Leading Practice
Sewage Treatment Plant
Environmental Management Review

Great Barrier Reef Catchment

Final Report

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Contents

Summary

There has been a strong focus over the last 20 years on removal of nutrients from domestic wastewater, particularly nitrogen and phosphorus. In Queensland, Sewage Treatment Plants (STPs), defined as Environmentally Relevant Activity (ERA) 63, are often required to achieve annual median concentrations of 5 mg/L total nitrogen and 1 mg/L total phosphorus for authorised release to water. With population increases, increased release volumes and nutrient loads are likely to occur, even if release concentrations remain the same. The increased nutrient loads will contribute to overall catchment loads to Queensland waters and potentially environmental decline. Wastewater reuse/recycling and alternative disposal solutions, such as release to land, can reduce nutrient loads released to aquatic environments. However, in an urban setting, both options appear to be significantly constrained at present. Increased nutrient removal via treatment is also constrained by available technology and capital and operating costs.

The main aim of this review is to define and review key areas of STP leading practice environmental management for facilities within the Great Barrier Reef (Reef) catchment and adjacent islands. A second objective is to help define leading practice levels for wastewater release to waters, particularly in relation to nutrient removal, to assist with management and investment decisions. The review provides potential benchmarks for councils looking to upgrade or improve performance of their STPs with respect to nutrient removal, but also acknowledges the need to consider site-specific factors, such as size and location, and broader environmental and economic implications. It is specifically aimed at centralised, publicly owned STPs and facilities involving releases to surface waters, whether inland or coastal.

In this review, leading practice management is defined as management approaches currently being used in Queensland that achieve the highest levels of nutrient removal from wastewater. Environmental management can be related to any activity, including design, operation, maintenance and monitoring of the system in relation to wastewater management used to achieve leading practice. Activities include all forms of reuse/recycling, treatment, chemical usage, energy usage, greenhouse gas production and solid waste (sludge/bio-solids) management—although the information on some of these areas is currently limited. This review focused on the sewage treatment facility, and to a lesser extent, broader wastewater management and sewer management.

The review presents qualitative and quantitative information on leading practice environmental management of STPs. The qualitative information, which was obtained from interviews and meetings with Queensland regional councils and water utilities, as well as scientific and business papers, will help councils compare and explore opportunities for improvement. The quantitative analysis was based on 5 years of release monitoring data for STPs in the Reef catchment and adjacent islands, environmental approval information and results of an industry survey undertaken in 2019. Of the 137 council owned STPs operating in the Reef catchment, nutrient data were available for 65 authorised to release to water, 50 of these being on the mainland.

Key water quality indicators commonly used to monitor STP release to water in Queensland include total nitrogen (TN), total phosphorus (TP), ammonia, biochemical oxygen demand (BOD_5), total suspended solids (TSS), enterococci, pH, electrical conductivity (EC) and chlorine. Typical release limits for indicators are presented based on a review of the environmental authorities (EAs) for STPs in the Reef catchment at the time of this review. The remainder of the review focused on nutrient indicators TN, TP and ammonia. It was noted that STP release monitoring and limits specified in EAs do not generally include oxidised nitrogen or filterable reactive phosphorus (FRP) concentrations but generally include TN, TP and ammonia concentrations. Therefore, data are generally only available for these indicators.

Leading practice examples are presented for sewer management, wastewater reuse/recycling and various aspects of wastewater treatment. Sewer design, including the level of treatment prior to bypass, is mainly based on the state's Planning Guidelines for Water Supply and Sewerage (2014). There are several successful examples of reuse in Queensland: including large-scale agricultural reuse in Mackay; irrigation on Magnetic Island (Townsville) and in the Scenic Rim region; plantation timber-based reuse in the Fraser Coast; and major reticulated reuse in the Gold Coast. High levels of nitrogen removal are occurring at many STPs located in the Reef catchment. Most of these plants include biological nutrient removal (BNR) processes which promote nitrification and denitrification. High levels of phosphorus removal are also occurring, and it appears this strongly relies on the use of alum (aluminium sulphate) dosing, or phosphorus accumulating organisms (PAOs) to a lesser

extent. There are also examples of “green” passive technology, such as the use of artificial wetlands or algal treatment.

Energy requirements and costs were also explored in this review. Although there were limitations with the data, the energy usage for leading practice STPs in the Reef catchment ranged from 4 to 142 kWh/equivalent persons (EP)/year with four plants achieving less than 50 kWh/EP/year. These levels of usage are within the range reported in previous studies for Australia and New Zealand. To manage energy needs, some facilities have adopted solar energy. Further work could be undertaken to look at methods for assessing and optimising energy usage.

Relative capital and operational costs were also examined in this review. The whole of treatment costs ranged from \$41 to \$401 per design EP per year for operation and from \$4 to \$2199 per design EP for capital for the leading practice plants. Assuming a 25-year operating life for each facility, the most cost-effective plant had a cost of approximately \$50 per design EP per year for the large facilities. For smaller plants (<10,000 EP), the most effective plant had a cost of approximately \$125 per design EP per year. Given a lack of available inflow data further work would be required to work out the cost per kilogram removed of TN and TP.

Treatment facilities displaying leading practice treatment were extracted from the dataset based on their operational performances, i.e. the facilities achieving low nutrient concentrations in the release water. These treatment plants were then assessed and compared in terms of the operational data that was available. Benchmarks were then developed for three levels of leading practice treatment based on release concentrations for TN, TP and ammonia. The highest category is considered “best practice” and is defined as the highest standard that has been demonstrated successfully in the Reef catchment for plant sizes greater than 1,500 EP.

Leading practice treatment levels for TN and TP treatment have been defined based on long-term TN and TP median concentrations achieved by STPs in the Reef catchment for final release water. Three different levels of leading practice treatment have been proposed for each. Based on 65 STPs with data, approximately half were found to be achieving one of these leading practice levels for TN treatment and TP treatment. The top level, which is considered current best practice, corresponded to an annual median and maximum concentration of less than 2 mg/L and 10 mg/L for TN and 0.4 mg/L and 2.0 mg/L for TP, respectively. These levels were achieved by at least 10 facilities (approximately 15%) based on data from 2015 to 2019 for both TN and TP. Two leading practice levels were also developed for ammonia treatment based on 99th percentiles of the final release water. All STPs achieved a long-term median ammonia concentration of less than 0.3 mg/L. The top level, which is considered current best practice, corresponded to less than 2.5 mg-N/L for maximum ammonia concentrations and was achieved by 16 facilities (25%) based on data from 2015 to 2019. The average loading, based on current and design EP, was assessed for facilities within each leading practice level. The different levels of leading practice had average facility loading rates ranging from 50 to 70%. Hydraulic and organic loading and wastewater characteristics may be a contributor to improved nutrient removal, particularly for biological removal plants, and it may be difficult to achieve such high nutrient removal levels at higher loadings.

Although technical guidelines are available for both reuse/recycling and release to land, no specific levels can easily be developed on the extent of their use, as these will depend on site-specific factors such as demand, location, climate (rainfall), wastewater characteristics (suitability for use) and land availability. Some level of reuse/recycling and release to land have been demonstrated at many plants in Queensland, with smaller facilities more often adopting release to land. Reuse/recycling and release to land must be considered before release to water. Where adopted, release management involving large-scale reuse or release to land schemes should involve minimal or no dry weather release to water. Aspirationally, long-term strategies for wastewater release management should involve net-zero release of nutrients to water through a combination of reuse/recycling, release to land, and best practice treatment for release to water.

The proposed leading practice levels presented in this report are potentially relevant to new and expanding facilities in the Reef catchment which employ continuous release to water but will require case-specific economic and environmental assessment. The use of green/passive technologies, including artificial wetlands, should also be considered where appropriate, particularly for green-field sites. The leading practice levels are also potentially relevant more broadly across Queensland although further information on larger facilities and more urbanised catchments is required.

Glossary of terms

Term	Description
Alum	Aluminium sulphate—coagulant used during the treatment of wastewater, effective as a clarifying and sludge dewatering agent. Alum binds with phosphorus in water under most conditions so the phosphorus can no longer be used as food by algae organisms and will accumulate in the sludge.
ADWF	Average dry weather flow—the combined average daily flow rate entering the sewage treatment plant during dry conditions (when no stormwater runoff is occurring).
AWA	Australian Water Association.
Best practice	Best practice is defined in the *Environmental Protection Act 1994*. For the purposes of this report, best practice is defined as treatment or management approaches that achieve the highest standard successfully demonstrated at full-scale in Queensland. This may relate to several different areas of wastewater management and pollutant removal. Also see Leading Practice.
Biosolids	Biosolids are the nutrient-rich organic materials resulting from the treatment of domestic sewage in a sewage treatment facility (i.e. treated sewage sludge).
BNR	Biological nutrient removal—a treatment process using microorganisms/bacteria to remove nutrients such as nitrogen (ammonia, nitrate, nitrite, organic nitrogen) and phosphorus (phosphate, organic phosphorus, and all other forms).
BOD_5	Biological Oxygen Demand (5-day)—measure of the amount of oxygen required to breakdown organic pollutants biologically with microorganisms. It gives an indication of the contamination of the water by organic substances. It is expressed as the number of milligrams of oxygen required by microorganisms to oxidise the organics in a litre of water over a 5-day period at 20°C.
COD	Chemical oxygen demand—measure of the amount of oxygen needed to oxidize the chemical organic materials present in the water. Similarly to BOD_5, COD gives an indication of the quantity of organic contaminants in wastewater.
Contaminants of Emerging Concern (CECs)	CECs may be defined as any natural, manufactured, or manmade chemical seldom monitored in the environment that is suspected, or known, to cause adverse ecological effects. These include a wide array of pharmaceuticals, personal care products, food additives, illicit drugs, microplastics, nanomaterials, pesticides, flame retardants, plasticisers, and other industrial chemicals (Kuskopf et al., 2020).
CPR	Chemical phosphorus removal— referred to as the use of metal salts, mainly alum, to remove phosphorus from wastewater.
Denitrification	Denitrification is the microbial process of converting nitrate and nitrite to gaseous forms of nitrogen, i.e. nitrous oxide (N_2O) and nitrogen gas (N_2). This process requires anoxic conditions.
DES	Department of Environment and Science, Queensland Government.
DEWS	Department of Energy and Water Supply, Queensland Government.
Digester	Typically a closed and deep circular tank that uses the naturally occurring anaerobic (i.e. living without oxygen) microorganisms to break down organic materials into methane and carbon dioxide.
Disinfection	A process that destroys, inactivates or removes microorganisms. The three common methods of disinfection for wastewater treatment systems are chlorination (using chlorine), ultraviolet radiation, and ozonation (using ozone).
Domestic wastewater	Wastewater from residential settlements and services, such as houses; and which originates predominantly from toilets, bathrooms, and kitchens. Also referred to as sewage.
Effluent	The liquid released from a treatment unit or system. It is usually qualified according to the type of prior treatment received, e.g. septic tank effluent, secondary treated effluent.
Environmental Approval	In this report, Environmental Approval refers to an Environmental Authority (EA) issued under Queensland Environmental Protection legislation. Also known as a permit or licence.
Environmental Management	Actions, including design, operation, maintenance and monitoring of the system, that will help ensure environmental impacts related to these activities are mitigated and minimised, particularly in relation to wastewater management.
EP Act	*Environmental Protection Act 1994.*
EP	Equivalent Persons—The quantity of sewage release for a person resident in a detached house. A person living in a typical home is estimated to generate 200 litres of sewage per day, carrying 60 grammes of BOD. Therefore, 1 EP is equal to 200 L of flow containing 60 g of BOD.
ERAs	Environmentally Relevant Activities—include prescribed ERAs (e.g. sewage treatment plants, quarries, abattoirs, and aquaculture operations) and resource activities (e.g. mining). Sewage treatment plants are prescribed ERA 63.

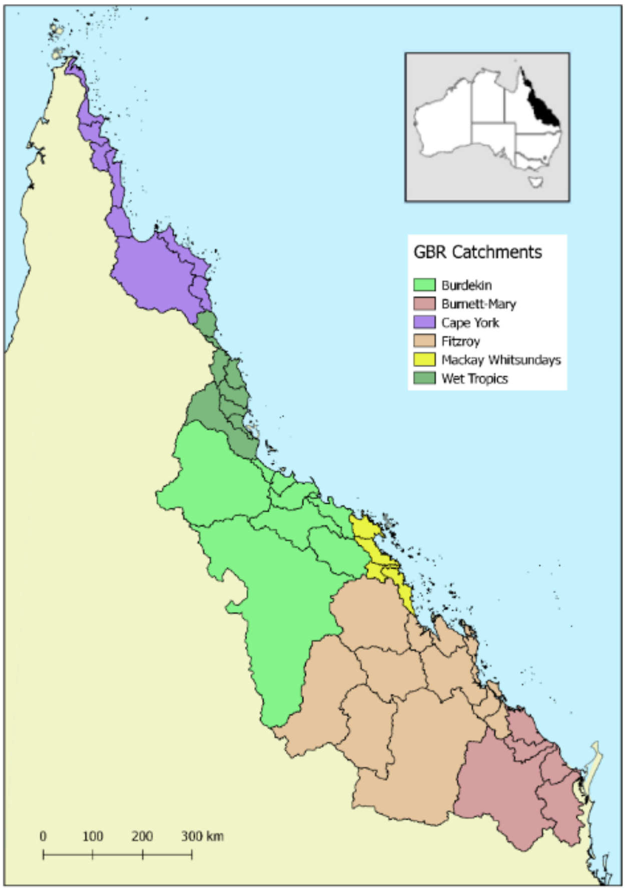
Term	Description
EVs	Environmental values—for water these are the qualities that make it suitable for supporting aquatic ecosystems and human uses. EVs define the human uses of the water to include drinking water, irrigation, aquaculture, recreation, and cultural/spiritual values.
Facility	A plant or system for the treatment and disposal of sewage, not including the sewage collection system or reclaimed/recycled/reused water distribution system.
FRP	Filterable Reactive Phosphorus—a measure of orthophosphate, the filterable (soluble, inorganic) fraction of phosphorus. FRP is the form directly taken up by plant cells.
GHG	Greenhouse gases—most commonly carbon dioxide, water vapour, methane, nitrous oxide and chlorofluorocarbons.
IDEAL or IDAT	Intermittently Decanted Extended Aeration Lagoon or Intermittently Decanted Aerated Tank—a technology used to treat domestic wastewater which includes an aeration period, a settling period, and a decanting period successively repeated in that order in a single lagoon. It focuses on eliminating solids and ammonia in wastewater. The IDEAL can provide full nitrification while removing most of the total nitrogen through denitrification, while low phosphorus levels, when required, are usually accomplished by addition of chemicals.
Leading Practice (LP)	In this report, Leading Practice is defined as wastewater treatment or management approaches that meet the most stringent environmental approval standards in Queensland. See also Best Practice which is a sub-set of Leading Practice.
Load	In this report, Load refers to the total amount of a nutrient, i.e. total nitrogen or total phosphorus, or other contaminant, entering the water over a specific period, e.g. kg/year.
Nitrification	A biological process that converts ammonia to nitrite and nitrite to nitrate. This process requires aerobic conditions.
Nutrient releases	Point source releases that are likely to contain significant quantities or concentrations of nutrients, particularly nitrogen and phosphorus.
Nutrient offset	Alternative investment options to meet wastewater discharge requirements through the inclusion of water quality offset conditions that delivers an improvement in water quality in the receiving environment—see https://environment.des.qld.gov.au/__data/assets/pdf_file/0033/97845/point-source-wq-offsets-policy-2019.pdf . Under this Offset Policy, offset contaminants include total nitrogen (and/or stated chemical species e.g. dissolved inorganic nitrogen), total phosphorus (and/or stated chemical species e.g. filterable reactive phosphorus) and total suspended solids.
PFAS	Perfluoroalkyl and Polyfluoroalkyl Substances—a group of over 4,000 chemicals. Some PFAS are very effective at resisting heat, stains, grease, and water, making them useful chemicals for a range of applications. They are highly mobile in water and can be found long distances from their source-point. They do not fully break down naturally in the environment, and they are toxic to a range of animals.
Point source	Industrial activities that release water and contaminants to the environment from a specific location. In this report, point sources are ERAs.
Primary Treatment	Processes for separation of suspended and settleable solids (sludge) from liquids by sedimentation. Solids are stabilised by digestion.
Reef catchment	Geographical areas related to the Great Barrier Reef Lagoon.
Release	Release of treated effluent to the environment, typically either to water or to land.
REMP	Receiving Environment Monitoring Program—monitoring programs often required under EAs with authorised release to water.
SBR	Sequencing Batch Reactor—a type of activated sludge process used to treat wastewater/sewage. The SBR process involves a single complete mix type reactor in which aeration takes place followed by clarification. Sludge settles when aeration is shut down and a drainage mechanism is used to draw off the supernatant liquor. The various treatment stages take place at predetermined and programmable intervals, all the stages constituting a cycle.
SCADA	Supervisory Control and Data Acquisition—a distributed computer system that is used by operation and management staff for process monitoring and automation. This includes monitoring pH levels, turbidity, salinity, temperature, flows, water levels and more.
SEQ	South East Queensland.
Settlement Pond	Treatment unit designed to encourage the sedimentation of particulate material from the water column to reduce total suspended solids but is less efficient at removing nutrients.
Sewage	Any human excreta or domestic waterborne waste, whether untreated or partially treated.
Sewerage System	Sewerage systems include the main infrastructure and ancillary works for the conveyance of sewage to treatment systems for treatment and disposal.
Sludge	The settled solids from wastewater treatment processes.

Term	Description
STP	Sewage Treatment Plant—In this report, it is defined as a facility designed to treat sewage that is received from a sewerage system, typically from domestic households but can also include trade waste from commercial and industrial activities.
TN	Total Nitrogen—includes dissolved and particulate nitrogen.
TP	Total Phosphorus—includes dissolved and particulate phosphorus.
Trade Waste	Wastewater (other than sewage) that comes from manufacturing, processing, or other commercial or industrial premises.
TSS	Total Suspended Solids.
UQ	University of Queensland.
Water Recycling	A process where treated wastewater is further treated to a level suitable for a range of purposes.
WaTERS	Water Tracking and Electronic Reporting System—database system used to submit water monitoring data electronically to the Department of Environment and Science.
WQOs	Water Quality Objectives—set of limits needed to protect the environmental values for a particular waterbody. May be scheduled under the Environmental Protection Policy for Water and Wetland Biodiversity.

1. Introduction

Centralised treatment is the most common method for managing domestic wastewater in Queensland, as well as the whole of Australia. This is particularly the case in urbanised areas where populations are greater than 1,500 equivalent persons (EP). Available technology, the site location, wastewater characteristics and the fate of the treated wastewater often determine the level of treatment adopted. The fate of treated wastewater can involve release to water, release to land (often via irrigation) and various forms of reuse. In Queensland, large urban centres are often located in coastal areas and release of wastewater to estuarine and other inshore coastal areas is common. However, direct release to ocean and open coastal areas is less common in Queensland. Given this scenario, there has been a strong focus over the last 20 years on removal of nutrients from domestic wastewater, particularly nitrogen and phosphorus. Nitrogen is often considered the limiting nutrient in estuarine/marine waters, while phosphorus is considered the limiting nutrient in freshwater. The current concentration standards for sewage treatment plants (STPs) in Queensland are 5 mg/L nitrogen and 1 mg/L phosphorus in release water, irrespective of plant size or setting. These levels have been adopted in Environmental Authorities (EAs) as release limits for many modern STPs in Queensland (since the 1990's).

Ramsay et al., 2021, assessed the relative point source nutrient load contributions for the Reef catchment (Figure 1-1). Based on the 75 point source activities that had monitoring data, these were estimated to be less than 4% for total nitrogen (TN) and less than 9% for total phosphorus (TP) of overall anthropogenic catchment loads. Although these point source loads are relatively small, STPs contributed approximately 80% of both the nitrogen and phosphorus loads. Therefore, efforts to minimise nutrient loads from STPs should be explored. However, the majority of STPs in the Reef catchment are currently achieving very high levels of treatment and removing significant levels of nitrogen and phosphorus prior to the release of wastewater to the environment.



Cape York	Endeavour Jacky Jacky Jeanie Lockhart Normanby Olive Pascoe Stewart
Burdekin	Belyando Black Bowen Don Haughton Lower Burdekin Ross Suttor Upper Burdekin
Fitzroy	Boyne Calliope Comet Curtis island Dawson Fitzroy Isaac Mackenzie Nogoa Shoalwater Styx Waterpark Creek
Wet Tropics	Barron Daintree Herbert Johnstone Mossman Mulgrave-Russell Murray Tully
Mackay Whitsundays	O'Connell Pioneer Plane Creek Proserpine
Burnett-Mary	Baffle Creek Burnett Burrum Kolan Mary

Figure 1-1 Reef catchment regions and sub-catchments

More intensive levels of treatment, particularly for hard engineered solutions, do not appear to be economically viable at present, as treatment is constrained by the currently available technology and high capital and operating costs. Greater technical expertise is also often required for operating and maintaining such activities. More intensive treatment can also have higher environmental cost, including greater chemical and energy consumption and associated greenhouse gas (GHG) emissions. In addition, there is limited funding available for constructing new STP infrastructure in Queensland.

Populations are expected to continue to increase in many areas of Queensland. Nutrient release loads are therefore also expected to increase because of increased release volumes, even if release concentrations do not change. The increased loads will contribute to overall catchment loads in Queensland. Other options to reduce nutrient loads released to the environment include reuse and alternative disposal solutions. In the urban setting, both options appear to be significantly constrained due to space limitations and cost.

Other important considerations include the management of solids, particularly biosolids, especially in relation to their reuse and disposal. Broader environmental implications are also increasingly being considered, particularly greenhouse gas and carbon dioxide emissions, whether through the direct production of these gases from treatment or more broadly from production of chemicals used for treatment and the energy needed to operate the treatment systems. Potential changes to PFAS management nationally also pose increased barriers to effective and sustainable management of both recycled water and biosolids management.

The *Environmental Protection Act 1994* defines best practice environmental management as the “management of the activity to achieve an ongoing minimisation of the activity’s environmental harm through cost-effective measures assessed against the measures currently used nationally and internationally for the activity.” This definition suggests an element of change over time, i.e. continual improvement. For councils who own STPs, this is a challenge as infrastructure planning and implementation happens over decades. Operational optimisation is possible but will be limited depending on the treatment adopted. For regulators in Queensland, continual improvement cannot easily be enforced through the current approval process which provides approval and authorisation to operate indefinitely. Additionally, regulators in Queensland are unable to make changes to active EAs unless the client requests an administrative change or there is an application, i.e. expansion of the plant, or under other limited circumstances.

In this review, leading practice is focused on those STPs in the Reef catchment which are excelling in relation to wastewater treatment and management and are at, or above, the highest level of approval obligation. The focus of the review is on leading practice STPs in the Reef catchment in relation to removal of nutrients from wastewater, with particular attention on minimising contaminants released to water. However, in this review, environmental management is more broadly related to any activity, including design, operation, maintenance, and monitoring of the system, that will help ensure environmental impacts related to these activities are mitigated and minimised, particularly in relation to wastewater management. Activities include all forms of treatment, chemical usage, energy usage, greenhouse gas production and solid waste (sludge/bio-solids) management. The greater system view includes the sewage treatment plant and related wastewater management network, including the sewer network and treated wastewater management.

The main aim of this review was to present an overview of STP leading practice environmental management for facilities within the Reef catchment, including associated islands, and potentially others in Queensland. The second objective was to help define leading practice levels for wastewater release to waters, particularly in relation to nutrient removal, to assist with management and investment decisions. The review is expected to provide benchmarks for councils looking to upgrade infrastructure or improve performance of their STPs with respect to nutrient removal, but also considering site specific factors such as size, location and catchment characteristics (e.g. industrial load), and broader environmental and economic implications. The review is specifically aimed at centralised, publicly owned STPs in Queensland. Sewage treatment plants under 21 EP (not regulated as ERAs) and privately owned facilities were not considered in this review. On-site wastewater treatment, such as septic or soil absorption systems, were also outside the scope of this review.

