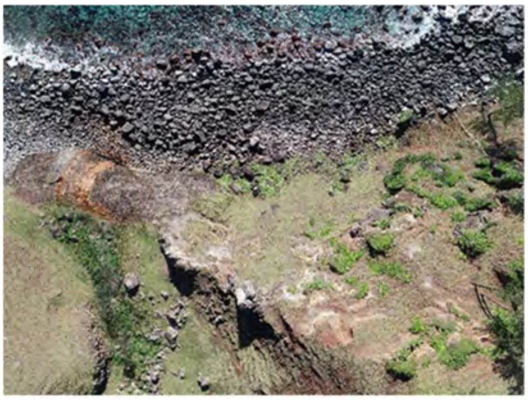
Norfolk Island

Environmental Assessment



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Norfolk Island Environmental Assessment

Executive Summary

In 2018, The Norfolk Island Regional Council (NIRC) identified the need to undertake an assessment of Norfolk Island's environmental capacity and provide scientific background on current land use, hydrology, soils, biodiversity and ecosystems to inform the development of a population strategy and ensure that an increase in population on Norfolk Island does not exceed its carrying capacity. The Community Strategic Plan 2016-2026 – *Our Plan for the Future* (NIRC, 2016), and its Delivery Program 2016-2020, mandate the development of a sustainable population policy, acknowledging that population growth needs to be considered within the bounds of environmental sustainability. The Community Strategic Plan also provides some strategic directions for an environmentally sustainable community, which include the following objectives:

- Develop a clean energy future,
- Protect and enhance water quality,
- Reduce, reuse and recover waste and end disposal of waste into the sea,
- Create a food secure community,
- Create a water secure future,
- Retain open spaces and low-density development,
- Protect and preserve environmentally sensitive areas and those of high conservation value, through improved land management and pest control practices,
- Support threatened species and minimise the presence of invasive species,
- Ensure a healthy, diverse marine ecosystem and,
- Protect and preserve vegetation communities and habitat.

In this context, and in accordance with those objectives, NIRC commissioned The Norfolk Island Environmental Assessment, which was conducted in the period ranging from May 2019 to April 2021 by a team of scientific researchers led by Monash University, Monash Sustainable Development Institute, and The University of Newcastle. The research team carried out a desktop review, some consultation with key stakeholders, data collection and analysis, according to the four main streams of the Environmental Assessment:

- Land-use capability, coastal zones and soils, the extent to which existing land use is consistent with environmental sustainability;
- Hydrology, examining surface and groundwater resources, existing use and long-term sustainability;
- Ecosystems and biodiversity; and,
- Systems and technologies that have applicability on Norfolk Island for waste management, energy and food production.

NIRC will include scientific evidence obtained from these assessments in the community engagement program, to develop a sustainable population strategy for Norfolk Island. It will review the Norfolk Island Community Strategic Plan in line with this evidence to bring in a system of planning controls that: a) better reflects ecosystem and population dynamics; and, b) aligns with economic development objectives and community expectations.

BACKGROUND

Norfolk Island is an Australian External Territory situated in the South Pacific Ocean, located at 29°02'S 167°57'E, with an area of 35 km^2, some 1,600 km northeast of Sydney. Norfolk is a volcanic island with a coastline of some 32 kilometres of mainly precipitous cliffs, except for a small section on the south side, and its highest point is at 318 meters above sea level (mAHD). According to the recent census by Australian Bureau of Statistics (ABS), the population was 1748 (ABS, 2016). Norfolk Island's population has seen a steady decrease since 2001 due to migration of 20-34 year olds, thereby creating a predominantly ageing population (Administration of Norfolk Island, 2011a). The Administration also indicated that the Island has a potential to increase its population up to 10,900 people based on achieving the maximum development potential of land, and the likely dwelling occupancy rates (Administration of Norfolk Island, 2011b). However, it also raises questions about sustainability in the event of population growth that could impact land system capability and natural resources, thus necessitating an assessment of the resource variables (such as hydrology, biodiversity and land capability) for shaping future population dynamics and sustainability on Norfolk Island.

Islands are unique in terms of their geography and biological productivity. Biological productivity is determined by the stability of the island ecosystem, which in turn is shaped by factors such as climate and hydrology. Additionally, coastal areas are most at risk of sea level rise, increased sea surface temperature, increased storm intensity and frequency, ocean acidification and changes to rainfall, run-off, wave size and direction and ocean currents (COAG, 2007). This renders island ecosystems vulnerable to climate variability.

Norfolk Island's average annual rainfall is around 1300mm/yr with most rain received in the winter. This has decreased to ~1105 mm/yr over the past 25 years (Petheram et al, 2021). Norfolk Island is of volcanic origin and dominated by a plateau 100-300 mAHD. The plateau is dissected by several river valleys, which, with the exception of Watermill Creek, reach the coast in hanging valleys with waterfalls (Bird, 2010). Throughout the Island, there is an upper water table in porous alluvium and weathered rock aquifers. During periods of drought, these aquifers tend to dry up due to extraction and natural drainage. At the base of the weathered profile, groundwater moves towards the sea through a complex network of fractures. Semi-confined aquifers are estimated to attract 20-30% of the Island's total rainfall. Groundwater recharge is from direct rainfall infiltration and runoff from Mount Pitt and Mount Bates (Abell and Falkland, 1991; Norfolk Island Regional Council, 2018). The Bureau of Meteorology data indicates an overall decline in rainfall on Norfolk Island during the period 1990-2020 (BOM, 2020).

Water is the most critical of all resources on oceanic tropical islands to sustain life. In the case of Norfolk Island, there is concern over whether available freshwater resources can sustain expected population growth. Currently water demand is met through rainwater harvesting, collection from freshwater springs, and extraction of groundwater. Another key concern is water quality, with cases of surface waters being polluted from sewage effluents and nutrients, and groundwater by wastewater and livestock. The majority of the island is serviced by on-site sewage treatment systems, with only ~12% connected to a reticulated sewage system.

Generally, islands have the highest proportion of recorded species extinctions (up to 80%). Currently, the International Union for Conservation of Nature's Red List warns that 45% of endangered species occur on islands. Analysis of biodiversity and land use capability on islands is particularly critical due to limited natural resources and living spaces, interconnected and more complex ecosystems, high vulnerability to natural hazards, and the impacts of climate change on ocean systems (Ahmadi et al., 2017).

In addition to their ecological value, islands' terrestrial and marine ecosystems provide important natural resources necessary for the economies and cultures of island communities. Balancing national priorities with environmental protection poses challenges. These challenges are made more difficult due to isolation and limited human resources, which is very much relevant to Norfolk Island.

CHAPTER 1: CLIMATE, COASTAL DATA, LAND USE CAPABILITY, ECOSYSTEMS & BIODIVERSITY ASSESSMENT

Climate trends

Climate trends for Norfolk Island can be characterised by the warming of the seas, increasing mean annual temperatures, decreasing mean annual rainfall, and increasing mean annual evaporation from Norfolk Island. These trends indicate a shift in climate patterns that are likely to decrease available water, potentially affect biodiversity and land productivity over the next 100 years.

Coastal resilience

The coastline of Norfolk Island is protected under the Australian Marine Park, and every effort should be made to protect sensitive areas and improve coastal resilience. The Norfolk Island Natural Resource Plan (2009) provided a detailed assessment of coastal issues on Norfolk Island, and it recommended that achieving the Resource Condition Targets and Management Action Targets (Table 7-2 in PB, 2009) should be a primary goal.

Soil conservation

The management of Norfolk Island's soils and land use is limited in its scope and impacts – e.g. highly dispersive soils, easily eroded when no vegetation cover, previously cultivated land overgrown with woody weeds. Land and soils need to be managed more effectively.

In the past, the Norfolk Island Administration has commissioned various reports, the aims of which were to provide advice and direction regarding land degradation and conservation strategies. Several prior reports provided a number of recommendations (Stephens and Hutton, 1954; Clive Lucas, Stapleton and Partners Pty Ltd, 1988; Abell & Falkland, 1991; Mosely, 2001). For example, the report prepared for the Norfolk Island Conservation Society by Mosley (2001) recommended a soil and land use study, and the development of policies and long-term plans to manage soil care, land degradation and rehabilitation.

There has been insufficient attention to recommendations made in previous reports. We urge that effective action is taken with regard to assessing/monitoring erosion, nutrients and restoration techniques, the development of a soil conservation policy with appropriate long term planning, protection of the most fertile areas by limiting subdivision, planting of trees, and better control of over grazing.

The stability of soils on Norfolk Island is solely reliant on land use and vegetation cover. Primary management options for Norfolk Island soils in improving soil stability should include:

- Maintaining constant ground cover in all areas;
- Improving cattle management such as temporarily fencing off sensitive areas;
- Management/removal of woody weeds;
- Develop a strategy for land and soil management that focus on land and ecosystems regeneration, soil organic carbon, agrobiodiversity and crop diversification.

Ecosystems and biodiversity

The ecosystems and biodiversity study sought to broadly categorize land use in terms of vegetation (abundance, density) and catchment condition (degrees of disturbance). Vegetation and Catchment condition maps provided in the report were based on satellite imagery and analyses using Support Vector Machine (SVM) approaches. The use of drone surveys improved resolution of images captured and provided additional information using Normalised Distribution Vegetation Index (NDVI) and Digital Terrain Models (DTM) outputs.

Modelling shows that three disturbance classes (Classes 1, 2, and 3) cover 2,192 ha of land area on Norfolk Island, or approximately 64% of land area (excluding major roads and shorelines). The worst condition class (Class 1) includes degraded open grass areas with evidence of sheet and gully erosion which covers ~900 ha (~25% of land area). The report shows that impacts from trampling, grazing, farming and poor vegetation management have a strong correlation with this class.

Probability of occupancy for four threatened bird species have been presented based on catchment and vegetation condition. Probability of occupancy for different catchment and vegetation conditions provides a baseline condition for monitoring changes in bird population, and/or changes in probability of occupancy with respect to planned/future changes in land use. For example, if a species has a high probability of occupancy in a given catchment/vegetation condition (disturbed or undisturbed), then any changes in land use such as clearing is likely to have a negative effect on that population. In contrast, forest restoration, regenerative farming, and weed management will promote a higher catchment/vegetation condition, and likely increase the probability of occupancy for endangered species as new ecosystems evolve. Outputs from this report provide a baseline for environmental impact planning and future comparison.

Existing projects involving plant identification, vegetation community restoration, and weed/pest management, will support gathering and disseminating environmental data to better understand vegetation mapping and management for Norfolk Island (E.g. Mills, 2018; Naomi Christian Consulting, 2020 are developing a transparent, open-access to vegetation mapping for all of Norfolk Island).

The study identified:

- 2,192ha of Norfolk Island (total of 3,460ha) classed as moderate to very poor catchment condition;
- Higher classes of disturbance condition (less disturbed) mostly comprise reserve areas and coastal areas with hardwood forests, and the National Park with some small pockets in the east;
- 52 exotic "weed" species on Norfolk Island;
- Approximately 80% of the endemic flora species are threatened according to the provisions of the Environment Protection and Biodiversity Conservation Act 1999, and the Norfolk Island pine (Araucaria Heterophylla) is on the International Union for Conservation of Nature Red List of Threatened Species.

It recommended:

- Developing a strategy to restore "disturbed" environments of low catchment condition, at a small-scale, and include a range of approaches such as planting projects and drainage line restoration to reduce erosion;
- Connect all biodiversity/ecology programs undertaken on island with the Norfolk Island Flora & Fauna Plan, and provide a knowledge-sharing platform for current flora and fauna experts, National Parks & Marine Parks staff, and other interested individuals;
- Promote community awareness and education, via e.g. developing online tools, citizen science projects. "iNaturalist" as a global flora and fauna app could support citizen science on Norfolk Island.

