluated. However, it is clear that there is:

- Not much consistency in the treatment methods used globally;
- Limited scientifically robust information on the effectiveness of these methods at a farm scale; and
- Limited information on the cost-effectiveness of these methods.

6.2.1 Settlement ponds

As indicated in Section 3.5.1 above, at the time of the survey 86% of the respondent farms were using settlement as the main form of treatment for pond discharge water. Primarily, settlement ponds are designed to detain discharged water, reduce the velocity and minimise turbulence to encourage the sedimentation of particulate material from the water column (Summerfelt, 1999). Studies have shown that settlement ponds can achieve an 88% reduction in BOD_5 (Teichert-Coddington et al., 1999; Preston et al., 2000). However, they are less efficient at removing nitrogen (10–31% TN) and phosphorus (15–55% TP) (Teichert-Coddington et al., 1999; Preston et al., 2000; Jackson et al., 2003b).

Nutrient cycling within the settlement pond also affects the efficiency of treatment. The microbial community utilise the organic matter in the sedimented material, remineralising nutrients. Burford and Lorenzen (2004) estimated that the pool of nitrogen within the sedimented material in a prawn production pond is remineralised at a rate of 6% per day. It is likely that this rate would be similar in a settlement pond since the sediment sources are the same. The remineralised nitrogen, in the form of ammonia, may be utilised by microalgae or aquatic plants, or as substrate for nitrification, and ultimately transformed to N_2 gas via denitrification and anammox, or directly volatilised. The potential for N_2 production through denitrification and anammox was studied in sediments from prawn and barramundi settlement ponds in Queensland (Castine et al., 2012). The potential rates measured were like those of a sub-tropical constructed wetland, so these processes could be important for reducing nitrogen in water discharged from farms. However, hydrogen sulphide, which forms in thick organic-rich sediment layers, inhibits processes such as nitrification, with flow-on effects to denitrification (Bejarano Ortiz et al., 2013). Therefore, further examination of processes and technologies that enhance denitrification would be useful.

Periodic removal of the built up, organic-rich sedimented material is required to maintain the efficiency of nutrient removal in a settlement pond. Additionally, this build up reduces the effective volume of the pond, which reduces the time that the water is retained in the pond (hydraulic retention time or HRT). Preston et al. (2000) suggest that an HRT of 2–3 days should reduce TN by 15–25% and TP by up to 35%. To achieve this HRT, between 10 to 25% of the production pond area needs to be allocated to settlement ponds. However, Jackson et al. (2003b) showed that HRT alone, was not the determinate factor affecting the efficiency of nutrient removal in prawn ponds in Queensland. Despite this, there is a commonly quoted assertion around the Queensland industry, that a minimum of 30% of the production area is required. The source of this figure is unknown, but it is clear from the available research that TN reduction through settlement is only modest, typically considerably less than 50%.

There have been some attempts to analyse the cost benefit of settlement ponds in prawn production (Brennan, 2002; Engle and Valderrama, 2004). Brennan (2002) estimated the cost of nitrogen reduction (based on the 20 to 25% nitrogen removal in settlement ponds) was $45 per kilogram nitrogen for Australian farms. This included opportunity costs associated with lost production area. Accounting for inflation, the cost would be equivalent to $70 per kilogram nitrogen in 2021. However, a re-evaluation of costs, given the increased stocking densities, feed inputs and the production efficiency of prawn ponds is needed.

The design of settlement ponds for aquaculture follows the principles used for the design of sedimentation basins in other applications. Boyd and McNevin (2015) have outlined some general guidelines for the design and effective operation of these ponds for aquaculture:

- Water to be treated should enter at the surface of one end and release from the surface at the opposite end.
- The minimum area of the pond is dependent upon particle density and the maximum operational flow rate. These factors determine the HRT required for efficient settlement. Settling ponds should be built 50% larger than the minimum size to allow sediment storage whilst maintaining the HRT. A length to width ratio of > 4:1 promotes laminar flow and reduces turbulence within the pond (Browdy et al., 2001).
- Baffle structures can reduce short-circuiting of the flow directly to the outlet and promote settlement.
- No aeration should be used as this increases turbulence and inhibits settlement. If aeration of the water prior to release is required, this should be downstream of the settlement pond in the treatment process.
- Periodic removal of sedimented material is required to maintain the hydraulic residence time and to reduce the remineralisation of deposited nutrients from the decaying organic material. During production, removal of sediment should preferably be done through pumping rather than draining to reduce the impact on the biota within the system which contribute to the nutrient removal efficiency (Preston et al., 2000).
- Removed sediments need to be stored in a bunded area and treated appropriately.
- Settlement ponds should be designed with one inlet, so when a farm has numerous drainage directions the number of settlement ponds required increases (Engle and Valderrama, 2003).

6.2.2 Bioremediation

There are several mechanisms through which biota can reduce nutrient discharge from aquaculture pond facilities. This includes using the flora and fauna that are naturally occurring in the water, sediment and structures within a treatment system—which will be referred to as opportunistic bioremediation by flora and fauna. The other is applying a source of animals or plants to a treatment system—bioremediation through introduced flora and fauna.

6.2.2.1 Opportunistic use of pre-existing flora and fauna

The efficacy of settlement ponds for nitrogen and phosphorus removal can be influenced by the presence of animals and plants which opportunistically colonise these ponds. Filter feeders, for example, which colonise hard surfaces within ponds (for example, barnacles) can remove particulate nitrogen in the form of microalgae. Naturally occurring benthic algae, macroalgae (marine and brackish waters) and macrophytes or aquatic plants (freshwaters) will utilise DIN and phosphorus. Naturally occurring species of filamentous algae have been evaluated for their potential to remove nitrogen from settlement ponds (De Paula Silva et al., 2008). Under optimal conditions, modelling estimated that 4 tonnes of *Cladophora* regularly harvested is capable of removing a maximum of about 23 kg nitrogen from the system.

Microalgal phycoremediation is used for a variety of applications including agricultural, industrial and municipal wastewater treatment (Craggs et al., 2014; Phang et al., 2015), but has also been used in treatment systems for recirculating aquaculture systems (Jusoh et al., 2020). While algae are efficient at removing dissolved nutrients, ultimately the microalgal cells also need to be removed from the water to reduce the total nutrient load being released. This requires further treatment, for example through the addition of chemical or biological flocculants and settlement or filtration.

Natural fauna can also establish in settlement ponds, contributing to the reduction in total nutrient load released. Filter feeders (for example, barnacles, tubeworms and bivalves) become established if there are sufficient hard surfaces (Preston et al., 2000). These organisms can have a significant impact through feeding on microalgae, depending on the surface area available for colonisation. Adding barnacles to a settlement system for *P. vannamei* production showed only a modest (8%) reduction in TN, although this system had an HRT of just 6 hours (Kohan et al., 2020).

6.2.2.2 Introduced flora

Plants and aquatic animals have been produced together for many centuries, in both freshwater and marine systems. It provides the advantages of better nutrient utilisation, possible income from secondary crops, and pest and disease control.

Freshwater aquaculture discharge water may be used for irrigation and the sedimented material used as fertiliser (Lan, 1999; Muendo et al., 2014), although accumulated salts from feed and feeding need to be monitored to ensure that the soil structure and terrestrial plant growth are not compromised. Additionally, it may be impractical to continuously utilise the large volumes of discharge water without major storage infrastructure. There is very limited freshwater aquaculture discharging to waters in Queensland, so this option is of limited value.

Incorporating plants into freshwater fish and crustacean production systems can improve water quality and reduce nutrient concentrations (Corpron and Armstrong, 1983; Srivastava et al., 2008; Seymour et al., 2009). A project in Queensland used native lotus (*Nelumbo nucifera*) for bioremediation of freshwater barramundi pond discharge, removing an extra 15% of TN over the unplanted controls (Seymour et al., 2009).

Several species of marine macroalgae have been studied for their potential to phycoremediate aquaculture discharge. This includes the green algae, *Caulerpa sp.* (Paul and De Nys, 2008; Bambaranda et al., 2019) and *Ulva sp.* (Shpigel et al., 1993; Neori et al., 2003; Ben-Ari et al., 2014; Kang et al., 2021) as well as the red algae *Gracilaria sp.* (Jones et al., 2001; Samocha et al., 2015; Yeh et al., 2017). While some have potential to provide a commercial return, their suitability and performance needs further assessment. Paul and De Nys (2008) concluded that while *Caulerpa sp.* had promise for use in Queensland pond aquaculture systems, the competition from filamentous algae (*Cladophora* and *Chaetomorpha sp.*) meant that *Caulerpa* could not be used in settlement ponds. Another study showed that nitrogen uptake rates of *Ulva rigida* were relatively high (equivalent to 5.5 kg N ha^{-1} d^{-1}) under controlled conditions, but results in treatment ponds were less impressive (240g N ha^{-1} d^{-1}) (Bartoli et al., 2005). Identifying algal species that occur naturally in the region may be a first step in determining their suitability for nutrient removal, however, this does not guarantee success in real-world pond culture systems.

Another study identified *Ulva ohnoi* as an ideal target species for phycoremediation of aquaculture pond discharge in Queensland, due to its fast growth and geographical distribution (Lawton et al., 2013). This species tolerated temperatures from 18 to 34.5°C but the optimal temperature was 28°C (Mata et al., 2016).

Beyond studies and development at a pilot scale, phycoremediation has so far not been widely adopted in the Queensland pond aquaculture industry, or more generally by the aquaculture industry worldwide (Mata et al., 2010). This is despite many years of research and suggests that phycoremediation does not provide a practical solution for aquaculture farmers. One contributing factor may be the low economic value of the algae. Cultivation of the red alga *Asparagopsis sp.* has been investigated around the world for potential pharmaceutical applications (Mata et al., 2017). In Australia, *Asparagopsis taxiformis* has been shown to reduce methane production from cattle by 80% (Roque et al., 2021). However, while Australian organisations are looking to develop and commercialise the production of *A. taxiformis*, it may not be suited for use in tropical pond aquaculture systems. Despite samples being collected from Tropical North Queensland, the best growth for this species was at the lowest temperature examined (20.2°C) (Mata et al., 2017).

6.2.2.3 Introduced fauna

Filter feeding organisms like oysters and mussels (Shpigel and Blaylock, 1991; Jones et al., 2002; Palmer and Rutherford, 2005; Sanz-Lazaro and Sanchez-Jerez, 2017), as well as planktivorous or detritivorous species of fish and crustaceans (Sandifer and Hopkins, 1996; Palmer et al., 2005), have been investigated for their potential to assist in nitrogen removal from aquaculture discharge. Bivalves remove microalgae and other particulates, including inorganic matter, from the water column. Inorganic matter is agglomerated into pseudofaeces which settle relatively easily. If the silt load is too high, filtration is supressed, and growth and survival of the bivalves may be compromised. Nitrogen removal efficiency is not necessarily high, as bivalves retain only about 25% of the nitrogen consumed (Troell et al., 2003), the remainder will be either excreted as inorganic nitrogen or organic nitrogen in urine and faeces. Sydney rock oysters (*Saccostrea commercialis*) decreased the TN concentration of prawn farm discharge water by about 33% but increased the proportion of DIN in the TN from 9 to 46% (Jones et al., 2001). Building on these results, a pilot scale system initially showed improved nutrient removal efficiency by the oysters, but the suspended solids load in the discharge caused fouling and mortality (Jones et al., 2002).

Northern Queensland has an emerging oyster production industry based on the blacklip rock oyster (*Saccostrea sp.*). Currently, they are grown commercially in waters around Bowen, taking about 20 to 30 months to mature. However, to date there has been no study using this species in a bioremediation system.

A study in Queensland used low density stocking of banana prawns (*Penaeus merguiensis*) in prawn farm settlement ponds to utilise waste nutrients from the production of *P. monodon* (Palmer et al., 2005). Penaeid prawns, in particular banana prawns, consume microalgal detritus, bacterial flocs and meiofauna as part of their natural diet (Baguley et al., 2019; Vance and Rothlisberg, 2020), appearing to make them a good candidate for converting some of the organic nutrients in settlement ponds into biomass. However, the system was not effective as the biomass of banana prawns harvested from the settlement ponds was relatively low and rather than reducing TN output from these ponds, it was slightly increased.

Although animals in a treatment system may provide some benefit in reducing nutrient loads, currently in Queensland, bivalves produced cannot be sold for human consumption due to contamination and food safety concerns. It is unclear whether this would extend to other animals produced as part of a treatment system. This would limit the cost offsetting opportunities available to the farmer. Additionally, a treatment system that is stocked with animals as a secondary crop would need to have containment structures (e.g. ponds) built above the 1-in-100 year flood level, the same as any production pond. Further, if cropping cycles were longer for the secondary crop than the main production species, supplementary feeding may be required to support these animals through periods where treatment systems are not able to supply sufficient nutrient to sustain the animals. A new EA may be required depending on the species chosen as the secondary crop.

6.2.3 Wetlands

Wetlands and constructed wetlands have the potential to significantly reduce nutrient loads from aquaculture. They are already used for the treatment of municipal, industrial and agricultural wastewater and catchment runoff (Lin et al., 2010). In both fresh and saltwater aquaculture, they may be used as a final polishing step before water is recirculated back to production units or prior to release into the surrounding environment.

Constructed wetlands are artificial wetland systems supporting vegetation where waterflow can be controlled, so that natural plant and microbial processes can reduce nutrient loads. There are different designs categorised by the path of waterflow (for example, vertical, horizontal, free water surface, subsurface flow) and the vegetation (Vymazal, 2019). The design, construction and choice of vegetation can influence the efficiency of nutrient removal. Wetlands that are flooded, planted basins which allow a shallow layer of water to flow across the surface of the soil are known as free water surface (FWS) wetlands. Horizontal subsurface flow (HSF) wetlands are designed to keep the water level below the surface while also supporting vegetation. Vertical subsurface flow (VSF) wetlands are designed to operate with a pulse flow of input water which floods the surface of the wetland, then percolates through the substrate to be collected from the bottom of the wetland basin. Vegetation is very important to vertical flow wetlands. Details and benefits of each type of wetland are outlined below (Table 16).