This review involved an assessment of both qualitative and quantitative information on STPs. Qualitative information on Queensland’s STPs was obtained from interviews and meetings with Queensland regional councils and water utilities, as well as scientific and business papers. The quantitative analysis was based on two main sources: firstly, release monitoring data was obtained from the department’s Water Tracking and Electronic Reporting System (WaTERS) for water quality and quantity collected as required by environmental approvals between 2015 and 2019. Some of this data were obtained from a specific data request in 2019. Release monitoring information was available for 65 council owned STPs authorised to release wastewater to water bodies in the Reef catchment, with 50 of these being on the mainland. Secondly, an STP environmental management questionnaire was developed and sent to all council STP operators in the Reef catchment as part of the work undertaken by Ramsay et al., 2021. Information was obtained on a range of operational details including design capacity, current operational level, treatment upgrades, major treatment units, chemical use, reuse information, bio-solids, energy use, and capital and operating costs. Information was available on 124 of 137 council owned STPs operating in the Reef catchment at the time of the survey. A selection of this data were used for this review. In addition, approval information, including release limits, was available for 93 council owned STPs that are authorised to release to water in the Reef catchment.

Treatment facilities achieving low nutrient concentrations in the treated wastewater prior to release were the major focus. These treatment plants were then assessed and compared in terms of the operational data that was available. Benchmarks were then developed for several categories of leading practice; the highest category being called best practice.

The report firstly includes a review of regulation of STPs in Queensland, with particular emphasis on requirements typically associated with wastewater release to water. Key water quality contaminants associated with STPs are then discussed along with the typical wastewater release limits that are currently observed in environmental approvals in Queensland. A major part of the report focuses on an assessment of leading practice environmental management of STPs, including a critique of current approaches and case studies of selected facilities. The final section of the report presents a set of leading practice benchmarks for STPs involving wastewater release, before recommending further work needed to better define leading practice of STPs in Queensland and the Reef catchment.

2. Queensland Regulation

The principal environmental objective of regulation is to ensure that development is environmentally sustainable and that environmental values, such as for surface and groundwater (e.g. drinking water, stock watering, irrigation, etc.), are protected. In Queensland, environmental protection legislation defines certain activities as Environmentally Relevant Activities (ERAs). Sewage treatment is defined as ERA 63 and it is a requirement for such activities to have environmental approvals (EAs) that contain conditions regarding operation, including monitoring and release limit criteria. In Queensland this process is administered primarily by the Department of Environment, Science and Innovation (DESI) and standard operating conditions, along with site-specific conditions, typically apply.

In assessing applications for ERA 63, regulatory requirements for assessing wastewater releases are covered in the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 and the standard criteria contained in the EP Act. Section 63, Part 13, Schedule 2 of the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 defines ERA 63 – sewage treatment and the relevant thresholds (intensity categories) – available at https://www.legislation.qld.gov.au/view/html/inforce/current/sl-2019-0155#sch.2-sec.63.

The administering authority will consider the regulatory requirements in the context of information about the environmental impacts of a project, provided through application documentation for an environmental authority. Additionally, the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 outlines the waste management hierarchy, which 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, and
(g) DISPOSE of waste only if there is no viable alternative.

In a wastewater treatment and disposal context, the hierarchy from the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 can be summarised as:

(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, and
    - appropriate treatment and release to surface waters or groundwaters.

There are many environmental laws and authorities that regulate sewage treatment. Generally, the level and type of regulation depends on the scale of the activity and level of environmental risk. In other words, the standards for release should be fit-for-purpose. Therefore, leading practice management may vary depending on the circumstances. Typically, there is a development approval and conditioning requirement that focuses on minimising development related impacts to the environment. The EPP Water and Wetland Biodiversity 2019 defines sewage treatment intensity thresholds based on the plant’s total peak design capacity and not the actual, average or estimated flows (Table 2-1).

Table 2-1 Sewage treatment activity classification (size)

STP Size	Equivalent Person (EP)
63-(1a) (i)	>21 to 100 EP - IT or IR
63-(1a) (ii)	>21 to 100 EP - no IT or IR
63-(1b) (i)	>100 to 1500 EP - IT or IR
63-(1b) (ii)	>100 to 1500 EP - no IT or IR
63-(1c)	>1500 to 4000 EP
63-(1d)	>4000 to 10000 EP
63-(1e)	>10000 to 50000 EP
63-(1f)	>50000 to 100000 EP
63-(1g)	>100000 EP

Note: IT = Infiltration Trench, IR = Irrigation

Point source activities have been indicated as potential contributors 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 activity will have a "residual impact" on Reef catchment 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. This offset is therefore relevant to all new and expanding STPs in the Reef catchment.

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 of receiving environment, and risk of environmental harm. Domestic wastewater contains a range of contaminants that may require nutrient release limits along with limits on release flow or volume, which restrict the quantities of contaminants (or loads) released to the environment. Typical monitoring conditions for sewage treatment activities involving release to waters include indicators and limits as discussed in Section 3. In addition, the release volume (or rate) is also monitored, generally on a daily basis.

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

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

3. Wastewater Contaminants

The levels of nitrogen, phosphorus, organic matter, suspended solids, pathogens, and a range of other contaminants in wastewater may need to be considered when assessing environmental management practices of STPs. These contaminants are discussed in more detail below.

3.1 Total Nitrogen, Ammonia and Oxidised Nitrogen

In a domestic wastewater treatment context, the major contributor to nitrogen is human urine (Van der Hoek et al., 2018). However, by the time a waste stream reaches a sewage treatment plant, most of the urea from the human urine has been hydrolysed to ammonia. As a result, the total nitrogen (TN) concentration in sewage treatment is an aggregate of organic nitrogen, ammonia (including ammonium), nitrate and nitrite. The TN of human waste streams has typical concentrations up to 8,800 mg/L (Van der Hoek et al., 2018). In comparison, sewage Kjeldahl nitrogen concentrations that enters sewage treatment plants typically range from 1 to 100 mg/L (Camargo and Alonso, 2006). In addition to nutrients from human waste, food waste, cleaning products, hygiene products, pharmaceuticals, other industrial loads and ointments can increase nitrogen loads. The resulting influent nitrogen concentrations to STPs typically contains between 2 mg/L and 85 mg/L and can exceed 120 mg/L with very low water consumption per EP or when suitable trade waste is released (Camargo and Alonso, 2006).

Nitrogen in STP releases in Queensland is currently regulated using TN concentrations, but often also includes ammonia concentrations. Ammonia is both a dissolved nutrient and toxicant that is assimilated in the local receiving environment. According to the National Water Quality Guidelines (ANZG, 2018), ammonia has a toxicity trigger value of 0.9 mg/L for fresh and marine water based on the 95% level of species protection. High ammonia concentrations can also indicate low levels of treatment in terms of nitrogen removal or poorly/overloaded operating facilities. Nitrate (and nitrite) are also relevant indicators for STPs and nitrate concentrations in wastewater releases can be high depending on the type of treatment that is adopted. Nitrate is also a potential toxicant in freshwater ecosystems. The combined nitrate and nitrite concentrations is referred to as oxidised nitrogen (or NO_x) and is a relevant environmental indicator. Organic nitrogen can also be present in wastewater releases in significant concentrations depending on the type of treatment that is adopted and the source of wastewater. This may be present in a dissolved or particulate form, although it is generally considered as the difference between TN and the sum of ammonia and NO_x.

Typical TN annual median release limits for STPs in the Reef catchment are shown in Table 3-1. Fifty-five of 93 STPs have TN release limits and this relates to 87% of plants involving release to water. The most common median TN release to water limit, particularly for the larger STPs, is 5 mg/L. Plants with this TN concentration limit are currently considered in Queensland as achieving “best practice” for nutrient removal. Smaller size STPs may have higher median TN release limits, up to 20 mg/L. The most common maximum TN release limit is 15 mg/L across all size categories, although a value of 10 mg/L is also commonly applied.

Table 3-1 TN release to water limits for STP facilities in the Reef based on STP size

ERA 63 Category	EP	Number of STPs	TN Annual Median (mg/L)	TN Maximum (mg/L)	Number of STPs with a TN limit*
1b(ii)	>100 to 1500	24	15 (5–20)	30 (10–40)	12 (50%)
1c	>1500 to 4000	23	7 (3–20)	15 (2–30)	13 (57%)
1d,1e,1f,1g	>4000	46	5 (3–12.5)	15 (10–30)	30 (65%)

Note: limits show the middle value and range (in brackets) for all facilities with limits in that category. The percentage of STPs is calculated based on the total number of STPs which are authorised to release to waters in the Reef catchment. *TN limits can be either medians or maximums or both.

Ammonia concentration limits for STPs in the Reef catchment that release to water are shown in Table 3-2. Forty-six of 93 facilities have ammonia release limits relating to 73% of STPs involving release to water. Maximum limits range from 1 to 10 mg-N/L across all size categories. The most common maximum limit is 3–5 mg-N/L. There is currently no release to water limit for nitrate or oxidised nitrogen (NO_x) for these STPs. However, nitrate is a potential toxicant in freshwater environments and may need to be monitored and assessed where high release concentration and low receiving water dilution presents a potential risk.

Table 3-2 Ammonia release to water limits for STP facilities in the Reef based on STP size

ERA 63 Category	EP	Number of STPs	Ammonia Maximum (mg-N/L)	Number of STPs with limits
1b(ii)	>100 to 1500	24	8 (1–10)	13 (54%)
1c	>1500 to 4000	23	2 (1–10)	11 (48%)
1d	>4000 to 10000	18	3 (2–7)	8 (44%)
1e	>10000 to 50000	22	5 (2–6)	8 (36%)
1f	>50000 to 100000	4	5 (3–6)	4 (100%)
1g	>100000	2	3 (1-4)	2 (100%)

Note: limits show the middle value and range (in brackets) for all facilities with limits in that category. The percentage of STPs is calculated based on the total number of STPs which are authorised to release to waters in the Reef catchment.

3.2 Total Phosphorus

Phosphorus as phosphate is another nutrient used in food production and is important as a structural element in DNA. Like nitrogen, it is present in excess in wastewater systems due to agricultural runoff and human excreta, and to a lesser extent, domestic cleaning products (Bunce et al., 2018). A report from the UK estimated the contribution of phosphate by certain domestic activities, and diet, was estimated at 40% of the domestic load, food additives were 29%, and household cleaning products including laundry and dishwashing products contributed 23% (Comber et al., 2013). The authors suggested that the UK context would be mirrored in other locations with similar socio-economic conditions. The consequences of excess phosphorus concentrations and loads in the environment are similar to those caused by excessive nitrogen levels, with nitrogen having the largest impact on seawater and coastal systems, and phosphorus having bigger impacts inland (Kogawa et al., 2017).

Phosphorus exists in water as both dissolved and particulate forms. Total phosphorus (TP) measures both of these forms. Particulate phosphorus includes phosphorus bound up in organic compounds such as proteins and phosphorus adsorbed to suspended particulate matter, such as clays and detritus (dead and decaying organisms). Dissolved phosphorus is considered the most bioavailable and is most commonly characterised as filterable reactive phosphorus (FRP) but is not typically monitored by STP operators.

Typical annual median release limits for TP for STPs in the Reef catchment are shown in Table 3-3. Fifty- five of 93 facilities have TP release limits relating to 87% of plants involving release to water. The median release to water limit for TP ranges from below 1 to 10 mg/L. The most common median limit, particularly for larger size plants is 1 mg/L. This value is currently considered best practice release concentration limits for modern STPs in Queensland. The maximum release to water TP limits range from 1 to 30 mg/L; the most common maximum limit, particularly for larger size plants, is 3 mg/L. Monitoring and regulation of FRP in release water is generally not a requirement of the environmental approvals.

Table 3-3 TP Release to water limits for STP facilities in the Reef based on STP size

ERA 63 Category	EP	Number of STPs	TP Annual Median (mg/L)	TP Maximum (mg/L)	Number of STPs with limits
1b(ii)	>100 to 1,500	24	8 (0.5–10)	15 (1–15)	12 (50%)
1c	>1,500 to 4,000	23	3 (0.1–10)	8 (1–30)	13 (57%)
1d,1e,1f,1g	>4,000	46	1 (0.3–10)	3 (2–30)	30 (65%)

Note: limits show the middle value and range (in brackets) for all facilities with limits in that category. The percentage of STPs is calculated based on the total number of STPs which are authorised to release to waters in the Reef catchment.

3.3 Organic Matter and Suspended Solids

Treatment of sewage containing organic matter is one of the main purposes of the STP. Organics and suspended solids can be removed during a number of stages in the STP through different processes including preliminary treatment (e.g. removal of large objects, grit, fat and grease, and flow equalisation), primary treatment (gross solids removal through sedimentation tanks), secondary treatment (biological removal), and tertiary treatment (finer sediment removal).

The organic fraction contained in the wastewater is largely digested and reduced in the secondary treatment using biological processes involving microorganisms to treat wastewater and measured as biochemical oxygen demand (BOD_5). The treatment is mainly using aerobic (in the presence of oxygen) and anaerobic (in the absence of oxygen) processes. These processes can be performed with either suspended growth or a biofilm (attached) process. At the end of the treatment, biosolids (including biomass) are expected to be settled as a sludge, leaving the treated wastewater significantly free of solids, and potentially with a considerably reduced concentration of pollutants.

Table 3-4 describes a comparison and recapitulation of different secondary treatment units used to remove organic matters in the Reef's STP facilities. It was found that activated sludge (suspended growth biological process) is the most common technology used in the STP facilities in the Reef catchment followed by wastewater treatment pond systems (Ramsay et al., 2021).

Table 3-4 Comparison of secondary treatment units used in removing organic matter in Reef STPs

Treatment unit	Number of STPs	Percentage of STPs (%)*
Activated sludge (suspended growth)	65	47
Ponds/lagoons/wetlands	60	44
Trickling filter	19	14
Septic tank/Imhoff tank	13	9
Trenches	5	4

*compared to 137 council owned STPs operating in the Reef catchment at the time of the survey

Biochemical Oxygen Demand

BOD (commonly expressed as BOD_5 for the 5-day biochemical oxygen demand) is a measure of the concentration of organic matter within environmental systems. It is important to remove BOD_5 from water systems, as its breakdown consumes dissolved oxygen in the water (Tchobanoglous et al., 1991). This reduction of oxygen leads to anoxic conditions, with negative impacts on aquatic life relying on dissolved oxygen for respiration. As a result, dissolved oxygen is commonly measured in treated sewage which is released to the environment, although these oxygen levels will change over time if BOD is present. Conventional technologies for BOD_5 removal include activated sludge or other biological treatment systems, physical separation of particulate organic matter such as clarifiers, and primary sedimentation treatment.

Generally, BOD limits are applied as maximums and long-term 80th percentiles (sometimes short-term as well). The maximum is generally 20 mg/L, while the long term 80th percentile is typically 10 mg/L, although these may vary from plant to plant.

Chemical Oxygen Demand

Chemical Oxygen Demand (COD) measures the amount of oxygen consumed by strong oxidants (e.g. potassium dichromate) in chemical oxidation of organic material in water. The main benefit of COD tests includes fast results within two hours, versus a week for BOD_5 tests. Additionally, COD tests are not subject to interference from toxic material, as with BOD_5 tests. The test results may also be more reproducible and detect lower levels than BOD_5 tests. However, given more organic compounds can be chemically oxidised than biologically oxidised, COD is normally two to three times higher than BOD (BMS, 2013) and will overestimate oxygen demand likely to occur in receiving waters. As a result, few STP approvals in Queensland have COD release limits, although some operators monitor COD in wastewater releases.

Total Suspended Solids

Total suspended solids (TSS) are another form of organic pollutant, and they also contain nutrients which can be liberated as pollutants in reef systems (or any other environment). It is important to note that most of the TSS associated with STP releases are likely to be organic in nature, from algae or bacteria, rather than more geologically derived sediment observed from catchment runoff. Therefore, potential disadvantages of excessive TSS are similar to those of nutrient and organics. Additionally, solid particles can be vectors for pathogens and they can attenuate sunlight penetration, which has flow on effects, not only to the ecosystem that requires sunlight to sustain life, but to tourism through poor diving and snorkelling visibility. Process units involved in the treatment of suspended sediment include primary treatment units such as equalisation tanks, sedimentation tanks or clarifiers, and grit removers (Tchobanoglous et al., 1991).

Generally, TSS limits are applied as maximum and long-term 80th percentiles. The maximum is generally 30 mg/L while the long-term 80th percentile (or 90th percentile) is in the order of 14 or 15 mg/L, although these may vary from plant to plant.

3.4 Pathogens

As the main goal of wastewater treatment is the protection of public health, careful consideration needs to be taken in relation to pathogens in wastewater streams. Pathogens can be classed into viruses, bacteria, protozoa, and disease-causing parasites. Microbial pathogens are one of the major health issues related to municipal wastewater. Humans can experience a range of symptoms from pathogen infections including mild to severe illnesses and even death (Jimenez et al*.,* 2010). Sewage wastewater may contain different species of pathogens, such as *Salmonella, Shigella, Escherichia coli (E. coli), Streptococcus, Pseudomonas aeruginosa, mycobacterium* and *Giardia lamblia*. Standard parameters of faecal contamination include *E. coli*, total coliforms, enterococci, and *Clostridium perfringens*.

Pathogen monitoring and setting of release limits for STPs in Queensland has traditionally used faecal coliform and *E. coli* counts as the standard measure. Faecal coliform bacteria consist of six species that are found in animal wastes and human sewage. The monitoring of faecal coliforms as a pathogen indicator is no longer recommended, instead favouring the monitoring of other pathogen indicators such as *E. coli*. *E. coli* measurement is relatively straightforward and inexpensive. However, it is not possible to know whether *E. coli* are of human, animal, or avian origin. *E. coli* is more commonly used to assess recycled water based on the National Guidelines for Water Recycling: Managing Health and Environmental Risks (National Water Quality Management Strategy/NWQMS, 2006), available at: https://www.waterquality.gov.au/sites/default/files/documents/water-recycling-guidelines-full-21.pdf.

Enterococci are another group of bacteria commonly used as indicator organisms for marine and estuarine waters. Additionally, enterococci are widely accepted as useful indicators of faecal contamination in both marine and freshwater systems because they are:

- Always present in the faeces of warm-blooded animals,
- They are unable to multiply in sewage contaminated water, and
- Their persistence rates are greater than *E. coli* and more similar to those of waterborne pathogenic bacteria (but not viruses).

Enterococci are typically more human-specific than the larger faecal streptococcus group. The World Health Organization advocates the use of enterococci as the preferred microbial indicator for assessing the risk of faecal contamination (NHMRC 2008; WHO 2003).

The faecal coliform or enterococci limit applied to the release water will depend on the recreational value of the receiving water, either primary or secondary. The recreational water quality guidelines are generally applied directly to the point of release (i.e. no consideration of mixing zones). Enterococci is the preferred indicator for both fresh and marine waters; however, most EAs for STPs still specify release limits based on faecal coliforms.

3.5 Chlorine and Disinfection By-products

Treatment methods for pathogen removal may include chlorination, ultraviolet (UV) radiation treatment, and ozonation (Tchobanoglous et al., 1991). Many pathogens are also removed through solids separation (Tchobanoglous et al., 1991). Chlorine as sodium hypochlorite or chlorine gas is one of the most common methods used for disinfection of treated wastewater in Queensland. In general, a residual level of free chlorine is targeted within the disinfection tanks to ensure adequate reduction of pathogens. Free chlorine can be toxic to aquatic organisms if released to the environment. In addition, chlorine can react with other chemicals and organics to form disinfection by-products. Given the availability of ammonia and organic amines in many wastewaters, chloramines are a common disinfection by-product in treated wastewater that has been disinfected with chlorine. Total chlorine is the sum of free and combined chlorine (i.e. chloramines). Total chlorine is persistent in the environment and is toxic to aquatic organisms at very low levels.

Free chlorine limits have been applied to STP wastewater for many years. More recent approvals include monitoring of total chlorine, but to date limits have not generally been imposed. Nonetheless, the ANZ Guidelines for total chlorine in freshwater is 3 µg/L and has similarly been adopted for marine water as a low reliability number. This toxicity guideline value is in the order of 500–1000 times lower than the total chlorine levels typically observed in pre-treatment wastewater and is a major risk for STPs using chlorination as a treatment method. To reduce the risk of chlorine toxicity, dichlorination is recommended as best practice management; although application appears to be limited to only a few large plants in Queensland currently.

3.6 pH

The term “pH” refers to the measurement of hydrogen ion activity in a solution. A neutral pH condition, in the context of release water and receiving waters, is generally preferred over an acidic or alkaline pH. The pH can control the availability of nutrients, biological functions, microbial activity, and the behaviour of chemicals. Because of this, controlling the pH of water/wastewater is important for a wide variety of applications. pH is typically monitored and regulated for treated sewage wastewater releases. In most STPs, pH is measured continuously using an automatic pH recorder. Determination of pH plays an important role in wastewater treatment and will help control the treatment process to ensure optimal operational level of treatment units as well as help to explain the overall performance of the plant. Release monitoring data is necessary for proper regulation to ensure no potential adverse environmental impacts to the receiving environment occur from wastewater involving excessively high or low pH.

Generally, pH can easily be controlled within the treatment process and is not a major concern for wastewater releases to water. Wastewater release limits for pH are typically between 6 and 9 (or between 6.5 and 8.5). Elevated pH (>9 pH) can be observed for wastewater after treatment via ponds, due to high algal activity and loss of dissolved CO_2 during algal growth. This is not considered a major risk to most receiving environments, particularly if the wastewater is irrigated.

Along with pH, buffering should also be considered. Buffering refers to the ability of the water to resist changes in pH when mixed with an acid, base, or receiving water, and is due to the presence of weak acids and bases (CO_2, weak organic acids, calcium, magnesium). Water from wastewater treatment ponds may have a high pH but be poorly buffered due to loss of CO_2. Water from wetlands and conventional wastewater treatment may be circumneutral (~7) but highly buffered due to the presence of CO_2 and alkali salts. Neither circumstance poses a high risk to the environment, but an acidic or basic discharge with substantial buffering (e.g., where acid or base has been added) would represent an elevated risk.

3.7 Electrical Conductivity and Total Dissolved Solids

Most sewage treatment plants that treat wastewater originally sourced from a drinking water supply have relatively low levels of salinity, which is usually measured as electrical conductivity (EC) or total dissolved solids (TDS). Although EC and TDS are often monitored as part of treated wastewater releases, they are generally not regulated using limits, as the salinity is dependent mainly on the source of the water and is not changed significantly during treatment processes. These levels, for example less than 1,000 µS/cm, are not typically of concern when releasing to surface water or to land. Higher levels may be observed if the source water is derived from groundwater or there is saltwater infiltration into the sewer system, as sometimes occurs in coastal areas. Salinity is not a contaminant of concern for releases to estuarine and marine waters, however it can be a limitation if the treated wastewater is to be applied to land.

3.8 Emerging and other Water Contaminants

Emerging contaminants/pollutants can be defined as chemicals (synthetic or natural) contained in household and industrial products or microorganisms that are not usually monitored in the environment but have the potential to pollute the environment and could cause negative ecological and/or human health effects (Geissen et al., 2015). Many emerging contaminants are persistent in the environment and are able to disturb the physiology of target receptors, therefore they are considered pollutants of emerging environmental concern in recent years (Rout et. al., 2020). These chemicals have been labelled “emerging” due to the rising level of concern linked to them. Examples of emerging contaminants include pharmaceuticals (antibiotics and other drugs), personal care products such as sunscreen, pesticides, herbicides, endocrine disrupting compounds, microplastics, and flame retardants such as PFAS (per- and polyfluoroalkyl substances). There are potentially many different emerging contaminants that may enter the sewer system from commercial (trade waste) and domestic sources prior to treatment. There are limited source control strategies or initiatives for many of these emerging contaminants in Australia and there is a limit to the degree of control by councils and water utilities treating the wastewater.

At the time of this review, a comprehensive summary of emerging contaminant removal technologies in STPs is limited. The efficiency of emerging contaminant removal in STPs ranges between 20 and 50%, 30 and 70%, and >90% in the primary, secondary, and tertiary treatment stages, respectively (Rout et. al., 2020). In terms of emerging contaminant removal, the tertiary treatment technologies are considered as the most appropriate alternatives, but total emerging contaminant removal is yet to be accomplished. Technologies, such as pyrolysis for emerging contaminant removal from sludge, show potential but are currently in early stages of application. Methods such as ozonation and advanced oxidation may be applied, but are generally very expensive, carry secondary environmental impacts (due to energy, chemical consumption and emissions), and may result in polluting by-products. Therefore, innovations in developing the most efficient treatment technologies for emerging contaminant removal are still required (Rout et. al., 2020).