CHAPTER 2: HYDROLOGICAL ASSESSMENT AND PRELIMINARY WATER BALANCE

Norfolk Island's water security is under threat due to the historical reduction in rainfall and increasing temperatures (since 1970's) (BOM, pers. comm.). The reduction in water availability will have significant implications for the future of Norfolk Island. Water shortages will directly impact upon household supply, food security (from the perspectives of crop irrigation and stock watering), tourism, public health, and commercial businesses. The Emergency Management Norfolk Island Committee (EMNIC) has recently identified several gaps in Emergency Management Response Plans that sit beneath the Norfolk Island Disaster Plan (NORDISPLAN), namely water security and increased risk of unplanned wildfire given a drier, hotter environment.

Major findings from this study confirm that:

- Norfolk Island's water security is under threat due to the historical reduction in rainfall and increasing temperatures;
- Groundwater levels in 2019/20 were at lowest point in recent history and future recharge rates remain uncertain;
- Approximately 131 ML/yr of harvested rainwater and 128 ML/yr of groundwater extracted for Island water demand;
- All wastewater is discharged via septic tanks across the island, or treated through the Water Assurance Scheme before discharged to the ocean;
- Attributed to livestock and non-sewered areas (septic tanks), surface water quality in major creeks often exceed ANZECC guidelines after heavy rain, sometimes causing closure of Emily Bay (as a human health hazard);
- Poor monitoring and metering of water use across the island;
- Up to 65% of buildings do not have optimised roof/tank volume for increasing rainwater yields;
- Initiate water-metering projects to determine demand and diurnal water use patterns for a range of sites (hospital, school, residential, commercial, tourist accommodations and industrial sites). The use of water meters has proven useful for leak detection in water systems and the use of "smartmeters" can incorporate a citizen science approach to Norfolk Island water management;
- Continued monitoring of surface water discharge throughout the island using stations installed by CSIRO;
- Monitor of groundwater levels and rainwater tank levels at appropriate sites, and;
- Update Development Application (DA) standards for new dwellings (in progress).

Norfolk Island Regional Council (NIRC) has made progress towards the upgrade of the Norfolk Island Sewerage Treatment Plant by commissioning the Balmoral Report (2019), which also canvassed feedback from the community, and provided several options available to NIRC. The community and Emergency Management Norfolk Island Committee (EMNIC) strongly supported *"Option 1 - Membrane Aerated Biofilm Reactor with water recycled to agriculture and community standpipe. Reticulated pressure system for priority areas."* An estimated 55 ML/y of recycled Class A water would initially be available, which would be used to provide irrigation and stock watering, reducing the demand on rainwater and groundwater. The proposal for the Wastewater Treatment Plant (WWTP) upgrade was developed in consultation with Norfolk Island Regional Council and the community in response to the business needs, and assessment of appropriate treatment technologies for the replacement of Norfolk Island's wastewater treatment plant. The total cost for Option 1 was ~$18 million.

In this study, an "available water" assessment identified all alternate water options. Figure 1 highlights the main sources of water used, proposed, or available for Norfolk Island in 2019/20. Figure 2 highlights how available water could be better utilised, whilst reducing the need for desalination or increasing groundwater extraction rates. The significant differences between water availability now (Figure 1), and what could be utilised (Figure 2) are based on:

- Recycled water used for ~43% of the Island's demand ("fit for purpose" users) and is climate independent, resulting in an additional 103 ML/yr for Island water demand.
- Rainwater harvesting improved by a conservative estimate of 15% by optimising roof area/tank volume on existing dwellings/accommodations.
- Decreased dependency on groundwater extraction (lowers extraction by 55 ML/yr, effectively reducing extraction to pre-1990's levels) (lubbe side is).
- Desalination and deep groundwater extraction pre-feasibility options only provide 30.8 ML/yr and would be almost ineffective in a "dry" period similar to that experienced by Norfolk Island in 2019/20.

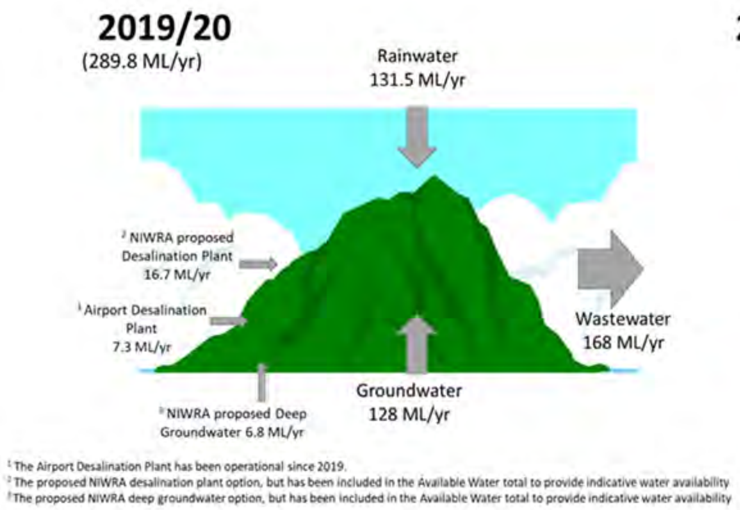

Figure 1: Available water on Norfolk Island during 2019/2020

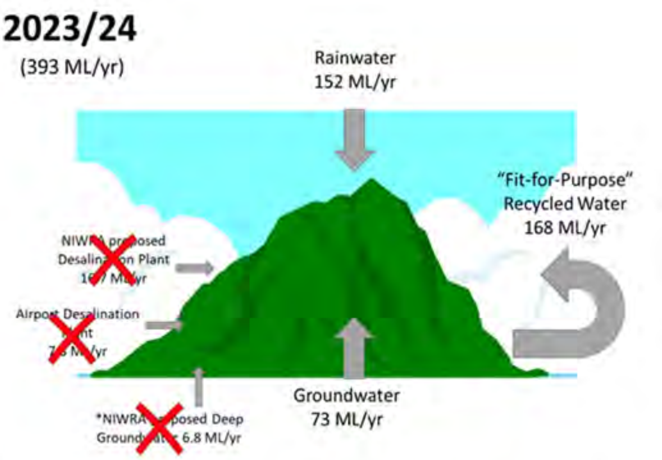

Figure 2: Available water on Norfolk Island after the WWTP upgrade and Reuse Option 1 in the Balmoral Report

The fact is that Norfolk Island is not short of water, the Island only lacks the infrastructure to provide a sustainable approach to utilising all available sources and increasing water security into the future (refer Figure 2). The cost of a new Norfolk Island Sewerage Treatment Plant alone is ~$9 million. However, to not invest the full amount of $18 million for the additional new connections, reticulated water to "fit-for-purpose users" (commercial growers, services/industry, and livestock, reflecting ~43% of the Island's water use), and community stand-pipe; would be significant opportunities missed. For example, ocean discharge would continue to enter the Marine Park at considerable environmental costs and economic losses through fines, septic tanks will still pollute surface and groundwater, and the loss of 103 ML/yr of available water (~38% of existing total water demand). By investing the full $18 million these significant opportunities can be realised.

The increasing risk of fire, especially within the eucalypt plantations of the Norfolk Island National Park (NINP) has been flagged with EMNIC and NINP as a real and emerging threat. It is recognized the WWTP upgrade and reuse (Option 1 in Balmoral Report) would provide a reliable supply of water that may be utilised for firefighting purposes, which currently do not exist. There has never been a more compelling argument for water security, improved food production, and emergency management on Norfolk Island. The full WWTP upgrade, connection of additional dwelling/accommodations to the Water Assurance Scheme, a reticulated network to "fit-for-purpose" users, and stand-pipe for other users; all point to a sustainable water and food future for Norfolk Island.

CHAPTER 3: NORFOLK ISLAND'S WASTE MANAGEMENT SYSTEM

Norfolk Island Regional Council (NIRC) is uniquely challenged in developing a modern waste management system protective of the marine park in which they exist and equivalent to mainland Australian Councils. NIRC lacks the resource base that mainland Australian Councils have and has waste management costs that are magnitudes higher due to a current reliance on exporting wastes back to Australia. This comes at great cost through reliable air-freight or infrequent shipping often limited to breakbulk operations.

Port Macquarie Council for example has total waste management revenue of $20.5 million per annum from a population of 85,000 from a revenue base (2019) of $213 million (48% from rates), which includes $31.6 million in grants from the NSW and Australian Governments1 . Waste management costs for Port Macquarie-Hastings Council therefore consumes 9.6% of its total budget while total per capita waste management costs are an economical $241 per annum due to modest disposal costs.

Norfolk Island reported collecting total waste management revenue of $793,492 from a population of 1748 from a revenue base (2019) of $41.70 million (7.8% from rates), which includes $20.4 million in grants from the Australian Government. Waste management costs for Norfolk Island Regional Council is equivalent to 2.3% of its total budget with grants, or 4.5% without, while total per capita waste management costs for NIRC was $454 per annum, approximately double the Port Macquarie per capita costs due to high export and disposal costs (comparable to the $500 charged per person on Lord Howe Island).

Unique to remote locations the economics of waste management in Norfolk Island are extreme and closer to the situation in Antarctica than a mainland council in Australia. For comparison, the costs of disposing of a cubic metre (to landfill) for 1 tonne of mixed household waste to landfill in Port Macquarie 3 is approximately $240, while for Norfolk Island disposal of the same waste to landfill costs approximately 10 times this cost. For example, sea freight and disposal costs $1,169, and air-freight and disposal costs $2,288 based on costs incurred by NIRC in 2020/2021.

This quantity of exported waste is also likely to increase both as NIRC reduces the amounts of waste being disposed of at headstone and with increased consumption if regular shipping is introduced through construction of a temporary groyne at Cascades Pier which eliminates break bulk cargoes and permits full shipping containers to be unloaded.

Conversely, there is also a prospect of lowering shipping costs from the $6,500 charged by Boral for a 20 FCL, to be reduced to approaching costs around $2,500 to$3,500. This is similar to that experienced by similar locations in the Pacific (Tuvalu, Kiribati, Niue, and Nauru) through negotiating a regular back loading rate which would significantly reduce export and disposal costs by sea freight though still remaining at estimated costs of $708 for residual waste and $344.06 for recyclables per tonne.

However, the clear gap in available funding versus costs in pursuing higher levels of waste management to protect Norfolk Island's unique environment is not easily answered. The suitability of thermal treatment systems such as incineration, pyrolysis or gasification on paper are an appealing proposition. However, based on international, regional and Australian experience these are still speculative propositions for Norfolk Island. Uncertainty about the viability of thermal treatment systems for Norfolk Island based on high costs and risks were raised in two assessments already conducted by Norfolk Island Administration in 2009 and 2015. In contradiction to Circular Economy principles, these systems would be significant emitters of greenhouse gases and a major source of air pollution and ash.

A reduction in expensive waste exports may be achieved through greater emphasis of Circular Economy principles, through fast tracking and better resourcing of programmes, equipment and human resourcing, to ensure waste such as glass and cardboard (which together make up 53% of all commercial and household municipal wastes) are processed and utilised on Norfolk Island as soon as possible. Though cardboard utilisation as 'renewable' material as part of the biomass load in the energy sector is a possibility either as cogeneration with timber trash and woody wastes such as occurs in Fiji at the sugar and timber mills or as part of biogas generation.

Partnering with plastic packaging companies is an option to convert residual waste bales, which currently contain 60% to 70% plastic, from a quarantine waste to plastic bales through concentrating the plastics and addressing contamination. For example, food and hygiene products could be diverted to the Hot-Rot system, through a NIRC program subsidising bio-based nappies and feminine hygiene products.

Clean plastic bales could potentially be used in new Circular Economy applications now being developed. Through leveraging packaging brand audits conducted under this project and linking with new initiatives, such as the ANZPAC Plastic Pact and the Commonwealth's new projects working in the same space, this could be achieved.

Further engagement with the private sector is needed to move toward packaging free and low packaging products. Following the example of the Prinke store and commitments made by the private sector in Australia, with the aim of reducing the flow of waste materials into Norfolk Island that add to the waste management problem.

The Waste Management Centre and its staff should be recognised for the great strides in improved waste management that have occurred since 2015. However, its services are not fully utilised by the entire population as shown in the survey results and the persistence of damaging practices of waste burning, burial and dumping (via Headstone).

Many individuals choose to use the Waste Management Centre to dispose of only certain waste streams that they cannot easily burn on their properties such as glass. Others opt to boycott the Waste Management Centre entirely due to the required fees and misinformation about what is done with their waste once deposited at the centre.