Constructed wetlands are generally considered as being highly efficient in removing organics, suspended solids and bacterial pollutants, but less efficient at removing nitrogen and phosphorus (Verhoeven and Meuleman, 1999). In aquaculture, constructed wetlands (usually FWS) have been investigated for treating fish and crustacean discharge water. While most of the focus has been on freshwater or low salinity discharge, there are some studies using brackish or seawater. Generally, constructed wetlands take time (60–90 days) to establish before effective nutrient removal is apparent (Sansanayuth et al., 1996; Lin et al., 2002). Once established, the reported removal efficiency for TN has been shown to be highly variable, that is, 27–64% (Schwartz and Boyd, 1995; Sansanayuth et al., 1996; Lin et al., 2010; Liu et al., 2014). Like settlement ponds, the accumulation and remineralisation of nutrients from organic matter (including leaf litter and other dead material from within the wetland itself) can lead to increases in the dissolved inorganic nutrient concentration of the outflow. Wetlands provide habitat for birds and other animals, which can also input nutrients to the wetland (Gautier et al., 2001).

In constructed wetland systems, the vegetation helps oxygenate the root zone to facilitate bacterial and chemical nutrient transformations, but it is the microbial community that is more important as a direct sink for nutrients. Erler et al. (2010) found that in a constructed wetland only 7.4% of the nitrogen input was retained in the plant material. Salt tolerant plants (halophytes) and marine algae can provide similar benefits to freshwater plants in treatment systems for saltwater aquaculture, but the range of plants that can be used is greatly reduced. Seagrass for example, while native to a marine environment, does not survive the higher turbidity and fouling from solids in aquaculture pond discharge, and as such would not be suitable in an aquaculture treatment system. In coastal farms, salt tolerant plants like mangroves and mangrove fern (*Acrostichum aureum*) have been used to vegetate constructed wetlands. However, selecting the plants used can impact on the effectiveness of nutrient reduction through the wetland. A comparison of different mangrove species in an aquaculture system showed that the river mangrove (*Aegiceras corniculatum*) was most tolerant to the conditions while the orange mangrove (*Bruguiera gymnorhiza*) had the fastest growth rates (Peng et al., 2013). However, its ability to remove nutrients from the water column was markedly lower than for the river mangrove.

In the Northern Territory, there is the example of a barramundi farm employing a substantial wetland system. The wastewater treatment system for the farm is described in documents available from the Northern Territory public register. This facility is discussed in more detail below.

The Northern Territory barramundi farm example is a saltwater barramundi farm producing over 3,000 tonnes of fish per year. The farm consists of 57 production ponds with a total area of 45 ha and wastewater treatment ponds composed by settlement and wetland areas totalling 63 ha, or 140% of the production area. Average annual precipitation is approximately 1,400 mm and production ponds keep a one metre freeboard under normal operating conditions. The wetland system requires periodic maintenance to remove excess vegetation growth and the production ponds can be dried and desludged by diverting water to remaining areas of the system.

The water used on the farm is gravity-fed from production ponds to wetland treatment ponds then recirculated back to header and production ponds. Discharges are usually limited to peak wet season to prevent overflow and dry season to control salinity. The wastewater residence time is approximately 12 days. Water quality must be monitored at least once when discharging and at least weekly if discharge is longer than a week. Water quality triggers are based on the 80th percentile of reference data comprising 2 years' worth of monitoring data on the local river. The farm must report non-compliance where samples exceed the trigger values for 3 consecutive samples or where a sample is over 3 times the trigger value. Trigger values for TN and TP are 1.00 mg/L and 0.13 mg/L, respectively. In 2019, the Northern Territory Environment Protection Authority provided an EA exemption to the farm, deeming the risk of environmental harm to be very low (Northern Territory EPA, 2020).

Table 16. Basic categorisation of constructed wetlands (Vymazal, 2019). Wetlands may be further categorised based on the choice of vegetation used.

Flow Category	Construction and Operation	Removal Efficiency and Processes			Role of Vegetation
		Solids/Organics	Nitrogen	Phosphorus	(e.g. Mangroves, reeds, macroalgae, water plants)
Free Water Surface (FWS)	Soil based. Flooded planted basin. Water flows across the soil surface	High. - settlement and detention	Moderate - Nitrification / denitrification. - NH_3 volatilisation.	Moderate Slow - settlement and soil adsorption.	Contributes to nutrient removal but usually retains < 10% N input load. Needs to be harvested regularly. Algal growth promotes NH_3 volatilisation ($pH > 8$).
Horizontal Subsurface Flow (HSF)	Materials to allow high hydraulic conductance. Water flows beneath the substrate surface	Pre-treatment required to reduce load and maintain flow. - Very effective filter, but clogs easily if no pre-treatment	Moderate - Nitrification / denitrification. - may be restricted through low oxygenation. - NH_3 volatilisation ineffective.	Low due to poorer sorptive capacity of construction materials.	May contribute if harvested regularly - but usually retains < 10% N input load.
Vertical Subsurface Flow (VSF)	Pulse flow (empties before next pulse of inlet water). Water floods surface and percolates down through substrate. Materials to allow percolation. Complex to design, operate and maintain.	Very effective. - Filtration	Moderate - NH_3 volatilisation. - Promotes nitrification but denitrification limited by fewer anoxic areas.	Moderate - depending on construction materials.	Very important to: - reduce clogging. - provide bed stability. - provide aerobic zones for bacteria.

While wetlands can be effective at a pilot scale, there is little information regarding the effectiveness of farm scale treatment wetlands. Scaling up wetlands to provide sufficient retention time for the large volumes of discharge water from pond aquaculture is challenging. Ultimately, the area required is a function of the hydraulic retention time needed to remove the nutrient load and the maximum flow rate of water to be treated. Schwartz and Boyd (1995) estimated that a 1 ha (15 ML) freshwater catfish pond which was drained over 7 days through a wetland with a 4-day hydraulic retention time, would require 2.7 ha of wetland. Draining the same pond in one day would increase the area required to 18.75 ha.

Wetlands and constructed wetlands are considered land-intensive, low input systems, but they do require maintenance and monitoring. Common issues identified in a survey of agricultural and municipal wetland treatment systems in New Zealand include sparsely vegetated areas due to plant mortality promoting short-circuiting and reduced sedimentation; poor inlet/outlet maintenance leading to scouring and resuspension of solids and clogging; and operating outside the designed water depth (Tanner and Sukias, 2003). The cost effectiveness of constructed wetlands for municipal and agriculture applications has recently been assessed (Kavehei et al., 2021). Governments have previously funded projects aimed at reducing nutrient levels entering the Great Barrier Reef catchment from agriculture farmland. Based on this expenditure, the wetlands in this study were on average more cost effective at reducing DIN. However, the reduction of DIN achieved was highly variable. Equivalent analysis has not been undertaken for pond aquaculture.

6.2.4 Integrated systems

6.2.4.1 Production systems

Integrated aquaculture production is a concept that involves farming of terrestrial and aquatic species together. Integrated multi-trophic aquaculture (IMTA) is farming species from different trophic levels within the same system or near proximity. More simply it is combining the cultivation of species fed with a formulated feed, and species that utilise the waste nutrients from that production (Troell et al., 2003; Boyd et al., 2020). IMTA uses the waste from the fed aquaculture (for example, finfish or prawns) as a source of nutrients for the extractive organisms to exploit and recycle into a productive resource. These extractive organisms may be herbivorous/detritivorous/planktivorous fish or shellfish which can utilise the organic nutrients, and aquatic plants and macroalgae which extract the inorganic nutrients. The term integrated aquaculture will be adopted here to cover all these integrated systems.

Integrated aquaculture has been studied using, for example, open-water cage culture (Fang et al., 2016), land-based pond culture (Bunting and Shpigel, 2009) and in recirculating systems (Bambaranda et al., 2019). A study of an experimental integrated fish, bivalve and macroalgae system showed that 63% of the nitrogen input as feed was harvested in the combined yield from the 3 components, with 33% in the sediments and only 4% being discharged (Shpigel et al., 1993). However, the efficiency with which the macroalgae was able to extract nitrogen was 60% lower when the macroalgal density was increased. In a regulatory environment where farmers need to achieve specific release targets, predicting the ultimate efficiency of these systems to ensure compliance is currently unreliable. While integrated aquaculture has been the subject of a global research effort and has shown potential for bioremediation capacity, there has been limited commercial success globally (Naylor et al., 2021).

6.2.4.2 Other treatment systems

The final concept examined was the combination of physical, chemical, and biological treatment for nutrient reduction. It is commonly used in municipal wastewater treatment systems and has also been adopted in tank based recirculating aquaculture systems (Castine et al., 2013; Boxman et al., 2015; Lindholm-Lehto et al., 2021; Pulkkinen et al., 2021). There have also been some attempts at combining various elements into treatment systems for pond aquaculture. Castine et al. (2013) presented a conceptual model treatment system for a hypothetical 100 ha prawn farm in Australia. This model combined physical and biological treatment systems, but only accounted for about 43% of the nitrogen input in the nutrient budget presented.

These integrated systems rely on a combination of component units that would each have a particular role within the system. While not an exhaustive list, some of these components are further described below.

6.2.4.2.1 High-rate algal ponds

High-rate algal ponds (HRAP) (Figure 24) are an element that might be used in an integrated treatment system. The water often requires pre-treatment to remove suspended particulate material (including existing microalgae) and remineralise organic nitrogen before being introduced to the HRAP. HRAP are shallow, open raceway ponds with circulating water, which are used to transform nutrients into microalgal biomass (Young et al., 2017). The ponds are designed to maximise exposure to solar radiation to optimise microalgal productivity. Nitrogen removal in these ponds is mainly through uptake of DIN by microalgae, although there can be some pH dependent ammonia volatilisation and limited nitrification by microbes. While microalgae are efficient at converting the DIN into biomass, the nitrogen cannot be removed without harvesting the algae, which is expensive to achieve. Flocculation is a common method but requires the addition of metal salts, clays, or polymers to promote aggregation (ballast flocculation). Harvesting, whether by flocculation or dissolved air floatation can contribute 20-60% to the total cost of biomass production (Van den Hende et al., 2014b). More recently, bioflocculation using bacteria, fungi and other organisms has been investigated as an alternative (Van Den Hende et al., 2014a; Young et al., 2017; Nguyen et al., 2019). Challenges with harvesting microalgae have led to the development of similar systems using macroalgae like *Ulva*. In these systems it is important to reduce the microalgal biomass in the pond discharge prior to entering the HRAP to reduce fouling of the thalli and shading of the macroalgae. Production data for these systems may allow prediction of the area and biomass required for treating a known nutrient load over a season or year (R. De Nys, *pers. comm.*). However, the variability in algal productivity in the shorter term may require more research to ensure that release limits can be achieved reliably.

Figure 24. Macroalgae production raceways. Source: Fisheries Resource & Development Corporation

6.2.4.2.2 Physical filtration

Sand filtration was investigated as a treatment measure for prawn pond discharge when water from the pond was exchanged at 5% per day (Hopkins et al., 1995). The design required an area of about 6% of the production pond. While it did reduce the turbidity in the outflow water, the organic load removal was poorer than expected, and DIN levels were often increased through the remineralisation of the organic matter trapped by the filter (which is an advantage if used as a pre-treatment before an HRAP). The beds were also prone to clogging. To alleviate this issue, Palmer (2010) used a polychaete worm-assisted sand filter (PASF) design to remove solids and nutrients from prawn pond discharge in Queensland. The sand beds were populated with the inter-tidal polychaete (*Perinereis helleri*) to consume the organic matter and help prevent clogging. The results showed that while percolation rates were maintained for about a week, the rates slowed after this period as the rate of organic matter accumulation on the surface of the filter overcame the ability of the worms to clear the filter. TN and TP reduction was low and inconsistent so commercial application of this technology may be limited (Palmer et al., 2016).

A further study of PASF using pond discharge water from a gilthead seabream facility showed that although effective in removing particulate organic matter and suspended solids, the TN concentration in the outflow was unchanged and TP was increased (Jerónimo et al., 2020). The effective mineralisation of organic matter in the PASF was demonstrated by the increased levels of DIN and TP in the outflow. While this may be useful as part of a treatment system, the flow through these filters (in this study, 2000 L/m^2/day) and the ability of polychaetes to maintain the flowrates in a practical application need to be considered in the design.

6.2.4.2.3 Denitrification bioreactors

There has been an increasing interest in the use of denitrifying bioreactors in treating agricultural runoff containing high nitrate concentrations (Addy et al., 2016). These bioreactors promote anaerobic conditions and have a carbon source added to stimulate denitrification and release of nitrogen gases (NO, NO_2 and N_2). The carbon source commonly used is woodchips from either softwoods or hardwoods. The decay rate of softwoods is faster which may affect the longevity and nitrate reduction performance over time. As with most treatment systems, higher influent nitrogen levels (> 10 mg/L N) increase the efficiency of nitrate removal (Addy et al., 2016). Nitrate removal rate is also affected by the hydraulic retention time and the age of the bed.

In aquaculture, denitrifying bioreactors are more commonly used in recirculating aquaculture systems (RAS) where the stocking density of animals and the nutrient concentrations are higher, making the treatment more efficient and cost-effective. Their use in treating aquaculture pond discharge is being investigated. Von Ahnen et al. (2016) found 11 days was needed to establish the biota in a reactor treating trout farm discharge. The establishment phase for another study treating trout RAS discharge was 162 days, although these units were designed for a much higher influent nitrate concentration (60–80 mg/L N) (Christianson et al., 2016; Lepine et al., 2016).

Once established, Christianson et al. (2016) reported very high nitrate (70–100%) and TSS (> 90%) removal. However, as the experiment progressed, the bioreactors experienced some clogging and changes in the flow within the reactors. This suggested that these units need to be preceded by filtration to remove most of the solids. Considering that the discharge was from a RAS with no microalgae or inorganic sediment from pond erosion, this filtration would be a very important inclusion for a system treating pond discharge.

The Wet Tropics Major Integrated Project (MIP) also trialled bioreactors, though the trial industry was agriculture rather than aquaculture. This was sponsored by the Queensland Government.

6.2.5 Alternate production systems

6.2.5.1 Bioflocculant pond systems

Biofloc pond production systems are low or no discharge systems which rely on microalgae, bacteria and other microorganisms to control toxic ammonia and waste accumulation in the production pond (Emerenciano et al., 2017). At a high biomass, these organisms form flocculated material, known as bioflocs (Burford et al., 2003b). This material is available to fish and prawns as a beneficial feed source, recycling nutrients that would otherwise have been unavailable to the production animals. Burford et al. (2004b) found that 18–29% of the nitrogen retained by prawns (*P. vannamei*) in a biofloc pond was derived from the flocculated material. A similar retention rate (25%) was measured for tilapia grown in a biofloc system (Avnimelech and Kochba, 2009). The conversion of waste nitrogen into biofloc requires adding carbon sources to maintain a high carbon to nitrogen ratio (up to a ratio of20:1 initially and then 6:1 once high ammonia levels are established). Heterotrophic bacteria use these energy sources and available nitrogen for growth. Since excessive concentrations of nitrogen and phosphorus in ponds can lead to microalgal blooms and possibly dominance of harmful algal species, promoting conversion through microbial action can provide a more stable pond environment.