Starting in 2020, James Cook University partnered with Townsville City Council to identify and study the potential impact of Contaminants of Emerging Concern (CECs) being released from the Cleveland Bay Sewage Treatment Plant (CBSTP), which services more than 100,000 EP from Townsville suburbs (Kuskopf et.al., 2020). A second research project, started in 2021, is specifically evaluating impacts to Cleveland Bay’s turtle populations from the effects of antibiotic resistant genes and bacteria and what the transferal mechanism for antibiotic resistance is (Drane et al*.,* 2020). Kuskopf’s study also reviewed the types, concentrations, and environmental risks of emerging contaminants entering and leaving the CBSTP, the effectiveness of CBSTP’s membrane bioreactor in treating emerging contaminants, and better management techniques for future contaminant issues. One of the outcomes from the study revealed that the treatment plant was reducing up to 75% of detected emerging contaminants from sewage. However, residual loads could still be of concern as the CBSTP is a large facility.

Other known pollutants of potential concern in treated sewage wastewater include metals/metalloids, pharmaceuticals, and other organic pollutants. Metals/metalloids are generally not licenced and concentrations in the treated wastewater are typically very low when they are monitored at larger STPs. Most metals/metalloids are adsorbed to solids and end up in biosolids. Most organic and emerging pollutants are not monitored for routinely in treated sewage wastewater in Queensland as part of regulation, this includes PFAS and micro-plastics and this is increasingly a focus area of research.

A recent review of different types of emerging contaminants in sludge or biosolid samples from wastewater treatment plants and the impact of gasification of the biosolids on the emerging contaminant concentrations was recently undertaken by Kumar et al., (2022). It is available at: (https://www.sciencedirect.com/science/article/pii/S2405665022000117). This study was a collaboration between James Cook University, QLD Water, Townsville, Burdekin, Mackay, Cairns, Whitsunday, and Isaac Regional Councils.

4. Environmental Management of STPs

Sewage treatment is defined as the process of reducing or removing contaminants from wastewater transported by sewer networks managed by councils or water utilities. The source of sewage can be from residential, institutional, commercial, and industrial establishments but is predominantly residential in most cases. Residential or "household" wastewater is derived from toilets, baths, showers, kitchens, and sinks that drain to the sewer systems. The wastewater derived from industrial and commercial sources will vary depending on the activities involved and is typically managed through council "trade waste" agreements.

The flow rate or volume of wastewater produced varies between STPs and depends on the water usage levels of the service area of an STP, which can change during drought periods. There is strong correlation between the number of households in the area and the potential amount of wastewater, which will eventually define the effluent contaminant levels. However, there are other factors that may reduce the impact on the environment, such as effluent reuse technology, release to land or irrigation strategy, and intermittent effluent release options. Figure 4-1 illustrates general STP processes and leading practice strategies in environmental management of STPs. In this figure, pre-treatment can be included in trade waste LP – Strategies and biosolids are included in sludge management.

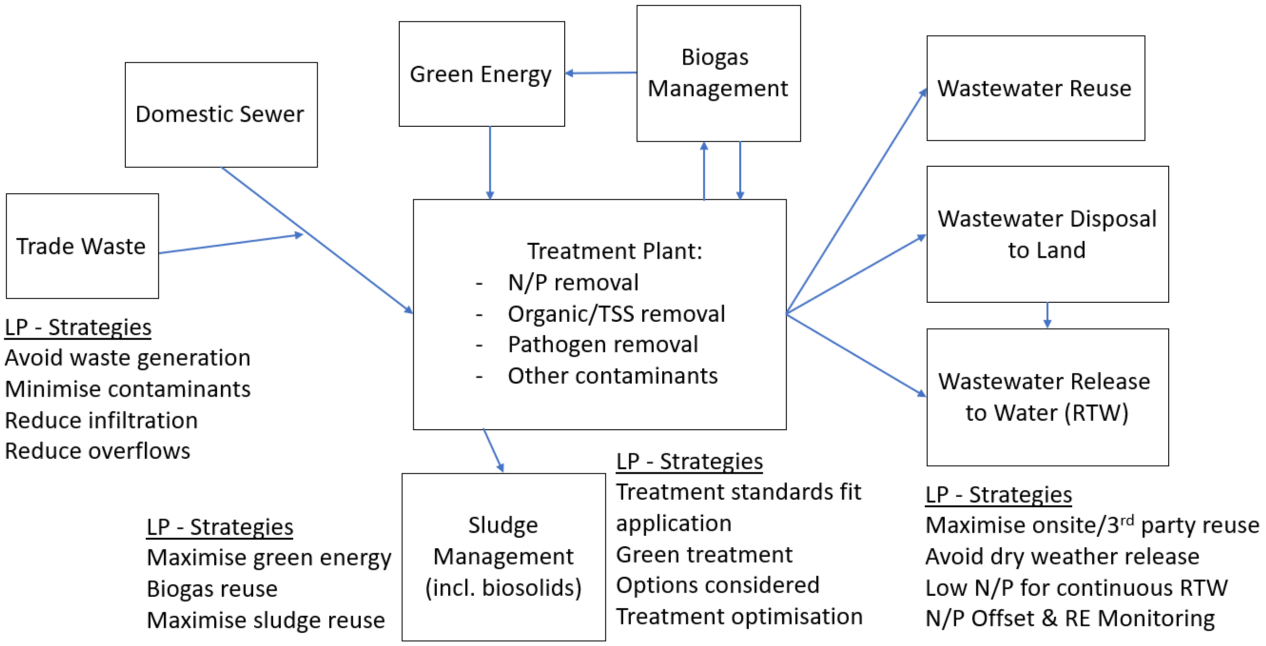


Figure 4-1 Overview of leading practice strategies in STPs

Leading practice examples of STP environmental management in Queensland have been gathered through a qualitative assessment (see Appendix A). This assessment was undertaken based on a literature review as well as interviews with relevant councils and Water Utilities in Queensland and other parts of Australia which have applied environmental management initiatives that could be classified as leading practice.

Scientific and business papers review

The collection of information on Leading Practice Management of STPs was by way of press releases, Australian Water Association (AWA) Water Source articles (2019) and scientific journal articles. Resources from the AWA were instrumental in developing an idea of what leading sewage treatment practice resembles around the country. In the AWA's Innovation category, there are many current examples of novel practices, and the list of articles was routinely updated. Articles discussed in this report reflect South Australia's drive to achieve net-zero electricity costs by 2020 using photovoltaic arrays (Water Source, 2019), South Australia's work on reducing nitrous oxide emissions by 30% in collaboration with the University of Queensland (Booth, 2019), and the use of smart water metering at Sydney Water for better water management, resulting in reduced water flowrates through sewage treatment plants (Prackwieser et al., 2019).

The peer-reviewed scientific articles related to the Great Barrier Reef catchment were provided by Townsville City Council from their collaboration with James Cook University (Cole et al., 2016; Neveux et al., 2016). These studies were focused on the recovery of nutrients by macroalgae as a tertiary treatment process for existing wastewater treatment plants (Cole et al.,2016), as well as on the possibility of conversion of macroalgal biomass to bio-derived crude oil (Neveux et al., 2016). The collaboration between Townsville City Council and James Cook University led to various awards including *Excellence in Sustainable Water Management from the United Nations Association of Australia Environment Day.* Another macroalgae trial was undertaken by Burdekin Shire Council as part of their wastewater management in protecting the Reef catchment from aquaculture and sewage treatment facilities. This small-scale pilot trial is part of a collaborative research project with James Cook University in partnership with Pacific Biotechnologies Pty Ltd (PacBio). The trial has demonstrated a reduction in nutrient concentrations in the treated effluent and is considered as an effective, low cost, scalable solution for all Councils (Townsville Enterprise, 2021).

Interviews and meetings

Contact was made with utilities known to have taken measures outside of what is considered conventional wastewater treatment. The following municipalities had sewage treatment plants which were known to use leading methods for nutrient removal, effluent reduction, or resourceful operation:

- Mackay Regional Council (comprehensive water recycling schemes)
- City of Townsville (macroalgae for nutrient removal), offsets trial program for Bohle River stormwater treatment and Condon STP nutrient offsets
- South Burnett Regional Council (first Nereda plant installed in Australia at Kingaroy Wastewater Treatment Plant)
- Unitywater (use of diatoms for nutrient removal)
- Cairns Regional Council (reduction and elimination of chemicals for phosphorus removal)

In order to develop an idea of leading practice for the Reef, it was necessary to extend the region of interest beyond the Reef to the whole of Queensland and the rest of Australia. The following councils and organisations were highlighted as being particularly active in innovative approaches to wastewater treatment.

- Urban Utilities (wide array of projects spanning reuse, cost reduction, energy reduction, and effective nutrient removal)
- Gold Coast City Council (holistic approach to wastewater treatment accounting for not just nutrient and pollutant removaland concurrently costs, energy requirements, minimising wastage, and reuse)
- South Australia Water (reduction in nitrous oxide emissions by 30% with engineered infrastructure and electronic monitoring)

Interviews were conducted with Urban Utilities (Brisbane region), Gold Coast City Council, and Unitywater (Sunshine Coast extending to the Reef catchment). During these interviews, utility representatives discussed various aspects of their catchment including technological solutions for wastewater treatment, community aspects of decision making, environmental impact considerations and the overarching theme that available funds and budgeting are the biggest barriers to the adoption of novel treatment technologies and approaches.

Much insight was derived from these meetings and interviews, and one key takeaway message is that this format for information gathering is complementary to questionnaires as it gives the interviewee the liberty to drive the conversation and uncover information which would not have necessarily been identified through questionnaires. The findings from these interviews are discussed in more detail in Appendix A.

4.1 Sewer Management

Sewer systems (sewerage) convey municipal wastewater (sewage) to a sewage treatment plant. Sewers usually consist of piping systems, chambers, maintenance holes/manholes and pumping station(s). In a combined sewer system, industrial wastewater can be connected to the sewer under a trade waste scheme/agreement. The sewer network is extensive and often aged. Issues may arise in the sewer systems, such as root intrusion, joint displacement, cracks, hole formations that lead to leakages and infiltration into soil and groundwater, and overflow through manholes during extreme wet weather with some risk to the environment and public health.

The former Queensland Department of Energy and Water Supply (DEWS), which is now the Department of Regional Development, Manufacturing and Water, published a document in 2014 titled Planning Guidelines for Water Supply and Sewerage (April 2010, amended in March 2014), which proposes standards for various aspects of sewer management in Queensland. Some of the key sewage flow parameters from this document are presented in Table 4-1.

Generally, the average dry weather flow (ADWF) or the combined average daily sanitary flow into a sewer from domestic, commercial, and industrial sources will be consistent with internal household water use and range from between 150-275 L/EP/d (DEWS, 2014). A useful review of methods used to estimate the ADWF is provided by de Haas et al. 2021.

For gravity sewers, the peak wet weather flow (PWWF) will be designed for a minimum of 5 times ADWF (Smart Sewers are based on 4 times ADWF). Based on DEWS (2014) and Water Services Association of Australia (WSAA) codes, full sewage treatment should be designed to provide for 3 times ADWF. A minimum of screening and settling should be provided for 3 to 5 times ADWF while coarse screening should be provided for greater than 5 times ADWF, noting more stringent conditions may be applied depending on the environmental sensitivity of the receiving water.

The approach historically adopted for Queensland sewage treatment is to design PWWF based on 5 times ADWF. Based on the equation presented in DEWS (2014), the peak dry weather flow (PDWF) is equal to a constant times ADWF. For EP of 5,000–100,000, the constant is equal to 1.9 to 1.4, respectively.

Leading practice sewer management involves having a good understanding of the sewer system through monitoring, modelling, and managing the system to minimise both dry and wet weather overflows, minimise groundwater infiltration and minimise wet weather infiltration.

Table 4-1 Key sewage flow parameters (taken from DEWS 2014)

Parameter	Abbreviation	Comments
Average dry weather flow	ADWF	This is the combined average daily sanitary flow into a sewer from domestic, commercial, and industrial sources. Note: this excludes any rainfall dependent inflow and infiltration (IIF).
Peak dry weather flow	PDWF	The most likely peak sanitary flow in a sewer during a normal day. It exhibits a regular diurnal pattern with morning and evening peaks.
Peak wet weather flow	PWWF	Indicates the peak anticipated sewage flow, expressed as the sum of the peak dry weather flow, groundwater infiltration (GWI), and rainfall dependent inflow (PDWF + GWI + IIF).
Groundwater infiltration	GWI	Groundwater (non-rainfall dependent) infiltration. Generally exists for sewers laid below groundwater table. Groundwater infiltration enters the system via defective pipes or joints and leaking manhole walls. GWI can generally be estimated as the flow between midnight and 4:00 am during dry periods.
Rainfall dependent inflow and infiltration	IIF	Peak (rainfall dependent) inflow and infiltration. This includes flow released into sewer from: • unauthorised roof, ground or stormwater drainage • leaking manhole covers • disconnected sewers • low disconnector traps • indirect infiltration of rainwater entering defective pipes and joints from the surrounding soil.

The sewer system is an essential element of Australia’s municipal infrastructure. The concrete network is susceptible to biogenic sulphide-induced corrosion leading to environmental issues (e.g. leakage, infiltration, odour, etc.). These issues have cost Australian water utilities and Regional Councils hundreds of millions of dollars each year for repair and maintenance. Some examples on sewer management projects undertaken by Gold Coast City Council in partnership with the University of Queensland can be found in Appendix A.

4.2 Wastewater Reuse and Recycling

As outlined in the Environmental Protection (Water and Wetland Biodiversity) Policy 2019 waste management hierarchy, water reuse and recycling are preferred over direct release to the receiving environment and water reuse practice is encouraged in promoting environmental sustainability. In waste management, reuse refers to using an object as it is without treatment whereas recycling involves reprocessing or treatment to make an alternative product that may generate some waste. Given wastewater generally involves some level of treatment, the application of these terms may be confusing, and they are often used interchangeably. The National Guidelines for Water Recycling (2006) refer to water recycling as "*water generated from sewage, greywater or stormwater systems and treated to a standard that is appropriate for its intended use*". A useful review of the management practices and definition of recycled water is provided by the Queensland Water Directorate (2021) discussion paper titled "Aligning Definitions of Recycled Water in Queensland". This paper recommends that the water recycling definition excludes release to land or water and that the classification should consider the "intended use".

On-site reuse is a commonly adopted method and more preferred than release to land. Third party agreements or off-site reuse is often used to support surrounding areas which would benefit from the wastewater irrigation, e.g. surrounding farms (agricultural areas), sport fields including golf courses and council parks. Reuse schemes reported growing crops such as grapes, cotton and mung beans. The Department of Environment, Science and Innovation encourages these third-party agreements. However, it is important that the off-site uses are well managed to ensure there is no human health or environmental harm issues. Often, higher levels of disinfection may be required for these types of application, but other types of treatment are often minimal. Nonetheless, off-site uses can be considered as beneficial reuse.

Some councils and water utilities in Queensland have been proactive in reducing wastewater by forming local partnerships with industry, such as collaborative projects on low technology reuse rather than the implementation of treatment technologies (see more details in Appendix A). Additionally, some councils have provided different services, such as managing to reduce dry weather discharge to zero by monitoring customers water meters and ensuring that the water provided to third-party stakeholders is Class A (see Table A- 1 in Appendix A for this recycled water classification).

In this study, the total volume of treated STP effluent being reused (total reuse) was determined for some STPs. Sewage treatment plant release and reuse data between 2018 and 2020 were obtained from the WaTERS database. Table 4-2 demonstrates the percentage of reuse of 9 STPs located in the Reef catchment. The results indicated that the average of total wastewater reuse of each STP varied between 3 and 60%. The reuse quantity of a few STPs over a period of three years fluctuated. This can be caused by factors such as rainfall, wastewater characteristics (suitability for use) and the availability of third-parties to use the treated wastewater. Table B-1 in Appendix B provides more detailed information on reuse components for selected facilities based on 2018 to 2020 data.

Table 4-2 Reuse information for selected facilities based on data available between 2018 to 2020*

STP Facility	ERA 63 Category	Average Reuse Volume per Year (ML)*	Average % Total Reuse
Horseshoe	1c	0.2**	100**
Picnic Bay	1c	92	60
Condon	1e	605	52
Port Douglas	1d	509	49
Yeppoon West	1e	437	24
Millbank	1e	184	14
Marlin Coast	1e	380	14
Mt St John	1g	649	9
Northern (Aeroglen)	1f	185	3
Southern (Woree)	1f	218	3

*based on the percentage of reuse compared to the total of reuse and release water for 2018 to 2020; ** value provided by Townsville Regional Council.

For further examples on leading practice recycling and reuse, refer to the following (see Appendix A):

1. Large scale agricultural reuse in Mackay
2. Reuse practice from six STPs in Townsville
3. Low technology reuse and reduction of dry weather discharge (Urban Utilities)
4. Innovative water reuse practices on the Gold Coast
5. Plantation timber-based reuse on the Fraser Coast

4.3 Wastewater Treatment

Wastewater treatment for nutrient removal should be fit-for-purpose and designed based on the specific circumstances, risk assessment and fate of the treated water. The following section is most relevant to cases where a high level of nutrient removal is required, such as with an ongoing release of treated wastewater to a waterway with important environmental values. It is acknowledged that social and economic considerations are also important, along with broader sustainability issues including energy and chemical usage, and greenhouse gas emissions (see Section 4.3.3 and Section 4.6 for further information).

In general, the most commonly applied wastewater treatment option in STPs is the activated sludge process. However, the efficiency of a conventional activated sludge in removing nitrogen must be enhanced as an anoxic stage is required to remove nitrates by denitrification. For advanced phosphorus removal, chemical addition is usually required. In small, regional communities, it may not be economical or practical to use large, engineered treatment solutions, in which case, alternative treatment technology is often adopted, such as biofilters and/or pond treatment. The leading practice water quality standards for wastewater release should relate directly to the type of treatment technology adopted and conversely, leading practice water quality standards will determine the types of treatment technology required.

More advanced levels of treatment technology are more likely to achieve a better environmental outcome in terms of nutrient release quality and loads, but may have broader environmental implications, particularly from energy use, chemical usage and the production of CO_2 and other greenhouse gases. Other environmental considerations include the fate of solid waste or biosolids. These considerations are important to assess the overall environmental sustainability of technological solutions. Understanding these factors requires information about the environmental management involved. Other important sustainability considerations include cost in terms of capital and operating expenditure.

Important factors, particularly in rural or remote areas, include the technical capacity of the staff needed to operate and maintain the treatment processes. Information on the entire life cycle and cost-benefit analysis is required in relation to specific technological solutions for facilities, but this is outside the scope of this review.

Some aspects of wastewater treatment in the context of the different constituents are discussed in Section 3 of this report. This section focuses on aspects of treatment related to nutrient removal and broader management considerations (monitoring, energy usage, costs). It provides a background to the types of treatment options available and the adoption of these options by STPs in the Reef catchment. Links to some examples of leading practice case studies of STPs in Queensland are also provided. It is acknowledged that many treatment units will remove more than one constituent, but this provides a useful basis to relate the treatment type back to water quality standards.

4.3.1 Nutrient Removal Technology

There are various configuration utilising aerobic, anoxic, and anaerobic biological processes and treatment schemes available for transforming or removing nitrogen from domestic wastewaters. Different biological nitrogen removal (BNR) technologies include nitrification, denitrification, anaerobic ammonium oxidation (anammox), bio-electrochemical systems and nitrogen recovery using microalgal growth or chemical processes. The most well-known biological process for removing nitrogen from wastewaters has been nitrification/denitrification that is nitrification of ammonia to nitrate, followed by organic reduction of the nitrate to diatomic nitrogen (N_2).

For nitrogen removal, wastewater enters a clarifier and is sent to a combined denitrification/nitrification process. Denitrification occurs in the first stage in an unaerated (anoxic) reactor, with nitrate recycled from a second stage aerated reactor, with oxygen supplied from atmospheric air. Biomass, carbon dioxide and nitrogen gas are produced from the combined process. Biomass is retained via a second stage clarifier. Figure 4-2 shows the nitrification and denitrification process of nitrogen removal.

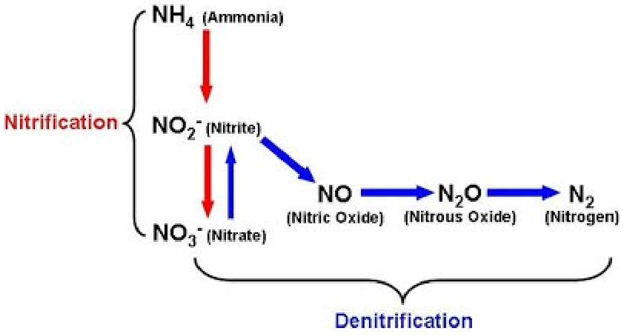


Figure 4-2 Nitrification and denitrification process

The removal of phosphorus from wastewater involves the incorporation of phosphate into solids and the subsequent removal from these solids. Phosphorus can be incorporated into either biological solid (e.g. microorganisms) or chemical precipitates. Treatment options for phosphorus removal include physico-chemical treatments such as precipitation by the addition of ferric chloride or other trivalent (3+) metal salts (e.g. alum), sorption, or ion exchange techniques; biological removal options such as enhanced biological phosphorus removal (EBPR) using phosphorus accumulating organisms (PAO); and novel phosphorus removal systems such as algal treatment (Bunce et al., 2018). It is noted that at small treatment plants, managing phosphorus, nitrogen and organic loads simultaneously is difficult, and current research is underway to develop more robust methods that require less operator intervention than the conventional treatment options discussed here (Bunce et al., 2018).

Table 4-3 describes the nutrient removal treatment technology used for leading practice plants in the Reef catchment. Most STPs categorised as leading practice facilities use a combination of activated sludge and biological nutrient removal (BNR) processes such as Sequencing Batch Reactors (SBR), EBPR or Intermittently Decanted Aeration Tank (IDAT) or Intermittently Decanted Extended Aeration Lagoon (IDEAL), 5 Stage Bardenpho N & P Removal Process. Some operators also use an oxidation ditch, membrane bioreactor (MBR), and different types of filtration techniques highlighting that these are the main treatment units leading to high efficiency of nutrient removals. The efficiency of the treatment (%) also seems to be influenced by the current operational level compared to the design capacity, as those plants achieving the lowest levels of TN have higher levels of remaining design capacity (Ramsay et al., 2021). Additionally, STPs in this category have been using chemical phosphorus removal (CPR) primarily with alum to effectively remove phosphorus from sewage.

There are different types of treatment processes on leading practice nutrient removal technologies. Below are some examples of nutrient removal technologies in Queensland (see Appendix A):

1. N/P removal optimisation by treatment process improvement
2. Nereda technology application at Kingaroy STP
3. Sequencing batch reactor operation improvement at South Caboolture STP

Table 4-3 Major treatment technologies used by leading practice plants in the Reef catchment

Facility Name	ERA 63 Category	Median Discharge TN (mg/L)*	Major Treatment Unit
Cooktown	1d	0.63	IDAT, Sand Filtration, CPR
Thabeban	1d	1.1	Activated sludge, BNR, CPR
Innisfail	1e	1.4	Activated Sludge, BNR, Oxidation Ditch, CPR
Rubyanna	1f	1.3	Activated sludge, BNR, Microfiltration, CPR
Tully	1d	1.5	Activated sludge, BNR, Oxidation Ditch, CPR
Millbank	1e	1.6	Activated Sludge, BNR
Edmonton	1e	2.1	Activated Sludge, CPR
Mossman	1c	2.1	Activated Sludge, Oxidation Ditch, Ponds/Lagoons, BNR
Southern (Woree)	1f	2.2	MBR, CPR
Mt St John	1g	2.2	5 Stage Bardenpho, BNR, Ponds/Lagoons, EBPR
Marlin Coast	1e	2.6	EBPR, CPR
Bargara	1d	2.6	Activated sludge, BNR, CPR
Sarina	1d	3.3	5 Stage Bardenpho, Ultrafiltration
Port Douglas	1d	3.5	SBR, BNR, Oxidation Ditch, Sand Filtration
Cleveland Bay	1g	3.7	MBR, Ponds/Lagons, Ultrafiltration, CPR
Northern (Aeroglen)	1f	4.0	MBR, CPR

** Calculated from 2015 to 2019 release data with outliers removed*

Algal Treatment and Artificial Wetlands (Green/Passive Technology)

In contrast to conventional biological nutrient removal, treatment using algae allows for the recovery of key nutrients such as phosphate and ammonium. The full-scale implementation of algae treatment is expected to minimise nutrient loads, bacterial pathogens and other pollutants with less maintenance and operational requirements compared with conventional wastewater treatment systems, meaning they can be good candidate systems for rural, regional, and sparsely populated catchments. Despite the potential benefits of an algal treatment system, performance can be sensitive to wet weather flow and low sunlight days, but in Queensland sunlight issues are weighted less compared to further south. Also, with high rainfall events, there is a dilution factor which means there is lower nutrient concentrations to treat. This can be overcome with wet weather bypass mechanisms commonly used in large plants.