This should be addressed through properly formulated Community-Based Social Marketing which has been successfully used in identifying barriers and benefits and developing targeted projects to change normative behaviours which would be needed to gain full partnership from the community.

Nonetheless, whether residents utilise the Waste Management Centre or dispose of their waste by other means, the sheer volume of waste on the island remains a key challenge. It is therefore critical that Norfolk Island moves towards a system that focuses on reduction and reuse, and that the accessibility and processes of the current Waste Management Centre are improved.

CHAPTER 4: NORFOLK ISLAND'S ENERGY SYSTEM

Chapter 4 provides a detailed overview of the energy system on Norfolk Island, addresses the shortfalls and current issues on the energy system and how can they be improved, referring to some relevant case studies of other islands and remote communities. Finally, it makes some recommendations for improving efficiency and the sustainability of the energy system on Norfolk Island.

The study has revealed the following issues associated with electrical energy generation, management and use:

- Norfolk Island has high diesel usage for electricity production, high energy costs and high overall greenhouse gas emissions;
- The power plant is old, lacking automation, and a lack of data on both the plant production and power grid;
- The power grid suffers from localised grid voltage issues because of unplanned high penetration of rooftop Solar PV (1.4MW of solar). This causes localised outages and tripping of Rooftop solar PV inverters;
- Most rooftop Solar PV inverters are nearing end of life and have a limited management ability to assist with grid stabilisation;
- There has been a moratorium in place since 2013 on the installation of Solar PV due to the high penetration of rooftop Solar PV. A high feed in tariff for rooftop Solar PV has resulted in an inequity between homes and businesses that have Solar PV and those that do not;
- Together with a mix of old disk type and bidirectional digital meters, there is no time of use tariffs, resulting in non-Solar PV users subsidising Solar PV users use of diesel generated electricity at night. At the time of writing the report a load bank was used to burn off power generated by rooftop Solar PV that cannot be utilised through the day rather than being stored for later use. The load bank itself caused outages to the grid in previous years. In addition, one diesel generator is running continually at minimum 30 per cent capacity for spinning reserve and other ancillary services. The commissioned TESLA Battery Storage System has provided electricity storage, smoothing of the Island 1.4MW distributed solar systems, and absorbs energy that would usually be diverted to the Power Station Load Bank.

Norfolk Island has abundant wind, solar, and wave resources. Solar and wind energy are mature forms of energy generation that have low running costs. Data from previous studies has shown that both solar and wind are viable forms of renewable energy to help satisfy energy demand on the island. Wave energy is an emerging technology as an alternative renewable energy source, which, in the longer term, could supply a sizeable part of the island's energy needs. While solar and wind are inherently variable in supply, with appropriate firming capacity from energy storage or dispatchable electricity generation, solar and wind energy could displace and potentially eliminate diesel generation. This could take the form of a hybrid system entailing wind, solar, battery storage, and diesel generation.

Battery storage can provide an effective form of energy storage, providing firming capacity for variable renewable energies such as wind and solar and can also be used to stabilize the grid and take that burden away from diesel generation that traditionally provided ancillary services on remote islands.

Energy efficiency can produce significant fuel and monetary savings for Norfolk Island through reduced power demand. Payback periods for energy efficiency are generally much shorter than renewable energy. Therefore, prior to investing in further energy generation it is essential that energy efficiency measures are undertaken first prior to the installation of renewable energy to minimize capital costs.

Prior to embarking in further renewable energy installations, several changes should be implemented. The electricity grid needs to be stabilised and this would include several changes:

- the replacement of old Rooftop solar PV inverters with new smart inverters that can assist with grid stabilisation;
- the implementation of a micro-grid control system, and;
- the implementation of a demand management system.

This should be undertaken in conjunction with the migration of ancillary services from the diesel generators to the centralised Battery Storage. These technologies will also assist in grid stabilisation. The power plant should be automated, together with improvements in data logging of both plant and grid generation and consumption. The diesel generation could also be reconfigured to be in standby mode (diesel off mode).

Once these measures are in place, tariff reform would be required to reduce the inequity between the Rooftop Solar PV haves and have-nots and reduce electricity charges across the island. This should be undertaken in conjunction with the removal of the Rooftop Solar PV moratorium.

Several renewable energy pilot projects could be considered with the objectives to identify the most effective ways to decrease costs and increasing resilience on the Island. These could include:

- Rooftop Solar PV and Home Battery bulk buys,
- Solar Farm/Community Owned Solar Farm,
- Solar Gardens,
- Grid/Community Battery Storage,
- Wave Energy,
- Electric Vehicle Strategy, and,
- Induction Cooking replacing LPG gas.

CHAPTER 5: NORFOLK ISLAND'S FOOD SYSTEM

This study sought to investigate the characteristics of Norfolk Island's food system, its organisation, capacity and constraints, to better assess the opportunities and challenges to build a sustainable and resilient food system for Norfolk Island. The context for this study was to inform the implementation of the Norfolk Island Community Strategic Plan 2016-2026 and make recommendations for the realisation of a 'Food Secure Community'.

Norfolk Island has seen a progressive shift from a strong reliance on local food supplies to food sourced from an increasingly globalised food industry network. This shift has brought substantial benefits in the form of competitive pricing and access to a wider variety of food types. Yet some aspects of Norfolk Island's food system have become heavily reliant on external supplies, that is for a range of consumable goods as well as farm inputs such as fertilisers, pesticides and stock feed. This reliance on importation creates vulnerability of both residents and businesses affected by freight delays and shortages of some products.

There is presently a strong interest in local food, as well as an increasing number of initiatives amongst community members that are/ or intending to take part in producing food. All interviewees reported a strong demand from both tourists and residents for better access to local food products, and many stated that they perceive significant untapped market potential. All the food producers interviewed expressed interest for expanding production, diversifying and improving their offerings, and taking advantage of new concepts, tools for land regeneration and sustainable farming. Similarly, aspiring food producers cited numerous opportunities for contributing to producing and/or adding value to food locally. Yet, Norfolk Island's agri-food businesses face a unique set of impediments, including higher energy costs, higher input costs, expensive freight and irregular freight schedules, frequent droughts and water unavailability.

This context demands attention and the development of a considered approach to simultaneously ensure long-term food security for Norfolk Island and leverage the economic, social and environmental potential of an underdeveloped economic sector, the agri-food sector.

The Norfolk Island Community Strategic Plan 2016-2026 determines to '*protect and enhance {Norfolk Island} unique culture, heritage, traditions and environment for the Norfolk Island People'.* It outlines the objectives to create a 'food secure community', as well as to safeguard environmental sustainability, reduce waste, and promote cultural diversity, social engagement, health and wellbeing, tourism and economic diversification.

Norfolk Island has a unique opportunity to strengthen its local food system to ensure food security for its residents, while placing food at the core of a place-based sustainable development strategy that would benefit the Island's economy, its tourism sector and the health and wellbeing of its residents.

A Strategic Approach to a Food Secure Community

Currently food security issues are addressed incrementally, in a siloed-approach. Responsibility for food policy is highly dispersed, food-related matters are scattered across various departments and agencies.

The implementation of the Norfolk Island Community Strategic Plan 2016-2026 warrants a strategic approach to building a more resilient and sustainable food system in Norfolk Island. That is a comprehensive and holistic approach to address food security and other related development objectives in a synchronized manner.

Effectively addressing the determinants of food security requires taking a multi-sector approach by operationalizing the linkages between agriculture, food security, nutrition, the environment, culture and heritage and the local economy. It necessitates a fit-for-purpose governance framework, inclusive and participatory mechanisms, community ownership of a vision and a policy agenda. Interventions do not happen if there is no shared vision for what is needed and why.

Government's involvement may be appropriate in supporting the development of a policy framework to provide support for the implementation of the community's vision and guide decisions to achieve rational outcomes.

The report highlighted some priority actions, and recommended a strategic framework to provide the foundations for a more resilient and sustainable food system, placing food production at the heart of a comprehensive sustainable development strategy.

Key Recommendations

Governance

- Mobilise key stakeholders within the community to drive a strategic approach to food security and sustainable development (e.g., setting- up a multi-stakeholder working group to lead the process).
- Consider the development of a policy framework [*Norfolk Island Food Strategy]* to improve coordination and synchronized action between key stakeholders and drive institutional support and investment in infrastructure and resources needed for sustaining a community food system.
- Address jurisdictional restrictions and other eligibility criteria, which make residents and businesses of Norfolk Island ineligible for some grants, subsidies or finance available in other Australian jurisdictions.

Agri-environmental innovation (Pilot Projects)

- Investigate setting up a '*Regenerative Farm Hub*' applying best practices in regenerative farming that focus on resource efficiency, land and ecosystems regeneration, soil organic carbon, agrobiodiversity and crop diversification.
- Investigate the setting up of hydroponic systems and the use of local nutrient sources.
- Investigate options (business models, finance, and participation) for infrastructure supporting local food preservation/transformation, distribution (and exports) (e.g., a Co-Op, or a community-owned facility).
- Investigate options to encourage and facilitate the cultivation of local grains (for animal feed and flours) that can enhance soil quality, biodiversity and agrobiodiversity on Norfolk Island.
- Investigate ways to support the (re)establishment of a dairy industry, including improving herd genetics, and mitigating lack of feed, water scarcity in order to increase productivity.

Facilitate knowledge building and sharing

- Allocate resources for the creation of a community learning space [*Food Knowledge Hub*] to facilitate sharing knowledge, build capacity in sustainable food production, and build community awareness around food, agrobiodiversity, nutrition and health, and food production/preserving.
- Examine the potential for developing a farm to school program at the Norfolk Island Central School (incl. providing local organic food meals at the canteen, garden-based learning and practicing).
- Investigate how to promote agri-ecotourism development, appropriate capacity building programs on agri-ecotourism for local community and food producers.

Water Security

- Investigate ways to mitigate the effects of climate change, drought, and seasonal water shortages on food producers, such as alternative sources of water for irrigation.

CHAPTER 6: THOUGHTS AND REMARKS FOR BUILDING A RESILIENT AND SUSTAINABLE FUTURE FOR NORFOLK ISLAND

Most of the challenges that Norfolk Island is facing – land and soil degradation, biodiversity loss, water scarcity, wastewater management, food shortages – are presently addressed in siloes, managed by various separate entities at the federal, state and regional levels. Exemplars of cross-sectoral innovation from Europe, North America and Asia show the importance, and benefits, of integrated approaches to address social, economic and environmental sustainability issues. Models, conceptual tools and approaches now exist to facilitate the transition to more sustainable, inclusive and ecological resilient societies.

The future of Norfolk Island needs to be considered from a strategic, whole-system perspective to drive an island-wide transition towards sustainable development. Many of the challenges Norfolk Island faces can be approached in a systemic, coordinated way, such as discussed in Chapter 5. Placing food at the core of a place-based sustainable development strategy would benefit the Island's economy, its tourism sector, the health and wellbeing of its residents and environmental health.

Norfolk Island will need an enabling environment to foster better coordination between all stakeholders, including the Norfolk Island community, and promote a multi-stakeholder/ multi-sector approach to enhance strategic and operational capacities and synchronise actions towards a comprehensive policy approach to sustainability and resilience on Norfolk Island.

Community empowerment and leadership have to be central to the approach. Effective public participation, associating the community to future research design, innovation and policy formulation, can be an important factor in enhancing community trust and ownership of the future.

From vulnerability to an exemplar of resilience and sustainability

We suggest an approach through which the Norfolk Island community is given the tools and structures to effectively participate in, and be at centre of, a new governance approach to envisioning and building its own future. Leveraging best practice and effective techniques for community engagement, the approach seeks to foster meaningful public participation in research, innovation and decision-making processes, to empower the community to define its own development trajectory, moving from its current vulnerability to become resilient and sustainable (Figure 1).

Figure 1: A Community working towards resilience and sustainability

A Norfolk Island Sustainability Lab

The concept, scope and aims of a 'Norfolk Island Sustainability Lab' will have to be discussed with, and determined by, the Norfolk Island community. In our vision, the lab would act as a research and innovation hub on Norfolk Island, assisting dissemination of research outputs, acting as a knowledge repository of past reports/strategies, and enabling the community to play a central role in future research, innovation and policy/ strategy formulation.