These systems have been most widely adopted for tilapia production, and intensive (yielding 6–10 tonnes/ha) and super-intensive (70–100 tonnes/ha) production of *P. vannamei*. This technology is not suitable for production of all species, as animals need to be omnivorous if they are going to take advantage of feeding on the floc. However, these systems can still be effective if the floc is not used as a food source since the floc is processing nutrients into forms that more readily settle. Animals must also be able to tolerate high stocking densities; DO at about 3–6 mg/L; and settling solids (floc) concentrations of 10–15 mg/L (Emerenciano et al., 2013). A recent small-scale study has used this system for growing barramundi in freshwater (Suwanpakdee et al., 2021). Although there appears to have been no difference in the growth of the fish with or without floc, the ammonia levels in the culture tanks were reduced by 15–75% indicating that the biofloc system was able to control water quality and did not harm the fish.

Maintaining water movement and DO is important to the success of biofloc systems. Water movement encourages aggregation of the particles to form the floc. The systems have a high biological activity, which in turn creates a high demand for oxygen, so aeration needs to be increased. The resulting water movement erodes earthen ponds, so ponds are usually fully lined to prevent this. Obviously, this requires a larger investment in infrastructure and increases the demand for electricity on the farm.

An Australian study examined the modified application of this technology to commercial production of *P. monodon* (Smith and West, 2009). Results of the project showed that using the modified system, production increased from 8 tonnes/ha in an open water exchange system to 12 tonnes/ha in the biofloc system. Additionally, the authors identified a 77% reduction in nitrogen discharge per tonne of prawns produced, although it is not clear how this affected final release concentrations. With further research and potentially added investment in adapting infrastructure, there may be scope for farms to adopt this system.

6.2.5.2 Closed or semi-closed systems without biofloc

Aquaculture pond discharge is characterised by large volumes and dilute nutrient concentrations compared with other point source discharges, for example, STPs. However, using approaches to concentrate the nutrient load, may make treatment systems function more efficiently. Several studies have used outdoor recirculating tank and recirculating pond systems with treatment to investigate production of either fish or crustaceans under reduced or zero exchange conditions (for example,Tilley et al., 2002; Lin et al., 2003; Neori et al., 2003; Lin et al., 2010). A project led by Queensland Department of Primary Industries investigated the feasibility of a recirculating pond production system for *P. monodon* in Far North Queensland in 2001 (Robertson et al., 2003). The recirculating system was compared with an open water exchange system on the same farm. The treatment area was a settlement channel plus a bioremediation pond with aerators to create a slow current between shade cloth baffles. These baffles also encouraged periphyton growth. Although the prawn production was relatively low for both the open water exchange ponds and the recirculated ponds, there was a marked decrease in the nitrogen discharge from the recirculation system (69 kg/ha N) in comparison to the open system (120 kg/ha N). The mean concentration of TN and TP in the recirculation ponds was almost double that of the open system, and DIN was a higher proportion of the TN in the recirculation system as well.

In another study, a pilot scale, earthen, recirculation pond for low salinity *P. vannamei* production was developed using a hybrid constructed wetland, with a wetland to production area ratio of 0.086 (Lin et al., 2010). The wetland had 28% of the area as a floating macrophyte basin flowing into a subsurface flow constructed wetland. Once water had passed through the wetland it was returned to the production pond. Nitrate and TP decreased slightly through the treatment system, but TN and ammonium concentration increased. These results were in contrast to previous work effectively using a similar constructed wetland to treat output from a low salinity recirculating tank production unit culturing the same species of prawn (Lin et al., 2003). In that study the wetland reduced the influent concentrations of suspended solids (71%), ammonia (57%), nitrate (68%) and phosphorus (5%).

While some of the farms surveyed (42%) within the Reef catchment do have systems in place to reuse water, they are currently deployed only when the quality of intake water is poor. However, the 2016 white spot virus outbreak in farms on the Logan River in SEQ has led to farmers in that area adopting technologies to reduce their reliance on intake water for pond management. These include water recirculation using drum filtration, ozonation and in-production pond sludge removal to supplement the existing settlement treatment ponds. Therefore, there may be scope to use these approaches more broadly.

Ozonation is a water treatment method for disinfection, inactivation of viruses, and microflocculation for removing suspended solids and algae. Although the equipment and electricity requirements add significant cost, ozonation is used in the recirculation system of a prawn farm on the Logan River to disinfect the water for biosecurity purposes. However, it may also play a role in transforming and removing nutrients. Developing a treatment system for a freshwater fish RAS, Sandu (2004) investigated the effects of ozonation on settled discharge. In the investigation, Sandu found that ozonation caused foaming which removed total solids by about 25% and organic nitrogen (proteins). After 30 minutes of ozonation the total Kjeldahl nitrogen had been reduced by 72–94%, even though ammonia increased by 13–45%, indicating that the organic nitrogen was being efficiently removed. Nitrite was totally oxidised to nitrate within the first 9 minutes of treatment.

In summary, the most significant improvement in nutrient management for the Queensland pond aquaculture industry in recent years has been improved efficiency of conversion of nitrogen-rich feed into animal biomass (that is, FCR). This has both facilitated increased production per hectare and reduced the per animal nutrient waste. However, overall, the increase in production across the industry means that there is more nutrient waste to manage. Wastewater from Queensland aquaculture farms is primarily treated using settlement ponds which, from the limited data available, appear to have relatively low and highly variable levels of nutrient removal efficiency. Internationally, studies have examined a range of other treatment approaches, that is, plant or animal based nutrient removal, as well as more technologically advanced systems. However, most countries do not have the same strict environmental regulations that exist in Australia, so there has been limited incentive to undertake the research and development required. Additionally, high-tech treatment approaches are expensive in terms of infrastructure and/or labour costs. To date, there is limited long-term application of any of the identified nutrient treatment options in Queensland, despite some trials and applications in Australia. Some treatment and management approaches have potential for the Queensland pond aquaculture industry, for example, recirculation systems used/proposed in the Northern Territory, but further investigation and research and development is needed before they can be applied. Release conditions, as part of EAs, may also need to be modified to allow the uptake of new treatment and management approaches.

7 Summary and Conclusions

7.1 Review of Pond Aquaculture in Queensland

7.1.1 Industry Overview

Most pond aquaculture production in Queensland which release water would be defined as intensive. The main farming type in Queensland is marine/brackish pond aquaculture for black tiger prawns (*Penaeus monodon*) and barramundi (*Lates calcarifer*). There are some freshwater barramundi farms as well. Other states in Australia more commonly farm other species and use production systems, such as cage farms, which cannot be compared to pond production. There are also several hatcheries and seafood processing facilities across the state, but these do not release significant amounts of water. The 2 peak industry bodies for prawn and barramundi aquaculture are the Australian Prawn Farmers Association (APFA) and the Australian Barramundi Farmers Association (ABFA). While production volumes of prawns in Queensland increased relatively rapidly during the past 2 years, there has been a much slower increase in the previous 10–15 years. Barramundi production in the state has also grown slowly in the past 15 years. Overall, the number of prawn and barramundi farms in production has declined during this time. Operating farms are located in South East Queensland (SEQ) and throughout the Reef catchment to Far North Queensland, excluding the Cape York natural resource management (NRM) region.

For this report, aquaculture farms are defined as a terrestrially ponded or aquatic area and its' buildings, used for the purpose of cultivating aquatic organisms such as fish, molluscs, crustaceans, and/or aquatic flora. Aquaculture farms typically augment aspects of rearing to increase production. Aquaculture facilities include aquaculture farms, as well as other relevant buildings such as hatcheries and seafood processing plants. In addition, farms have been defined as separate sites, typically defined under different development approvals. This is consistent with how production statistics are reported to the Department of Agriculture and Fisheries (DAF). Some companies operate multiple farm sites, with the remainder all being single entities from large-scale farms to smaller holdings. Typical production parameters for each farmed species are presented in this report.

Structures used in prawn and barramundi pond aquaculture may include intake reservoirs, supply channels, production ponds, release channels and treatment ponds. In general, the production process involves pumping water onto the farm where it is then gravity fed to a series of production ponds. In general, water can be drained from the production ponds and canals as needed and discharged to treatment ponds where some solid wastes settle before the water is released back to the receiving environment.

At the time of this project, there were 14 operating prawn farms situated within the Reef catchment and 5 operating farms outside the Reef catchment on the Logan River in SEQ. All the farms are situated relatively close to the coast and use saltwater from tidal creeks and rivers. There were 5 barramundi farms discharging to waters within the Reef catchment in north Queensland at the time of this study. These farms use seawater, brackish water or freshwater as intake water.

7.1.2 Pond Nutrient Budgets and Characteristics

The major source of nutrient input for intensive aquaculture pond production systems is the high-protein feed. The partitioning of these added nutrients into potential sinks varies over the growth period, and depends upon the feed characteristics, feeding practices, pond conditions and pond management practices. Typically, a significant, but highly variable, proportion of the nitrogen added to production ponds is present in discharged water as both dissolved and particulate forms (primarily in algae). Discharge volumes and associated nutrient loads increase throughout the latter part of the growing season to manage water quality in the ponds. Sedimentation within grow-out ponds can also be an important sink for both nitrogen and phosphorus, as can the incorporation of nitrogen and phosphorus into animal biomass. Other processes, such as denitrification (release of nitrogen to the atmosphere), are typically minor contributors to nutrient removal.

Particulate nitrogen and ammonia are 2 of the main forms of nitrogen released from aquaculture treatment ponds. Microalgae are typically the dominant component of particulate organic nutrients in settlement pond water. Ammonia is rapidly utilised by microalgae, but when the assimilative capacity of the microalgal population is exceeded, the ammonia concentration will rise. Both concentrations can vary substantially on a short-term basis but generally increase throughout the growing season.

Microalgal blooms that develop due to the pond nutrient inputs become unstable and therefore water is exchanged from the ponds to manage the blooms. Given the inherently dynamic and unpredictable nature of the processes occurring in the ponds, loads and concentrations of nutrients released in discharge water can vary greatly from day-to-day. A tool (presented in Appendix 3 - Aquaculture Pond Nutrient Budget Calculator) has been developed as part of this study to estimate whole of season nutrient loads discharged from production ponds prior to treatment.

7.1.3 Potential Impact of Releases

Potential impacts from aquaculture pond release mainly relate to the release of nutrients and particulate organic matter. This includes increases in algal biomass, higher nutrient concentrations, low oxygen (hypoxic) conditions and higher sedimentation rates compared with control sites. For very large release volumes, local erosion and scouring issues can also occur. A study of 2 north Queensland prawn farms in the late 1990s to early 2000s found nutrient related effects and impacts up to 2 km downstream from the release points in the tidal creeks. However, it should be noted that potential impacts will be specific to the farming practices (and intensity) at the time, as well as the size of the receiving estuaries and the related tidal mixing (hydrodynamics). Therefore, impacts need to be assessed on a case-by-case basis. Regardless, the focus of assessing potential impacts should be on the local receiving estuary (within kilometres of the release), rather than the broader receiving water, such as the bay or Reef lagoon. Beyond the local receiving environment, it would be extremely difficult to differentiate the contribution of point source nutrients from diffuse or pelagic sources.

A better understanding of potential water quality impacts from aquaculture releases will be gained through the analysis of historical receiving water quality data from operating farms. This could be used in combination with water quality models to help interpret short-term variability and determine the assimilative capacity of local receiving waters. A better understanding of potential hydrodynamic impacts to local receiving waters is also needed where large volumes are released to small receiving waters.

7.1.4 Aquaculture Industry

Fourteen farms (~75% of Reef farms) in the Reef catchment agreed to participate in a survey developed during this project. Farmers cited management of nutrient discharge to meet their licence requirements as a key challenge for the industry. Currently, most farmers use settlement ponds as their main treatment system to reduce concentrations and loads of nutrients in release water. Information is lacking on how effective these ponds are on a farm-by-farm basis, although previous research suggests that they have only limited capacity for nitrogen removal and are somewhat better at removing suspended sediments. There is a willingness from some farmers to adopt new technologies, but a lack of information on what is available and concerns about whether it is cost-effective have been identified as significant barriers. Also, the regulation process can limit the ability to trial new or innovative technologies, given that reliable performance is needed to meet compliance requirements. Based on the responses received, improved understanding and certainty around how release regulation is applied and the options available to improve nutrient levels in release water is likely to improve industry investment.

7.2 Aquaculture Regulation Policy and Standards

Environmentally Relevant Activities have been identified as activities which will or may release contaminants into the environment and the release of the contaminant will or may cause environmental harm. Aquaculture is considered a prescribed ERA 1 if it involves cultivating or holding marine, estuarine, or freshwater organisms in enclosures that are on land and have a total area of more than 100 m^2. Please note that this does not cover cases where aquaculture is for display purposes only, there is no release to waters, or if the organisms are not augmented with food supply. In the case of an ERA, an application for an Environmental Authority (EA) is required and conditions in an EA will generally state what is permitted as part of the activity and should not typically authorise environmental harm. Key regulatory policy and standards relevant to aquaculture in Queensland under the EP Act 1994 include the Model Operating Conditions (MOCs) for Aquaculture, the Licensing wastewater releases from existing marine prawn farms in Queensland Operation Policy, the Point Source Water Quality Offsets Policy and various certification standards.

7.2.1 Model Operating Conditions

The aquaculture MOCs provide a framework of conditions that may be applied to all new Environmental Authorities (EAs) for ERA 1 (aquaculture). The aquaculture MOCs do not generally provide details on specific limit values as these are site/project-specific and are derived during the assessment of an application based on the predicted environmental impacts. However, the aquaculture MOCs present a range of indicators, limit types, limit calculations and definitions that guide the regulation and management of the aquaculture industry. Although the MOCs are aimed at providing consistency across the industry, the administering authority may modify these conditions on a case-by-case basis considering information provided by applicants.