Floating wetlands and lagoons are two examples of green (passive) technology which appear to be quite attractive as a low-cost, passive treatment solution for polishing wastewater (removing more nutrients and sediments). Nonetheless, green technology requires some level of control, intervention, and operating expenditure to function as designed. Additionally, design and correct operations are important factors to be considered for the application of a green technology.

Wetlands are suitable for small populations as they have limited treatment capacity. They are ideal for stormwater harvesting, agricultural runoff nutrient removal, and final polishing of effluent from previous treatment processes, however require significant land space. They should also be included on the back of any lagoon or algae system to allow a final polishing of effluent and to allow pH adjustment.

A plain lagoon may not be considered as leading practice and is normally considered as a good practice for small populations. In general, to be classed as leading edge, a lagoon system would need an anaerobic system followed by facultative and maturation ponds. Lagoon systems may not reach very low TN and TP concentrations and hence, effluent reuse for irrigation is more appropriate that release to water. This lagoon system should also be followed by reed beds/filtration system for final polishing prior to irrigation (zero release to water).

These simple lagoon type processes benefit from upgrading with algae systems (e.g., High-Rate Algal Ponds - HRAP based system) or combining with more intensive processes. The Federal Government’s Clean Energy

Regulator is highlighting this shift in their recent guidance. In the next few years, lagoon systems may need to be replaced with another process or several plants may need to be connected to a more intensive centralised treatment plant.

The control of algae and other photosynthetic organisms can be a challenge in the operation of lagoons. Algae can present problems in the form of high solids concentrations leaving the wetlands. Another barrier to the successful adoption of these passive solutions is the current lack of standards around wetland and lagoon operation. This poses a significant risk for utility providers considering adopting these technologies. Well defined guidelines around lagoon construction and operational procedures could allow for more widespread implementation. Additionally, in some areas in Queensland, the challenge of using this passive technology is from wildlife, including crocodile and turtle intrusion.

Some current issues that are well known and documented about lagoons include:

- Poor nutrient removal
- Sludge accumulation
- Reduced treatment capacity from sludge accumulation
- Greenhouse gases particularly for anaerobic and facultative ponds
- Odours
- Blue-green algae blooms
- Unmanaged algae - high TSS, high pH
- Long treatment times
- High evaporation
- Prefer algae dependant on sunlight
- Sensitive to high rainfall

Apart from lagoon treatments, the use of High-Rate algae ponds is currently gaining popularity for removing nutrients from the wastewater. Like other treatments, this system needs an inlet screen for rag and grit removal. The use of an upfront anaerobic step will result in better treatment performance from algae. This could be as simple as a septic tank system (household level), through to a covered anaerobic lagoon or Up-flow Anaerobic Sludge Blanket (UASB). The algal component of the system needs to be optimised with a paddlewheel mixed process; this is still low cost compared to other listed technologies. To achieve low TN and TSS levels, algal biomass should be harvested which can add some complexity to the system. However, this is already addressed in current lagoon treatment practices (micro-filtration, dissolved air flotation or other filtration techniques). Another consideration is the the need for pH adjustment due to high photosynthetic activity, which could be achieved via a maturation pond or CO_2 adjustment.

Some green technology projects in Queensland include:

1. Low technology algae treatments (Urban Utilities)
2. Diatoms trialled at the Dayboro STP (Unitywater)
3. Kenilworth floating wetlands (Unitywater)
4. Maleny STP wetlands

4.3.2 Monitoring and Data Analysis

An additional aspect for potential future leading practice in STPs is the implementation of data-driven modelling combined with process modelling to optimise processes, predict failures and allow utilities to take preventative measures to halt events before they occur. Smart water metering, initially introduced as a method for more seamless billing, is also thought to improve treatment outcomes and minimise operating costs by allowing utilities to identify pipeline leaks, and to better respond to water demand in real time (Randall and Koech, 2019). Many utilities Australia-wide have taken steps in the direction of data-driven decision making and smart metering, including Sydney Water (Prackwieser et al*.,* 2019; Harris, 2019). This is a domain which will complement the expertise of treatment plant operators and engineers to provide more effective treatment outcomes at reduced costs for councils and residents into the future.

Supervisory control and data acquisition (SCADA) is a system that monitors and controls field devices at a remote site that can be accessed by operators. This SCADA system is a centralized procedure that helps maintain efficiency by collecting and processing real-time data. The main goal of this supervisory system is to monitor and control equipment in the industrial processes. The SCADA system is now common and widespread and is found in industrial plants, manufacturing, transportation, oil and gas, power distribution, water control, wastewater treatment plants including STPs, etc. Furthermore, the SCADA system has advantages for ongoing STP operation and under any circumstances where access has become limited (e.g. remote areas).

With an ever-growing base of connected items such as smart meters and remote-control systems—such as SCADA—there comes an increasing risk of potential cybersecurity problems. The motivations for cyber-attacks are unique and wide ranging. Great care must be taken when implementing smart systems in the water industry. Some examples include:

1. Innovative licensing (Urban Utilities)
2. Process control, modelling and data analytics
3. Data visualisation (Tasmania Water)
4. Limitations and considerations for data analysis
5. Challenges encountered

4.3.3 Energy Requirements and Costs

Australian water utilities and regional councils face a reality where the largest portion of their total energy consumption is from the use of energy for wastewater treatment (de Haas and Dancey, 2017). Within the overall wastewater treatment process, the aeration and internal plant recirculation systems are the major energy consumers. Although the energy use for wastewater treatment is considered relatively small, it is a major contributor to energy use and greenhouse gas emissions profiles for water utilities and local governments (de Haas and Dancey, 2017).

Energy use for wastewater treatment is associated with raw influent characteristics (e.g. volume, organic and inorganic concentrations) that link to the catchment population served ("per capita" or "per population equivalent, PE"). The term "equivalent persons" (EP) is typically defined as 60 g/day biochemical oxygen demand (BOD) load in the raw wastewater (Crawford, 2010; Krampe, 2013). Therefore, a load-specific basis unit (i.e. kWh/EP/year) is preferable, particularly if STPs are grouped according to size and type, for energy efficiency comparisons (Crawford, 2020; de Haas and Dancey, 2017). The average energy use for wastewater treatment plants across cities in Australia and New Zealand varies between 27 and 67 kWh/EP/year (Kenway et al., 2008; Cook et al., 2012). The Water Services Association of Australia (2014) report suggests that this range is even larger: between 1 and 270 kWh/EP/year.

Ramsay et al., 2021, gathered information related to the energy use of STP facilities in the Reef catchment. There are some limitations and uncertainties in the data provided. Nonetheless, based on the survey, the energy usage per EP for the 2019 results for different STPs in the Reef catchment ranged from 4 to 142 kWh/EP/year (Table 4-4). Four plants have achieved less than 50 kWh/EP/year. The energy usage per current EP was generally lower for larger STPs (higher EP number) as shown by Ramsay et al*.,* 2021. In terms of energy usage, the values of the data collected generally confirm the average energy use for wastewater treatment across cities in Australia as mentioned by Kenway et al., 2008, and Cook et al., 2012. The use of solar energy has seen growth as photovoltaics have become cheaper and more reliable as a result of improved research, development and engineering practices. Solar power has become a significant proportion of the energy consumption at many water utilities and Regional Councils. Some examples on solar energy applications can be found in Appendix A.

Information on both relative capital and operating cost were gathered for each council owned STP from the industry survey (Ramsay et al., 2021) and standardised using design EP levels. The cost calculations were based on the present-day costs, i.e. replacement costs in 2019 to estimate capital, but again had some limitations and uncertainties in terms of validating the information provided. In general, there was a significant variation of capital costs between very small (1b) and very large (1g) STPs in the Reef catchment. However, the capital cost for STP size in the range of 1,500–100,000 EP (1c to 1f respectively) was in the order of $1,000 per EP (Ramsay et al., 2021). The whole of treatment capital cost based on the 2019 results for 16 leading practice STP facilities (median TN <5 mg/L) in the Reef catchment ranged from $4 to $2199 per design EP (Table 4-4).

Table 4-4 Energy usage and capital and operation costs for leading practice STPs in the Reef catchment

Facility Name	ERA 63 Category	Median discharge TN (mg/L)*	Operational Capacity (%)**	Energy usage (kWh/EP/year)	Capital Costs ($ per design EP)	Operating Costs ($ per current EP)	Overall Cost‡ ($ per EP per year)
Mossman	1c	2.1	93	59	346	240	254
Cooktown	1d	0.63	33	76	38	291	293
Thabeban	1d	1.1	42	77	1656	93	159
Tully	1d	1.5	63	6	262	145	155
Bargara	1d	2.6	88	66	1632	60	125
Sarina	1d	3.3	35	142	2199	401	489
Innisfail	1e	1.4	53	4	4	119	119
Millbank	1e	1.6	87	39	1145	41	87
Rubyanna	1f	1.3	59	31	873	44	79
Southern (Woree)	1f	2.2	66	104	5	47	47
Northern (Aeroglen)	1f	4.0	69	79	140	60	66
Cleveland Bay	1g	3.7	58	126	12	232	232

** Average calculated from 2015 to 2019 data; ** operational capacity based on comparison of current EP to design EP connections; ‡ cost based on a 25-year effective life.*

All operating costs for the facilities, including disinfection, reuse, etc were included in the operating costs provided with the data. Similar to the capital costs, operating costs were standardised based on current EP levels. In general, the operating costs/EP increased with the smaller facility size classification, as did the average energy cost/EP. Ramsay et al., 2021, reported that the average operating cost ranged from approximately $50 per EP per year for larger STP facilities (i.e. 1f and 1g) to around $500 per EP per year for the smallest facilities (i.e. 1b(ii)). The whole of treatment operating cost per EP for the 2019 results for 15 leading practice STP facilities in the Reef catchment ranged from $41 to $401 per design EP per year (Table 4-4).

Assuming a 25-year operating life for each facility, the most cost-effective plant had a cost of approximately $50 per design EP per year for the large facilities. For smaller plants less than 10,000 EP, the most effective plant had a cost of approximately $125 per design EP per year.

4.4 Wastewater Disposal

4.4.1 Release to Land

The objective of wastewater release to land is to release wastewater to the environment through evapotranspiration, evaporation, or infiltration. Release to land can increase soil fertility, supporting and maximising plant/crop growth, whilst disposing of the treated wastewater with minimal impact to surface water, groundwater, or ecosystems at or near the application site. In practice, land applications in most cases in Queensland involves irrigation to land owned by the local council or operator. Evaporative dams are used in some instances.

In Queensland, release to land is the preferred option over release to water. However, although release to land systems are often designed with storage tanks, release to water may be required during or after periods of heavy rainfall. Leading practice release to land involves minimising the quantity and frequency of potential release to water from overflows. Typically, overflows cannot be eliminated. Runoff from the irrigation area and deep drainage to groundwater should also be minimised. These can both be a potential source of nutrients and other contaminants to receiving waters. However, the nutrient limits for release to land can be much less stringent than release to water as nutrients can be beneficial to the vegetation and soil ecosystems. Typically, routine harvesting of crops is required to remove nutrients from the system though. For further information on leading practice release to land via irrigation, refer to the Disposal of Effluent using Irrigation Technical Guideline (DES, 2020).

From the information on approvals gathered by Ramsay et al*.,* 2021, 96 out of 139 STP facilities in the Reef catchment were authorised to dispose of wastewater to land for different on-site and off-site purposes, such as land irrigation for grasses, natural vegetation and native plant forests, cotton plantations, eucalyptus trees, grape farms, and vetiver pastures, etc. Of these 96 facilities, 38 utilised dedicated release to land and were not specifically authorised to release to water. In general, release to land is a controlled release onto land as conditioned in the EA, while third party is considered as reuse (see Section 4.2). Environmental monitoring programs may also be required for soil or irrigation monitoring (often part of Irrigation Management Plans - IMPs) and groundwater monitoring plans. A review of water quality and other release to land monitoring information was outside the scope of this review.

4.4.2 Wastewater Release to Water

Under certain circumstances, release of wastewater to local surface water is required. This may be a continuous release or only during or after rain events when reuse or land irrigation is not possible. Other types of sewage releases include sewer overflows and STP bypasses. Both include little or no treatment and are most commonly used during wet-weather events. Ultimately, all releases of wastewater to the environment have the potential to contribute to nutrient loads exported to the receiving environment. This review focuses mainly on developing release standards for continuous release—as discussed in Section 5. These standards are based on what can currently be achieved by modern sewage treatment practices. Regardless, best practice environmental assessment requires that the wastewater release proposal be assessed against the receiving environment characteristics, relevant legislative, policy and technical requirements, as summarised briefly below.

The Technical Guideline (Licensing) on Wastewater Release to Queensland Waters (2022) provides technical information and guidance to officers when assessing applications for wastewater releases to Queensland waters against the provisions of the EP Act and subordinate legislation. This guideline applies the principles of the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018). The National Health and Medical Research Council's (NHMRC) 2008 Guidelines for Managing Risks in Recreational Waters are also relevant where wastewater release may potentially impact recreational waters. For recreational waters, enterococci is recommended as the preferred indicator for both marine and freshwater.

For authorised release to surface water, particularly for continuous releases, environment monitoring usually involves a Receiving Environment Monitoring Program (REMP). The aim of a REMP is to monitor and assess potential impacts of controlled or uncontrolled releases of wastewater, and associated contaminants, to the environment from a regulated activity over time. The program provides a basis for evaluating whether the release limits or other conditions imposed upon an activity have been successful in maintaining or protecting receiving environment values. Further guidance on surface water monitoring can be obtained from the Receiving Environment Monitoring Program Guideline (2014).

4.5 Solids and Biogas Management

4.5.1 Solids Management

A slurry or semi-solid waste is generally produced from each stage of the treatment process. From the primary treatment, this includes gross solids, gravels, and grit; the second stage produces a waste stream called sewage sludge, a by-product of the biological treatment process. Sewage sludge often undergoes further treatment, including digestion, stabilisation, and dewatering, before being suitable for disposal or reuse to land as biosolids. Gross solids, rags and grit are usually disposed of to landfill, whereas stabilised biosolids can be released to land in many cases.

In Queensland, regulatory information on the management of sewage sludge or biosolids is provided in the End of Waste (EOW) Code – Biosolids (ENEW07359617). This code states the criteria for determining when biosolids waste stops being a waste and becomes a resource. A waste that is a resource under this code is considered a resource only for the uses approved in the code. An example of this would be where a STP treats biosolids to the extent that it satisfies the End of Waste code criteria. The producer may then use, sell, or give away the biosolids to third parties, in accordance with the code.

Ramsay et al., 2021, showed that there are at least 34 (of 139) STP facilities in the Reef catchment that dispose of their biosolids to landfills. No STPs are recorded to use biosolids for on-site purposes, while 61 STPs reuse their biosolids off-site for purposes such as agriculture, composting/fertiliser, mine rehabilitation, commercial landscaping, and forestry. The biosolids reuse percentage is generally higher (nearing 100%) for larger STPs (larger ERA categories, i.e. 1c to 1f). Larger STPs within the Reef catchment generally use activated sludge systems as the primary treatment units, generating a significant amount of sludge which leads to the production of biosolids from their anaerobic tanks.

In addition, the extensive application of wastewater treatment using ponds/lagoons in regional Queensland also produces large amounts of sludge. In the pond/lagoon systems, the accumulation or settling of biosolids at the bottom of the pond/lagoon over time is affected by several factors, including flow rate, loading, wind and depth, etc. If this accumulation is excessive, the pond/lagoon loses its ability to provide effective treatment. Therefore, regular desludging/desilting the pond/lagoon is an important operational aspect in the application of wastewater treatment using ponds/lagoons. It should be noted that the desludging/desilting process is expensive and time consuming, as it typically involves isolation and bypassing the pond/lagoon system and de-watering and earthmoving. Urban Utilities has undertaken sludge management improvements for some STP ponds within South East Queensland, such as the desludging process of the Toogoolawah Pond. Process optimisation has also occurred at the Aratula STP on both treatment performance and biosolids accumulation (Turner, K., pers. Comm., 2022). Examples on solids management applications can be found in Appendix A.

Biogas is produced mainly in the digester tank (anaerobic digestion unit) of a wastewater treatment plant, where the sludge is stabilised and assimilated in order to reduce its volume. This biogas can be used as a renewable energy to reduce the fuel consumption within the treatment plant (on-site) in the form of heat and electricity, through a combined heat and power (CHP) process, for their treatment process. Additionally, the biogas can be cleaned to produce biomethane, which can then be injected into the gas network or utilised as a vehicle fuel.

Generally, biogas may include methane, carbon dioxide and nitrous oxide, and may be reused, removed, or released (typically flared) to the atmosphere. Biogas can be used as a heat source, electric power, or other power generation. Nonetheless, this is currently only economically feasible for very large plants. Two examples of on-site energy reuse from biogas as heat in the Reef catchment were discovered from the industry survey (Ramsay et al*.,* 2021): Eli Creek STP and Maryborough/Aubinville STP. No off-site/third party energy reuse from biogas was recorded in this survey.

4.6 Greenhouse Gas Management

The greenhouse gases (GHG) include water vapor, carbon dioxide (CO_2), methane (CH_4), ozone (O_3), nitrous oxide (N_2O), and chlorofluorocarbons (CFCs). However, N_2O is one of the main GHG with a global warming potential about 300 times greater than CO_2 in equivalent terms (NGER, 2016). For sewage management, the wastewater collection and treatment stages dominate the global warming and ozone depletion impact potentials (Lane et al., 2015). In addition, STP operation results in the direct emissions (from the biological processes) of greenhouse gases such as CH_4, CO_2 and N_2O, as well as indirect emissions resulting from energy usage. When organic materials decompose in an anaerobic (oxygen-free) environment (e.g. deep in a landfill), methane is generated. This methane can be captured and used to produce energy, instead of being released into the atmosphere.

Advanced wastewater treatment methods that reduce nitrogen and have lower treatment costs and energy usage, could have a considerably higher risk of N_2O emissions, which will likely cancel out (or exceed) the benefits of reduced indirect emissions associated with lower use of grid electricity (de Haas, 2018). N_2O

emissions vary between STP facilities with different treatment process configurations and there can be an environmental benefit trade-off between reduced GHG emissions and receiving environment impacts.

Some researchers have indicated that higher emission of N_2O may relate to 'nitritation' shortcut pathways for nitrogen removal methods that involves the liberation of nitrites, particularly when there are process issues and high nitrites accumulate. This method is commonly used in removing ammonia-rich wastewater from anaerobic digestion tanks, which includes the deammonification/anammox processes. However, increased emissions of N_2O related to potential 'nitritation' shortcut pathways is not currently well understood and is an active area of research. In addition, the application to different types of activated sludges, particularly one with step feed and batch/intermittent reactors, significantly increases the N_2O releases (de Haas, 2018). Therefore, active mitigation measures are required to assess and control the risk of greenhouse gas releases and its negative potential impacts.

Figure 4-3 illustrates the nitritation method to avoid nitrate generation in the ammonia removal process, which on the other hand, may increase the production of GHG (N_2O) if the process is not managed or operated properly.

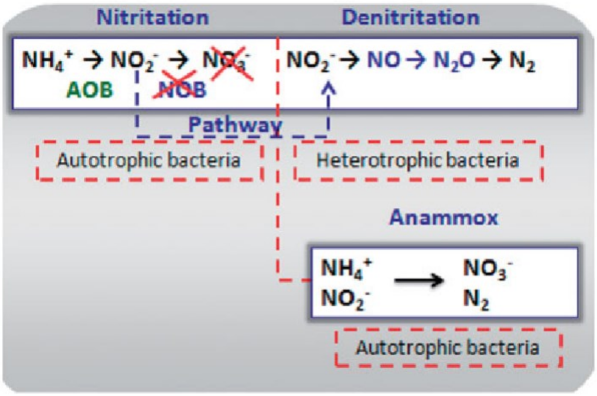


Figure 4-3 Nitritation to prevent nitrate generation in the ammonia removal process

Greenhouse gas emissions are identified as a potential concern which has led some Australian water utilities undertaking GHG emissions monitoring and measurement for their facilities.

A study involving 41 SEQ STPs was undertaken by CSIRO, Queensland Department of Environment and Resource Management, and GHD Pty Ltd through their SEQ Water Strategy for operational energy use and greenhouse gas emissions for urban water and wastewater services. The aim of this study was to review the relative contribution to greenhouse gas emissions of centralised water and wastewater services, decentralised (on-site) water and wastewater systems, and diffuse emissions from wastewater treatment and handling and urban water reservoirs (Hall et al*.,* 2009). It provided an estimation of the energy use and GHG emissions generated from sewage management in SEQ, which can now be used as the baseline for setting targets and identifying areas for mitigation (Hall et al*.,* 2009).

No Information on GHGs was collected as part of the industry survey undertaken by Ramsay et al*.,* 2021,. Given the potential relevance of GHGs on climate change and impact on the Reef, further work is recommended in this area. Greenhouse gas estimation/measurement needs to be promoted within STP facilities to understand the emissions footprint, through reporting of CO_2e (carbon dioxide equivalent) tonnes for example, and to inform decisions to prevent/minimise greenhouse gas releases. However, any effort to achieve a reduction in GHGs should never increase the risks of compromising the Qld Environmental Values and particularly aquatic ecosystem health.

An example for nitrous oxide emissions reduction:

1. Nitrous oxide emission reduction (South Australia Water).

4.7 Nutrient 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. Under this policy, offset contaminants include total nitrogen (and/or stated chemical species e.g. dissolved inorganic nitrogen), total phosphorus (and/or stated chemical species e.g. filterable reactive phosphorus) and total suspended solids.

For those STPs in the Reef catchment, 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. Nutrient offsets of DIN (or TN as a surrogate) will therefore be important for such activities in the future.

The nutrient offset strategy provides an alternative option for managing point source water release, however, there needs to be an improvement to the environment by reducing the overall amount of nutrients, or other contaminants, entering waterways. Nutrient offsetting 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. The operational costs were also lower, saving $5 million over the 10-year life of the offset. Further information is provided in the example below. A further example is provided on the Blue Heart Project which is not specifically related to point source nutrient offsets.

1. Nutrient offset trial for the Beaudesert STP to the Logan River (Urban Utilities)
2. Blue Heart Project (Unitywater)

5. Leading Practice Nutrient Release Levels

Nutrient concentration levels for wastewater release from STPs are often set considering the size and type of treatment to be adopted. The type of treatment will usually be determined by the location of the STP, wastewater chacrateristics and the fate of the wastewater. For example, STPs that release to land may not be required to have a high level of nutrient removal as compared to those that release to water, given nutrients are considered beneficial for release to land. Traditionally, higher levels of treatment are required for larger facilities and where release to water occur, especially if the receiving waters have sensitive ecological values. In Queensland, many large STPs release to coastal estuaries which are connected to the Great Barrier Reef Lagoon or the Moreton Bay Marine Park. Release limits can be set for a range of contaminants including pathogens, organic carbon, suspended sediments and nutrients. This section focuses only on nutrients. It firstly outlines release limits and guidelines adopted in other states of Australia. Leading practice nutrient levels for Queensland are then developed based on available information, with a particular focus on STPs in the Reef catchment.