In our view, the lab would:

- Constitute a platform for the Norfolk Island community to be engaged in co-designing and co-implementing projects of value to the Island and participate in decision-making processes more effectively;
- Provide the tools, materials and a network of global experts to support education and training in a broad range of areas of relevance and necessity for long term sustainability and resilience of Norfolk Island – biodiversity conservation, land stewardship, regenerative farming and sustainable food production, eco-entrepreneurship, etc;
- Facilitate the development of new projects taking a systemic, participatory approach, and connecting needs, expertise and funding;
- Apply best practice and develop innovative methods, tools and approaches to better understand land use dynamics and develop strategies to sustainably manage Norfolk Island's resources.

The development of the Norfolk Island Sustainability Lab will rely on the willingness and dedication of the Norfolk Island community, which would have to play a central role in its instigation, management and delivery.

KEY FINDINGS AND RECOMMENDATIONS

<table>
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<td>Chapter 1:
CLIMATE, COASTAL DATA & LAND USE CAPABILITY ASSESSMENT (SOILS), ECOSYSTEMS & BIODIVERSITY</td>
<td>
Summary/Findings

Decreasing rainfall, increasing evaporation, and increasing temperatures characterise the future climate of Norfolk Island.
Rainfall not uniformly distributed over Norfolk Island.
Increasing sea levels.
Decline in reef integrity.
Highly dispersive clay soils (in absence of vegetation cover).
Only 10ha of cultivated land exists in 2020, down from ~460ha in the 1830's.
Woody weeds dominant on previously cultivated land left unused.
2,192ha of Norfolk Island (total of 3,460ha) classed as moderate to very poor catchment condition.
Higher classes of disturbance condition (less disturbed) mostly comprise reserve areas and coastal areas with hardwood forests, and the National Park with some small pockets in the east. This area of 633ha of vegetation provides the most significant area of habitat on Norfolk Island.
The relatively high correlation of lower biodiversity with disturbed lands is a common issue, also resulting in land degradation in sensitive areas.
There are 52 exotic "weed" species on Norfolk Island.
Approximately 80% of the endemic flora species on Norfolk Island are threatened under the provisions of the EPBC Act, and the Norfolk Island pine (Araucaria heterophylla) is on the International Union for Conservation of Nature Red List of Threatened Species.

Recommendations

Improve reef integrity – studies investigating the potential of "re-seeding" existing coral reef systems using a range of artificial reef-based systems.
Marine surveys – temporal and spatial in various areas within the Norfolk Island Marine Park. Topics may include monitoring reef restoration efficacy, shark movements/numbers and/or studies on other species of interest.
Coast Watch initiatives involving litter clean-up days and other community activities that promote reef improvement.
Effective implementation of the Norfolk Island Coastal Management Plan (Chapter 7, Table 7-2 in particular).
Livestock management projects – these may include investigating the use of E-Shepherd collars (these act as "virtual fencing" and significantly reduce the cost of fencing and cattle grids).
Undertake pest and weed eradication projects.
Utilise LANDCARE initiatives involving weed removal days and other community activities that promote sustainable living.
Use of solar pumps to offset livestock watering points in the landscape (reduces soil erosion).
Develop a strategy/ action plan to improve land cultivation /productivity, applying best practices in regenerative farming and integrated landscape management that focus on resource efficiency, land and ecosystems regeneration, soil organic carbon, agrobiodiversity and crop diversification.
Develop a strategy to restore "disturbed" environments of low catchment condition, at a small-scale, at first, and include a range of approaches such as planting projects and drainage line restoration to reduce erosion. Satellite imagery or drone images can been used to monitor changes/improvements over time.

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	• Connect all biodiversity/ecology programs undertaken on island with the Norfolk Island Flora & Fauna Plan, and provide a knowledge-sharing platform for current flora and fauna experts, National Parks & Marine Parks staff, and other interested individuals. • Promote community awareness and education, via e.g. developing online tools, citizen science projects, and 4G apps. For example, "iNaturalist" as a global flora and fauna app could support citizen science on Norfolk Island.
Chapter 2: HYDROLOGICAL ASSESSMENT AND PRELIMINARY WATER BALANCE	**Summary/Findings** • Norfolk Island's water security is under threat due to the reduction in rainfall and increasing temperatures. • Groundwater levels in 2019/20 at lowest point in recent history and recharge rates remain uncertain. • Approximately 131 ML/yr of harvested rainwater and 128 ML/yr of groundwater extracted for Island water demand. • All wastewater discharged via septic tanks across the Island, or treated through the Water Assurance Scheme before discharged to the ocean. • Attributed to livestock and non-sewered areas (septic tanks), surface water quality in major creeks often exceed ANZECC guidelines after heavy rain, sometimes causing closure of Emily Bay (as a human health hazard). • Poor monitoring and metering of water use across Norfolk Island. • Up to 65% of buildings do not have optimised roof/tank volume for increasing rainwater yields. **Recommendations** • Investigate ways to mitigate the effects of climate change, drought, and seasonal water shortages, such as alternative sources of water for irrigation. Option 1 in the Balmoral Report provides a climate dependent source of recycled wastewater into the future. • Alleviate pressure on groundwater extraction by utilising wastewater discharged to the ocean, thus also eliminating nutrient loads on the Marine Park. • Investigate approaches to decreasing runoff, such as leaky weirs, and other retention/detention devices in the landscape. • Digitise location of existing septic tanks and improve operational processes, such as initiating a septic tank inspection program to reduce poorly performing systems contributing to surface and groundwater quality issues. • Incrementally over time, connect dwellings to the Water Assurance Scheme, further securing "fit-for-purpose" water into the future. • Optimise roof area/tanks volume on up to 65% of dwellings to improve rainwater harvesting yields. • Initiate water-metering projects to determine demand and diurnal water use patterns for a range of sites (hospital, school, residential, commercial, tourist accommodations and industrial sites). The use of water meters has proven useful for leak detection in water systems and the use of "smartmeters" can incorporate a citizen science approach to Norfolk Island water management. • Continued monitoring of surface water discharge throughout the island using stations installed by CSIRO. • Monitor of groundwater levels and rainwater tank levels at appropriate sites. • Update Development Application (DA) standards for new dwellings (in progress)

Chapter 3: NORFOLK ISLAND'S WASTE MANAGEMENT SYSTEM	**Summary/Findings** • Waste management costs significantly high due to a reliance on exporting wastes back to Australia. • Waste management costs for NIRC is equivalent to 2.3% of its total budget with grants, or 4.5% without, total per capita waste management costs is $454 per annum. • Quantity of exported waste likely to increase both as NIRC reduces the amounts of waste being disposed of at Headstone and with increased consumption if regular shipping is introduced. • Clear gap in available funding versus costs in pursuing higher levels of waste management to protect Norfolk Island's unique environment. • Suitability of thermal treatment systems such as incineration, pyrolysis or gasification not conclusive (high costs, risks, source of air pollution and ash. **Recommendations** • Develop a Circular Economy strategy for better resourcing of programmes, equipment and human resourcing, to ensure waste such as glass and cardboard (which together make up 53% of all commercial and household municipal wastes) are processed and utilised on Norfolk Island. • Engage in partnership with plastic packaging companies as an option to convert residual waste bales, which currently contain 60% to 70% plastic, from a quarantine waste to plastic bales through concentrating the plastics and addressing contamination. • Implement a NIRC program subsidising bio-based nappies and feminine hygiene products so food and hygiene products could be diverted to the Hot-Rot system. • Engage further with the private sector to move toward packaging free and low packaging products, following the example of the Prinke store on Norfolk Island. • Formulate a Community-Based Social Marketing strategy to develop targeted projects to change normative behaviours with regard waste. • Develop some guidelines – and implement - a system that focuses on reduction and reuse.
Chapter 4: NORFOLK ISLAND'S ENERGY SYSTEM	**Summary/Findings** • Norfolk Island has abundant solar, wind and wave energy resources. • Norfolk Island has high diesel usage for electricity production, high-energy costs and generates high overall greenhouse gas emissions. • The Island power plant is old, lacking automation, and a lack of data on both the plant production and power grid. • The power grid suffers from localised grid voltage issues because of unplanned high penetration of rooftop Solar PV (1.4MW of solar). This causes localised outages and tripping of Rooftop solar PV inverters. • Most rooftop Solar PV inverters are nearing end of life and have a limited management ability to assist with grid stabilisation. • A high feed-in tariff for rooftop Solar PV has resulted in an inequity between homes and businesses that have Solar PV and those that do not. • An initial centralised battery storage system has been commissioned smoothing of the Island 1.4MW distributed solar systems and to absorb energy that would otherwise be diverted to the Power Station Load Bank.

	Recommendations • Prior to undertaking further renewable energy installations several changes should be considered to stabilize the electricity grid, including the replacement of old rooftop solar PV inverters with new smart inverters that can assist with grid stabilisation, the implementation of a micro-grid control system, and the implementation of a demand management system. This should be done in conjunction with the migration of ancillary services from the diesel generators to the centralised Battery Storage. The power plant should be automated, together with improvements in data logging of both plant and grid generation and consumption. The diesel generation would also be reconfigured to be in standby mode (diesel off mode). • Consider tariff reform to reduce the inequity between the Rooftop Solar PV haves and have-nots and to reduce electricity charges across the island in conjunction with the removal of the Rooftop Solar PV moratorium. • Consider the deployment of additional battery storage to provide firming capacity for variable renewable energies such as wind and solar, to stabilize the grid and take that burden away from diesel generation that traditionally provided ancillary services on remote islands. • Consider a hybrid system entailing wind, solar, battery storage, and diesel generation, and increasing capacity of energy storage or dispatchable electricity generation, so that solar and wind energy would displace and potentially eliminate diesel generation. • Consider several renewable energy pilot projects, such as Rooftop Solar PV and Home Battery bulk buys, Solar Farm/Community Owned Solar Farm, Solar Garden, further Grid/Community Battery Storage, Wind Farm, Wave Energy, Electric Vehicle strategy, and Induction Cooking replacing LPG gas.
Chapter 5: NORFOLK ISLAND'S FOOD SYSTEM	**Summary/Findings** • Progressive shift from a strong reliance on local food supplies to food sourced from an increasingly globalised food industry network. • Norfolk Island's food system is heavily reliant on external supplies, for a range of consumable goods (fresh and processed food), as well as farm inputs such as fertilisers, herbicides, pesticides, and stock feed. • Reliance on importation means vulnerability of both residents and businesses affected by freight delays and shortages of some inputs. • Strong demand within the Norfolk Island community for better access to local food produce. • Acknowledgement of a significant untapped market potential to grow more food, diversify crop and food produce, and process food on island. • Norfolk Island's agri-food businesses face numerous impediments, such as high energy costs, water scarcity and limited access to finance and grant support. **Recommendations** • Develop a strategic approach to food security, sustainability and resilience to drive an island-wide transition towards increased availability, accessibility and affordability of local foods to support healthy-eating practices, sustainable economic development and enhanced landscape functions. • Mobilise key stakeholders within the community to drive a strategic approach to food security (e.g. setting- up a multi-stakeholder working group). • Consider the development of a policy framework, *Norfolk Island Food Strategy* to improve coordination and synchronized action between key stakeholders

	and drive institutional support and investment in the infrastructure and resources needed for sustaining a community food system. • Address jurisdictional restrictions and other eligibility criteria which make residents and businesses of Norfolk Island ineligible for a range of schemes, grants, subsidies and finance available in other Australian jurisdictions. • Investigate setting up a '*Regenerative Farm Hub*' applying best practices in regenerative farming and integrated landscape management that focus on resource efficiency, land and ecosystems regeneration, soil organic carbon, agrobiodiversity and crop diversification. • Investigate the setting up of hydroponic systems and the use of local nutrient sources. • Investigate options (business models, finance, and participation) for the development of infrastructure supporting local food preservation, distribution and retail (e.g., a Co-Op, a community-owned facility). • Investigate options to encourage and facilitate the cultivation of local grains (for animal feed and flours) that can enhance soil quality, biodiversity and agrobiodiversity on Norfolk Island. • Investigate ways to support the establishment of a dairy industry, including overcoming regulatory challenges around importation of ruminants and improving herd genetics, and mitigating lack of feed to increase productivity. • Allocate resources for the creation of a community learning space' 'Food Knowledge Hub' to facilitate knowledge sharing, build capacity in sustainable food production, and build community awareness around food, agrobiodiversity, nutrition and health, and food production/preserving. • Examine the potential for developing a Farm to School program at the Norfolk Island Central School (incl. providing local organic food meals at the canteen, garden-based learning and practicing). • Investigate how to promote agri-ecotourism development, appropriate capacity building programs on agri-ecotourism for local community and food producers. • Investigate ways to mitigate the effects of climate change, drought, and seasonal water shortages on food producers, such as alternative sources of water for irrigation.