Many elements within the aquaculture MOCs are comprehensive and fit-for-purpose for aquaculture ERAs. However, some areas need further policy development considering broader cost-effective options for overall water management and treatment. These include differences between prawn and barramundi farm operation, intensity and scale (smaller and larger facilities), net concentrations as well as net loads, effects of rainfall on release volume and loads, application of ebb-tide releases and the process for determining load limits, including offsets. Some farms are voluntarily measuring and assessing intake water, but this is only required in the aquaculture MOCs when net loads are adopted.

7.2.2 Prawn Farm Policy

The Licensing wastewater releases from existing marine prawn farms in Queensland Operational Policy (Prawn Farm Policy) aims to set consistent licensing standards for wastewater release, including minimum standards, for existing marine prawn farms in Queensland, while allowing for ecologically sustainable development. The Prawn Farm Policy was first approved in May 2001. It was based on the best available information and the policy/legislation of that time. However, there have since been major changes in the regulatory environment including legislation, policy and guidelines. In particular, the “per hectare” load-based release standards are potentially in conflict with these updated approaches.

There are parts of the Prawn Farm Policy that are still very relevant to current-day prawn farming operations and these parts should be retained and applied across the industry in Queensland to ensure a consistent approach to regulation. However, there are key areas that require revision, including updating the Prawn Farm Policy to implement approaches for new and expanding prawn farms and relevant legislation, policy and guidelines. The concentration and load standards (kg/ha/day) for total nitrogen (TN), total phosphorus (TP) and total suspended solids (TSS) should be replaced with a more outcome focused approach considering the assimilative capacity of the receiving waters and to allow for more modern operational configurations for farms in the industry. Similar policy material should be developed for barramundi farms or be industry wide.

7.2.3 Water Quality Offsets

Point source nutrient and/or sediment offsets is a policy area relevant to aquaculture farms in Queensland and typically involves a mechanism whereby point source emitters undertake catchment remediation of nitrogen or sediment (for example, riparian area restoration to reduce diffuse nutrients from erosion, streambank and gully restoration, constructed or remediated wetlands), in order to compensate any residual impact resulting from releases of these contaminants from their facility into receiving waters. There is also the possibility that the offset could be arranged as a “trade” between seller and buyer. Reef Credits is a potential example of this type of arrangement in Queensland relevant to nutrient and sediment offsets. Reef Credits were designed for offsetting agricultural practices against land remediation but have the potential for application to some point source emitters. It should be noted that this is not a “cap and trade” as the price is negotiated between seller and buyer.

There is a need for nutrient/sediment offsets in the Reef catchment where new or amended approvals involving point source releases must ensure that the intent of the ‘no residual impact’ condition relating to the presence of DIN and fine sediments to the Reef waters is met. However, current point source offset examples in Queensland relate to TN and TSS, not DIN and fine sediment (Point Source Water Quality Offsets Policy 2019). Furthermore, most EAs for point source emitters do not include the monitoring of dissolved nutrients or fine sediment in releases

(Queensland Public Register). As a result, the *EP Act 1994* Guideline on Reef discharge standards for industrial activities in reference to Section 41AA of the *Environmental Protection Regulation 2019*, states that TN and TSS can be used as surrogates for DIN and fine sediment, respectively, although these indicators are potentially quite different in terms of their concentrations, loads and ecosystem effects. The Point Source Water Quality Offsets Policy 2019 is due for review in 2024, allowing the policy to be updated given developments in science, technology and market-based offset schemes.

Currently, there is no coordinated government strategy for managing nutrient offsetting and one-on-one agreements must be negotiated with the Department of Environment and Science for each facility. Nutrient offsetting schemes have been trialled for STPs, but not yet for aquaculture. Several scientific knowledge gaps remain for all point source offsets, including limited information on the available offsetting options and their efficacy and nutrient equivalency of aquaculture releases versus nutrient runoff from catchments. Filling such information gaps is critical to give the industry and other partners confidence when investing in such schemes.

7.2.4 Certification Standards

The aquaculture sector has developed codes of practice to address potential issues in some countries around regulation and environmental impacts. These include the Global Seafood Alliance's "Best Aquaculture Practices" (BAP) and the Aquaculture Stewardship Council (ASC) certification programs. Both standards have elements addressing environmental values, animal health and welfare, social responsibility, and traceability of product and feeds through the supply chain. These certification programs have been developed for the industry worldwide, with an aim of continual improvement. The ASC Shrimp Standard (Version 1.2, October 2022) is assessed against annual nitrogen and phosphorus discharge loads. Where environmental regulations are more stringent, the farms are assessed against their EA conditions, although other factors are also considered in assessing comformity. Where a parameter is not defined in the EA, the BAP values are used for assessment. Most prawn farms in Queensland were found to be using either BAP, ASC or both, while barramundi farms used the BAP certification and the Australian Sustainably Farmed Barramundi Certification Program (ASFBC).

The standards (indicator levels) and indicator types used for accreditation vary considerably between the BAP and ASC standards, but some common approaches are used that could be incorporated into EAs to provide more consistency. These could include maximum TSS levels (such as less than < 50 mg/L) and minimum dissolved oxygen levels (such as ≥ 65% saturation in release water; ≥ 70% in ponds—for the ASC Shrimp standard and ASC Marine Tropical Finfish standard respectively) which are all more stringent than many current Queensland EA limit criteria. There is no threshold for TN or TP concentrations in either scheme, instead thresholds for total ammonia nitrogen (< 5 mg/L for BAP and < 1.5 mg/L maximum for ASC) and soluble phosphorus (< 0.5 mg/L for BAP) are used. The standards also use annual nutrient loads which are calculated based on the weight of feed applied, or release concentrations of TN and TP, divided by tonnes of product. ASC sets load limits for feed derived nutrient release for *P. monodon* (32.4 kg N per tonne of prawns and 5.4 kg P per tonne of prawns). In certain conditions, monitoring of intake water quality is also required with these accreditation programs.

7.3 Review of Environmental Authorities and Monitoring Data

7.3.1 Environmental Authority Review

The Public Register listed 48 granted EAs involving pond aquaculture in the state of Queensland at the time of commencing the review in November 2021. Thirty-three EAs were located within the Reef catchment and encompassed 37 facilities. The remaining 15 EAs were in SEQ and related to 16 facilities. Of the 53 facilities identified in Queensland, 37 were found to be operating at the time of this review. Most aquaculture activities are either prawn (ERA 1.1) or barramundi (ERA 1.2) facilities.

The most common release limit types for Queensland aquaculture EAs are for TN, TP and TSS. Concentrations and limits were grouped into averages (or 80th percentiles) and maxima (or 95th percentiles). The average TN release limits range from 0.6 to 2.5 mg/L, while maximum TN limits range from 0.8 to 5 mg/L. The average TP release limits range from 0.05 to 0.4 mg/L, with maximum TP limits ranging from 0.08 to 0.8 mg/L. These limits are lower than most other point source activities, including best performing STPs in the Reef catchment. However, STPs are markedly different from aquaculture in that they typically treat sewer wastewater rather than environmental water and have much higher nutrient and other contaminant concentrations in the intake water.

Most facilities had minimum dissolved oxygen (DO) concentration limits. Fourteen facilities operating in the Reef catchment also had release limits for chlorophyll-a concentrations. Five facilities operating in the Reef catchment had 5-day biochemical oxygen demand (BOD_5) maximum limits. No commercial facilities operating in the SEQ catchment had monitoring requirements for these 2 indicators. But for 2 exceptions, monitoring of dissolved inorganic nutrients, such as ammonia, nitrate and filterable reactive phosphorus, in the release is not required. Each of the above parameters have direct relevance to the health of the local receiving environments. Both high BOD_5 concentrations and low levels of DO (in the release water) may lead to hypoxic events. Chlorophyll-a is an important indicator of the abundance of algae. High nutrient levels may increase algal biomass, resulting in algal blooms and water quality issues. Chlorine is typically used as a cleaning agent, to cull harmful bacteria or unwanted fish. Elevated chlorine levels may have deleterious effects. Hence, most SEQ facilities have EA requirements for monitoring free residual chlorine, but only one facility in the Reef catchment has similar EA stipulations.

Although there is a similar structure to EA conditions for Reef and SEQ catchment facilities, there are notable differences. There is more variability in nutrient limits, but generally more stringent TP limits for aquaculture activities in the Reef catchment. In comparison, there are higher maximum TN limits (accounting for ambient concentrations), more stringent maximum TSS limits and the use of chlorine limits for activities in the SEQ catchment. South East Queensland facilities also generally include TN, TP and TSS load limits but not limits to the release volume. In contrast, only 3 facilities in the Reef catchment have annual load limits for TN and TP, and the majority have limits applied to the release volume. There is also a difference in TN and TP sampling frequency: except for one farm which monitors weekly, monitoring is monthly during discharge from farms in the Reef catchment but generally semi-monthly during discharge for the SEQ catchment. These differences are most likely due to different regulatory approaches historically used in each region, rather than based on specific differences in environmental risk.

In general, the EAs reviewed in the Reef catchment are intended for farms that do not involve recirculation of water within the farm. Recirculation is quite commonly practiced in some countries overseas. Alternative EA conditions would be required to allow for water recirculation, and these could be developed with a more outcome-focused set of conditions for nutrient management, such as using monthly or annual loads or volumes rather than maximum release concentration limits. These would need to ensure that risks to the local receiving waters was acceptable, considering short term increases in nutrient loading and effects on DO. Environmental Authority conditions could also be improved to ensure limit types and calculations are more clearly defined in the EA and the more complex limits based on comparison with background could be simplified. Other potential issues that could be addressed include consideration of rainfall, tidal releases and different production types.

The nutrient release limits for TN and TP imposed on most prawn farms in Queensland are much more stringent than one comparable prawn farm site in New South Wales. The more stringent limits are assumed to be due to the proximity of the Queensland aquaculture activities to iconic environmental values such as the Reef and Moreton Bay. One barramundi farm in Northern Territory had lower nutrient release limits but is potentially not comparable to the Queensland landscape given it involves recirculation within the farm and extensive wetland/treatment ponds. Given there are only a few relevant examples, it is difficult to make a conclusion based on the interstate comparison.

7.3.2 Release Monitoring Data

Release monitoring data were available for 10 separate aquaculture farms in the Reef catchment covering varying periods between 2013 to 2022. This can be attributed to no specific requirement in EAs to provide data regularly and the available data are being the result of different data requests. Nonetheless, the available data were combined (averaged) over all years with a full year of operational data to allow for a comparison of all facilities. Given multiple factors such as seasonal conditions, management styles and practices, and production intensity can vary significantly between years, combining data in such a way may not be accurate. Due to the lack of data, this was still felt to be the best approach. No monitoring data was available for facilities in the SEQ catchment.

The annual release volume from aquaculture farms in the Reef catchment which provided data was estimated as 75 GL per year (STPs were estimated as 66 GL per year for 2018). The annual nutrient release loads were estimated at approximately 113 tonnes TN per year and 11.4 tonnes TP per year. This latest TN load estimate is an increase of 30% and the TP load is an increase of 43% compared to aquaculture loads reported by Ramsay et al. (2020) for 2018. Based on the analysis done in this report, 2 large farms produced half of the release volume, and more than 60% of the TN load for the aquaculture farms in the Reef catchment which provided data. Four farms produced nearly 80% of the reported TN load.

There is considerable variation in nutrient concentrations within farms, and between farms, for both TN and TP for both barramundi and prawn farms. Some farms can achieve an average TN release concentration of near to, or less than, 1 mg/L, and an average TP concentration at, or below, 0.1 mg/L. Overall, the average TN concentration released from barramundi farms was 2.25 mg/L compared to 1.51 mg/L for prawn farms. The average TP concentration from barramundi farms was 0.17 mg/L compared to 0.12 mg/L for prawn farms. Nonetheless, these average release concentrations are relatively low compared to other point source activities that release nutrients (Ramsay et al., 2020).

There are significant differences in the operation of prawn and barramundi farms, and the resulting nutrient concentrations and loads of wastewater releases, although available data are limited. Prawn farms produce a crop in 4–5 months and typically operate in summer months, with a focus on Christmas and Easter markets. Peak release volumes and highest TN concentrations occur between December to May, although this may be earlier for some farms depending on their growing season. This is when the prawn biomass is highest in the production ponds. There was significant variation in the average TN concentrations over this time. Barramundi farms typically operate on an 18–24 month crop cycle. For one barramundi farm operation, release volumes were relatively constant over the year, with slightly higher levels in the spring/summer months, while average TN concentrations were higher in the summer months (January/February) and winter concentrations were about half these levels.

Total suspended solids and chlorophyll-a concentrations were correlated, particularly in summer months, where peak concentrations were observed for both indicators, although elevated levels can occur at other times for both prawn and barramundi release water. This correlation is indicative of the fact that TSS is dominated by algae (with chlorophyll-a concentrations being the indicator). Total suspended solids, chlorophyll-a and BOD_5 appear to be important water quality indicators for aquaculture farm releases as they can be elevated during the growing cycle, at levels that could potentially cause an impact on receiving waters. One potential impact is the lowering of DO in the receiving waters. This would also depend on the wastewater concentrations and the level of mixing with receiving waters. Nonetheless, this should be evaluated during the initial assessment of the aquaculture activity prior to approval and be monitored and regularly reviewed as part of release and Receiving Environment Monitoring Program (REMP) monitoring.

7.3.3 Receiving Environment Monitoring Program (REMP) Assessment

Most aquaculture farms are required to develop and implement a REMP to monitor the water quality of local receiving waters and undertake an annual assessment of impacts. A desktop review was undertaken of REMP reports for 7 aquaculture farms (including 4 prawn farms and 3 barramundi farms). Receiving Environment Monitoring Programs were found to vary significantly between farms in terms of scale, design and analysis. In general, the programs relied on control sites to assess the water quality condition of impact sites. Some assessment approaches included pooling data from different monitoring sites or pooling data over various years, which limited the degree of spatial and temporal assessment. Also, in general, water quality objectives and current water quality guidelines approaches were not used. None of the REMPs considered the timing and magnitude of the release, which is important if the release varies over time, such as over the growth period with prawn farming. Further work is required to assess the suitability and consistency of all aquaculture REMPs and relevant EA conditions.