5.1 Approaches by other Australian States and Territories

In general, nutrient release limits vary between states and between facilities within states. Each state appears to have different methods for determining release limits, although treatment technology appears to be a key consideration.

In 2001, Tasmania's Department of Primary Industries, Water and Environment (now the Department of Natural Resources and Environment Tasmania) published limit guidelines for new and upgraded STPs that release pollutants into fresh and marine waters (see Table 5-1). The limit guidelines is available at: https://epa.tas.gov.au/documents/emission_limit_guidelines_june_2001.pdf. These limits are achievable using accepted modern technology (AMT), considered economically viable and incorporate both disinfection and nutrient removal (DPIWE, 2001). Release limits for marine waters (near-shore coastal, bay and estuarine waters) are the same as for fresh waters except where alternative values are specified in Table 5-1. Advice on release from marine deep-water outfalls is not included.

Table 5-1 Tasmanian nutrient release limits for new and upgraded sewage treatment plants – achievable using accepted modern technology (AMT)

Parameter	Fresh waters (Marine*)		
	50th percentile	90th percentile	Maximum
Total Nitrogen (mg/L)	7	10	15
Ammonia (mg-N/L)	1	2	5
Total Phosphorus (mg/L)	0.5 (1*)	1 (3*)	3 (5*)

**Alternative emission limit for discharge to marine waters*

Table 5-2 shows the maximum release to water limits for some AMTs used in Tasmania for new STPs (DPIWE, 2001). In general, it shows that the release limits rely on the technology adopted (Plant Type). Table 5-2 indicates that release limits are more stringent for the more advanced treatments. It is assumed that the ability to remove more nutrients will be obtained by a higher level of treatment.

Additionally, the use of chemical phosphorus removal appears superior in removing TP, as a lower release limit is adopted for plants that involved chemical P removal. This supports the results obtained from Ramsay et al., (2021). Furthermore, a higher level of technology (with stricter limits) seems to apply for certain STP locations—environmental values at these locations may need greater protection or this may be due to the size of the STP.

Table 5-2 Plant specific accepted modern technology (AMT) of Tasmanian nutrient emission "maximum" limit (adapted from 1999 Load Calculation Protocol for STPs, NSW EPA)

New Column	Plant Type	TN Maximum (mg/L)	TP Maximum (mg/L)
Activated Sludge Plants	Extended Aeration (EA) + Biological Nutrient Removal	10	5
	EA + Ponds* + Chemical P Removal	5	<1
	EA + Ponds + Bio P Removal	5	5
	EA + Ponds + Chemical P Removal + Filtration	5	0.5
Hybrid Plants	Trickling Filters + EA + Ponds + Chemical P Removal	5	1
	Conventional Activated Sludge + EA + Ponds + Bio P Removal	5	5

'pond' refers to detention of effluent for more than 10 days in a form of open effluent impoundment

Table B-2 (Appendix B) illustrates interim release requirements for different treatment types of existing plants (or plants in the process of upgrading) in Tasmania. Although these are specifically used in Tasmania, the information can also be compared to STP facilities in other states of Australia. Based on this table, the interim TN release limit for a conventional activated sludge, or for an oxidation pond treatment, is 40 mg/L; 20 mg/L for an extended aeration; and 15 mg/L for a trickling filter + extended aeration with denitrification. For TP, the interim release limit for all of the above-mentioned treatment types is 10 mg/L.

For New South Wales (NSW), information was collected from the relevant Environmental Authority through the NSW public register which listed 12 large active STPs (>10,000 ML annual maximum) and 252 small active STPs (>20 ML and ≤10,000 ML annual maximum). For larger STPs, the maximum release to water concentration limits are 45 mg/L and 5 mg/L for TN and TP, respectively. Furthermore, for smaller STPs, maximum release to water concentration limits for 31 STPs are 10 mg/L for TN, 5 mg/L for ammonia, and 1 mg/L for TP. Table B-3 (Appendix B) shows information on the maximum release concentration limits for STPs taken from the NSW public register.

In terms of treatment plant technology, trickling filters and intermittent decanted extended aeration (IDEA) are the most common secondary processes in NSW, with some plants using both methods in parallel (NSW EPA, 2019). Sydney Water manage 28 wastewater treatment plants (water resource recovery facilities) in Greater Sydney. Most of their STP facilities (60%) are categorised as tertiary treatment level facilities where treated wastewater from primary (physical process) and secondary treatment (biological process) units is filtered, disinfected, and prepared for recycling (Sydney Water, 2022).

In Victoria, a working group report on "Effluent Standards and Compliance for Waterways" was published in 1994 by the Environment Protection Authority and Department of Conversation and Natural Resources. This report presents the findings of a review of the performance of water authorities against environmental standards and makes recommendations for actions to improve effluent management and water quality. Based on the STP EA information that is included in the appendix of the working group report, the concentration limits for STP nutrient release to water vary between authorities. Table B-4 (Appendix B) presents nutrient limits used by different authorities in Victoria. The most stringent maximum limits for release to water are 10 mg/L for TN, 2 mg-N/L for ammonia, and 1 mg/L for TP.

Based on the South Australia (SA) Environment Protection (Water Quality) Policy 2015, nutrient maximum release to water concentration limits in SA are only regulated for treated wastewater from septic systems, i.e. 5 mg/L for TN and 0.5 mg/L for TP. There are also maximum nutrient release limits for greywater (10 mg/L for TN and 1 mg/L for TP), but there is no specific information on nutrient limits for blackwater. Table B-5 (Appendix B) describes the STPs and their treatment technologies in SA (SA Water, 2013). However, the SA EPA manages nutrients as total load rather than concentrations and there is a total discharge load target for Spenser Gulf. Therefore, STPs in marine waters have an annual total discharge limit that must not be exceeded.

Icon Water Ltd. And Queanbeyan Palerang City Council are the two main sewage treatment businesses in the Australian Capital Territory (ACT). Based on the existing STP EA information under the Environment Protection Act 1997 (Schedule 2), treated effluent is not to be released from the site unless it complies with the concentration limits of ≤30 mg/L for TN and ≤0.5 mg/L for TP. Table B-6 (Appendix B) illustrates the STP nutrient concentration release limits in the ACT under the *Environmental Protection Act 1997*.

5.2 Queensland Leading Practice Nutrient Levels

5.2.1 Application of Leading Practice Nutrient Levels

The water quality limits imposed on an STP wastewater release will depend on the circumstances of the application. For release to water, particularly for continuous releases, nutrients are considered a major contaminant of concern. However, the nutrient levels of STP releases will be constrained by the treatment technology used. Therefore, alternative methods for reducing nutrient loads may be required, such as recycling/reuse, release to land and, ultimately, nutrient offsets. Nonetheless, this section provides information on leading practice levels for when there is a significant and ongoing STP treated wastewater release. Other considerations such as cost, location and broader environmental consideration, as discussed elsewhere in this review, are also important.

There will also be a significant difference between existing facilities that already have a treatment system and EA as compared to a greenfield development that does not have an existing facility or EA. For existing facilities, space to expand can be a significant constraint, as the plant needs to remain operational during construction of a new facility and augmentation is often the focus rather than building a new plant. In addition, a greater focus may be on the current authorisation in the EA (including nutrient loads) and capping environmental impacts considering the historical release and results of receiving environment monitoring, such as REMPs. Nonetheless, each proposal should consider best practice, existing policy and legislation, and look for opportunities for improved environmental outcomes. For greenfield development, no release or load authorisation currently exists, therefore greater work is often required to reduce the need for continuous, dry-weather release by considering alternative wastewater management strategies. Where continuous release is required, applying best practice management (or beyond) would be expected. Generally, even the highest practical level of nutrient treatment for STP wastewater will exceed the water quality objectives for most receiving waters and contribute to cumulative impacts of nutrients from catchment-wide sources.

In some cases, operators of existing facilities may voluntarily choose to improve nutrient release loads to help improve catchment management or help comply with catchment-wide nutrient targets, such as in the Great Barrier Reef. Leading practice levels could be used to assist with this process, along with the leading practice case studies and examples. However, this is more likely to involve modification to plant operation or minor augmentation rather than major capital investment.

5.2.2 Development of Leading Practice Levels

In Queensland, regulated activities for STPs relate to ERA 63 which is defined as facilities of a capacity greater than 21 EP. However, most small STPs do not involve a release to water, and for the few that do, limited monitoring data is available, particularly on nutrients. As a result, most of the information presented below relates to facilities greater than 1,500 EP (ERA 63c and above) which release to water. Up to three categories of leading practice have been proposed for each key indicator for STPs. Therefore, facilities may be ranked at different levels of practice for TN, TP and ammonia. The levels were determined based on STP EAs sourced from the Queensland Public Register, nutrient release data for STPs in the Reef catchment and industry survey data collected by Ramsay et al*.,* 2021. Firstly, obvious outliers were removed from the available dataset, as listed in Appendix B - Table B-10, along with facilities with less than 10 data points. Of the 65 remaining facilities, 33 of these had less than 100 data points for TN and TP.

These levels are for authorised release to water, mostly for continuous releases. In general, it was found from the available monitoring data that there was no significant difference in the nitrogen or phosphorus release concentrations between ERA 63 categories c through f. This result infers that plant size is not a major factor in determining final nutrient release concentrations. Additionally, nutrient release concentrations are linked to treatment type, although this is not the only important factor. Loading rate, both hydraulic and organic, is a further important consideration and has also been assessed in this review considering the EP load in 2019 compared to the original design EP.

Ramsay et al*.,* 2021, found that biological nutrient removal (BNR) is the most common technique in removing TN for STP facilities in the Reef catchment (https://www.publications.qld.gov.au/dataset/gbr-point-source-metadata-collection-project). Additionally, the most common BNR treatment approach was the sequencing batch reactor (SBR). In terms of phosphorus treatment technology, Ramsay et al*.,* 2021, found chemical phosphorus removal as the most common approach within the industry to remove phosphorus, particularly using alum and/or its combination with polyelectrolytes to enhance fine-sediment removal. Some plants have also adopted phosphorus accumulating organisms (PAOs) for advanced phosphorus treatment.

5.2.3 Total Nitrogen Concentrations

Sewage treatment plants in the broader Reef catchment, including adjacent islands, have been categorised based on the median TN concentrations of treated release water (see Table 5-3). These categories were determined by looking at the STPs achieving the highest TN removal (i.e. lowest wastewater nitrogen concentration) and grouping them accordingly based on the long-term median TN over the 5 years of data from 2015 to 2019. The plants achieving a long-term median TN of less than 1.5 mg/L were classified as the top level of leading practice N treatment, i.e. "best practice". Ten facilities were identified in this category based on the data. The second category involved a long-term median TN of less than 2.5 mg/L, achieved by 12 facilities. A third category was classified involving a long-term median TN of less than 4 mg/L, achieved by 13 facilities.

Table 5-3 Leading practice release levels for TN

Leading Practice TN Treatment Level	Long-term Median (mg-N/L)	Annual Median Upper Range (mg/L)	Maximum Upper Range (mg/L)	Number of STPs Achieving Level**	Average Loading (% EP /design EP)***
1*	<1.5	2	10	10	51
2	1.5 to <2.5	3.5	15	12	66
3	2.5 to <4.0	5	15	13	68

current best practice; ** based on overall release data for 2015 to 2019 from facilities in the Reef catchment; * based on 2019 survey data*

Table 5-3 shows demonstrated TN concentrations, annual medians and upper ranges for leading practice STPs based on an analysis of monitoring data between 2015 and 2019 based on the categories and levels proposed. Most top-level facilities were found to achieve an annual median TN concentration of less than 2 mg/L and a maximum TN of 10 mg/L for the 5 years of data. A similar analysis was completed for the two other leading practice levels for nitrogen treatment, which corresponded to long-term median concentrations of TN in the final release water of <2.5 mg/L and <4.0 mg/L, respectively. The annual median TN and the maximum TN upper ranges proposed for the second category are 3.5 and 15 mg/L, respectively. Similarly, the annual median TN and the maximum TN upper ranges for the third category are 5 and 15 mg/L, respectively.

The annual nitrogen medians presented in Table 5-3 are below the typical current EA limit of 5 mg/L. In comparison, the maximum TN limit for the second and third category are the same as the typical current maximum EA limit of 15 mg/L. Please note that obvious outliers of the raw data, as listed in Appendix B, Table B-10, were removed from the dataset prior to calculating these statistics to account for plant disturbances from rainfall, flooding or operational issues that occurred during the 5-year data period which are likely to impact the maximum concentrations that are measured over that time. Also note that there is significant uncertainty around estimating maximums and any application of the proposed maximum values should consider these limitations.

The average loading based on current and design EP is shown in Table 5-3 for each leading practice level. The top level has an average of 51% loading compared to 66 and 68% for the other two categories. Hydraulic and organic loading is likely to be a key contributor influencing nitrogen removal. However, both loading and nitrogen removal varied significantly from plant to plant and may be more important for some plants, such as those that involve biological removal.

5.2.4 Ammonia Concentrations

Sewage treatment plant facilities have also been categorised based on median and 99th percentiles of long-term ammonia concentrations in the treated wastewater which is released to water (see Table 5-4). These categories were determined by looking at the STPs achieving the lowest ammonia levels. The STPs were divided into two different leading practice categories based on the ammonia concentration over the 5 years of data from 2015 to 2019. All STPs achieved a median ammonia concentration of less than 0.3 mg/L. The STPs for the two levels of leading practice also achieved a 99th percentile ammonia concentration of less than 1.5 mg-N/L and less than 3.0 mg-N/L, respectively.

Table 5-4 Leading practice release levels for ammonia

Leading Practice Ammonia Treatment Level	Long-term Median (mg-N/L)	Long-term 99th Percentile (mg-N/L)	Maximum Ammonia Level (mg-N/L)	Number of STPs Achieving Level**	Average Loading (% EP /design EP)***
1*	<0.3	<1.5	2.5	16	58
2	<0.3	<3.0	4	11	54

** current best practice; ** based on overall release data for 2015 to 2019 from facilities in the Reef catchment with outliers removed; **** based on 2019 survey data

Table 5-4 proposes two leading practice levels for ammonia release concentrations based on STPs that release water in the Reef catchment. For the 5 years of data between 2015 and 2019, 16 facilities achieved a maximum ammonia concentration of equal to, or less than, 2.5 mg-N/L. This first level is considered best practice for STPs. A further 11 facilities achieved a maximum ammonia concentration of equal to, or less than, 4 mg-N/L, which is considered a second level of leading practice for ammonia treatment. Please note that obvious outliers of the raw data, as listed in Appendix B, Table B-10, were removed from the dataset prior to calculating these statistics to account for plant disturbances from rainfall, flooding or operational issues that occurred during the 5-year data period which are likely to impact the maximum concentrations that are measured over that time. Also note that there is significant uncertainty around estimating maximums and any application of the proposed maximum values should consider these limitations.

The average loading based on current and design EP is shown in Table 5-4 for the two levels of leading practice. The two levels have an average of 58 and 54% loading. Hydraulic and organic loading may be a contributor to improved ammonia removal, particularly for biological removal plants, and it may be more difficult to achieve low levels for plants with higher loading.

5.2.5 Total Phosphorus Concentration

Sewage treatment plant facilities have also been categorised based on the long-term median concentrations of TP in the treated wastewater which is released to water (see Table 5-5). These categories were determined by looking at the STPs achieving the highest TP removal (i.e. lowest wastewater phosphorus concentration) and grouping them. The STPs were divided into three different leading practice categories based on the long-term median TP over the 5 years of data from 2015 to 2019. STPs achieving a median TP of less than 0.25 mg/L are classified as “best practice” P treatment and this category was achieved by 12 facilities. The second category involved a long-term median TP of less than 0.5 mg/L, achieved by 12 facilities. A third category was classified involving a target median TP of less than 2 mg/L, achieved by 10 facilities.

Table 5-5 Leading practice release levels for TP

Leading Practice TP Treatment Level	Long-term Median (mg/L)	Number of STPs Achieving Level**	Annual Median Upper Range (mg/L)	Maximum Upper Range (mg/L)	Average Loading (% EP /design EP)***
1*	<0.25	12	0.4	2.0	56
2	<0.5	12	0.6	4.0	66
3	<2.0	10	2.0	8.0	70

** current best practice; ** based on overall release data for 2015 to 2019 from facilities in the Reef catchment with outliers removed;* *** based on 2019 survey data

Table 5-5 shows demonstrated TP concentrations annual medians and upper ranges for leading practice STPs based on an analysis of monitoring data between 2015 and 2019 based on the categories and levels proposed. Most top-level facilities were found to achieve an annual median TP concentration of less than 0.4 mg/L and a maximum TP of 2.0 mg/L for the 5 years of data. A similar analysis was done for the two other leading practice levels for phosphorus treatment, which corresponded to long-term median concentrations of TP in the final release water of <0.5 and <2.0 mg/L, respectively. The annual median TP and the maximum TP upper ranges proposed for the second category are 0.6 and 4.0 mg/L, respectively. Similarly, the annual median TP and the maximum TP upper ranges for third category are 2.0 and 8.0 mg/L, respectively.

The average loading based on current and design EP is shown in Table 5-5 for each leading practice level. The top level has an average of 56% loading compared to 66 and 70% for the other two categories. Hydraulic and organic loading may be a contributor to improve biological phosphorus removal and is less likely to be a concern for chemical phosphorus treatment.

5.3 Other Potential Measures

Current standards for design of sewer systems and treatment as presented in DEWS (2014) https://www.resources.qld.gov.au/__data/assets/pdf_file/0016/80053/water-sewerage-planning-guidelines.pdf (April 2010, amended in March 2014) are relevant to all public STPs in Queensland. Full sewage treatment should be designed to provide for 3 times the average dry weather flow (ADWF). A minimum of screening and settling should be provided for 3–5 times ADWF while coarse screening should be provided for greater than 5 times ADWF.

Although standards exist for the quality of reused/recycled water, it is not possible to provide standards in relation to the amount or volume that should be expected, other than to state that all possible opportunities for reuse/recycling should be explored prior to seeking approval to release to water. This should include both on-site and off-site (third party) reuse. The extent of reuse will depend on site-specific factors such as location, climate (rainfall), wastewater characteristics (suitability for use) and the availability of third parties to use the treated wastewater. Best practice examples include reusing 50% or greater of treated wastewater produced.

Dedicated release to land is also a preferred method for disposing of treated wastewater as compared to release to waters. However, it is not possible to specify the extent of wastewater that should be disposed of to land as it depends on site-specific factors such as location, climate (rainfall), wastewater characteristics (suitability for use) and land availability. Release to land disposal is most common for smaller facilities treating less than 10,000 EP. Leading practice wastewater release involving reuse or release to land should involve minimal or no dry weather release.

Best practice treatment for release to water, particularly for greenfield sites, should consider the use of green/passive technologies, including artificial wetlands where land space is sufficient. Best practice release management should involve the application of nutrient offsets for any additional authorised dry or wet weather nitrogen load to receiving waters.

Information on current limits for other relevant contaminant indicators for STPs is presented in Section 3 of this review. Key indicators for release to water include BOD, TSS, enterococci, total chorine, pH, and EC/TDS.

Further information is required to investigate standards for energy usage for STPs. Preliminary information suggests that achieving less than 50 kWh/EP/year is possible for leading practice STPs treating greater than 1,500 EP.

Leading practice biosolids management for all sizes of STPs involves reuse offsite rather than disposing to landfill. Biogas use for heating has been demonstrated as best practice management for STPs greater than 10,000 EP. Best practice monitoring for continuous release to water involves daily flow rate/volume and water quality monitoring of the release (weekly for sampled indicators) and routine monitoring of the receiving environment (e.g. monthly. Receiving environment monitoring should be reviewed annually.

6. Conclusions

Conclusions from this review are presented below.

- Reducing nutrient loads from STP releases in the future will require a combination of management involving reuse/recycling, release to land, best practice treatment and nutrient offsets.
- Although technical guidelines are available for both reuse/recycling and release to land, no specific standards can easily be developed on the extent of their use, as these will depend on site-specific factors. Some level of reuse/recycling and release to land has been demonstrated at many plants in Queensland, with smaller facilities more often adopting release to land. Reuse/recycling and release to land must be considered prior to seeking approval for release to water.
- High levels of nutrient removal may not be warranted or economically viable in some cases, such as for event releases, release to oceanic waters, or release from small facilities. Application of the STP leading practice levels for release to water needs to consider the case-specific environmental and economic circumstances.
- The leading practice treatment levels for this study were based mainly on release monitoring data collected by councils who operate STPs. The samples and analyses were assumed to be collected as per the requirements of the environmental approvals and the Queensland Water Sampling Manual, and adequately quality assured. It was assumed that the nutrient results provided were representative of overall daily and weekly plant performance.
- Three levels of leading practice have been proposed for STPs involving release to water for indicators TN and TP based on 5 years of release monitoring data. There were at least 10 examples of facilities within the Reef catchment achieving each level of leading practice for both nitrogen and phosphorus treatment. An expected range for annual median and maximum concentrations has been proposed for each level along with an expected long-term, average concentrations. The annual median range for each leading practice level for these two indicators were:
    - Annual TN median concentrations: (LP1) <2 mg/L, (LP2) <3.5 mg/L, and (LP3) <5 mg/ L, and
    - Annual TP median concentrations: (LP1) <0.4 mg/L, (LP2) <0.6 mg/L, and (LP3) <2.0 mg/L.
- Similarly, two levels of leading practice have been proposed for ammonia release concentration. Each level requires a long-term median concentration of less than 0.3 mg-N/L and the following maximum concentrations:
    - Maximum Ammonia release concentrations: (LP1) <2.5 mg-N/L, and (LP2) <4 mg-N/L
- More than half of the 65 STPs with data involving release to water in the Reef catchment achieved one of the proposed leading practice levels for nitrogen and phosphorus removal.
- Leading practice treatment for STPs involves biological nutrient removal (BNR) processes which promotes nitrification and denitrification, and advanced phosphorus removal using alum or phosphorus accumulating organisms (PAOs). The use of green/passive technologies, such as artificial wetlands, is less well demonstrated, but given potential broader environmental benefits, should be considered wherever possible.
- The average loading, based on current and design EP, was assessed for facilities within each leading practice level and ranged from 50 to 70%. For some treatment types, such as biological treatment, which are strongly affected by loading rates, these leading practice levels may not be applicable at higher loadings.
- The majority of STPs in the Reef catchment are reusing their biosolids offsite rather than disposing of them to landfills as part of their leading practice management. In terms of biogas, leading practice management in the Reef catchment is focusing on heating for STPs with size greater than 10,000 EP. The potential risk of greenhouse gas generation from STPs is significant and effective methods for assessing and mitigating greenhouse gases are required.

7. Recommendations

Recommendations of this review are presented below.

- The STPs achieving leading practice levels 1 and 2 for nitrogen and phosphorus concentrations should be investigated further to determine the key design factors or operating features or approaches, including wastewater characterisation loading rates, power costs and chemicals usage, that are contributing to the low level of nutrients in release water. These features or approaches could then be considered for application in other facilities.
- Given the limitations with cost data collected in this study, leading practice STPs in the Reef catchment that have recorded low capital and low operating costs should be further assessed. Features contributing to low costs should be identified and considered for application in other facilities.
- Further work should be undertaken to assess the cost of nutrient removal per kilogram of nitrogen, or phosphorus, for different facilities and treatment types. In addition to commonly reported release data, this would require measurements or estimates of influent loads to the sewage treatment plant and refined cost data for each facility. This would also facilitate benchmarking against other methods of reducing nutrient inputs to the Great Barrier Reef (e.g. from diffuse sources, land release, etc).
- Further work should be undertaken looking at methods for assessing and optimising energy usage. The STPs achieving low energy usage, should be investigated further to determine the key design or operating features, such as biogas recovery for heating and solar, that are helping achieve this.
- Further work is required on standards for GHG management. In addition, further work is needed looking at mitigation measures to assess and control the potential risk of greenhouse gas releases and negative potential impacts, particularly from methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) associated with different treatment technologies.
- Further work should be undertaken looking at the suitability of weekly grab samples of STP release water, in comparison to composite samples, to reliably assess nutrient concentrations and loads and overall nutrient removal.
- Further work should be undertaken looking at the influence of wet weather events when comparing plant operation and performance. Even though rainfall events were not considered in this review, it is noted that rainfall average was different for the different regions of the Reef catchment. During the period used for the study, some STPs in the catchment may also have been affected by extreme events (Cyclone Debbie, March 2017).
- Further work would be required to confirm the application of the leading practice levels across Queensland to ensure they are applicable to larger STPs and to take into account potential impacts of different influent sewage quality, including industrial and trade waste sources, on treatment performance.
- Subject to the above further work, the leading practice levels proposed for nutrient release quality in this report could be considered as aspirational targets for all new and expanding STPs in the Reef catchment, subject to case-specific environmental and economic assessment.
- Further work should be considered to help develop strategies to achieve net zero nutrient release from STPs in the Reef catchment, and more broadly in Queensland in the long-term for both urban and rural settings. This could include exploring alternative/innovative technologies not currently demonstrated at scale for the industry.