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INTRODUCTION

In 2018, The Norfolk Island Regional Council (NIRC) identified the need to undertake an assessment of Norfolk Island's environmental capacity and provide scientific background on current land use, hydrology, soils, biodiversity and ecosystems to inform the development of a population strategy and ensure that an increase in population on Norfolk Island does not exceed its carrying capacity. The Community Strategic Plan 2016-2026 – Our Plan for the Future (NIRC, 2016), and its Delivery Program 2016-2020, mandate the development of a sustainable population policy, acknowledging that population growth needs to be considered within the bounds of environmental sustainability.

The Community Strategic Plan also provides some strategic directions for an environmentally sustainable community, which include the following objectives:

- Develop a clean energy future,
- Protect and enhance water quality,
- Reduce, reuse and recover waste and end disposal of waste into the sea,
- Create a food secure community,
- Create a water secure future,
- Retain open spaces and low-density development,
- Protect and preserve environmentally sensitive areas and those of high conservation value, through improved land management and pest control practices,
- Support threatened species and minimise the presence of invasive species,
- Ensure a healthy, diverse marine ecosystem and,
- Protect and preserve vegetation communities and habitat.

In this context, and in accordance with those objectives, NIRC commissioned The Norfolk Island Environmental Assessment, which was conducted in the period ranging from May 2019-May 2021 by a team of scientific researchers led by Monash University, Monash Sustainable Development Institute and The University of Newcastle. The research team carried out a desktop review, some consultation with key stakeholders, data collection and analysis, according to the four main streams of the Environmental Assessment:

- Land-use capability, coastal zones and soils, the extent to which existing land use is consistent with environmental sustainability;
- Hydrology, examining Norfolk Island's surface and groundwater resources, existing use and long-term sustainability;
- Ecosystems and biodiversity; and,
- Systems and technologies that have applicability on Norfolk Island for waste management, energy and food production.

NIRC will include scientific evidence obtained from these assessments in the community engagement program, to develop a sustainable population strategy for Norfolk Island. It will review the Norfolk Island Community Strategic Plan in line with this evidence to bring in a system of planning controls that: a) better reflects ecosystem and population dynamics; and, b) aligns with economic development objectives and community expectations.

BACKGROUND

Norfolk Island is an Australian External Territory situated in the South Pacific Ocean some 1,600 km northeast of Sydney. Norfolk is a volcanic island with a coastline of some 32 kilometres of mainly precipitous cliffs, except for a small section on the south side. It is a remnant of past volcanic activity jutting out of the sea from a submarine ridge, which stretches in an arc from New Caledonia to New Zealand. The average elevation of the Island is about 110 metres (350 feet) and two peaks (Mt Pitt and Mt Bates) rise to slightly over 305 metres (1000 feet).

Norfolk Island is a picturesque island with a deep and unique history, first occupied in the 13th to 15th centuries as a Polynesian settlement (Anderson and White, 2001). Captain Cook rediscovered the Island in 1774 during his second voyage around the world. Britain established Norfolk Island as a penal settlement in 1788, which was secondary to the main Australian settlement in Sydney, settled only six weeks earlier.

In 1803, the British government decided to move the settlement to Van Diemen's Land (Tasmania) and by 1814, the settlement closed and the Island abandoned. In 1825, a second penal settlement established by the British on Norfolk Island and used for the worst felons. After 30-odd brutal years, the decision was made to evacuate the Island and transfer of convicts to Hobart. By 1856, the last convicts had left and the Pitcairn Islanders were gifted the Norfolk Island by Queen Victoria. That same year, 194 "Pitcairners" transferred to Norfolk Island and became the "third settlement" on the Island (Gibbs et al, 2017); taking with them customs they had developed on Pitcairn, including the mixed English-Tahitian language now known as Norf'k and a significant commitment to mutual self-help. (Hoare, 1988; Wettenhall, 2016; SGS Economics and Planning, 2015). The Pitcairn Islanders were descendants of the Bounty mutineers from Pitcairn Island and people of Polynesian background.

Governance

For the first 50 years, the settlement of Norfolk Island had the status of a separate British colony but with shared governance with the Australian State of New South Wales. In 1913, the Island became an Australian External Territory, governed by an Administrator and the Norfolk Island Council. The Island became a tax haven in the 1960s and early 1970s, a status brought to an end in 1976 following an Australian High Court Case (the Berwick case) and a Royal Commission (Nimmo, 1976; Wettenhall, 2016). A number of recommendations by the Royal Commission were undertaken. In terms of governance, the main change was the replacement of the Norfolk Island Council by the Norfolk Island Legislative Assembly. The Norfolk Island Legislative Assembly formed after the Norfolk Island Act 1979 was passed in the Australian parliament, and was the prime legislative body of Norfolk Island from 1979 to 2015. The first members were elected on 10 August 1979. These recommendations, coupled with a series of local referenda that supported a pro-autonomy position (JSCNCET, 2014; Wettenhall, 2016), gave the Island a degree of self-governance within the Australian Federation.

However, the Norfolk Island Legislative Assembly had difficulty raising enough revenue to deliver the range of government functions needed (SGS Economics and Planning, 2015; NIG, 2014). Furthermore, issues of representation in the Federal Parliament and the extension of federal legislation to Norfolk Island, that had been raised in the Royal Commission, persisted (Centre for International Economics, 2006; Wettenhall, 2016). These issues, in conjunction with a deterioration of the economic situation from 2011, a decline in tourism, and a decreasing population (particularly with those in their prime working years), resulted in the abolishment of the Legislative Assembly in 2016 by the Australian Government. The status of a local government area within NSW was provided to Norfolk Island, however its residents/citizens were effectively "residing" in yet a different state, the Canberra federal electorate (ACIL Tasman, 2012; Centre for International Economics, 2006; JSCNCET, 2014; Wettenhall, 2016).

Tourism, a pillar of Norfolk Island's economy

With 28,000 visitors per year, tourism is the Island's principal economic activity and is a key pillar of Norfolk Island's economy accounting for around 41% of Norfolk Island Gross Island Product. A major attraction is Kingston and Arthur's Vale Historic Area (KAVHA); a World Heritage listed former convict settlement. Other attractions include the National Park and Botanic Gardens, the scenery of the Island, its biodiversity and the history of the Island including its Pitcairn community. As well as tourism, employment opportunities on the Island include farming and fishing, largely catering for local consumption (KPMG, 2019; NIRC, 2016; SGS Economics and Planning, 2015).

Approximately 66% of current visitors to Norfolk Island are aged 60 and over. Furthermore, 98% of visitors come from Australia and New Zealand. Therefore, there is considerable scope to increase earnings from tourism by targeting different age groups and market segments (SGS Economics and Planning, 2015).

Principles supporting economic development actions detailed in the 2015 Norfolk Island Economic Development Strategy included:

- Focus tourism attraction efforts on the Island's unique opportunities and circumstances and build on the existing cultural and clean and pristine environmental attractions; and

- Replacement of goods and services purchased from elsewhere with locally produced goods (SGS Economics and Planning, 2015).

The Norfolk Island Tourism Strategic Plan stated, "*Norfolk Island should seek to establish itself as a beacon for sustainable practice in our region*" (Norfolk Island Tourism, 2013). It recognised that using natural resources without destroying the ecological balance has been a priority within Norfolk Island society since the arrival of the Pitcairn Islanders in 1856 and sought to facilitate wider uptake of sustainable practices within the industry leading to greater efficiencies, new eco-tourism markets, better waste solutions and global green recognition. The 2012 Norfolk Island Economic Development Report supported this by promoting and marketing the Island's green image to target the increasing ecotourism industry (ACIL Tasman, 2012). The 2015 Norfolk Island Economic Development Strategy, which sought to leverage the economic opportunities from the unique natural environment of Norfolk Island, including research and eco-tourism, also noted the potential benefit from a growing interest in nature tourism and research (SGS Economics and Planning, 2015).

Norfolk Island Community Strategic Plan 2016-2026 – Our Plan for the Future

In 2016, the Norfolk Island community identified waste infrastructure, renewable energy infrastructure and environmental sustainability as key issues addressed as part of the *Norfolk Island Community Strategic Plan – Our Plan for the Future* (NIRC, 2016). The plan identified the community's vision for the future to be "the Best Small Island in the World" through the strategic directions of:

- An environmentally sustainable community,
- A proud, diverse and inclusive community,
- A caring community,
- A successful and innovative community,
- An informed and accountable community, and
- A healthy and safe community.

The strategic direction of an environmentally sustainable community noted the objectives of "*Use and manage our Resources wisely*" and "*Preserve a healthy environment*". Proposed to achieve these objectives include, to:

- Develop a clean energy future,
- Protect and enhance our water quality,
- Reduce, reuse and recover waste and end disposal of waste into the sea,
- Plan for additional pressures on water resources, transport, utilities and telecommunications infrastructure,
- Create a food secure community,
- Create a water secure future,
- Keep our waters around Norfolk Island sustainable for the enjoyment of future generations.
- Retain open spaces and low-density development,
- Recognise growth of the population is linked to the long-term environmental sustainability of the Norfolk Island community,
- Protect and preserve environmentally sensitive areas and those of high conservation value, through improved land management and pest control practices,
- Support threatened species and minimise the presence of invasive species,
- Ensure a healthy, diverse marine ecosystem and,
- Protect and preserve vegetation communities and habitat.

Context for the Environmental Assessment

Norfolk Island is an island located at 29°02'S 167°57'E, with an area of 35 km^2, a coastline of 32 km, and a highest point at 318 meters above sea level. According to the recent census by Australian Bureau of Statistics (ABS), the population was 1748 (ABS, 2016). The Island's population has seen a steady decrease since 2001 due to migration of 20-34 year olds, thereby creating a predominantly ageing population (Administration of Norfolk Island, 2011a). The Administration also indicated that the Island has a potential to increase its population up to 10,900 people based on achieving the maximum development potential of land, and the likely dwelling occupancy rates

(Administration of Norfolk Island, 2011b). However, it warns that, if population increases it would impact land system capability and natural resources, thus necessitating a study on the variables shaping future population dynamics and sustainability on Norfolk Island.

Islands are unique in terms of their geography and biological productivity. Biological productivity is determined by the stability of an island ecosystem, which in turn is shaped by factors such as climate, biodiversity and, most importantly, hydrology. Coastal areas are most at risk of sea level rise, increased sea surface temperature, increased storm intensity and frequency, ocean acidification and changes to rainfall, run-off, wave size and direction and ocean currents (COAG, 2007). This renders island ecosystems vulnerable to variability and change.

Parsons Brinckerhoff (2005) outlines that the majority of Norfolk Island soils are well-drained, clay-based soils with high plasticity. This makes them vulnerable to slippage. Such slippage can lead to sedimentation and subsequent impacts on surface water quality, particularly following vegetation clearing. Erosion control of exposed and degraded land due to rural land uses, such as farming and cattle grazing, can improve surface water quality. Norfolk Island soil type is suitable for the implementation of erosion control, including infiltration systems and Water Sensitive Urban Design (WSUD).