It was not possible to draw any strong conclusions about the conditions of the environments that receive aquaculture farm releases from the review, given the site-specific nature of most receiving environments. Visual and tabulated information in the reports showed that water quality within the local receiving estuary downstream of the aquaculture farm release was different for indicators such as TN, chlorophyll-a and DO concentrations compared to further-a-field results. The degree of difference seemed to depend on the size of the estuary, release volume, and most likely the size and intensity of the farm, although no information was provided on this. The assessment of the spatial extent of this influence against water quality objectives would require access to the raw monitoring data (that is, tabulated results from measurement) and a more detailed/in-depth and consistent analysis considering the relevant water quality guideline assessment approach.

7.4 Nutrient Management and Treatment

7.4.1 Feeds and feeding management

Food conversion ratios (FCRs) are a measure of the conversion of feed weight into animal biomass, which are used in the industry to define the efficiency of feeds and feeding protocols. These ratios have decreased over the years as feeding practices become more sophisticated, and feed stability and nutritional performance have increased. Feeding protocols are typically more efficient for fish than prawns where it can be more difficult to optimise feeding in ponds. However, technological advances such as passive acoustic feeding systems are showing promise. Both automated feeding systems and low-tech timer feeders have been shown to improve growth response in comparison to broadcast feeding at set intervals with amounts fed using feed trays as indicators.

7.4.2 Settlement Ponds

Settlement ponds are the main treatment unit used in most Queensland pond aquaculture farms which release to receiving waters. They are primarily effective at reducing sediment concentrations but are less effective at reducing nutrient levels. The removal of TN and TP from settlement ponds is estimated to range from 10 to 30% and 15 to 50%, respectively. The literature suggests settlement pond efficiency is quite variable, with their effectiveness dependant on the design, operation and maintenance of these ponds.

Ideally, the ponds should be designed to minimise turbulence and short-circuiting. Sedimented material should be routinely cleaned out to maintain the required hydraulic retention times. If organic matter is not removed, the remineralisation of nitrogen can raise the ammonia and TN concentration in the settlement pond above that of the inflowing production pond discharge, which would be counterproductive. There is scope to optimise settlement ponds to convert them into more effective treatment ponds.

Standards for settlement pond design had not been endorsed by either the prawn or barramundi aquaculture industry associations at the time this report was written. There are several documents created by private companies and non-governmental organisations which provide guidance for the design of aquaculture settlement ponds; however, these guidelines are not legislative requirements of Queensland. Queensland's *State Development Assessment Provisions Guideline – State code 17: Aquaculture* specifies that ponds used solely for treatment and settlement shall be constructed such that the lowest point of the top retaining wall is at least at the height of the 1 in 50-year flood event. Another document, *Guidelines for constructing and maintaining aquaculture containment structures*, created by DAF, states that all aquaculture ponds must maintain a freeboard height which is adequate to prevent overflow and that the minimum freeboard is 0.5 m. No guidelines, public sector or private, provide standards on the depth, surface area or volume of settlement ponds.

7.4.3 Bioremediation

Vascular plants, algae and filter-feeding animals can remove dissolved and particulate nutrients respectively if encouraged to grow in settlement ponds or as part of a treatment system. However, their benefits vary considerably based on factors that may be outside of a farmer's control, for example, salinity, temperature and species present. In the case of aquatic plants and algae, they also need to be managed and regularly harvested to ensure optimal extraction of nutrients from the water column. This is an additional monetary and time cost for farmers.

Naturally occurring filter-feeding fauna will populate hard surfaces within water treatment areas. Introduced bivalves would need infrastructure to produce a commercial-quantity crop whether within settlement ponds or separate units which also adds cost and complexity. Previous studies have shown that the relatively high sediment loads in aquaculture ponds can prevent filter feeders from filtering effectively. The time needed to produce a commercial bivalve crop also adds complexity, particularly for prawn farmers where the bivalves would need to be grown for a longer period than prawn production ponds are operating. Previously, the sale for human consumption of bivalves produced as part of a treatment system was prohibited in Queensland due to safety concerns. It is currently unclear whether fish and crustaceans grown in a treatment system would be able to be sold for human consumption. Treatment ponds which are stocked with fish or crustaceans for bioremediation must be built to sustain the 1 in 100-year flood events, like production ponds. These complexities are potential disincentives to the adoption of this as a treatment strategy.

7.4.4 Wetlands

Wetlands and constructed wetlands have been shown to be effective in removal of nutrients in some studies (Erler et al., 2010; Boxman et al., 2015). However, the efficiency of nutrient removal is highly variable, and there is little evidence that they can reliably reduce nutrient loads at a farm scale over longer timeframes. Additionally, to maximize efficiency, they must be well designed and constantly maintained. The species of plants used in the wetlands also need to be site specific and are likely to require research and development to ensure suitability. The issue of whether there is sufficient land available within farms may also limit uptake of this treatment solution. There is a study commencing in SEQ to examine the efficacy of mangrove wetlands for treatment of STP discharge over multiple years.

Harvesting mangroves (or other marine plants) from constructed wetlands and treatment systems to contribute to nutrient removal may prove effective, but there is a need for permits. While marine plants are protected in Queensland under the *Fisheries Act 1994,* authorisation for flora management for maintenance of these systems may be sought through the accepted development provisions of the *Planning Act 2016.* However, there is some uncertainty within the industry which may hinder further development of these systems. Some farms have used constructed wetlands for treatment of discharge water, however at the time of this study there is only one farm in Queensland where this remains in use.

7.4.5 Treatment Design and Research

Most of the treatment alternatives discussed rely on biological processes to transform or remove nutrients from the discharged water prior to release. There have been many studies in the past on the use of wetlands, algal culture ponds, the use of filter feeders and other animals, the use of aquatic vascular plants, and so on (Gautier et al., 2001; Avnimelech and Kochba, 2009; Jerónimo et al., 2020). However, none of these are used across the industry currently. There are technologies used in other industries that can reduce nutrient levels, however they are designed for higher input concentrations of nutrients and relatively low water volumes compared with aquaculture farm discharge. As such, these technologies are likely to be inefficient and cost prohibitive. Enhancing settlement ponds remains an option but research is needed to examine ways to do this.

Treatment systems need to be cost-effective and designed at scale to treat the maximum flow rate, variable water volume and changing nutrient concentrations of the production system. In prawn production, maximum nutrient concentrations and discharge volumes occur toward the end of the growing season when prawn biomass and feeding rates are high. Additionally, draining of production ponds for harvest requires more effective treatment systems to deal with the high volumes of water. For barramundi farms, there is likely to be a more consistent pond discharge and water quality, although peak discharge periods can occur that could be used to set design specifications.

Recirculation systems with and without bioflocs (the accumulation of particulate material into clumps containing algae, bacteria and detritus) can reduce nutrient waste by incorporating the nutrients in flocs into animal biomass as well as improved settlement compared with algae and providing an environment for improved denitrification (atmospheric removal of nitrogen). There remain some knowledge gaps in the use of biofloc systems, particularly for the black tiger prawn, to optimise its use. Recirculation systems typically reduce nutrient release from aquaculture farms but increase the concentration of nutrients within the closed system. This can be an issue when release is unavoidable, for example, during harvest, or if there is a disease risk. However, elevated nutrient concentrations may make previously untenable treatment options from other industries relevant. Although this approach requires farmers to invest in modifying their farm configurations, it is likely to be more cost-effective than investing in many of the other treatment systems outlined above.

Designing an effective and efficient pond water treatment system relies on prediction of the nutrient loads and volumes that will need to be treated. Nutrient budgeting within the farm pond system will inform these predictions. A spreadsheet-based nutrient budget calculator has been developed as part of this project and is presented in this report to assist the industry to more easily assess different scenarios within the production pond system and estimate the range of loads that would be passing through a treatment system. With further information and development, it may be possible to extend this tool for the estimation of treatment system efficiency.

7.5 Future work

Multiple facets of aquaculture nutrient load management and regulation need to be further investigated, as there are currently no solutions to allow for industry-wide expansion of aquaculture in Queensland, and specifically in the Reef catchment. Further investigation is needed around an integrated approach considering technical, economic, regulatory and planning aspects. Research, development and full-scale demonstration is needed to determine the applicability of treatment and management approaches in a Queensland context for both barramundi and prawn farms. Priority research and development areas include alternative treatment (such as high-rate algal ponds or sand filtration), wetlands and recirculation systems that can reduce nutrient discharge loads. Recirculation presents the greatest opportunity to reduce overall nutrient loads but will require significant changes to farm operation and approvals to accommodate event releases. Further work should also be considered on enhancing and augmenting settlement ponds to make them more effective for nutrient removal.

More information regarding risk assessment and regulation of aquaculture farms, including improved guidance material and tools, should be developed, and provided to support development assessment and operation. Increased guidance on options for nutrient offsetting and information about how the policy has been implemented for other industries, particularly for activities in the Reef catchment, is recommended.

Opportunities could be explored to review the ERA 1 definition to allow greater flexibility for operation while maintaining environmental standards and outcomes for the Reef. The aggregate environmental score for ERA 1 could be reviewed and the potential use of planning codes could be explored to help ensure risks associated with intensity and scale (production density) are adequately reflected. The Prawn Farm Policy could be reviewed, along with updating the aquaculture MOCs and better alignment with certification standards. Any review would require further stakeholder engagement, including industry, community and environmental sectors.

When the current Water Quality Offset Policy is next reviewed, the information provided in this report should be considered to ensure that the revised policy and its application to aquaculture is clear. Funding of scientific research in relation to key aspects of the Water Quality Offset Policy should be supported, where possible, to continually improve the technical knowledge and environmental outcomes of water quality offsets. For example, further guidance could be provided for the potential application of TN and TSS as a surrogate for DIN and fine sediments in the application of point source water quality offsets in the Reef catchment.

This review did not include any economic assessment of current legislative requirements or environmental management practices, including different management options for treating and offsetting nutrients. These have the potential to affect the viability of the aquaculture industry in Queensland given current and potential future market considerations. This is an area of potential future work.

A list of draft recommendations is provided in Section 8 of this report and each recommendation requires further scoping, prioritisation and resourcing, as well as allocating responsible organisations. Ongoing communication and collaboration across government, industry and research organisations is essential for implementing each of these recommendations.

8 Draft Recommendations

Draft recommendations of this report are presented below.

Release management

1. Gather further information and undertake research to improve the operation of settlement ponds for the treatment of aquaculture pond discharges. Based on this work, available guidance on sedimentation ponds, that is potentially applicable to aquaculture farms in Queensland, should be reviewed with the aim of developing best practice aquaculture sedimentation pond guidelines.
2. Gather further information and undertake research on nutrient treatment technology for potential use with aquaculture farms in Queensland with the aim to reduce overall nutrient loads and concentrations of pond discharges. As a minimum, this could include collating information on current or historical projects and initiatives used by industry or government that have the potential to reduce nutrients in pond discharges, whether specifically applied to pond aquaculture or, more broadly, in other applications.
3. Gather further information and undertake research on the potential application and use of recirculation systems to aquaculture farms in Queensland with the aim to reduce release volumes and nutrient loads and protecting local receiving environment water quality.
4. Further work should be undertaken into the most suitable monitoring indicators and standardised limits for aquaculture releases. This should, as a minimum, consider the need for supplementary indicators including ammonia, chlorophyll-a, 5-day biochemical oxygen demand (BOD_5) and dissolved oxygen (DO), as well as evaluating current industry accreditation standards, available monitoring data and EA limits, and the potential application of real-time monitoring of DO in releases or receiving waters.

Decision support

5. The Point Source Information Portal that has been developed as part of this study should be maintained and improved to provide data and other relevant information to the industry, other government agencies, and the public on point source activities in the context of nutrient inputs to the Reef catchment and be linked with other relevant portals where appropriate.
6. The nutrient budget calculator that has been developed as part of this study to estimate whole of season nutrient inputs, release loads and sinks, should be made available to the industry and tested for potential endorsement and use to help improve the understanding of nutrient generation from aquaculture farms.
7. Develop standardised approaches and procedures to assist aquaculture operators with project design, development, and ongoing release management, and to assist with the regulation of the potential impact from aquaculture releases to local receiving waters (also refer to Recommendations 9 and 10), including specific approaches for use in Aquaculture Development Areas (ADAs).
8. An aquaculture REMP guideline should be developed and made available to industry for review and endorsement. An approved REMP guideline could be used to improve the suitability and consistency of aquaculture farm REMPs—this could be included as part of requirements within EAs. Current aquaculture REMPs and REMP EA conditions should be assessed against the approved REMP guideline to ensure the REMP monitoring is fit-for-purpose throughout Queensland and where required EAs updated with contemporary conditions relating to REMP monitoring and reporting.

Receiving environment assessment

9. Further gathering and collation of industry data on both release water quality and REMPs is recommended to help assess the current sustainability (footprint) of current aquaculture releases and help inform the need for potential future studies for the industry. It is recommended that implementation of the department's Water Tracking and Electronic Reporting System (WaTERS) database for reporting of monitoring required by EA conditions is a requirement of existing EAs.
10. Develop a methodology for assessing and applying the potential assimilative capacity of receiving waters for use with aquaculture developments, including priority Aquaculture Development Areas (ADAs). This would consider available water quality models and their potential application, including data requirements.

Stewardship

11. An aquaculture stewardship program should be developed jointly by the Queensland state government, industry associations and other stakeholders, to trial and support the development and implementation of improved nutrient management strategies, technologies, and initiatives. This should also include strategies for sharing experience with technologies trialled and potentially adopted for the aquaculture industry in Queensland, or more broadly, for the benefit of the entire industry.

Environmental approvals

12. Develop alternate outcome-focused and flexible EA conditions for aquaculture ERAs to allow for more up-to-date operational configurations for industry, but also considering the capacity of receiving waters to receive release water.
13. Review and update existing aquaculture EAs to ensure conditions reflect contemporary best practice environmental management in consultation with industry. Specific considerations include, but are not limited to:
    I. setting release loads and characteristics that are sustainable and achievable;
    II. different approaches based on the intensity of operation rather than area of production ponds;
    III. acknowledging differences between prawn and barramundi farm operations where needed;
    IV. release volume and load conditions which accommodate extreme rainfall events;
    V. limit types and calculations being clearly defined for all indicators;
    VI. removal of limits based on comparison with background;
    VII. procedures for when tidal release conditions are required;
    VIII. removing specified operational/settlement pond areas (or percentages);
    IX. relevant release (and intake) water quality indicators;
    X. options for monitoring frequency and timing, considering intensity, scale and timing of production; and
    XI. routine submission of release and REMP data to the department.

Nutrient Offsets

14. Nutrient offset examples that can potentially be applied to new or expanded aquaculture farms in Queensland should be developed, along with a framework and strategy for implementing and managing the example offsets.