8. References

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Appendix A - Leading practice management options of STP environmental management in Queensland

This section considers the leading practices as reported by the various utilities in Queensland and interstate, as well as the white papers, business communiques, and media releases concerning leading practices in the region. The categories of management options have been classed in the following formats:

- Source and sewer management
- Water reuse and recycling
- Engineered treatment and optimisation
- Green passive technologies including ponds and wetlands, and offsets
- Energy reduction
- Biosolids and biogas management
- Management, monitoring and data analysis

These findings have been based on the councils and utilities assisted during the process of information gathering, and there is a possibility that this information will not be representative of all councils in the Great Barrier Reef catchment. Any extrapolations and generalisations based on the findings of the participants are speculative but can present a foundation for qualitative understanding and development of leading practices for wastewater treatment.

Sewer management

In terms of sewer management, Gold Coast City Council's aims include developing control strategies for the prevention of asset failures due to premature corrosion; and managing and understanding system behaviour for optimal process control, sewer corrosion and odour management plan. Gold Coast City Council in collaboration with the University of Queensland (ACWEB, previously AWMC) have undertaken numerous sewer management projects on corrosion and odour control, which include:

- Sulphide Generation Model Development (UC09), 2003
- ARC Linkage Project 1 (Biotransformation project), 2004-2007
- ARC Linkage Project 2 (SCORe project), 2008-2013. The SCORe project was a five-year (12/2008 – 11/2013), $21 million research project jointly funded by the Australian government ($4.7M) and many major water utilities in Australia. This was likely the largest ever research project worldwide focusing on sewer corrosion and odour. The project was collaboratively and successfully delivered by its five research and eleven industry partners.
- Odour Control at Elanora (Rising main) and STP, 2010 & Elanora Catchment Optimization (sulphide modelling results, reduction of H_2S using Oxygen dosing, reduction of H_2S using Ferric Chloride dosing, reduction of H_2S using Magnesium Hydroxide dosing). Gold Coast City Council obtained an optimal network-based sulphide control strategy for the Elanora rising main system. Implementation of the strategy removed a number of oxygen injection stations and saved $0.5 million/year of oxygen injection cost, an added bonus of asset protection in the network (asset deterioration estimated at $1.5 million/year for the Elanora catchment, SKM 2007)
- Cloevis pilot study, 2012
- Coombabah Wastewater Treatment Plant Odour Abatement Project, 2013

Inflow & infiltration (I&I) are any external source of water, stormwater, or groundwater that ingress to the city's sewerage system. Most of the inflow is caused by illegal rainwater connections into the sewer network or landscaping that diverts stormwater into manholes or overflow relief gullies. Infiltration is caused by stormwater or groundwater that enters the wastewater network through cracked pipes and leaky or faulty manholes. Inflow & infiltration may increase the volume of water in the sewer systems which can instigate the network capacity being surpassed. This can cause overflows, system strains and interruptions which will result in environmental harm, customer impacts and create risks to human health.

There are indications when a sewer network is having I&I issues These include:

- Pumps run for hours and inflows increase significantly during storm events
- The hydraulic loading of wastewater treatment plants increases significantly after a rain event
- Localised overflows within the collection system network during heavy storm events
- An increase in inflow during dry weather conditions compared to previous months

Inflow & infiltration management should be started by undertaking early identification and reducing their levels. Furthermore, there are steps that provide a simple overview of an I&I reduction plan that can assist in identifying the various stages associated with reducing I&I within the wastewater network (F. Bashir, 2019). These steps include:

1. Identifying the general vicinity of the issue through monitoring wastewater flows within the network,
2. Identifying the exact problem whether it is an inflow or infiltration,
3. Finding out where they are occurring (source detection), and
4. Undertaking rehabilitation including actions to improve the situation. Rehabilitation can involve sealing manholes and replacing leaky covers.

Inspections to support the I&I management (F. Bashir, 2019) could include:

- Private property inspections that consist of visual assessments of the stormwater and wastewater networks within a property,
- Manhole inspection that can identify leaks from broken benches and joints due to tree root intrusion or design issues as well as leaky covers,
- Smoke testing traces I&I sources by finding stormwater drain cross connections, broken pipes, and unsealed manholes, and
- Dye testing to monitor leaks and confirm smoke testing results.

As an example of I&I management, Gladstone Regional Council has committed to reduce the occurrence of unlawful and unintended inflows into the sewerage network. The Council has embarked on a monitoring program to identify prohibited connections and the unintended routing of water into the sewerage reticulation system. The Council fines people who deliberately flaunt the law but offers an amnesty for those who seek to rectify the situation within a 30-day grace period.

Water reuse and recycling

Large scale agricultural reuse in Mackay

Mackay Regional Council is involved in water recycling and reuse at their Mirani Wastewater Treatment Plant (WWTP), Sarina Water Recycling Facility (WRF) and Mackay South WRF. Mackay South WRF, Mirani WWTP and Sarina WRF serve three separate recycled water schemes within the Mackay Regional Council. Treated wastewater is reused from the three plants and supplied to local cane growers and golf courses in the vicinity for irrigation. There are several large, recycled water storage tanks, so that irrigation can occur during periods of dry weather. The scale of the operation is as follows:

- Mackay South WRF designed for 97,000 equivalent persons (EP)
- Mirani WWTP designed for 3,500 EP
- Sarina WRF designed for 8,000 EP

This recycled water scheme allows overdrawn groundwater resources the time to refill by limiting the groundwater demand from surrounding industries such as the sugar cane industry. Sugar cane growers and sports facilities are responsible for irrigation management and exposure control on site.

In terms of performance, about 80% of treated wastewater from Mackay South WRF was reused in the 2017/2018 financial year. The same percentage was reused from Mirani WWTP. At Sarina WRF, 40% of the treated wastewater was reused over the same period. This recycling scheme is well matured, and its performance has been demonstrated for more than two decades. Mackay South WRF has been supplying recycled water since 1998 and Mirani WWTP since 2002. Sarina WRF is a relatively new facility, commissioned in 2014 after the old Sarina Sewage Treatment Plant was decommissioned.

Reuse practice from six STPs (Townsville)

As a part of its *Reef Guardian Council* status, water reuse plays an important role in Townsville City Council's explicit commitment to implement best environmental practice across all facets of operation, planning, education, and communication. There are six STPs controlled by Townsville City Council. Except for Toomulla, a 160 EP plant treating only residential wastewater, all STPs have reuse practices. The largest plant, Cleveland Bay, is a conventional biological nutrient removal (BNR) plant, with membrane filtration to remove solids. Its reuse includes service and site irrigation and formerly, livestock water requirements. The remaining wastewater is released to the ocean. A proportion of treated wastewater is released to the ocean. Mount St John, the other large treatment plant operated by Townsville City Council, treats 16 ML/d and reuse includes irrigation at the Rowes Bay Golf Course, process and service water for use on site, the balance being released to the Bohle River. Townsville City Council is currently in the process of building a multi-million-dollar reuse facility for both irrigation and industrial customers. Bio-solids are also used as fertiliser on land.

All other plants in the region are considerably smaller. Condon (22,000 EP), Magnetic Island (1,260 EP), and Horseshoe Bay (700 EP). All have reuse practices including golf courses and sports fields irrigation, dry tropics wetlands, and on-site service water. Both Magnetic Island and Horseshoe Bay employ 100% water reuse.

Bio-solids from the main plants are used as fertiliser after stabilisation, including solids transferred from Condon and Magnetic Island to Cleveland Bay for agricultural reuse. Options are currently being explored for bio-solids treatment through gasification/pyrolysis and reuse of biochar for agriculture.

Low technology reuse and reduction of dry weather discharge (Urban Utilities)

Urban Utilities (UU) has been active in reducing wastewater discharged by forming local partnerships with industry. An example of this is their focus on low technology reuse at Boonah in the Scenic Rim region, rather than the implementation of additional treatment technologies. As a part of this project, UU have supplied the neighbouring golf course with storage and control infrastructure to accept wastewater. The result of this project is that the golf course is irrigated more frequently than before the agreement, and UU has managed to reduce dry weather discharge to zero. Similar initiatives have been implemented at Beaudesert, with five external participants from industry. This has also led to improvements for both UU and their external partners. Urban Utilities has provided irrigation management, storage infrastructure and pumping costs to these third parties, as well as employing a full-time recycled water customer manager. Urban Utilities has managed to avoid license breaches by reducing their discharge to zero, and the participating sporting fields increased their irrigation volumes by almost 100%. Previously, the sporting clubs would not have been able to afford the electricity bill of $12,000/year for irrigation, but now they are able to double their irrigation volumes. The golf club involved is now the only viable club in the town. According to UU, engaging third parties for reuse is an enormous risk, and this has been mitigated by the employment of the full-time customer manager. Continual management is key to the success of the program.

Innovative water reuse practices (Gold Coast)

Much of the innovative practice at the Gold Coast City Council is around their water reuse. To render this project feasible, innovative accounting approaches were required, which placed values on environmental aspects. The cost tool, developed by Jacobs, had to consider aspects that had traditionally not been considered in economic analyses, such as the quality-of-life aspects of the water recycling project.

Golf courses, sporting fields, and schools are all recipients of this reused water, which is charged at $0.01/kL. This cost covers the pumping from the master meter, but the environmental treatments are not factored into the costs. There are other controls provided by Gold Coast City Council, which ensure that the water provided is Class A (see Table A- 1). A full-time customer irrigation manager is employed to maintain the customer network. A customer manager was entirely necessary for the project to be a success.

As part of the services provided, the council provided and monitored smart water meters for all 100 schools in the recycling programs, and for most of the golf courses. It was found that over 50% of the schools had water leaks, with the average leak being 10 L/s. In one case, leakage rates reached 120 L/s. This corresponded to $11,000 wasted by the schools over a month of testing. Despite this exercise costing the utility money, in the bigger picture, government money was saved, and water was not needlessly wasted.

The remainder of the reused water is taken by a constructed community wetland. In addition to the improved aesthetic aspects of the wetland, the cost of implementation is effectively offset by the fact that the construction of a $40M pipeline upgrade is no longer necessary. Additionally, the inclusion of this wetland means that the recycled water no longer requires post-use treatment.

Table A- 1 Guideline values for recycled water (Source: Guideline for low-exposure recycled water schemes)

Class of recycled water	Guideline values
Class A+	Less than 1 *E. coli* cfu/100mL or less than 1 *E. coli* MPN/100mL in at least 95% of samples taken in the previous 12 months*,
Class A	Less than 10 *E. coli* cfu/100mL or less than 10 *E. coli* MPN/100mL in at least 95% of samples taken in the previous 12 months
Class B	Less than 100 *E. coli* cfu/100mL or less than 100 *E. coli* MPN/100mL in at least 95% of samples taken in the previous 12 months
Class C	Less than 1,000 *E. coli* cfu/100mL or less than 1,000 *E. coli* MPN/100mL in at least 95% of samples taken in the previous 12 months
Class D	Less than 10,000 *E. coli* cfu/100mL or less than 10,000 *E. coli* MPN/100mL in at least 95% of samples taken in the previous 12 months

Note: Microbiologists sometimes refer to the “enzyme hydrolysable substrate method”, which is one variation of MPN method. The standards for recycled water contained in the PH Regulation are given legal effect via the recycled water provisions of the Water Supply (Safety and Reliability) Act 2008. Recycled water providers supplying recycled water for low exposure uses should therefore refer to Table 2 for the recycled water standards relevant to their scheme(s).

* When Class A+ recycled water is being supplied to households as part of a dual reticulation scheme, and when it is used to irrigate minimally processed crops, there are additional microbiological criteria that must be met (see Public Health Regulation Section 58). However, it can be provided for low exposure uses without testing for anything other than *E. coli*.

Plantation timber-based reuse (Fraser Coast)

Fraser Coast Regional Council’s recycled water program has been in place for more than 25 years, making them one of the national leaders in reusing treated effluent for farming and agroforestry. They have been using 90–100% of their treated effluent for tree plantations, golf courses, turf farms, sporting fields and sugar cane crops.

Fraser Coast Regional Council has undertaken a new wastewater reuse project to irrigate their timber plantation. A 28 hectare plantation at Nikenbah is developed to grow up to 30,000 trees with the assistance of local Aboriginal and Torres Strait Islander employers. An additional 3,000 million litres of treated effluent are used by Maryborough and Hervey Bay farmers.

Approximately 2,441 million litres per year of recycled water are currently used by the Council to irrigate their timber plantation. This new plantation is predicted to increase the recycled water use by 135 million litres to 2,576 million litres per year. It is anticipated that by reusing surplus treated effluent, this project will prevent over 4,000 kilograms per year of nutrients being released to the receiving waters. Additionally, the new plantation will ensure that the reuse scheme keeps pace with the increase in effluent as the Hervey Bay population grows.

The Queensland Government has committed to reduce carbon emissions by no less than 30% by 2030 compared to 2005 levels, and to reach zero net emissions by 2050. So far, there are approximately 250 carbon farming projects already in existence in Queensland.

The Government thinks that a carbon farming industry in Queensland can create jobs in regional areas and contribute to reducing the state’s carbon emissions while improving the health of waterways. Additionally, carbon farming could provide a new income stream for Councils to assist with their operating costs.

This project, with a total cost of $460,000, is part of the Cleaner Wastewater (Wastewater Stewardship) initiative, funded by the Queensland Government’s Reef Water Quality Program ($235,000) and by Council ($225,000).

Engineered treatment and optimisation

N/P removal optimisation by treatment process improvement

Figure A-1 demonstrates the common nitrification/denitrification process in which biodegradable organics are removed from the liquid stream, as well as reactive nitrogen, which is converted to N_2 gas. A common adaption of traditional nitrification/denitrification processes is to place the denitrification stage ahead of nitrification, as in Figure A-2. This ensures there is sufficient readily biodegradable organic matter for denitrification to occur, reducing or eliminating the need for dosing of chemicals such as methanol (McCarty, 2018).

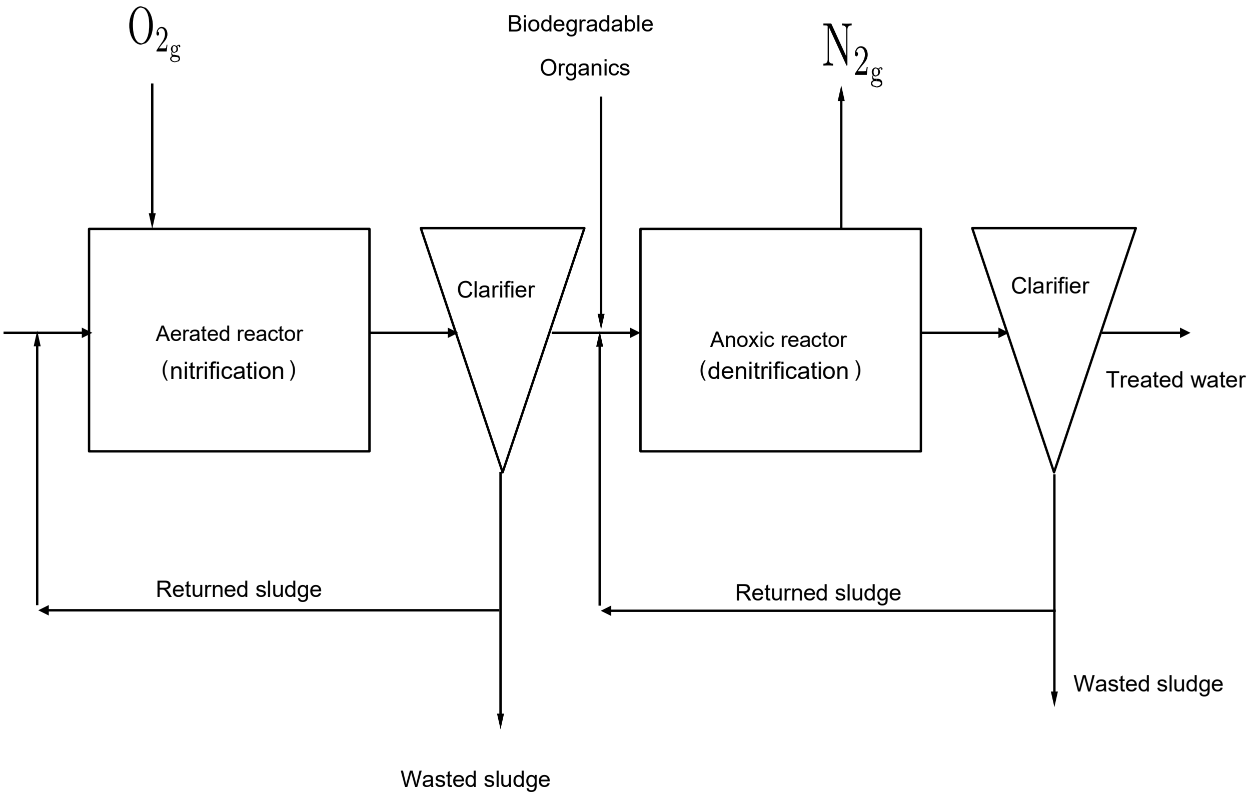

Figure A-1 Schema of a conventional nitrification/denitrification process for nitrogen removal

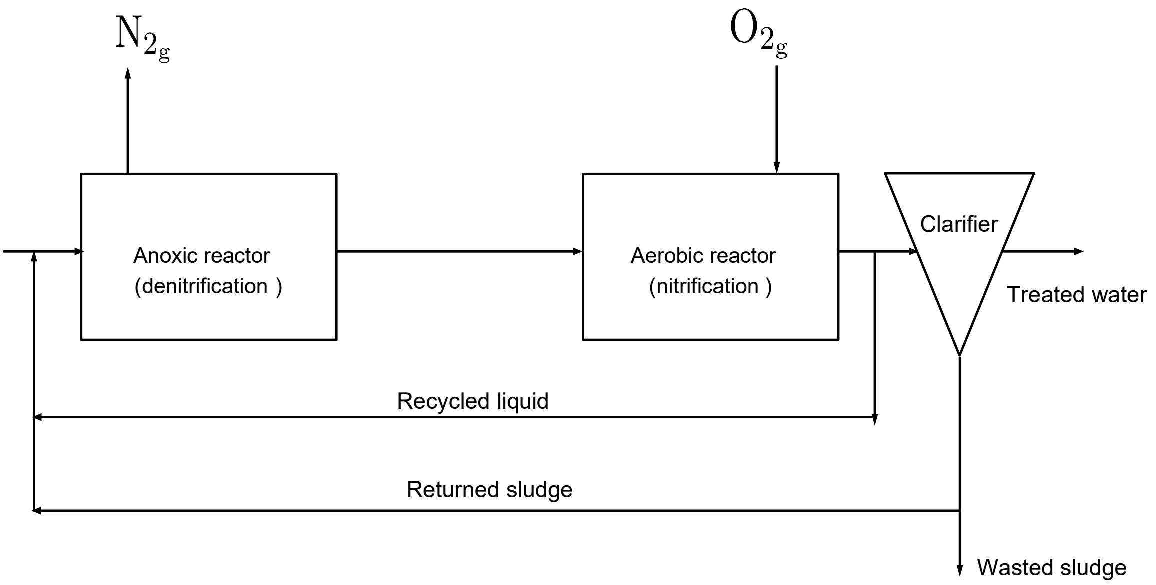

Figure A-2 Schema of a conventional denitrification/nitrification process for the removal of organics and nitrogen, and to a lesser extent, pathogens, and phosphorus

Nereda technology application (Kingaroy STP)

Kingaroy Wastewater Treatment Plant has been upgraded to a Nereda system, which involves granules to remove nutrients, some pathogens, and other pollutants. In addition to good removal rates, the activated sludge granules mean that settling occurs much faster than in other conventional systems, minimising the need for added chemicals for settling. By forming granules, the system is more resilient to environmental shock, and continues to function in adverse conditions. The new plant relies heavily on automated systems, with online analysers for TSS, chemical oxygen demand, all forms of nitrogen, TP, pH and DO. The monitoring is undertaken for both influent and effluent and treatment is controlled remotely.

After officially opening in early 2017, the plant has met the release limits of all their licence conditions. Wastewater concentrations for ammonia, TN, TP, and faecal coliforms were all met. The influent is medium strength domestic wastewater (60 mg/L TN, 40–50 mg-N/L ammonia, 10 mg/L TP) and the achieved treated wastewater concentrations are 2 mg/L TN, total removal of ammonia, and 1 mg/L TP, with a turbidity of 1–3 NTU. The current mixed liquor suspended solids concentration is between 3.5 and 6 g/L and 91% of the sludge is captured. The footprint of the treatment plant is roughly half the size of a conventional treatment plant, and the energy usage and operating costs are 45% less to achieve the same water quality.

Sequencing batch reactor operation improvement (South Caboolture)

The South Caboolture Sewage Treatment Plant was recently overhauled in 2011 and is an example of a focus on building on existing facilities and infrastructure, rather than the construction of a brand new STP to address population growth. As capital costs dwarf all other costs and factor heavily in the decision-making process, there is a desire and need to design for longevity to avoid frequent upgrades.

Another way this plant has been improved in response to population growth is through different operational approaches. There are currently four sequencing batch reactors (SBR) at the plant, which previously had a 50% aeration-feed time, and a 50% settling-decanting time. The raw feed was not completely reacted as per design specifications. Methanol addition was required to convert nitrate to nitrogen gas, and alum was added to remove phosphorus at the rate of 1000 L/d. Through modelling and process control, the operation of these SBRs was improved. The aeration regime was manipulated to 25% of the total time of the cycle. This allowed reactive nitrogen to be removed to its 5 mg/L limit without the addition of methanol. The addition of alum was also diminished to 200 L/d, a reduction of 80%. With the optimised aeration regime, there was also less power usage.

According to the engineer in charge of leading the control system implementation, the main motivator was the license limits (5 mg/L of TN), which fostered a culture to be creative to achieve process improvements with sufficient buffer for when these approaches might not work as initially thought.

Green passive technologies

Low technology algae treatments (Urban Utilities)

Low technology reuse rather than conventional engineered solutions for wastewater treatment, particularly in regional areas, was the major theme emanating from the interview with Urban Utilities.

Urban Utilities (UU) has been involved in several green passive projects including floating wetlands and lagoons in the Lockyer Valley region. At the outset, these projects appeared attractive as a low-cost, passive treatment solution that one could “set and forget”, not requiring ongoing high levels of intervention. However, a key finding from the implementation at UU is that some levels of control are still required.

Challenges associated with the floating wetlands at Forest Hill Sewage Treatment Plant include that the short-necked turtles which had nested in the wetland structure ate all the plants which were supposed to clean the wastewater. This resulted in poor performance, and netting was required to provide a barrier between the turtles and the wetland plants. The management bill was $150,000 for the relocation of 100,000 turtles. Two full-time employees were required to manage this situation. Additionally, the control of algae and other photosynthetic organisms proved to be a challenge in the operation of lagoons. Algae can present problems in the form of high solids concentrations leaving the wetlands. Other barriers to the successful adoption of these passive solutions include the fact that there are currently no standards around wetland and lagoon operation. This poses a significant risk for ambitious utility providers.