Average annual rainfall over the Island is around 1300mm/yr with most rain received in the winter. This has decreased to ~1105 mm/yr over the past 25 years (Petheram et al, 2021). Norfolk Island is of volcanic origin and dominated by a plateau 100-300 mAHD. The plateau is dissected by several river valleys, which, with the exception of Watermill Creek, reach the coast in hanging valleys with waterfalls (Bird, 2010). Throughout the Island, there is an upper water table in porous alluvium and weathered rock aquifers. During periods of drought, these aquifers tend to dry up due to extraction and natural drainage. At the base of the weathered profile, groundwater moves towards the sea through a complex network of fractures. Semi-confined aquifers are estimated to attract 20-30% of the Island's total rainfall. Groundwater recharge is from direct rainfall infiltration and runoff from Mount Pitt and Mount Bates (Abell and Falkland, 1991; Norfolk Island Regional Council, 2018). The Bureau of Meteorology data indicates an overall decline in rainfall in Norfolk Island during the period 1990-2020 (BOM, 2020).

Water is the most critical of all resources on oceanic tropical islands. In Norfolk Island, there is concern over whether available freshwater resources can sustain expected population growth. Currently, the Island has a population of around 1,800 people with up to 30,000 visitors each year, and water demand is met through rainwater harvesting, collection from freshwater springs, and extraction of groundwater. Another key concern is water quality, with cases of surface waters being polluted from sewage effluents and nutrients, and groundwater by wastewater and livestock. The majority of the island is serviced by on-site sewage treatment systems, with only ~12% connected to a reticulated sewage system.

Generally, islands have the highest proportion of recorded species extinctions (up to 80%). Currently, 45% of the species listed on the International Union for Conservation of Nature's Red List endangered species occur on islands.

Analysis of biodiversity and land use capability on islands is particularly critical due to limited natural resources and living spaces, interconnected and more complex ecosystems, high vulnerability to natural hazards, and the impacts of climate change on ocean systems (Ahmadi et al., 2017).

In addition to their ecological value, islands' terrestrial and marine ecosystems provide important natural resources necessary for the economies and cultures of island communities. Balancing national priorities with environmental protection poses challenges. These challenges are made more difficult due to isolation and limited human resources, which is very much relevant to Norfolk Island.

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CHAPTER 1: CLIMATE, COASTAL DATA, LAND USE CAPABILITY ASSESSMENT (SOILS), & ECOSYSTEMS AND BIODIVERSITY

1.1 CLIMATE, CLIMATE ANOMALIES AND CLIMATE FORECAST FOR NORFOLK ISLAND

Norfolk Island's sub-tropical climate is tempered by the surrounding sea and is principally affected by the belt of high-pressure systems which oscillate north and south over the Island annually (BOM[1], 2019). Comparison of recent trends indicates that the climate of Norfolk Island is changing, and these changes are likely to impact on available water resources and food production. Diurnal and annual temperature ranges are small. Average maximum temperatures range from 18°C to 19 °C in winter to between 23 °C and 25 °C in summer. Average minimum temperatures range from 13 °C to 15 °C in the winter and between 18 °C and 20 °C in the summer.

The median annual rainfall for is 1302 mm, and the annual mean rainfall is 1312 mm (1948 – 2019). Rainfall has historically been greatest during the four months from May to August, with monthly long-term means from 130 mm to 147 mm. Minimum monthly rainfall occurs from November to January averaging 75 mm to 87 mm. The wettest month is June having an average 147 mm and the driest month is November having an average of 75 mm. The highest monthly rainfall was 473.2 mm in December 1989. Norfolk Island averages 181 rain days per year, ranging from an average of 10 rain days in November to 21 rain days in July.

Relative humidity is generally high and averages in the 74% to 79% range at 9am and in the 71% to 74% range at 3pm. Winds are predominantly east to south-east during summer and autumn swinging to the south to south-westerly in winter and returning to the south in spring. The maximum wind gust recorded on Norfolk Island was 135 km/h from the SSW on 19th March 1992. Thunderstorms are most prevalent during the winter and spring, with an average of 12 thunderstorms per year. Hail occasionally accompanies thunderstorms in winter, with an average of one hailstorm per year. Tropical cyclones occasionally have an influence in the early months of the year. Mid latitude depressions move in from the Australian continent or southwest Tasmanian Sea and effect the island mostly from February to August.

Sea surface temperature anomalies indicate a warming ocean around Norfolk Island and this is shown in Figure 1.1. Sea surface temperature between 1915 and 1937 show an even number of warming/cooling anomalies, ranging between -0.49°C and +0.3°C. Sea surface temperature between 1938 and 1969 showed a similar frequency of warming/cooling anomalies however the range was much larger (higher intensity, -0.66°C to +0.7°C), and the frequency of longer durations of warmer sea surface temperatures is increasing. Since 1970, annual sea surface temperature anomalies have continually been higher than the 1961 – 1990 mean sea surface temperature. Figure 1.1 highlights the significant difference in sea surface temperature anomaly distribution pre and post 1950, where the post 1950 trends are longer periods of higher temperatures, and these trends will predominantly influence climate on Norfolk Island over the next 100 years.

An increasing trend in sea surface temperature influences the mean annual temperature on Norfolk Island. Figure 1.2 shows mean annual temperature from 1944 to 2018 with the black line representing the 10-year moving average (each point on the black line represents the average of the previous 10 years). The 10-year moving average was decreasing from 1954 to 1966, however both the mean annual temperature and the 10-year moving average have generally shown an increasing trend since 1967.

Figure 1.3 shows mean annual temperature anomalies from 1944 to 2018, compared to the 1961 – 1990 mean of 18.9 °C. Data used was sourced from the ACORN-SAT (BOM[2], 2019). Similar to the pattern of sea surface temperature anomalies observed in Figure 1.1, the frequency, duration and intensity of warmer (+) mean annual anomalies has increased since 1950. An increasing trend in sea surface temperature and mean annual temperature will influence rainfall depth and rainfall patterns on Norfolk Island.

Figure 1.4 shows the annual rainfall anomaly from 1915 to 2018, compared to 1961 – 1990 mean annual rainfall. Rainfall for 36 out of the last 48 years have been below the annual mean, and 17 out the last 20 years have been below the annual mean. Figure 1.5 shows the annual evaporation anomaly from 1976 to 2018, compared to the annual mean evaporation from 1981 to 2010. Annual Evaporation on Norfolk Island has generally exceeded the mean annual evaporation since 1995.

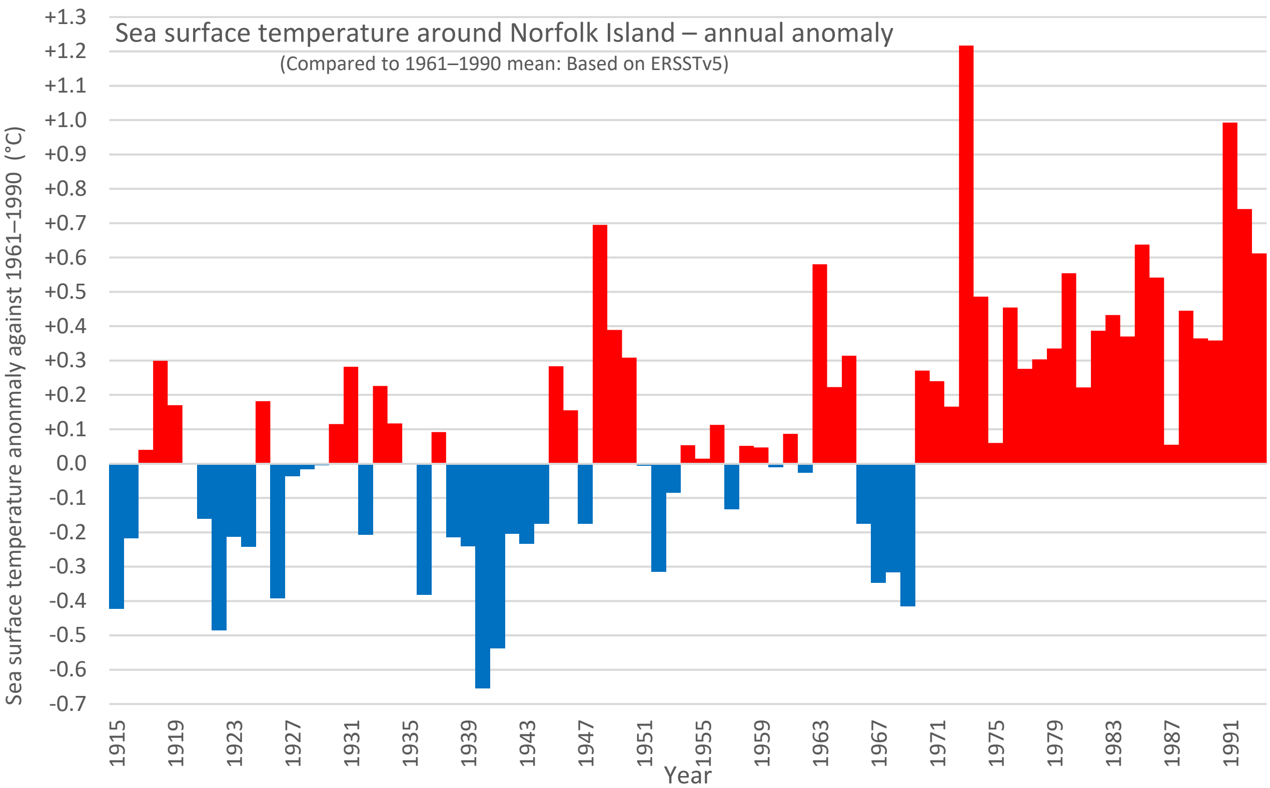


Figure 1.1: Sea surface temperature annual anomalies since 1915 (sourced from NOAA, 2019)