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Appendix 1 – Information on Regulatory Requirements for Aquaculture Farms in Queensland

Regulatory context

Regulation may be applied at a state, local government, or private entity level. Generally, the type of regulation depends on the nature, scale, and potential environmental risk of the activity.

Typically, there is a development approval and related environmental conditions that focus on monitoring and minimising potential environmental impact. There may also be an approval requirement for the activity itself, known as an Environmental Authority (EA) in Queensland.

In Queensland, environmental protection legislation defines certain activities as Environmentally Relevant Activities (ERAs). This legislation, administered primarily by the Department of Environment and Science (DES), requires an EA approval to be granted before conducting an ERA. Operating an aquaculture farm above a certain design capacity, based on pond size (> $100m^2$), requires EA approval.

The *Environmental Protection Act 1994* (EP Act), associated subordinate legislation and technical guides include overarching environmental protection requirements, including EA permit application processes, and offence provisions.

In Queensland, Schedule 2, Part 1 of the *Environmental Protection Regulation 2019* defines ERA 1 Aquaculture.

If the proposed activity meets the criteria, the operator will require an EA and must lodge an application to the Department (further information on how to apply is presented below). The *Environmental Protection Regulation 2019* defines aquaculture (ERA 1) thresholds (see Table A1-1).

Table A1-1. Aquaculture ERA classification

Activity Classification	Activity
1.1(a)	1-(1a) Aquaculture (crustaceans) >$100m^2$
1.1(b)	1-(1b) Aquaculture (crustaceans) >10ha but <100ha land
1.1(c)	1-(1c) Aquaculture (crustaceans) >100ha land
1.2(a)	1-(2a) Aquaculture (other than crustaceans) >$100m^2$ but <10ha land
1.2(b)	1-(2b) Aquaculture (other than crustaceans) >10ha but <100ha land
27	27-Seafood processing >500t per year

Under the EP Act, an Environmental Impact Statement (EIS) is usually prepared for large resource projects before an EA can be issued. An EIS is also used to consider alternative ways to carry out the project in order to limit its impact. In general, an EIS is used to assess:

- the current environment in the area of the project,
- potential environmental, economic, and social impacts of the project, and
- proposals to avoid, minimise, mitigate and/or offset any potential impacts.

Application process

In Queensland, when local government or the State Assessment and Referral Agency (SARA) requires a development application for a Material Change of Use (MCU), the proponent for the proposed activity will need to apply for an EA as a part of the development application.

Supporting information for the Environmental Authority application must include all information listed under s125 of the EP Act (available at https://www.legislation.qld.gov.au/). Most importantly, it must include relevant technical information, such as:

- A description of the proposed activities,
- A description of the land on which the activities will be carried out,

- An assessment of the likely impact of each relevant activity on the environmental values, including—
    - a description of the environmental values likely to be affected by each relevant activity, and
    - details of any emissions or releases likely to be generated by each relevant activity, and
    - a description of the risk and likely magnitude of impacts on the environmental values, and
    - details of the management practices proposed to be implemented to prevent or minimise adverse impacts, and
    - details of how the land the subject of the application will be rehabilitated after each relevant activity ceases, and
- A description of the proposed measures for minimising and managing waste generated by each relevant activity, and
- Details of any site management plan that relates to the land the subject of the application.

The following guidelines are useful for applicants when assessing activities and sending application supporting material to DES:

- Model operating conditions provide a framework of conditions that are applied to applications for ERA 1 across Queensland.

  https://environment.des.qld.gov.au/__data/assets/pdf_file/0016/230263/pr-co-aquaculture.pdf

  Assessment officers may modify or add new conditions, other than the model conditions, depending on the site-specific context of the activity and associated environmental risks.

- The administering authority must address the regulatory requirements set out in the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 (https://environment.des.qld.gov.au/management/water/policy) and the standard criteria contained in the EP Act and the standard criteria contained in the EP Act (https://www.legislation.qld.gov.au/view/pdf/inforce/current/act-1994-062).

- Please note that there are special considerations for large dams/ponds. Guideline for structures which are dams or levees constructed as part of an ERA are as follows.

  Firstly, the following manual delineates the process for determining if an activity structure is considered as a regulated structure: https://environment.des.qld.gov.au/assets/documents/regulation/era-mn-assessing-consequence-hydraulic-performance.pdf.

  Secondly, the following guideline includes model conditions and explanatory notes that would be considered when conditioning environmental authorities containing regulated structures: https://environment.des.qld.gov.au/assets/documents/regulation/era-gl-structures-dams-levees-eras.pdf.

  Regardless of whether a proposed lagoon/dam is considered a regulated structure, the applicant and Department may wish to consider these reference materials to help ensure the long-term structural integrity of the structure. Typical requirements for large dams include maintaining an overflow/spillway, maintaining 1.5m of freeboard, and testing the structural integrity by an appropriately qualified person.

- For further information, please refer to the Business Queensland website, which has a range of information on ERAs and EAs, including guidelines, application supporting information, forms, fees, explanatory notes, and a step-by-step process on how to apply for an EA (see: https://www.business.qld.gov.au/running-business/environment/licences-permits/applying/activities).

In summary, to apply for and gain EA approval, the applicant must provide information that demonstrates the activity will not adversely impact environmental values such as values relating to water, land, and air. Overall, the level of information required will depend on the potential risk of environmental impact. If the application is complete and is approved, the applicant will be issued an EA that includes conditions that must be complied with. These conditions are typically outcome based, control emission levels and mandate environmental monitoring. These may be based on model conditions or be site-specific.

Environmental considerations for applications

There are a range of criteria or otherwise environmental protection principles that assessment officers consider when deciding and conditioning aquaculture activities. Many of these principles are defined within the *Environmental Protection Act 1994,* policies, or originate from the Intergovernmental Agreement on the Environment. Applicants should therefore consider the following when planning an activity:

1. The Management Hierarchy

The waste management hierarchy (Figure A1-1) is a list of waste management options, in preferred order. These are:

(a) AVOID unnecessary resource consumption

(b) REDUCE waste generation and disposal

(c) RE-USE waste resources without further manufacturing

(d) RECYCLE waste resources to make the same or different products

(e) RECOVER waste resources, including the recovery of energy

(f) TREAT waste before disposal, including reducing the hazardous nature of waste

(g) DISPOSE of waste only if there is no viable alternative.

In an effluent treatment and disposal context, the hierarchy becomes:

(a) firstly—reduce the production of wastewater or contaminants by reducing the use of water

(b) secondly—prevent waste and implement appropriate waste prevention measures

(c) thirdly—evaluate treatment and recycling options and implement appropriate treatment and recycling

(d) fourthly—evaluate the following options for wastewater or contaminants in the order in which they are listed:

- appropriate treatment and release to a waste facility or sewer
- appropriate treatment and release to land
- appropriate treatment and release to surface waters.

Figure A3-1. Waste management hierarchy

2. *The precautionary principle*
    - Applications should propose actions to prevent or minimise serious harm even though there may not be full scientific certainty about the scale or causes of the harm.
3. *Intergeneration equity*
    - The current generation should ensure that the health, diversity, and productivity of the environment is maintained or enhanced for the benefit of future generations.
    - It is likely that an activity which would result in widespread and/or irreversible environmental harm, would not meet the principle of intergenerational equity.
4. *Conservation of biodiversity and ecological integrity*
5. *Any Commonwealth or State government plans, standards, agreements or requirements about environmental protection or ecologically sustainable development*
6. *Environmental impact assessment*
    - Discussed more below. A review of the findings and/or recommendations of applicable environmental impact study, assessment or report relevant to the subject site be undertaken to ensure that they are considered.
7. *Financial implications*
8. *Public interest*

Environmental Assessment

Environmental risk assessment approach

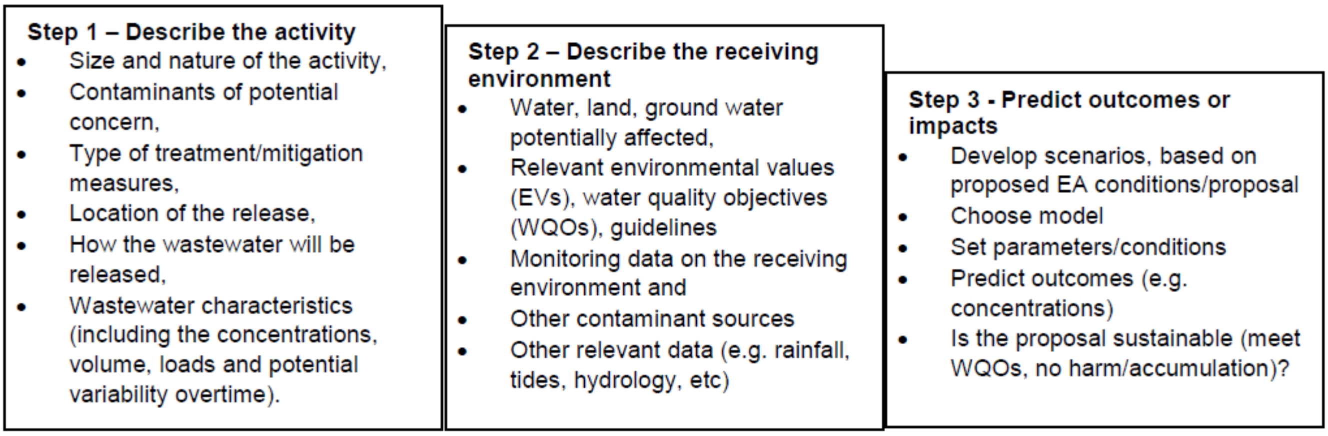
An environmental risk assessment should be conducted by the applicant, or their representatives, to determine the level of potential risk to the environment likely to occur from the proposed activity and whether the level of risk is potentially unacceptable. Additionally, the assessing department may independently assess the level of risks when deciding on an EA application.

Generally, if an activity poses a moderate risk or above, the operator should implement mitigation measures to reduce the risk to low or minor. Table A1-2 illustrates a generalised broad level risk assessment framework often used to assess potential environmental impacts.

Table A1-2. Broad level risk assessment framework and criteria

Impact or risk categories			
Major	**Moderate**	**Minor**	**Low**
Medium to long-term	Temporary to medium-term	Transient impact	No impact
Medium to wide-scale, or of medium to great intensity	Potentially on a localised or medium scale, or of low to medium intensity	Localised scale, or of a low intensity	No public concern or impact to public safety
High level of public concern or impact to public safety	Moderate level of public concern or impact to public safety	Low level of public concern or impact to public safety	Administrative nature - could not have been prevented

For assessing the potential risk of wastewater releases to the environment, a more quantitative and site-specific assessment is usually required. Figure A1-2 shows the broad approach and some key considerations recommended for assessing wastewater releases in Queensland.



Step 1 – Describe the activity

- Size and nature of the activity,
- Contaminants of potential concern,
- Type of treatment/mitigation measures,
- Location of the release,
- How the wastewater will be released,
- Wastewater characteristics (including the concentrations, volume, loads and potential variability overtime).

Step 2 – Describe the receiving environment

- Water, land, ground water potentially affected,
- Relevant environmental values (EVs), water quality objectives (WQOs), guidelines
- Monitoring data on the receiving environment and
- Other contaminant sources
- Other relevant data (e.g. rainfall, tides, hydrology, etc)

Step 3 - Predict outcomes or impacts

- Develop scenarios, based on proposed EA conditions/proposal
- Choose model
- Set parameters/conditions
- Predict outcomes (e.g. concentrations)
- Is the proposal sustainable (meet WQOs, no harm/accumulation)?

Figure A1-2. Recommended approach for assessing wastewater releases to the environment in Queensland

The final regulatory decision in relation to approval for wastewater releases are based on “standard criteria”, which includes environmental considerations, such as the outcomes of the risk-based assessment approach for potential impacts on surface water, groundwater and land values and other factors, such as best practice, financial implications, and public interest.

Community and Environmental Values

The Australian and New Zealand Water Quality Guidelines (ANZ, 2018) define a community value as a particular value or use of the environment that is important for a healthy ecosystem or for public benefit, health, safety or welfare, and requires protection from the effects of stressors. In Queensland, these community values are referred to as *environmental values* (https://www.waterquality.gov.au/anz-guidelines).

For Water Quality Guidelines, the ANZ (2018) guidelines recognise the following community/environmental values:

- **aquatic ecosystems** — the health or integrity of the waterway’s ecosystem(s)
- **cultural and spiritual values** — water is particularly important for indigenous peoples
- **drinking water** — water is suitable for human consumption
- **industrial water** — water is suitable for use by industry, for example mining, manufacturing, cooling and electricity generation
- **primary industries** — water is suitable for irrigation, livestock drinking water, aquaculture and human consumers of aquatic foods
- **recreational water and aesthetics** — recreation can be undertaken without risk of sickness or disease or loss of aesthetic appeal.

Environmental values apply to both surface water and groundwater. However, the above values may not apply to all waters. For example, marine waters are unlikely to have drinking water values. However, default values, such as for aquatic ecosystem, should apply in all cases, even for ephemeral, temporary or highly disturbed streams.

In Queensland, environmental values may be Scheduled as part of the Queensland Environmental Protection Policy (Water and Wetland Biodiversity) 2019. See the departments website at https://environment.des.qld.gov.au/management/water/policy for more information on each catchment including document and maps on Scheduled data for surface water. As an example, Figure A1-3 below shows Scheduled environmental values for the Plane Creek Basins within the Mackay-Whitsunday Basin. This area is within an Aquaculture Priority Development Area (PDA) and there are current prawn farms operating in this area.