Algae technologies are also a focus of Urban Utilities where they can be good candidate systems for rural, regional, and sparsely populated catchments. In contrast to conventional biological nutrient removal, algae allow for the recovery of key nutrients such as phosphate and ammonium. The algae technologies discussed here are referencing a specific algae treatment process, known as “High-Rate Algae Treatment”. This high-rate process is only currently feasible with an anaerobic treatment precursor process. There is a plan to assess full scale implementations of this algal treatment process in conjunction with Queensland’s Department of Environment and Science, the University of Queensland, and the Northern Territory. The stated claim for the full-scale implementation is that nutrient loads, bacterial pathogens, and other pollutants will be minimised with less maintenance and operation requirements compared with conventional wastewater treatment intervention, but operating expenditure are still required if these solutions are to perform as designed. Preliminary pilot results on medium strength domestic wastewater have shown that total nitrogen can be removed to 2 mg/L, and total phosphorus to 3 mg/L, oxygen levels remain at around 7 mg/L, and solids concentrations can be reduced to 10 mg/L after harvesting of algal biomass. For all the perceived benefits of an algal treatment system, performance can be sensitive to wet weather flow and low sunlight days. These limitations are particularly true in the Great Barrier Reef (Reef) context. The results of this project at full-scale implementations will dictate whether algal technologies can be adopted across the wastewater treatment industry, and more particularly, in the context of the Reef catchment.

Nutrient offset trial for the Beaudesert STP to the Logan River (Urban Utilities)

In Queensland, there is a policy in relation to nutrient offsets for point source releases[1]. Currently, the main example of nutrient offsets involves streambank stabilisation.

The nutrient offset trial for the Beaudesert STP was undertaken by Urban Utilities as a flexible option for managing point source water emissions. Overall, there is no evidence of potential harm to the receiving environment (Logan River) from the Beaudesert STP as a result of the nutrient offset arrangements. This is largely due to Urban Utilities undertaking a major reuse program and reducing dry weather flows released to the Logan River.

The dry weather, wet weather and overall nitrogen loads released to the Logan River from the STP have substantially reduced since the environmental approval amendment in 2014. For example, when comparing the nitrogen loads from 2008 to 2013 with 2014–2016, the average annual total nitrogen load decreased from over 10,000 kg/year to just over 4,000 kg/year. Similarly, the average wet weather nitrogen load decreased from just over 4,000 kg/year to around 1,500 kg/year. The reduction in discharge loads is largely attributed to reduced discharge flows as a result of increased reuse. The reuse appears to have also reduced the wet weather loads released. This reduction in load is not what would usually be expected of an offset arrangement where one would expect loads to be maintained or even increased. Nonetheless, this arrangement reduces the potential for any environmental risk.

The monitoring data obtained from upstream and downstream of the Beaudesert STP discharge point in the Logan River indicated an overall improvement in water quality levels downstream since the 2014 amendment, compared to previous years. There was no significant increase in medians of any contaminants including ammonia and oxidised nitrogen. This is likely due to the reduced discharge volumes and frequency during dry weather and significant dilution of the discharge with river water when the release was occurring.

The Logan River streambank rehabilitation nutrient offset project assets have been very successful at mitigating riparian soil erosion. In the rehabilitated project area, there has been minimal observed erosion of riparian soil between 2014 and 2016 despite five occurrences of Logan River high stream-power events with high streambank erodibility risk—see Figure A-3 below. The immature streambank rehabilitation offset works were subjected to significant stream power events beyond the modelled design of the stabilisation works and riparian zone resistance/stability (for Year 2 projected vegetation growth). The green assets performed beyond all expectations during these low to medium flood flow events with only minor rectification works required in a few small areas. It should also be noted that significant deposition of fine sediments across most of the revegetated project area occurred during these events. The more mature green assets have shown excellent

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[1] https://environment.des.qld.gov.au/__data/assets/pdf_file/0033/97845/point-source-wq-offsets-policy-2019.pdf

stability in the period post-2016 with the rehabilitated streambanks showing strong resistance to erosion during the more recent major Logan River floods in March 2017, February 2022 and May 2022.

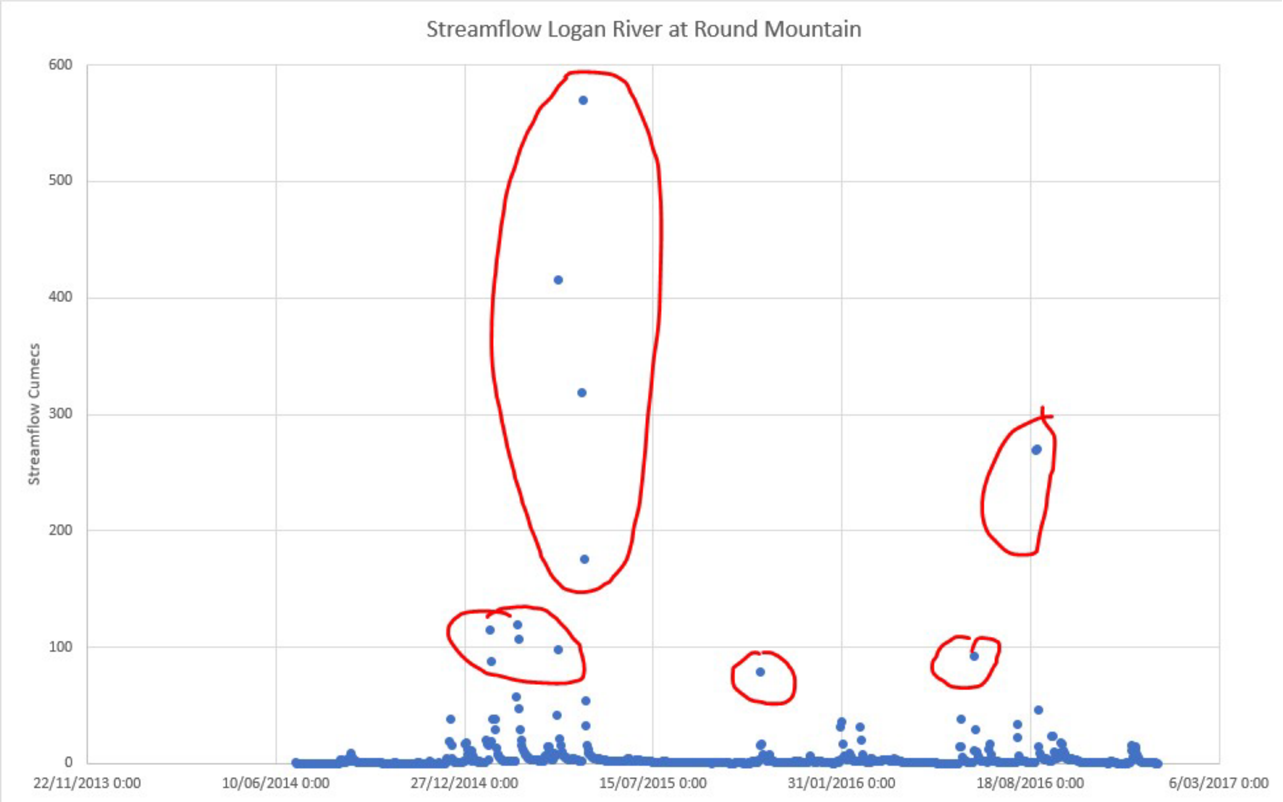

Figure A-3 Logan River streamflow: 2013-2017 (cumecs)

Blue Heart Project (Unitywater)

The Blue Heart project (Unitywater) comprises an area of 5,000 ha within the Maroochy River Catchment. The objectives of this project in this natural flood buffer include water quality improvement and nutrient offsets, renewable energy generation, and increasing ecotourism to the region. However, please note that this project was not specifically designed to be a point source nutrient offset.

One of the major initiatives within the Blue Heart project was the development of the Yandina Creek Wetlands, which in 2016, were purchased as 190 ha of sugar cane farming land near the Maroochy River. This land was converted to an estuarine wetland. These wetlands act by removing sediment and nutrients from water and increase the aesthetic value of the catchment. Extensive modelling was carried out to look at the effects of the wetland on the biodiversity, treatment performance, and the economic aspects. The modelling results of all of these categories were favourable. For example, a sensitivity analysis was done to compare the merits of the wetland against the building of a new sewage treatment plant to complement the Coolum Treatment Plant, and wetlands proved to be a more economical choice over a 10-year timeframe.

While there is currently no concrete monitoring data available from the wetland since its commissioning, there have been reports that the aquatic and bird life activity has increased significantly. Bandicoots and platypus have been filmed nesting in the wetland area. To better quantify and understand improvements to wildlife, a 4-year study is currently being conducted in conjunction with the University of the Sunshine Coast on the changes in biodiversity within the catchment.

With respect to nutrients, the wetlands have been able to remove 90% of nutrient loads from the catchment, handling loads of 10 kg/y (TN) and 2 kg/y (TP). As mentioned above, this wetland will share the nutrient and sediment removal load with the Coolum Sewage Treatment Plant, and this system will offset the requirement for another wastewater treatment plant in the next 10 years.

Kenilworth floating wetlands (Unitywater)

A floating wetland project in Kenilworth (Unitywater) has been in trial since January 2019. This project was initiated because Unitywater was looking for a solution requiring less chemicals and power to achieve sufficient nutrient and pollutant removal. This project drew on the experiences and lessons learned from wetland implementations in Rotorua, New Zealand, and Urban Utilities' Laidley Creek project and were designed accordingly. Unitywater is approaching this project with the knowledge that it is complex, multi-disciplinarian and is highly dependent on seasonality and other external factors. As such, a team of engineers, microbiologists, and university partners has been assembled to ensure the smooth operation of the floating wetlands, and the overall goal is long-term commitment rather than a mere proof of concept. The results from the wetlands have seen reductions in TN of 55%, suspended solids of 70%, and an increase in biodiversity in the region. There have also been considerable improvements to the aesthetics of the general area, with wildlife activity and native plants contributing to this. In addition to the nutrients and sediments removed though the floating wetland system, solar panels have been installed to ensure that the entire Kenilworth Sewage Treatment Plant is energy neutral, reducing carbon emissions by 12 tonnes CO_2e per year. While the system is complex, requiring sufficient monitoring and management for proper operation, there have been reductions in operating costs associated with Kenilworth STP.

Maleny STP wetlands (Unitywater)

Maleny STP is located on Landsborough-Maleny Road, Maleny (Sunshine Coast Regional Council) and currently treats sewage from Maleny township and surrounding areas. Treated wastewater is released from the STP to a land irrigation system comprising an irrigation forest and a treatment wetland on the northern side of Obi Obi Creek, which adjoins the northern boundary of the treatment plant site.

The treatment wetland is designed to collect and treat subsurface flows and rare surface runoff (which may occur as a result of heavy or extended rainfall events) migrating from the Irrigation Forest. The Maleny STP wetland is also designed as a shallow, low-profile system planted with rooted emergent macrophyte vegetation that have rapid growth rates and capacity to withstand inundation for extended periods, as well as filter water and assimilate nutrients and contaminants. Treated wastewater is piped to the wetland and enters rock beds to slowly distribute wastewater around the plants for maximum contact with plant surfaces.

Maleny STP's treatment wetland, constructed over 3 hectares, is designed to regulate water depth, contact time, duration and residence time to enable maximum treatment to occur. The wetland encompasses a series of low-slope terraces with a slight fall from one to another, divided by berms that will enable individual water level control and efficient distribution of flows to allow maximum retention time and prevent water channeling along narrow pathways (referred to as short-circuiting). Final treated wastewater is released into a drainage channel located about 400 meters upstream of Obi Obi Creek.

Diatoms trialled at the Dayboro STP (Unitywater)

At the Dayboro STP, Unitywater was having problems with cyanobacterial (otherwise known as blue-green algae) blooms in their dams. Combined with the high pH (10.5) and high metal concentrations, the cyanobacterial blooms were impacting the land application areas. The key concern was high phosphorus and low available nitrogen concentrations in the dams impacting treatment performance and sustainability of land application. In order to restore the health of the dams and their surrounds, Unitywater trialled Diatomix, a nutrient mixture (125 mL/d) which selectively fosters the growth of diatom microalgae. The microalgae interact with naturally occurring bacteria breaking the cyanobacteria control of available nitrogen and shading within the dams. The diatoms and bacteria re-establish balanced levels of nitrogen into both dam and soil, creating the conditions to consume excess nutrients in the dam and soil. In the dams, diatoms grow best at depth, distributing oxygen through the water column leading to higher biological activity for biochemical oxygen demand (BOD) removal. Growing at depth, diatoms improve UV penetration in the dam water for extra disinfection. Before the commencement of the trial, the concentration of TN was 5 mg/L, and the total phosphorus concentration was 7 mg/L. This was reduced to 2.0 mg/L TN and 0.0 mg/L TP. After a month of operation, the suspended cell count (which affects the turbidity of the water) dropped from 7 million to 300,000 cells/mL. With the success of this trial, Unitywater is incorporating this diatom system into operations at Dayboro STP and to some of their other facilities, including the Wamuran Irrigation Scheme.

Energy reduction and non-conventional energy sources

Solar energy applications

Solar has been adopted as an energy alternative at some Urban Utilities sites, Cairns and Gympie Regional Councils. It is also employed in the Kenilworth Floating Wetlands (Unitywater). Torres Strait Island Regional Council is exploring options for a solar powered aeration system for their ponds. Gold Coast City Council is also weighing up the use of solar as an option to power Coombabah STP. If implemented, a solar system would provide half of the required energy to treat the 85 ML/d of wastewater entering the plant. The solar panels at Kenilworth, operated by Unitywater, have led to a reduction in carbon emissions of 12 tonnes CO_2e per year, ensuring carbon neutrality.

Further afield, photovoltaic arrays have played a major role in SA Water's (South Australia) push for net-zero electricity generation by 2020. Production of 5 MW of solar energy across the three major facilities under control of SA Water are being used, with a view to expand solar capture to 70 SA Water sites. Coupled with the increase in solar energy capture, 34 MWh of battery storage have been planned. These measures demonstrate that utilities can achieve net-zero ongoing energy costs, while meeting all operational requirements.

Biosolids and biogas management

Management of Toogoolawah and Aratula STPs on biosolids accumulation and treatment performance (Urban Utilities)

In STPs that use pond/lagoon systems, sewage sludge/biosolids are settled at the bottom of the ponds. The accumulation of the sludge over time will potentially reduce the effectiveness of the treatment. Therefore, sludge removal (desludging) of the lagoon and regular maintenance is important. Urban Utilities has experience with sludge management of their STPs' lagoons within South East Queensland, with one example including the desludging and improvement of treatment processes of the Toogoolawah and Aratula STP ponds. Urban Utilities has also tested different technologies for the management of biosolids, including the application of suction, desludging, and geo-tube dewatering. Urban Utilities is exploring cost-effective opportunities to convert lagoon STP biosolids into a valuable resource. Figure A-4 below shows Urban Utilities' smallest plant after the lagoon was dewatered awaiting biosolids removal.

Figure A-4 Dewatered Urban Utilities lagoon prior to biosolids removal (Urban Utilities, 2021)

Biogas from anaerobic digestion system

The removal/separation of sludge from wastewater in sewage treatment plants occurs mainly in the primary treatment. This sludge is thickened and anaerobically co-digested with thickened waste activated sludge (if applicable) in anaerobic digesters. The digesters produce biogas that can be used as energy recovery (e.g. heat and power or on-site generation of electricity). Excess biogas can also be flared to the atmosphere after digester heating requirements are met (de Haas et al., 2009). Additionally, de Haas et al*.,* 2015, stated that the medium to large wastewater treatment plants in Australia are indicated to have better energy recovery systems, particularly from biogas, than smaller facilities.

Urban Utilities has developed co-generation units and has been successfully producing biogas from their sewage and trade waste (e.g. Luggage Point and Oxley Creek sewage treatment plants). The biogas is used to generate electricity for on-site usage (Urban Utilities, 2015). Additionally, Gold Coast City Council and Toowoomba STP are currently exploring options for co-digestion where solid wastes could be diverted from the landfill to produce biogas and to power sewage treatment plants.

Management, monitoring and data analysis

Innovative licensing (Urban Utilities)

One of the major factors to the holistic approach taken by Urban Utilities was the licensing structure. Bubble licensing over a catchment (in this case Lower Brisbane) allows each STP to manage its nutrient discharges, such that the total annual nutrient load (or nutrient load over a defined extended period) limit is not exceeded. This has allowed Urban Utilities to explore innovative practices with the knowledge that any reductions in performance would not be penalised. An overarching theme from Urban Utilities was that a conscious shift is being made away from technology upgrades to better management practices, and this was facilitated by bubble licensing.

A positive consequence of the bubble license was that Urban Utilities could remove total nitrogen to 80% reduction, maintain that performance, and address other facets of the plant which could be improved, such as focusing on ways to reduce the addition of chemicals, such as chlorine for disinfection, or methanol for denitrification. More broadly, the bubble licenses have allowed Urban Utilities to assess and minimise environmental harm over entire catchments rather than at release point sources and provided extra time to rigorously assess and screen potential new technologies, such as Nereda or anammox for more efficient nutrient removal.

Process control, modelling and data analytics

While valuable insight can be gained from the vast knowledge base of the operators and engineers who run wastewater treatment plants, there is a strong case for data analysis, modelling, and smart sensors to play a greater role in sewage treatment operations (Booth, 2019). The mathematics around data analysis and process modelling can be difficult for decision makers to understand (Booth, 2019), which can allow jargon to cloud the true extent to which such analyses can be useful. There are several cases in Queensland and Australia where utilities have taken the first steps into data analysis and modelling to drive process operation and decision making, with considerable degrees of success and insight.

Cairns Regional Council has begun a program to roll out smart water meters as a part of the Cairns Water Security Strategy. Smart water meters allow for more frequent readings of municipal water use. By having a more complete data set, the council can more quickly pinpoint problems such as leakages within the system. The benefits for customers also mirror those for the Council, as more timely repairs for leakages means lower utility bills. A customer portal is also slated for delivery, allowing customers to view an accurate picture of their water usage through a web interface. Cairns Regional Council was the first council in Australia to implement these smart water meters, however they have been demonstrated to be beneficial for all stakeholders in many cities across the world (Randal and Koech, 2019 ; Prackwieser, et al., 2019).

Unitywater is one example of a utility moving forward in data analysis and machine learning applications. They have recently partnered with GHD to develop a sewer overflow prediction tool using convolutional neural networks. This tool was able to serve as a predictor of overflow events based on precipitation echo imagery (Fisher et al., 2019). The mathematical implementation highlighted is out of the scope of this work, but the process of design thinking that was presented can provide a valuable insight for those who may be looking at implementing such technology. The design thinking was described as the following:

- Empathise: making sense of the physical problem at hand and try to identify the coupling between current results and other factors.
- Define: assessing all risks and how they can influence operational failures. These risks can be external, systemic problems, or issues associated with a piece of technology.
- Ideate: weighing up the factors that affect operation, and how their influence can be quantified (e.g. is the data set complete such that deterministic conclusions can be made, or is the data set sparse such that we can only draw probabilistic conclusions?).
- Prototype: the building of the neural network based on the three previous steps.
- Test: the comparison of the trained neural network to unseen data for validation purposes. If the model holds for unseen data, then that is a good indication that the model is a good representation of reality.
- Implement: deployment of the model so that it works properly with existing control, sensor and information systems within the organisation. The implementation phase includes the interface with which other members of the organisation can explore and interpret the model results without touching the underlying mathematics or computer code.

While this model did not provide a magic solution to faithfully predict disruptions to the system or the impacts of externalities, it does indicate that machine learning can be a useful tool if it is coupled with well-constructed process models.

Urban Utilities has recognised the need to manage their sewer network with the aid of sensors, meters, process modelling, and data analysis methods. Data and modelling form a large component of the innovation strategy of Urban Utilities. In sewage treatment plants, there are considerable quantities of raw data each day. The goal for Urban Utilities is to harness this data and convert them into insights to help with a range of aspects of plant operation, including generating visual reports to enable effective decision making and performance tracking. Specifically, intelligent operation comprises pressure and acoustic sensors to detect leaks before they become a serious issue, automated sensing of pressure and flowrates, better monitoring of disinfection processes to minimise chemical addition while assuring public health, and migration of data processing to third party data centres (commonly known as the “cloud”) to save on hardware and software maintenance of in-house server infrastructure.

To improve treatment outcomes at their STPs, Gold Coast City Council draws on SCADA (supervisory control and data acquisition) control systems that can be accessed remotely by operators. This has advantages for ongoing operation, and for when a STP has diminished access due to extreme weather events.

Gold Coast City Council also works on the philosophy that small improvements to operational practices can mean that major capital upgrades might be avoided or deferred. Such examples are pumping optimisation and the proper diffuser selection, which effectively increases the capacity of treatment plants.

Another axis for improvement is through the optimisation of chemical dosing. The council is currently undergoing testing across the whole sewer network, with the help of the Sewex model (https://www.sewex.com.au/). By using this model, which describes the biological reactions and physics occurring in sewers, Gold Coast City Council can minimise the hydrogen sulphide concentration in the network (which is responsible for offensive odours) and optimise the dosing strategy of chemicals. The council has experienced a decrease of 20% in chemical dosing across their network as a result.

Data visualisation (Tasmania Water)

TasWater (Tasmania) has been active in implementing a robust data visualisation strategy. This was in response to the volumes of data (often noisy and cumbersome to analyse) that utilities produce and that go unprocessed. Through this strategy, TasWater has seen improvements in efficiency as well as understanding of asset performance priorities. TasWater has been able to prescribe a standard across its water network to ensure that analyses are carried out in the same manner, so that everyone across the network is on the same page. The strategy has enabled all stakeholders in the business to maintain the same goals. The asset performance teams have used this tool to better understand the risks and potential benefits around their assets. This has led to better treatment outcomes as infrastructure can be better employed to achieve treatment goals (Rippon et al*.,* 2019).

Data visualisation can be daunting, especially when data are coming from various sources with different file formats. This can be off-putting to even the most motivated wastewater treatment providers. TasWater presented their key findings, which helped in cutting through the uncertainty and complexity of the data analysis process:

- All stakeholders need to be able to communicate with the operation's information technology provider for seamless access to the volumes of data available.
- All stakeholders must be subjected to the same standardised approach in order to avoid heterogeneous and confusing data sets and visualisations.
- The organisation must be able to articulate the need for data science. If no reason for data visualisation can be articulated, there is no point in employing a data science and visualisation strategy.

For any extension of the data science strategy, the three previous points should be revisited.

Limitations and considerations for data analysis

Data analysis and data driven modelling, such as machine learning and artificial intelligence, are not magic solutions to process operation. Examples presented here have highlighted standardised approaches to make the data analysis process more efficient, but these standard methods cannot replace people who are well versed in both statistical techniques and treatment technologies. There is a wealth of knowledge that exists in mechanistic technical modelling (whether that be financial, wastewater treatment, logistics *etc.*). It is preferable that statistical learning methods supplement mechanistic modelling in order to deepen the suite of understanding of water treatment operations, not dispense with it or diminish its influence in the name of artificial intelligence and progress.

With an ever-growing base of connected items, such as smart meters and remote-control systems (SCADA), comes an increasing surface for potential cybersecurity problems. The motivations for cyber-attacks can be wide ranging, from state actors to individual hobbyists wanting to prove their skills. Great care must be taken when implementing smart systems in the water industry.

Wastewater utilities are also not immune to such threats. In a briefing from the United States Environmental Protection Agency, potential threats include manipulation of valves, alarms, pumps and other equipment to disrupt treatment services, stealing customers' personal information, installing malicious software and degrading the image of a utility by defacing its website (US EPA, 2018). Such attacks can affect the treatment quality of water, place the public against the utility, and lead to legal and financial issues. Recommendations in this briefing were as follows:

- Keeping inventory of control system devices and ensuring the equipment is not exposed to networks outside of the utility.
- Segregation of networks.
- Using secure remote access methods, such as secure shell.
- Maintaining specific lists of users for different networks.
- Using password managers within the organisation.
- Keeping employees, especially executives, updated on cybersecurity best practices, and updating security patches when they are available.
- Having policies in place for secure mobile devices.
- Having the competence to detect a compromised network and act accordingly.

It was not clear if Queensland or Australian authorities had specific cybersecurity frameworks in place. A clear framework would be necessary if the adoption of smart technologies and internet-of-things devices continues to grow.

Community engagement needs

In a systematic treatment sense, Gold Coast City Council has experienced challenges associated with the public perception of wastewater treatment services.