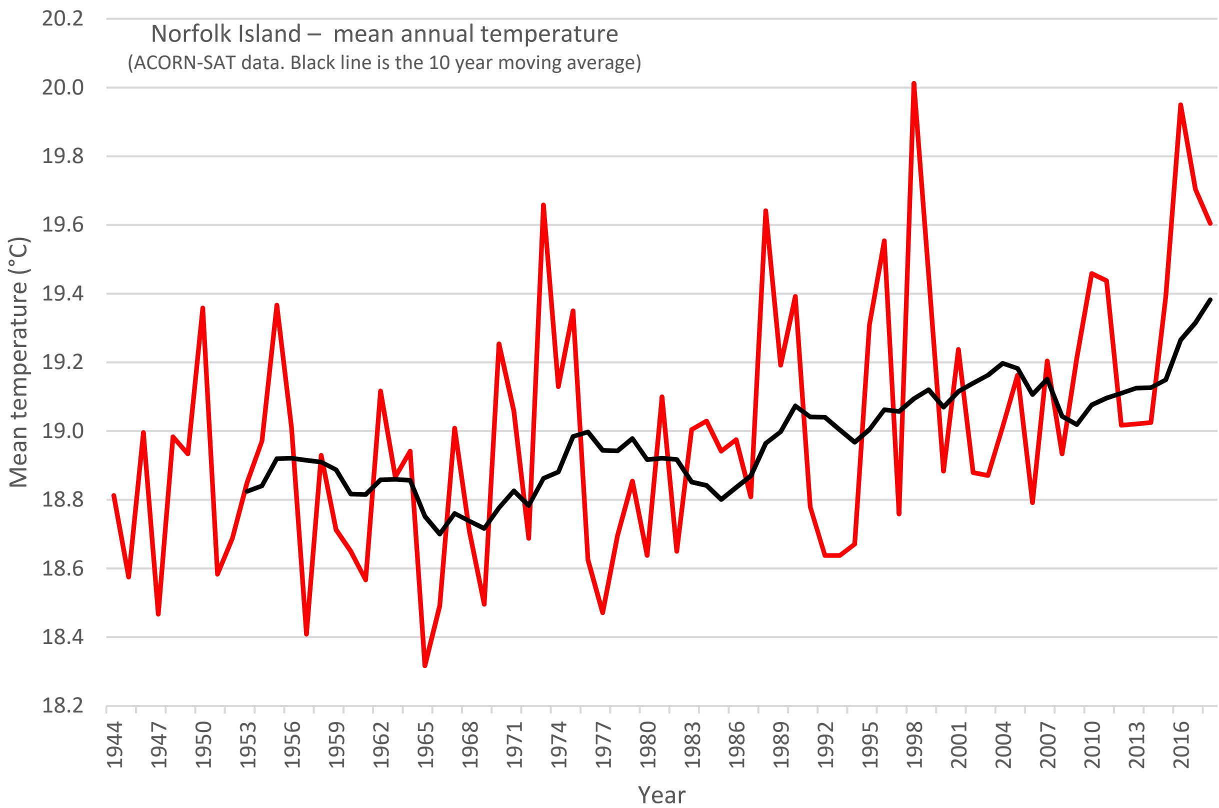


Figure 1.2: Mean annual temperature from 1944 to 2018

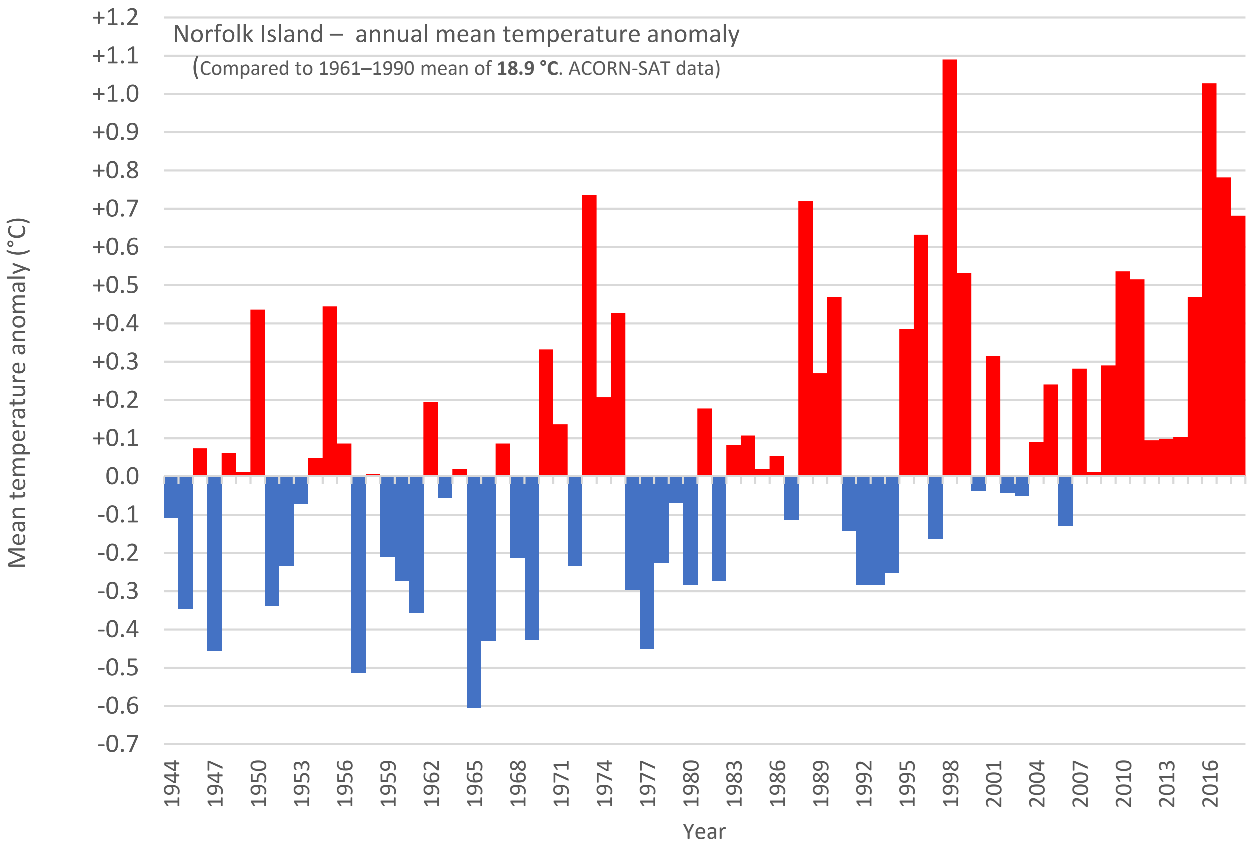


Figure 1.3: Mean annual temperature anomalies from 1944 to 2018

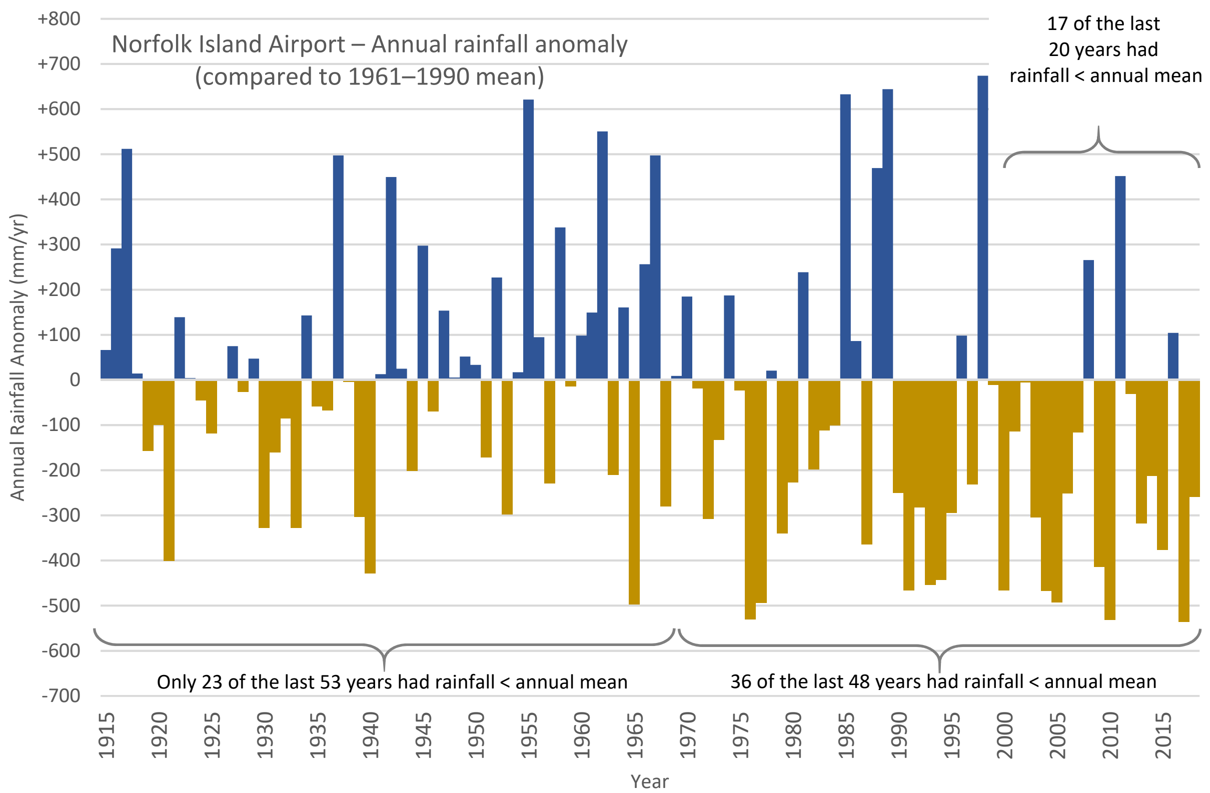


Figure 1.4: Annual rainfall anomaly from 1915 to 2018 compared to the 1961 – 1990 annual mean rainfall

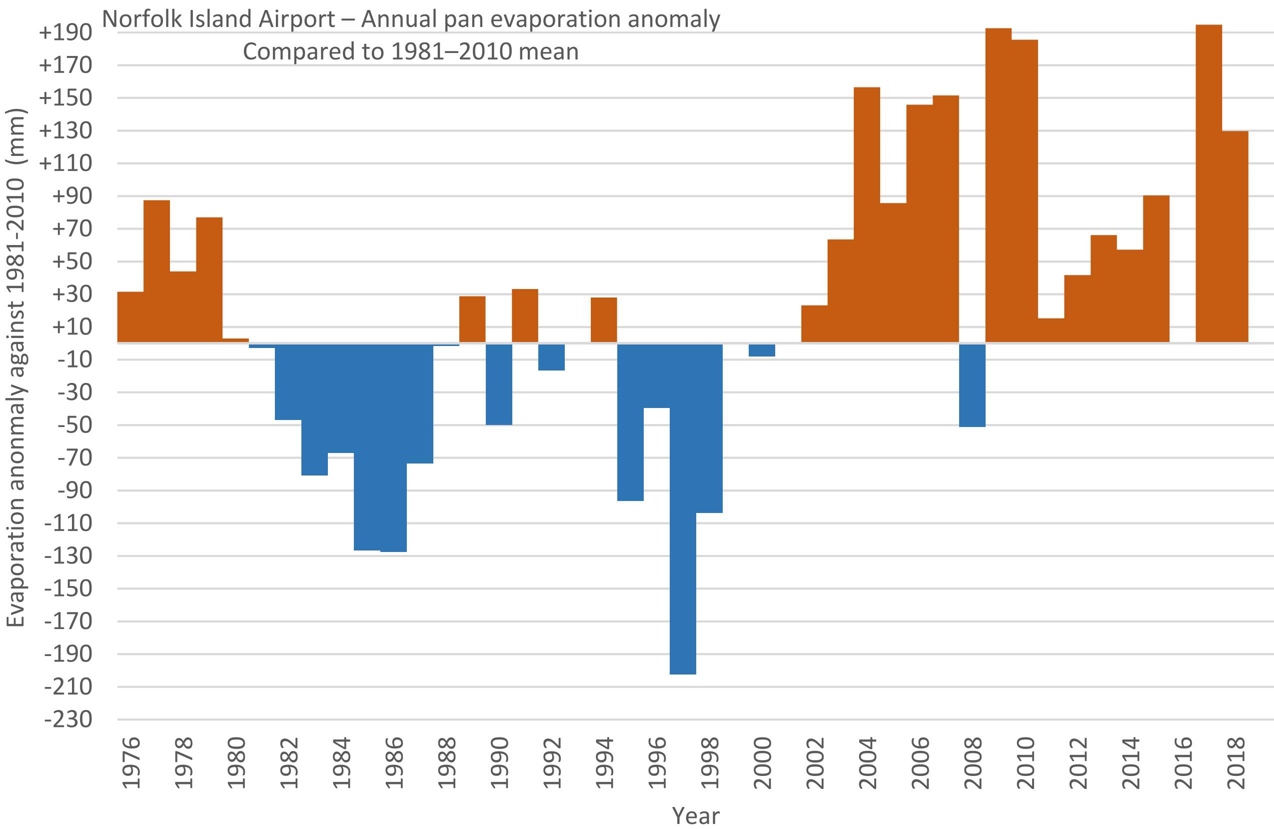
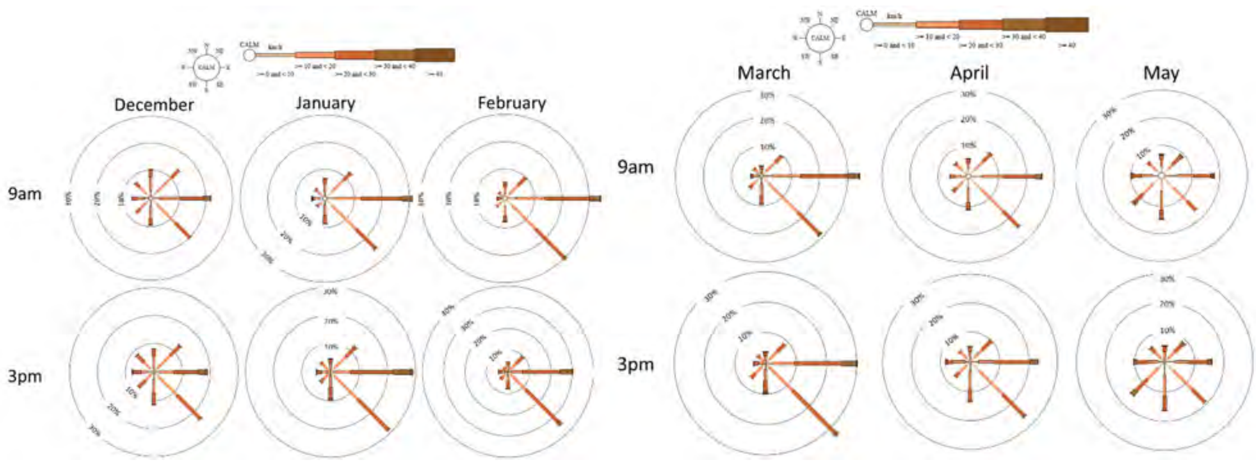


Figure 1.5: Annual evaporation anomaly from 1976 to 2018 compared to the 1981 – 2010 annual mean evaporation

Figure 1.6 shows wind roses from Norfolk Island Airport (BOM station number 200288) derived from data from 1939 – 2019, highlighting the prevailing East – South East from November to April. Winds start to shift to the West-South West winds during May, and strengthen from June to September, before starting to shift back to the East – South East in October/November.