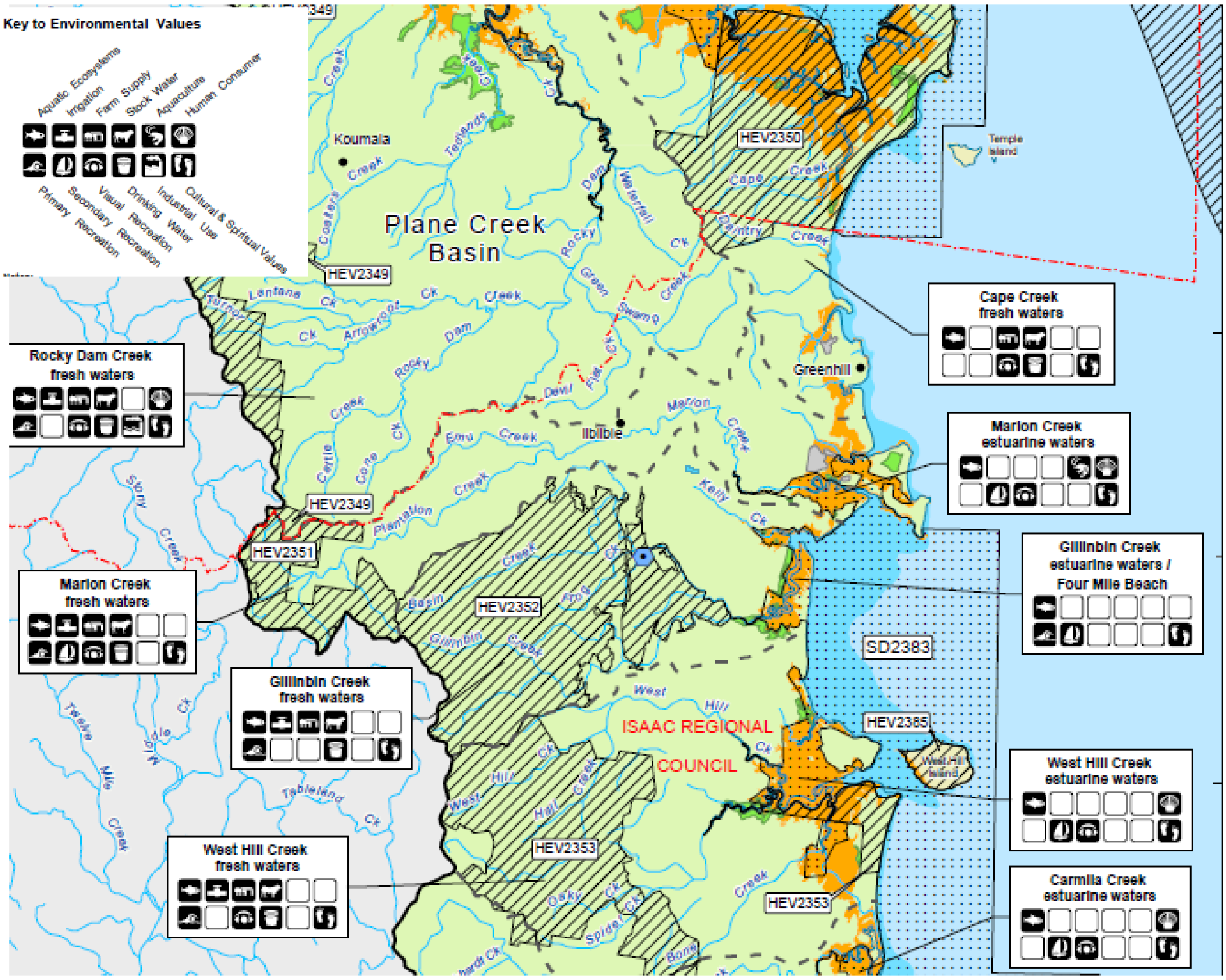


Figure A1-3. Map of Scheduled environmental values for the surface waters within the Plane Creek Basin within the Mackay Whitsunday Basin

Water Quality Objectives

The ANZ (2018) Water Quality Guidelines define the water/sediment quality objectives as the guideline value or narrative statement for each selected indicator that should ensure the protection of all identified community/environmental values. The main purpose of water quality objectives and sediment quality objectives is to guide management and decision making.

The Water Quality Objectives (WQO) for indicators relevant to water/sediment quality issues are derived from scientifically derived guideline values. When setting WQOs where multiple values exist with the same indicator, the most stringent guideline value for each indicator is selected to ensure that all values are protected.

WQOs used to protect aquatic ecosystems can be divided into 2 categories. The first category is based on reference monitoring, typically for ambient conditions. Different levels of protection apply but generally most water bodies are classified as moderately disturbed. Guidelines for these waters are usually based on the 80th percentile of long-term monitoring data (typically 18 to 24 months). Reference-based WQO indicators relevant to sewage treatment plant releases include nutrients (nitrogen and phosphorus), and other physical chemical indicators such as DO, pH and suspended solids. An example of Scheduled WQOs for the Pioneer River and Plane Creek Basins within the Mackay-Whitsunday Basin is shown in Table A1-3 below.

Table A1-3. Example of Scheduled WQOs for the Pioneer River and Plane Creek Basins within the Mackay-Whitsunday Basin

Water area/type (refer plans WQ1251, WQ1222)	**Management intent (level of protection)**	**Water quality objectives to protect aquatic ecosystem EV**
WATERS OUTSIDE PORT ZONES MD2341, MD2342, MD2343		
waters - outside Ports **(also applies to any marinas, boat harbours, tidal canals, constructed estuaries within this water type/management intent that are outside port sub-zones)**	moderately disturbed (MD)	colour) and occurring within inter-tidal zone adjacent to the enclosed coastal/lower estuary water type, these waters might have water quality characteristics more in common with the adjacent enclosed coastal/lower estuary water type. Under such circumstances, reference should be made to the WQOs for enclosed coastal/lower estuary water type. • ammonia N: <15 µg/L$^{c, n}$ • oxidised N: <30 µg/L$^{c, n, s}$ • dissolved inorganic N: <45 µg/L$^{b, c}$ • organic N: <200 µg/L$^{c, n}$ • total N: <250 µg/L$^{c, n}$ • filterable reactive phosphorus (FRP): <5 µg/L$^{c, n}$ • total P: <20 µg/L$^{c, n}$ • chlorophyll a: <3.0 µg/L^{n} • dissolved oxygen: 80-105% saturation$^{e, n}$ • turbidity: <10 NTU^{n} • Secchi depth: >1.0 m^{n} • suspended solids - Cabbage Tree and Louisa Creek subcatchment mid estuaries: – dry weather: 1.1–2.9–5.5 mg/L^{y} – wet weather: 7.1–13.0–22.7 mg/L ^{y} • suspended solids - other subcatchment mid estuaries: nd$^{k, n}$ • pH: 6.5-8.4^{n} • temperature: nd$^{j, k, n}$
Enclosed coastal/lower estuary waters outside port sub-zones Applies to EC waters outside port sub-zones, and not identified as SD or HEV. Also applies to any marinas, boat harbours, tidal canals, constructed estuaries within this water type/management intent that are outside port sub-zones.	Aquatic ecosystem—moderately disturbed (MD)	• ammonia N: <15 µg/L$^{c, n}$ • oxidised N: <10 µg/L$^{c, n, s}$ • dissolved inorganic N: <25 µg/L$^{b, c}$ • total N: <160 µg/L$^{c, n}$ • filterable reactive phosphorus (FRP): <5 µg/L$^{c, n}$ • total P: <20 µg/L$^{c, n}$ • chlorophyll a: <2.0 µg/L^{n} • dissolved oxygen: 85–105% saturation$^{e, n}$ • turbidity: <10 NTU$^{n, v}$ • Secchi depth: >1.0 m$^{n, v}$ • suspended solids: nd$^{k, n, v}$ • pH: 8.1–8.4^{n} • temperature: nd$^{j, k, n}$ • toxicants: refer to toxicants rows later in this table

The example in Figure A1-4 shows how WQOs, derived from reference-based guidelines, are applied to test sites. Reference-based guidelines apply to physico-chemical indicators used to protect aquatic ecosystems. These guidelines are applied to the median values of the test data set, typically 8 to 12 samples taken over a period of a year. Where the median is below the guideline (or WQO), the site is deemed to comply. If the median exceeds the guideline, the site is deemed to not comply.

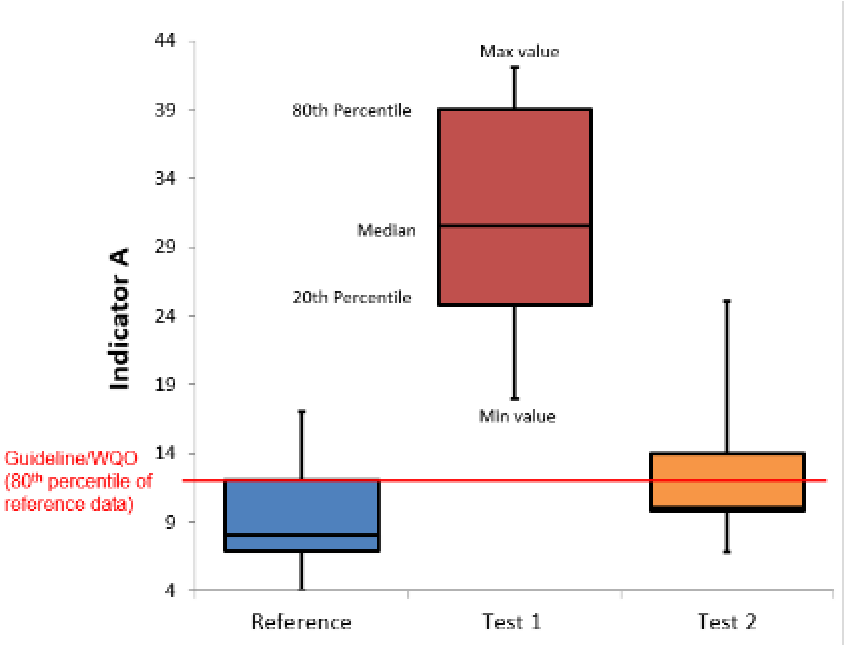


Figure A1-4. Example of how to apply Reference-Based Guidelines (WQOs) to test data to determine compliance.

The other category of WQO related to aquatic ecosystems is based on toxicity data and are called toxicant guideline values. These are typically based on a toxicity data for many species and are generally derived to ensure that 95 percent of species are protected. Often acute and chronic tests are considered. For bioaccumulating substances, a higher level of protection, such as 99 percent, may be required. For sewage treatment plant releases, toxicants can typically include ammonia, nitrate (for freshwater), and chlorine/total chlorine (including disinfection by-products). For Australia, toxicant guidelines are provided in the ANZ (2018) Water Quality Guidelines.

Fate of contaminants

Understanding the potential fate of contaminants present in wastewater is important to support environmental risk assessment. The fate may broadly be categorised as water, land (soil) or air.

Contaminant migration may be affected by a range of chemical, physical or biological processes. Often contaminants in sufficient quantities may ultimately impact on plants, animals, or humans.

One recommended way of understanding contaminant pathways to help inform risk assessment is through developing a conceptual model. A conceptual model can show the possible pathways and mechanism of impact from specific contaminants released to the environment. From this understanding, more targeted assessment, such as the use of numerical models, may be undertaken and applied to the proposal to estimate the potential environmental risk and provide a comparison with relevant environmental guidelines or objectives.

More specific information is provided below on contaminant risk assessment for releases to water.

Wastewater release to water

Although individual states and territories in Australia will have specific guidance in relation to managing wastewater release, they are underpinned by the National Water Quality Guideline (ANZQ 2018 or the previous 2000 ANZECC/ARMCANZ Version), Australian and New Zealand Guidelines for Fresh and Marine Water Quality available at: http://www.environment.gov.au/water/policy-programs/nwqms/index.html.

For proposals for wastewater release to waters undertaken in Queensland, more detailed technical guidance is provided in the document "Licensing wastewater releases to Queensland waters" available at:

https://environment.des.qld.gov.au/assets/documents/regulation/pr-gl-wastewater-to-waters.pdf.

Other relevant resources for Queensland include the following:

- Queensland Environmental Protection (Water and Wetland Biodiversity) Policy 2019 – sets out environmental values, goals, and water quality objectives for Queensland waters:

  https://www.legislation.qld.gov.au/view/whole/html/asmade/sl-2019-0156

- Queensland Water Quality Guidelines (2013) - guidelines values for a range of indicators for Queensland waters:

  https://environment.des.qld.gov.au/water/pdf/water-quality-guidelines.pdf

- Water Monitoring and Sampling Manual – approaches for monitoring and sampling required under the *Environmental Protection Act 1994* and *Environmental Protection Regulation 2019*:

  https://environment.des.qld.gov.au/management/water/quality-guidelines/sampling-manual

Typical release limit conditions

Wastewater contains a range of contaminants that may require limits. Along with limits on release flow or volume, these restrict the quantities of contaminants released to the environment. Table A1-4 shows the type of limits that may be applied to wastewater releases.

Table A1-4. Types of limits applied to wastewater releases.

Limit Type	Guidance for Limit Types
Maximum	• Maximum values are particularly important for toxicants that have an acute impact on the environment but may be applied to any indicator. • Values can be applied for compliance monitoring to a single sampling event. • Values ensure a proper standard of treatment applies at all times. Note that for maximum discharge volume, different limits could apply under different weather conditions such as wet or dry periods.
Minimum	• Values are important for parameters such as dissolved oxygen. • Values can be applied for compliance monitoring to a single sampling event. • Values ensure a proper standard of treatment applies at all times.
Percentiles, averages (means)	• Percentiles and averages are applied to the results of a number of sampling events. • Percentiles and averages may be used when performance or impact is regulated over a set time period, such as weeks or month. An example is with nutrient concentrations or loads to control risks of nutrient enrichment. • They can be based on expected treatment performance. • Percentiles and averages are important as they control performance over time, whilst allowing reasonable fluctuation in the shorter term.

A site-specific approach is often used to assess and condition environmental approvals. The primary factors that influence these conditions are the activity and emissions, proposed mitigation measures, relevant environmental values, and risk of environmental harm.

A condition to design and undertake an environment monitoring program may also be included as part of an environmental approval. The need for the program is usually determined when an environmental approval application is first assessed and is based on the nature of the activity and the potential environmental risks involved.

The aim of an environmental monitoring program is to monitor and assess potential impacts of controlled or uncontrolled releases of wastewater, and associated contaminants, to the environment from a regulated activity.

The program provides a basis for evaluating whether the discharge limits or other conditions imposed upon an activity have been successful in maintaining or protecting receiving environment values over time.

In general, the potential objectives of the environmental monitoring program include:

- Meeting EA conditions and General Environmental Duty,
- Defining background/reference condition,
- Assessing change over time and suitability of EA conditions, and
- Supporting non-compliance investigation and future EA amendments.