There is a divide between rural small operators about the merits of utility-provided water treatment services, with some preferring to opt for onsite septic systems. The nature of these properties, being so close to the rivers in the catchment, means that poor wastewater quality can have impacts across the whole catchment. There needs to be better awareness around the risks of poorly performing septic systems.

The proximity of the city to the sea means that salt is ever-present in the sewage system. This can have negative implications on the recycling and reuse scheme. Additionally, with long retention times, saltwater can increase the instances of sewer corrosion problems with increased sulphide.

Nitrous oxide emission reduction (South Australia Water)

Innovation is not only happening in the Great Barrier Reef catchment and Queensland. Interstate utilities can serve as inspiration for leading practice as well. SA Water (South Australia) has recently demonstrated 30% reductions in nitrous oxide (N_2O) emissions (McCarty, P., L., 2018). In partnership with the University of Queensland, SA Water installed several floating hoods at their Bolivar Wastewater Treatment Plant to trap emissions for analysis, which pinpointed problematic areas within the step-fed activated sludge process. Proper control and optimisation routines could then be implemented in response to the data analysis, leading to the reduction in emissions of N_2O.

Nitrous oxide is a greenhouse gas which is greater than 300 times more potent than CO_2 (Rippon et al*.,* 2019). Additionally, the volume of effluent released from wastewater treatment plants accounts for 50% of all emissions. This approach has been described as worldwide leading practice for process control and optimisation to reduce environmental impacts due to greenhouse gas emissions from wastewater treatment plants.

Appendix B – Data tables on leading practice facilities

Table B-1 Reuse component information for selected facilities based on 2018 to 2020

ERA 63 Category	STP names	Average Release Volume per Year (ML)	Average Reuse Volume per Year (ML)	% Total Reuse			
				2018	2019	2020	Average
63-(1d)	Port Douglas Sewage Treatment Plant	527	509	44	39	70	**51**
63-(1c)	Picnic Bay Sewage Treatment Plant	875	62		71	4	**37**
63-(1f)	Rubyanna Wastewater Treatment Plant	2360	9855	1	93	0	**31**
63-(1e)	Yeppoon West Sewage Treatment Plant	1381	437	29	25	19	**25**
63-(1e)	Millbank Sewage Treatment Plant	1157	147	1	20	13	**11**
63-(1g)	Mt St John Wastewater Treatment Plant	6476	649	9	9	10	**9**
63-(1e)	Marlin Coast Wastewater Treatment Plant	2387	225	4	11	10	**8**
63-(1f)	Northern Wastewater Treatment Plant (Aeroglen)	6802	185	4	2	2	**3**
63-(1f)	Southern Wastewater Treatment Plant (Woree)	7784	218	4	3	1	**3**

Table B-2 Interim release requirements (max) for existing plants in the process of upgrading, adapted from Tasmanian plant performance data and 1999 Load Calculation Protocol for Sewage Treatment Plants, NSW EPA (DPIWE, 2001).

Parameter Plant Type	BOD (mg/L)*	Non-Filterable Residue (mg/L)*	TP (mg/L)	TN (mg/L)	Oil & Grease (mg/L)	Total Residual Chlorine**	pH	Thermotolerant Coliforms freshwater (marine) (colony forming units/100 mL)
Activated Sludge Plants Conventional Activated	15	20	10	40	10	1	6.5–8.5	200 (1000)
Extended Aeration (EA)	15	20	10	20	10	1	6.5–8.5	200 (1000)
EA + Denitrification	15	20	10	10	10	1	6.5–8.5	200 (1000)
EA + Ponds	10	15	8	5	10	1	6.5–8.5	200 (1000)
EA + Filtration	8	8	8	20	10	1	6.5–8.5	200 (1000)
EA + Chemical P Removal	15	15	1	20	10	1	6.5–8.5	200 (1000)
EA + Chemical P Removal + Filtration	5	5	0.5	20	10	1	6.5–8.5	200 (1000)
Trickling Filter TF + EA with denitrification	15	20	10	15	10	1	6.5–8.5	200 (1000)
TF + Filtration	20	20	15	30	10	1	6.5–8.5	200 (1000)
Lagoons Oxidation Ponds	50	50	10	40	10	1	6.5–8.5	200 (1000)
Oxidation Ponds + Ponds	30	40	10	40	10	1	6.5–8.5	200 (1000)
Aerated Lagoon	40	40	10	40	10	1	6.5–8.5	200 (1000)
Aerated Lagoon + Ponds	20	30	10	20	10	1	6.5–8.5	200 (1000)

* Some plants may have been designed to produce an effluent quality based on the 1974 Environment Protection (Water Pollution) Regulation and are at maximum load.
These plants may adopt a permitted performance of BOD 20 mg/L and NFR 30 mg/L (or BOD 40 mg/L and NFR 60 mg/L where a 50:1 dilution requirement is met).
** Chlorination of effluent is not considered best practice within the definition of accepted modern technology

Table B-3 Best practice maximum release to water concentrations (NSW public register)

Plant size (ML annual max)	Company name	NH3-N (mg/L)	TN (mg/L)	TP (mg/L)
> 20–100	Bellingen Shire Council	2, 5	10, 15	0.5, 1
> 20–100	Charlotte Pass Snow Resort Pty Ltd	2, 5	10, 15	0.3, 1
> 100–219	Armidale Regional Council	5	15	1
> 100–219	Bogan Shire Council	5	15	10
> 100–219	Bourke Shire Council	-	15	10
> 100–219	Brewarrina Shire Council	-	15	10
> 100–219	Byron Shire Council	5, 10	15, 25	1, 3
> 100–219	Cabonne Shire Council	-	15	10
> 100–219	Cabonne Shire Council	-	30	10
> 100–219	Central Coast Council	15	10	10
> 219–1000	Bega Valley Shire Council	2, 10	10, 15	0.5, 2
> 219–1000	Bega Valley Shire Council	2, 5	10, 15	8, 10
> 219–1000	Bega Valley Shire Council	2, 5	10, 15	1, 2
> 219–1000	Bega Valley Shire Council	2, 5	10, 15	13
> 219–1000	Bega Valley Shire Council	2, 5	10, 15	-
> 219–1000	Bellingen Shire Council	2, 5	10, 20	0.5, 1
> 219–1000	Bellingen Shire Council	2, 5	10, 20	0.5, 1
> 219–1000	Blayney Shire Council	2	15	1
> 219–1000	Byron Shire Council	2, 5	10, 15	0.3, 1
> 1000–5000	City of Lithgow Council	2, 5	10, 15	0.5, 1
> 1000–5000	Byron Shire Council	-	10, 15	0.3, 1
> 1000–5000	Ballina Shire Council	2, 5	10, 20	0.5, 1
> 1000–5000	Bathurst Regional Council	15, 20		1, 2
> 1000–5000	Byron Shire Council	2, 5	10, 15	5, 1
> 5000–10000	Albury City Council	5, 10	15, 30	1, 2
> 10000–20000	Sydney Water Corporation	0.9, 1.4	45	5
> 10000–20000	Sydney Water Corporation	0.9, 1.4	45	5
> 10000–20000	Hunter Water Corporation	8	20	7
> 30000	Sydney Water Corporation	31, 52	-	-

Table B-4 Nutrient limits used by different authorities in Victoria

Authority	Ammonia limit (mg-N/L)	TN limit (mg/L)	TP limit (mg/L)
Central Highlands Region Water Authority	10	45	2
City of Horsharn	2	40	10
Town of Kyabram	-	20	5
Latrobe Region Water Authority	-	40	15
Melbourne Water	20	10	1
Macedon Region Water Authority	5	15	1
Tarego Water Board (Drouin)	10	-	-
Tarego Water Board (Warragul)	5	-	5

Table B-5 South Australia wastewater treatment plants and catchments

Plant	Population served (2011 Census)	Design capacity (ML/d)	Average daily inflow 2010-11 (ML/d)	Average daily inflow 2010-11 (% of design capacity)	Main (nutrient) treatment process
Aldinga	11,947	2.1	1.52	72.4	AS (OD), chlorination, lagoons
Angaston	1,909	0.43	0.45	104.7	Imhoff tank, aerated lagoon, polishing lagoons
Bird-in-Hand	5,129	2.4	1.15	47.9	AS, BNR, CPR, Filtration, UV disinfection, sludge treatment
Bolivar	695,630	165	144.39	87.5	AS, lagoons
Bolivar HS	75,023	32	23.87	74.6	AS (SBR), UV disinfection
Christies Beach	149,313	45	26.48	58.8	Plant A&B: AS, chlorination; Plant C: MBR, UV disinfection
Finger Point	26,283	6.0	5.19	86.5	IDEA, lagoons, chlorination
Glenelg	198,169	60	48.11	80.1	Integrated fixed film AS bioreactor (Plant B&C), BNR (Plant D), chlorination
Gumeracha	1,018	0.13	0.14	107.7	Imhoff tank, TF, humus tank, lagoons, filters, chlorination
Hahndorf	4,545	1.01	0.98	97.0	AS (OD), CPR, chlorination
Heathfield	13,016	3.6	2.07	57.5	AS (BNPR), UV disinfection
Mannum	2,567	0.81	0.38	46.9	Imhoff tanks, lagoons, chlorination
Millicent	5,024	1.4	1.00	71.4	Imhoff tanks, lagoons
Mount Burr	377	0.24	0.06	25.0	Imhoff tank, TF, lagoons
Murray Bridge	13,892	2.12	2.56	120.8	Imhoff tanks, aerated lagoons
Myponga	595	0.05	0.11	220.0	Imhoff tank, lagoons
Nangwarry	514	0.24	0.10	41.7	Imhoff tank, TF, lagoon
Naracoorte	5,691	1.54	1.01	65.6	TF
Port Aug East	13,985	2.66	1.51	56.8	Aerated lagoons, polishing lagoons
Port Aug West	13,985	1.26	0.75	59.5	Aerated lagoons, polishing lagoons
Port Lincoln	14,088	4.0	3.10	77.5	IDEA, lagoons
Port Pirie	13,825	4.1	4.23	103.2	AS (SBR), lagoons
Victor Harbor	12,483	3.40	2.59	76.2	AS (BNR), UV and chlorination
Whyalla	22,088	6.94	3.75	54.0	1st plant: Anaerobic and aerobic lagoons; 2nd plant: AS (SBR), chlorination

Note: AS=Activated Sludge, OD=Oxidation Ditch, BNR=Biological Nutrient Removal, CPR=Chemical Phosphorus Removal, UV=Ultraviolet, SBR=Sequencing Batch Reactor, MBR=Membrane Bioreactor, IDEA=Intermittently Decanted Extended Aeration, BNPR=Biological Nutrient & Phosphorus Removal, TF=Trickling Filter

Table B-6 STP concentration release limits under the ACT *Environmental Protection Act 1997* (Schedule 2)

Parameter	Limit
Acidity (pH)	6.0–9.0
Faecal coliforms	≤ 1000 cfu/100mL
Suspended solids	≤ 25 mg/L
Total nitrogen	≤ 30
Total phosphorus	≤ 0.5 mg/L
Total dissolved solids	≤ 3000 mg/L

Table B-7 Comparison of Leading Practice Facilities long-term median TN <1.5 mg/L (LP1), <2.5 mg/L (LP2) and ≤4 mg/L (LP3) shown in red with 95th and 99th percentiles and annual median TN concentrations (mg/L) for releases to water.

Leading Practice (LP) Level	Facility Name	ERA 63 Category	Operational Capacity (%)***	Long-term Median*	95th Percentile*	99th Percentile*	2015 Median	2016 Median	2017 Median	2018 Median	2019Median
1	Horn Island**	1c		0.13	0.28	0.39	0.20	0.10		0.13	0.14
1	Thursday Island**	1d	90	0.14	0.34	0.46	0.23	0.13	0.12	0.17	0.16
1	Maleny	1d	45	0.53	3.4	4.4		0.53	0.61	0.54	0.45
1	Cooktown**	1d	33	0.63	1.4	4.2	0.66	0.63	0.68	0.55	
1	Cooroy	1d	35	0.70	2.5	3.9	0.67	0.64	0.72	0.77	0.87
1	Thabeban	1d	42	1.1	3.7	4.5	*3.0*	1.2	1.0	1.0	1.0
1	Kuranda**	1c	40	1.2	5.7	8.6	1.1	1.0	1.3	1.7	1.0
1	Rubyanna**	1f	59	1.3	2.9	8.1				1.5	1.2
1	Innisfail	1e	53	1.4	2.8	4.2	1.6	1.0	1.5	1.2	1.5
1	Tully	1d	63	1.5	3.6	5.3	1.5	1.9	2.0	0.89	1.5
2	Millbank	1e	87	1.6	4.6	8.3	2.0	1.7	1.0	1.6	1.3
2	Picnic Bay	1c	70	1.8	4.6	7.7			1.9	1.6	2.2
2	Cannonvale	1e	-	2.0	3.1	3.4	1.6	2.1	1.7	2.2	2.6
2	Ravenshoe**	1b(ii)	50	2.0	3.8	3.9				2.3	1.8
2	Mossman	1d	93	2.1	6.2	8.6	2.3	1.9	1.7	3.0	1.6
2	Edmonton	1e	72	2.1	4.8	5.9	3.4	1.6	2.0	2.2	1.8
2	Gordonvale	1d	62	2.2	5.6	7.8	2.0	2.2	2.1	1.8	2.6
2	Tinaroo**	1b(ii)	70	2.2	6.6	9.8			1.6	2.1	3.1
2	Gympie Widgee Crossing	1e	39	2.2	7.4	11	2.8	2.2	2.4	2.1	2.2
2	Mt St John	1g	66	2.2	4.9	7.3	1.5	1.8	1.9	3.8	1.8
2	Southern (Woree)	1f	76	2.2	3.6	4.9	2.4	2.1	2.1	2.0	2.2
2	Toomulla**	1b(ii)	40	2.3	9.4	13			1.4	3.1	3.5
3	Bargara**	1d	88	2.6	6.1	10	3.9	2.6	1.5	2.6	3.4
3	Marlin Coast	1e	78	2.6	4.5	6.1	2.2	3.6	2.2	2.7	2.2
3	Wandoan	1c	44	2.6	5.0	9.4	3.1	2.6	2.0	3.3	2.1
3	Atherton**	1d	85	2.8	4.9	6.9			3.4	3.1	1.8
3	Yeppoon West	1e	100	2.8	7.6	13	1.6	2.8	2.6	4.0	3.3
3	Yungaburra**	1b(ii)	50	3.2	5.1	5.5			3.1	3.4	3.2
3	Sarina	1d	35	3.3	4.8	5.3	3.4	3.3	2.9	3.5	3.4
3	Proserpine	1d		3.3	6.7	7.8	2.7	3.1	3.3	4.8	3.3
3	Kingaroy STP	1e	60	3.5	6.2	6.9		2.7	4.5	3.3	3.7
3	Port Douglas	1d	58	3.5	5.5	6.3	3.5	3.5	3.9	3.8	2.9
3	Bowen	1d		3.7	8.3	9.9	3.9	4.1	4.1	2.9	3.8
3	Cleveland Bay	1g	69	3.7	7.8	12	3.6	3.2	4.1	5.5	2.1
3	Northern (Aeroglen)	1f	80	4.0	5.5	6.3	4.2	3.8	4.1	3.7	4.2

Median TN (mg/L) based on overall release data for 2015–2019 from facilities in the Reef catchment; ** facilities with less than 100 TN data points; * operational capacity based on comparison of current EP to design EP.*

Table B-8 Comparison of Leading Practice Facilities long-term median TP <0.25 mg/L (LP1), <0.5 mg/L (LP2) and <2 mg/L (LP3) in red* with 95th and 99th percentiles and annual median TP concentrations (mg/L) for releases to water.

Leading Practice (LP) Level	Facility Name	ERA 63 Category	Operational Capacity (%)**	Long-term Median***	95th Percentile*	99th Percentile*	2015 Median	2016 Median	2017 Median	2018 Median	2019 Median
1	Horn Island**	1c		0.05	0.05	0.05	0.05	0.05		0.05	0.05
1	Thursday Island**	1d	90	0.05	0.06	0.15	0.05	0.05	0.05	0.05	0.05
1	Cooroy	1d	35	0.05	0.15	0.49	0.05	0.05	0.05	0.05	0.05
1	Maleny	1d	45	0.07	0.18	0.32		0.05	0.07	0.07	0.09
1	Cooktown**	1d	33	0.07	0.25	0.35	0.05	0.09	0.10	0.05	
1	Picnic Bay	1c	70	0.10	0.32	0.55			0.10	0.10	0.07
1	Port Douglas	1d	58	0.11	0.55	0.85	0.32	0.17	0.17	0.06	0.05
1	Northern (Aeroglen)	1f	80	0.12	0.9	2.1	0.14	0.12	0.12	0.11	0.14
1	Innisfail	1e	53	0.15	0.59	1.1	0.19	0.15	0.14	0.13	0.13
1	Tully	1d	63	0.21	0.79	1.1	0.21	0.25	0.33	0.18	0.09
1	Kuranda**	1c	40	0.23	0.87	1.1	0.20	0.37	0.26	0.33	0.15
1	Ravenshoe**	1b(ii)	50	0.23	0.87	0.96				*0.42*	0.06
2	Mt St John	1g	66	0.25	1.3	2.0	0.24	0.27	0.27	0.29	0.18
2	Mackay North (Bucasia)	1e	68	0.28	0.85	1.7	0.32	0.30	0.21	0.51	0.19
2	Rubyanna**	1f	59	0.28	1.2	1.8				0.14	0.50
2	Proserpine	1d		0.30	1.3	3.2	0.30	0.50	0.50	0.40	0.20
2	Marlin Coast	1e	78	0.32	1.1	1.6	0.24	0.31	0.54	0.34	0.26
2	Edmonton	1e	72	0.32	0.65	0.88	0.36	0.37	0.22	0.25	0.20
2	Bargara**	1d	88	0.39	1.2	2.3	0.39	0.33	0.30	0.30	0.50
2	Masig**	1b(ii)	50	0.40	0.99	2.6	*0.78*	*0.68*	0.56	0.32	0.35
2	Sarina	1d	35	0.41	1.0	1.9	0.49	0.41	0.40	0.47	0.31
2	Southern (Woree)	1f	76	0.41	1.4	2.3	0.50	0.54	0.27	0.39	0.38
2	Tinaroo**	1b(ii)	70	0.42	1.3	1.6			*0.61*	0.22	0.36
2	Cleveland Bay	1g	69	0.49	2.1	3.5	0.56	0.47	0.53	0.59	0.24
3	Thabeban**	1d	42	0.50	2.6	4.3	1.4	0.49	0.45	0.50	0.50
3	Cannonvale	1e		0.50	1.6	1.9	0.60	0.50	0.50	0.50	0.70
3	Yeppoon West	1e	100	0.54	3.3	6.6	1.5	0.33	0.64	0.4	0.52
3	Atherton**	1d	85	0.68	1.3	1.8			0.66	0.61	0.76
3	Gympie Widgee Crossing	1e	39	0.76	3.4	4.8	0.61	0.84	1.2	0.30	0.81
3	Bowen	1d		0.86	5.4	6.7	4.5	1.7	0.86	0.54	0.29
3	Kingaroy STP	1e	60	1.3	3.0	7.7		1.9	1.1	1.3	1.3
3	Mackay South**	1f	68	1.6	4.3	5.3	4.5	2.2	1.2	1.6	1.4
3	Mossman	1d	93	1.6	3.3	3.7	2.2	1.7	1.7	1.6	0.99
3	Gladstone	1d		1.6	4.0	*6.9*	2.2	1.7	1.7	0.88	1.5

**Average TP (mg/L) based on overall release data for 2015–2019 from facilities in the Reef catchment; **facilities with less than 100 TP data points; ***operational capacity based on comparison of current EP to design EP.*

Table B-9 Comparison of various statistics for ammonia concentrations (mg-N/L) for releases from Leading Practice Facilities in the Reef catchment including long-term median, 95th, 98th, 99th and maximums of data for 2015–2019. Note 99th Percentile NH3 <1.5 mg-N/L is LP1 and <3 mg-N/L is LP2 in red.

Leading Practice (LP) Level	Facility Name	ERA 63 Category	Operational Capacity (%)***	Long-term Median*	95 Percentile*	98 Percentile*	99 Percentile*	Maximum*
1	Cooktown**	1d	33	0.02	0.05	0.11	0.17	0.3
1	Picnic Bay	1c	70	0.05	0.17	0.21	0.25	2.4
1	Gordonvale	1d	62	0.03	0.22	0.27	0.29	0.8
1	Thabeban**	1d	42	0.20	0.25	0.27	0.37	0.55
1	Masig**	1b(ii)	50	0.25	0.51	0.53	0.53	0.54
1	Cannonvale	1e		0.20	0.30	0.40	0.54	1.3
1	Sarina	1d	35	0.20	0.37	0.62	0.76	1.69
1	Tinaroo**	1b(ii)	70	0.02	0.38	0.62	0.79	0.96
1	Wandoan**	1c	44	0.18	0.51	0.73	0.80	0.87
1	Yungaburra**	1b(ii)	50	0.11	0.85	0.91	0.95	1
1	Southern (Woree)	1f	76	0.07	0.58	0.89	0.98	1
1	Port Douglas	1d	58	0.28	0.97	1.2	1.2	1.4
1	Kuranda**	1c	40	0.02	0.28	0.93	1.2	1.5
1	Edmonton	1e	72	0.14	0.77	1.0	1.2	1.7
1	Mossman	1c	93	0.15	0.77	0.92	1.2	2.1
1	Northern (Aeroglen)	1f	80	0.06	0.88	1.2	1.3	1.7
2	Gympie Widgee Crossing	1e	39	0.09	0.41	1.0	1.5	1.9
2	Marlin Coast	1e	78	0.03	0.29	0.86	1.6	3
2	St Pauls**	1f	32	0.02	0.63	1.3	1.8	2.4
2	Cooroy	1d	35	0.05	0.60	1.3	1.8	2.8
2	Rubyanna**	1f	59	0.20	0.70	0.99	1.9	2.3
2	Proserpine	1d		0.20	1.1	2.0	2.1	3.1
2	Kingaroy	1e	60	0.22	1.3	1.7	2.2	2.4
2	Innisfail	1e	53	0.08	1.1	1.8	2.2	2.8
2	Tully	1d	63	0.09	0.73	1.3	1.7	2.7
2	Cleveland Bay	1g	69	0.07	1.1	1.6	2.5	3.6
2	Bowen	1d		0.15	1.7	2.4	2.6	2.8

**Ammonia statistics based on overall release data for 2015–2019 from facilities in the Reef catchment; **facilities with less than 100 ammonia data points; ***operational capacity based on comparison of current EP to design EP.*

Table B-10 Outliers removed from the calculation of the statistics presented in this report

STP	Date	Values Removed (mg/L)		
		TN	NH3	TP
Atherton	1/08/2017	8.9	7.8	
	29/11/2017	37	33	
Bowen	24/03/2015	18.3	7.5	
	24/10/2017	10.9	8.2	
Cleveland Bay	14/02/2019	16.4	12.2	3.1
	22/02/2019	14.3		
Cooktown	7/15/2015	20	18	
Gladstone	26/05/2015			32
	29/05/2015			25
Gordonvalle	15/11/2017	21		
	23/12/2015	14		
Innisfail	25/01/2017	10	8.4	
Kingaroy	10/01/2018	10	8.8	14
Mackay South	23/01/2015			9.0
	17/01/2016			11.6
Millbank	20/07/2017	14.8		
Northern (Aeroglen)	4/02/2015			2.9
Proserpine	11/02/2015			12.1
	25/07/2018	15.7	12.8	
Ravenshoe	8/03/2017 - 3/10/2017	13-29		
Rubyanna	3/01/2019			5.77
Toomulla	17/10/2018	68.4		7.5
	14/11/2018	68.1		6.3
	12/12/2018	47.4		2.1
Tully	6/7/2016		4.6	
Yeppoon West	21/01/2015			10.4
	11/12/2019			14.5
	25/12/2019			14.5
	17/04/2019	15.2		
	24/04/2019	29.6		
	1/05/2019	13.3		
	8/05/2019	10.4		
	15/05/2019	11.8		