Relevant offences and obligations

- General environmental duty – which means a person must not carry out any activity that causes or is likely to cause environmental harm, unless measures to prevent or minimise the harm have been taken.
- Duty to notify of environmental harm – to inform the administering authority and landowner or occupier when an incident has occurred that may have caused or threatens serious or material environmental harm.
- Offence for carrying out an ERA without an EA – it is an offence to carry out an ERA without an EA pursuant to Section 426 of the EP Act.
- Offence for causing environmental nuisance – Section 440 of the EP Act.
- Offence for depositing prescribed water contaminants in waters – Section 440ZG of the EP Act.
- Offence for contravening a condition of an Environmental Authority

Appendix 2 - Industry Survey Additional Information

Griffith UNIVERSITY

Queensland Government
Department of Environment and Science

Great Barrier Reef Aquaculture Review Project

Participant Information Sheet

Background and purpose

Griffith University has been engaged by the Department of Environment and Science to assist in a review of Aquaculture Industry operating within the Great Barrier Reef Catchment. The aim of the review is to engage with the pond aquaculture industry to understand current environmental management practices for wastewater nutrient discharges in Queensland, as well as to help identify opportunities for improved management and streamlined environmental assessment and regulation for these activities. In addition, the project may assist the industry meet the requirements of new Reef legislation which will require no residual impact from new or expanded point sources that release nutrients.

The purpose of the discussion is to get input from industry stakeholders to help understand the operation of aquaculture farms and the challenges the industry face in managing wastewater and nutrient releases. The project team would also like to gather information on nutrient monitoring and current environmental management practices and treatment technologies used to manage wastewater and nutrient releases.

What does my participation involve?

As an aquaculture producer you are a key stakeholder for this project, and as such, are invited to participate in the conversation during a feedback session. Information can be provided verbally at the time and/or later as written feedback.

Privacy and consent

Your participation in this project is encouraged but is voluntary. Your acceptance to participate in the project will also indicate permission for use of the information provided for project reporting purposes. Any publication or report that is prepared will not include the names of facilities, organisations, or participants without their explicit permission.

What will the information be used for?

- The information will be used by GU and the DES team to help identify leading practices across the industry, identify opportunities for improved nutrient management at an industry level and recommend streamlined environmental assessment and regulation at an industry level.
- The results of this conversation will be summarised as part of a report provided to DES. This report will be reviewed by the industry associations and a stakeholder advisory group prior to completion.

Information collected as part of this project will **NOT** be used to inform compliance action against individual farms.

Prompts to start the conversation

- What are the main barriers to expansion and investment in the Aquaculture Industry in Qld?
- What are the top 5 challenges facing the industry today?
- Is nutrient management and regulation an issue in the industry?
- What are the best strategies currently available for nutrient management?
- Which current or emerging strategies have the most potential?
- Do you think DES should be more engaged with the industry? If so, how should they do that?
- What issues could DES help the industry with?

Contact

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Figure 25 - Information sheet provided as part of the industry engagement

List of issues covered during the verbal engagement with the industry

Industry-wide views

- What do you see as the main barriers to expansion and investment in the Aquaculture Industry in Queensland?
- What are the top 5 challenges facing the industry today?
- Is nutrient management and regulation an issue in the industry?
- What are the best strategies currently available for nutrient management?
- What current or emerging nutrient management strategies have the most potential?
- Do you think DES should be more engaged with the industry? If so, how should they do that?
- What issues could DES help you with?

Farm - background

- How long has the farm been in operation? Was it in production during 2020/21?
- Have you had challenges in the past with obtaining regulatory approvals?
- Do you have concerns about meeting your licence requirements now or into the future?
- Do you have any plans to expand your farm?
- If you were to expand, what are the main impediments to expansion that you see?
- Do you have room in your existing discharge limits to accommodate expansion?
- Are you aware of the new Reef regulations coming into play in June ‘21?
- How much does regulation affect your decisions about future expansion of your farm?

Farm details

- Total Pond area in production
- No. of Ponds in production
- Water depth of ponds
- Pond Construction (Lined, Partially lined, Earthen)

Intake Water

- Do you have concerns about the quality of your intake water / biosecurity?
- Do you monitor the quality of water on intake? What do you measure?
- Is intake water quality / nutrient monitoring a requirement of your EA?
    - Intake water source
    - Intake point location
- How often is intake water sampled?
- Is historical data available for intake water?
- How is intake volume measured/estimated?
- Seasonal volume of water intake
- If brackish or marine is freshwater used in ponds
    - Volume of FW used

Discharge

- How do you measure/estimate discharge volume?
- Where are the discharge point/s located?
- What would be a typical daily discharge (if relevant)?
- What was the total discharge volume last season/year (if known)?
- How often are water quality and nutrient levels in discharge monitored?
- What is measured/reported?
- Are the EA limits based on concentration, load or a combination of both?

Discharge Water Treatment

- Do you employ any treatment to meet your current discharge limits?
- What is your current treatment system?
- How long have you been using the current system?
- Treatment area and volume (if known)?

- What is the water residence time in the system (min, median, max)?
- Pond discharge channel area / volume? Does it contribute to treatment?
- Is the farm able to reuse treated water? Is treated water routinely recycled within the farm?
- Total volume treated last season?
- How frequently is the treatment system cleaned and/or dried out?
- Are water quality and nutrients measured throughout the system?
- Are you satisfied with your current treatment, do you know how efficiently it is functioning?
    - Estimated efficiency of TN removal
    - Estimated efficiency of TP removal
- If you don't know how efficient it is, would you like more data to investigate it?
- Do you intend to change your treatment system in the future? In what timeframe?
- If so, what methods have you considered and what are you planning?
- What are the main impediments to changing treatments system?
- Do you need more information on alternative treatment options, or how to make your current systems more effective?
- Do you think treatment methods are going to be too expensive for you in the future?
- What types of nutrient management are most likely to be adopted by the industry in the future?

Monitoring and Receiving Environment

- What is your view on current monitoring requirement for discharges?
- Who undertakes your intake and discharge monitoring? Farm staff, dedicated staff member or consultant?
- If you have a Receiving Environment Management Plan (REMP), who carries out the monitoring?
    - Location of monitoring points
    - Parameters measured and frequency
    - Are historical or current data available?
- Do you have any additional 3rd party monitoring requirement for your EA?

Pond Production Information

- Cropping strategy?
- Is fertiliser used in ponds - rate and type?
- Are stocks selectively bred (Y/N)?
- Stocking density (m^{-2})?
    - Stocking size / stage
- Typical crop length (d)?
- Typical exchange free period after stocking, if any?
- Typical water exchange rate?
- Typical animal size at harvest (g)?
- Average Production (t/ha)?
- Total Production last season/year (t)?
- Feed used (t)?
- Feed protein level (%)?
- Feed P level (%)?
- Is there a period post-stocking before feeding commences? How long is it typically?
- What feeding method is used (for example, broadcast blower, automated feeding system, manual)?
- How is feeding activity or level monitored and adjusted?
- What is the typical FCR achieved?
    - Average
    - Range
- Typical survival achieved in ponds (%)?
- Aeration strategy (hp/ha, number, type)?

Pond Water Quality

- What water quality parameters are typically monitored?
- Are nutrient levels measured in ponds?

- Is data available for pond nutrient levels?

Sediment

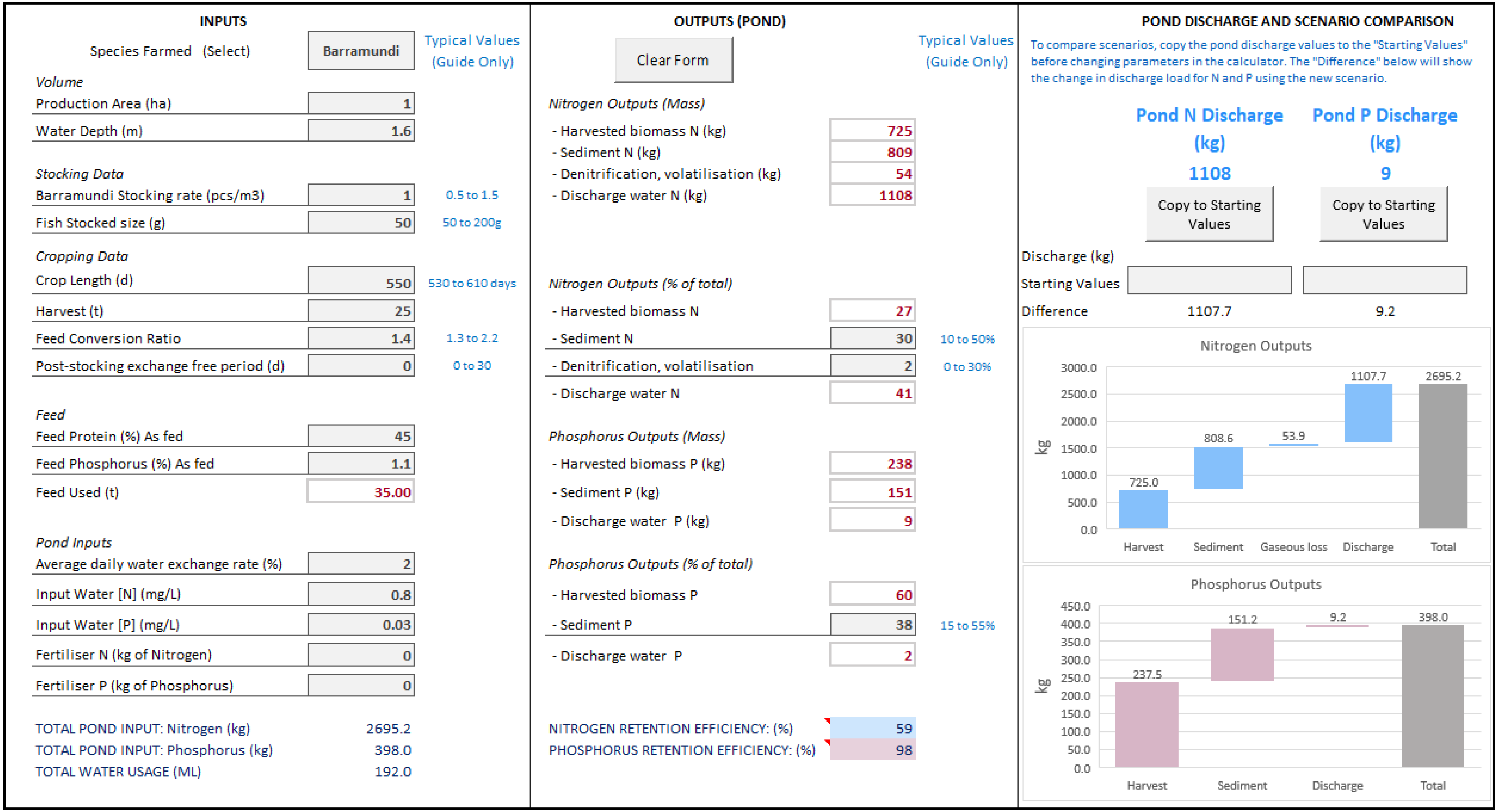
- What is your sediment collection, treatment and disposal strategy?
    - Are the same methods used for treatment system sediment?
- Typical volume / weight of sediment collected from production ponds?
- Has pond sediment composition ever been analysed?

Certification

- Do you currently use any of the aquaculture certification programs?
- If so, which programs are used?
- Does the certification have reference to water discharge and environmental impact?
- How do these differ from your EA requirements?

Appendix 3 - Aquaculture Pond Nutrient Budget Calculator

To assist producers in estimating the nutrient (nitrogen and phosphorus) load being discharged from barramundi and prawn production ponds prior to any treatment, a simple calculator has been developed. This calculator is excel based and follows the nutrient budget model of inputs and outputs from published literature. The nutrient inputs are calculated from user defined production parameters. The amount of each nutrient that is removed through harvested product is calculated from literature values for the nitrogen and phosphorus content of the species farmed, while the user defines the proportion of N and P input that remains in the pond sediments and the nitrogen removed from the system through gaseous losses. These proportions are guided by the available literature as discussed in this report. The calculator then provides an estimate of the weight of each nutrient that is removed from the system in each nutrient sink. The user can then change production parameters or the proportionality of the nutrient sinks to determine the effect on nutrient discharge in the water. This may be used to evaluate different strategies for nutrient reduction and to estimate the load that a treatment system may need to accommodate.



INPUTS

Species Farmed (Select)	Barramundi	Typical Values (Guide Only)
Volume		
Production Area (ha)	1	
Water Depth (m)	1.6	
Stocking Data		
Barramundi Stocking rate (pcs/m3)	1	0.5 to 1.5
Fish Stocked size (g)	50	50 to 200g
Cropping Data		
Crop Length (d)	550	530 to 610 days
Harvest (t)	25	
Feed Conversion Ratio	1.4	1.3 to 2.2
Post-stocking exchange free period (d)	0	0 to 30
Feed		
Feed Protein (%) As fed	45	
Feed Phosphorus (%) As fed	1.1	
Feed Used (t)	35.00	
Pond Inputs		
Average daily water exchange rate (%)	2	
Input Water [N] (mg/L)	0.8	
Input Water [P] (mg/L)	0.03	
Fertiliser N (kg of Nitrogen)	0	
Fertiliser P (kg of Phosphorus)	0	
TOTAL POND INPUT: Nitrogen (kg)	2695.2	
TOTAL POND INPUT: Phosphorus (kg)	398.0	
TOTAL WATER USAGE (ML)	192.0	

OUTPUTS (POND)

		Typical Values (Guide Only)
Nitrogen Outputs (Mass)		
- Harvested biomass N (kg)	725	
- Sediment N (kg)	809	
- Denitrification, volatilisation (kg)	54	
- Discharge water N (kg)	1108	
Nitrogen Outputs (% of total)		
- Harvested biomass N	27	
- Sediment N	30	10 to 50%
- Denitrification, volatilisation	2	0 to 30%
- Discharge water N	41	
Phosphorus Outputs (Mass)		
- Harvested biomass P (kg)	238	
- Sediment P (kg)	151	
- Discharge water P (kg)	9	
Phosphorus Outputs (% of total)		
- Harvested biomass P	60	
- Sediment P	38	15 to 55%
- Discharge water P	2	
NITROGEN RETENTION EFFICIENCY: (%)	59	
PHOSPHORUS RETENTION EFFICIENCY: (%)	98	

POND DISCHARGE AND SCENARIO COMPARISON

To compare scenarios, copy the pond discharge values to the "Starting Values" before changing parameters in the calculator. The "Difference" below will show the change in discharge load for N and P using the new scenario.

	Pond N Discharge (kg)	Pond P Discharge (kg)
	1108	9
	Copy to Starting Values	Copy to Starting Values
Discharge (kg)		
Starting Values		
Difference	1107.7	9.2