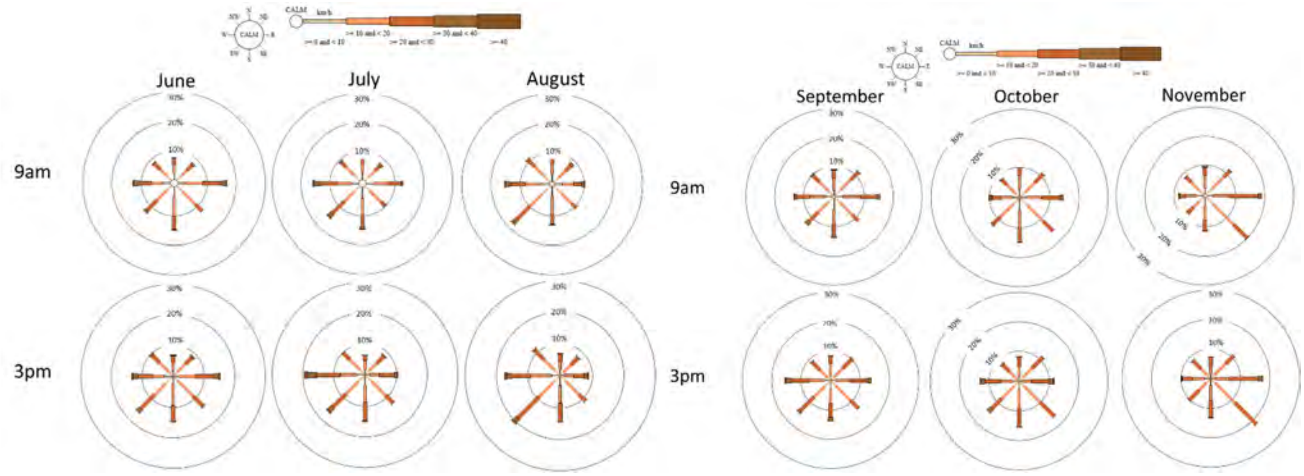


Figure 1.6: Norfolk Island wind rose data from 1939-2019

Climate Trend Summary:

- Warming of the seas surrounding Norfolk Island
- Increasing mean annual temperatures
- Decreasing mean annual rainfall
- Increasing mean annual evaporation
- These trends indicate a shift in climate patterns that are likely to decrease available water and potentially change existing food production systems and Island biodiversity over the next 100 years.

1.2 COASTAL DATA COLLECTION

The Norfolk Marine Park (formerly known as the Norfolk Commonwealth Marine Reserve) is located in the waters immediately offshore of Norfolk Island, and extends 700 km in a north–south direction and covers an area of 188,444 km^2. The park is assigned IUCN category IV and is one of 8 parks managed under the Temperate East Marine Parks Network (Director of National Parks, 2013). The aim of this desktop study was to gather (limited) coastal information important for planning and conservation projects on Norfolk Island, and designed to complement objectives in the Norfolk Island Natural Resource Management Plan (Parsons Brinckerhoff, 2009). Information obtained included beach morphology (shape/geometry/area, particle size and organic matter content), the estimated (relative) number of visitors to accessible coastal sites, reef integrity, and mean sea level variations. The data presented in this report can be used as a baseline for evaluating coastal changes/variability into the future.

1.2.1 INTRODUCTION

Norfolk Island has a coastline of approximately 32 km and most of the coast comprises steep cliff faces, with few safe public access points to the ocean below. However, several stretches of coastline are accessible and have sand beaches and reef systems. These include Emily Bay, Slaughter Bay and Emily Bay in the Kingston and Arthur Vale Heritage Area (KAVHA); Anson Bay, and Bumboras. Other coastal access points include Ball Bay and Cascade which are primarily used as ports for receiving goods. Figure 1.7 shows the locations of these sites on Norfolk Island.

Figure 1.7: Location of accessible coastal sites on Norfolk Island

Source: GoogleEarth, accessed 1/10/2019

The KAVHA is a popular tourist site and one of the oldest and best-preserved convict settlement sites in Australia. The majority of the ~30,000 visitors (each year) to Norfolk Island would likely visit Emily Bay, Slaughter Bay and Cemetery Bay, for purposes such as visiting historical/heritage sites, swimming/snorkeling/diving, fishing, bird watching, reef tours, and other aquatic activities.

The following descriptions and slope/particle size analyses of Norfolk Island beaches contribute to the Resource Condition Targets and Management Action Targets from the Norfolk Island Natural Resource Plan (Table 7-2 in PB, 2009); providing an initial baseline (2019) for future comparison.

1.2.2 EMILY BAY

Emily Bay beach is approximately 355 m long and comprises of a zeta-form (curved) beach with a reef system approximately 135 m offshore (refer Figure 1.8). The beach has minimal exposed bedrock/ancient reef materials.

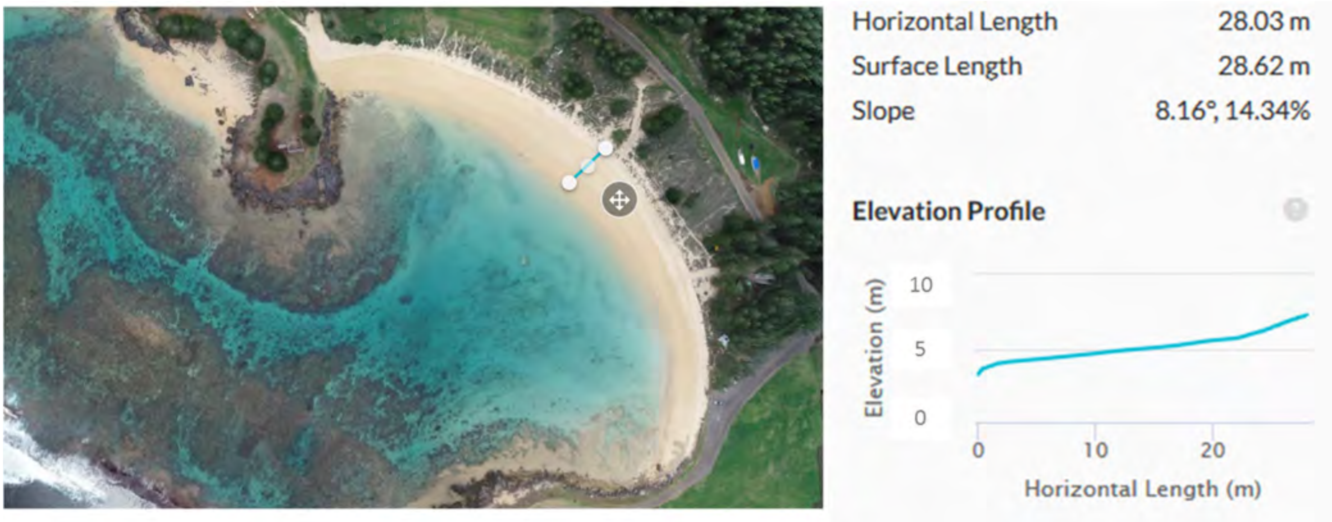


Figure 1.8: Emily Bay beach morphology (showing the transect line used in calculations).

1.2.3 SLAUGHTER BAY

Slaughter Bay is approximately 260 m long and comprises of a narrow beach with a reef system approximately 110 m offshore (refer Figure 1.9). The beach has intermittently exposed bedrock/ancient reef materials.

Figure 1.9: Slaughter Bay beach morphology (showing the transect line used in calculations).

1.2.4 CEMETERY BAY

Cemetery Bay is approximately 380 m long and comprises of a narrow beach (refer Figure 1.10). The beach has intermittently exposed bedrock/ancient reef materials and is more exposed to ocean swells than Emily and Slaughter Bays.

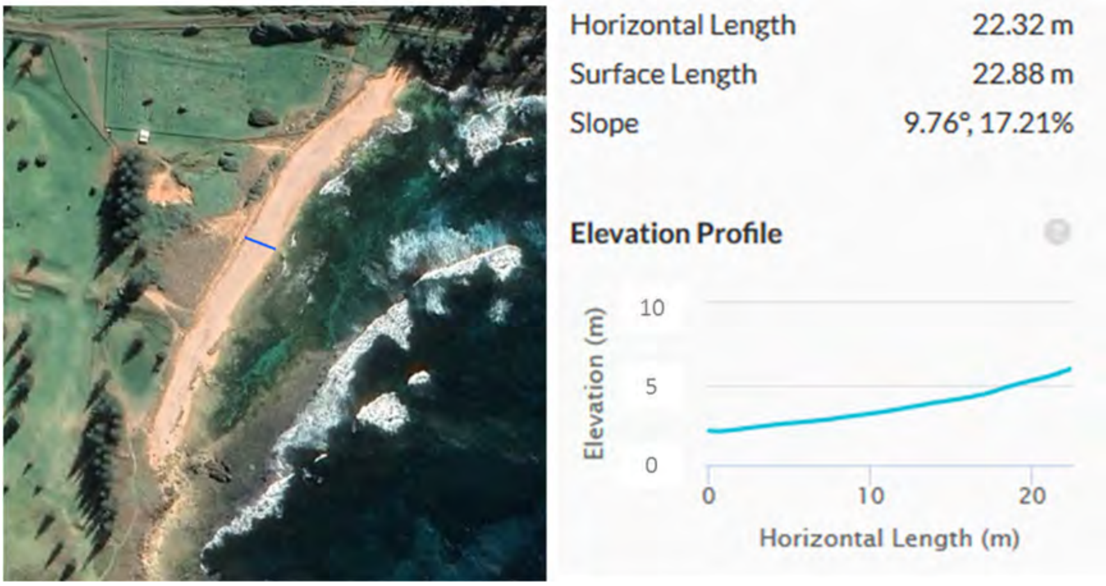


Figure 1.10: Slaughter Bay beach morphology (showing the transect line used in calculations).

1.2.5 ANSON BAY

Anson Bay beach is approximately 380 m long and comprises of a narrow beach with intermittently exposed bedrock (refer Figure 1.11). Anson Bay is located on the NW of Norfolk Island and access is limited to the very fit only. The walking track to Anson Bay Beach is approximately 1.3 km (one-way) however it winds its way down the cliff face to where the beach lies 70 m below. Vehicle access is limited to authorised entry only.

Figure 1.11: Anson Bay beach morphology (showing the transect line used in calculations).

1.2.6 BUMBORAS

Bumboras is located on the south of Norfolk Island (also known as Creswell Bay) and access is down a relatively easy 150 m walking track. Access to the lower carpark is difficult after heavy rainfall, which may limit visitors to this area during some periods. The beach is approximately 90 m long and comprises of a narrow raised beach where sand settles behind the rounded boulders that line the perimeter of the bay (refer Figure 1.12). Note the negative slope, which indicates that the sand is trapped behind the boulder beach and will likely be translocated after large storm events.

Figure 1.12: Bumboras beach morphology (showing the transect line used in calculations).

Particle size distribution of beach sand was undertaken for Emily Bay, Slaughter Bay, Cemetery Bay, Anson Bay and Bumboras.

1.2.7 PARTICLE SIZE DISTRIBUTION AND BEACH DESCRIPTION

Particle size distribution shows how well sorted, and at what size, the beach sands are on Norfolk Island. Results are shown in Figure 1.13.

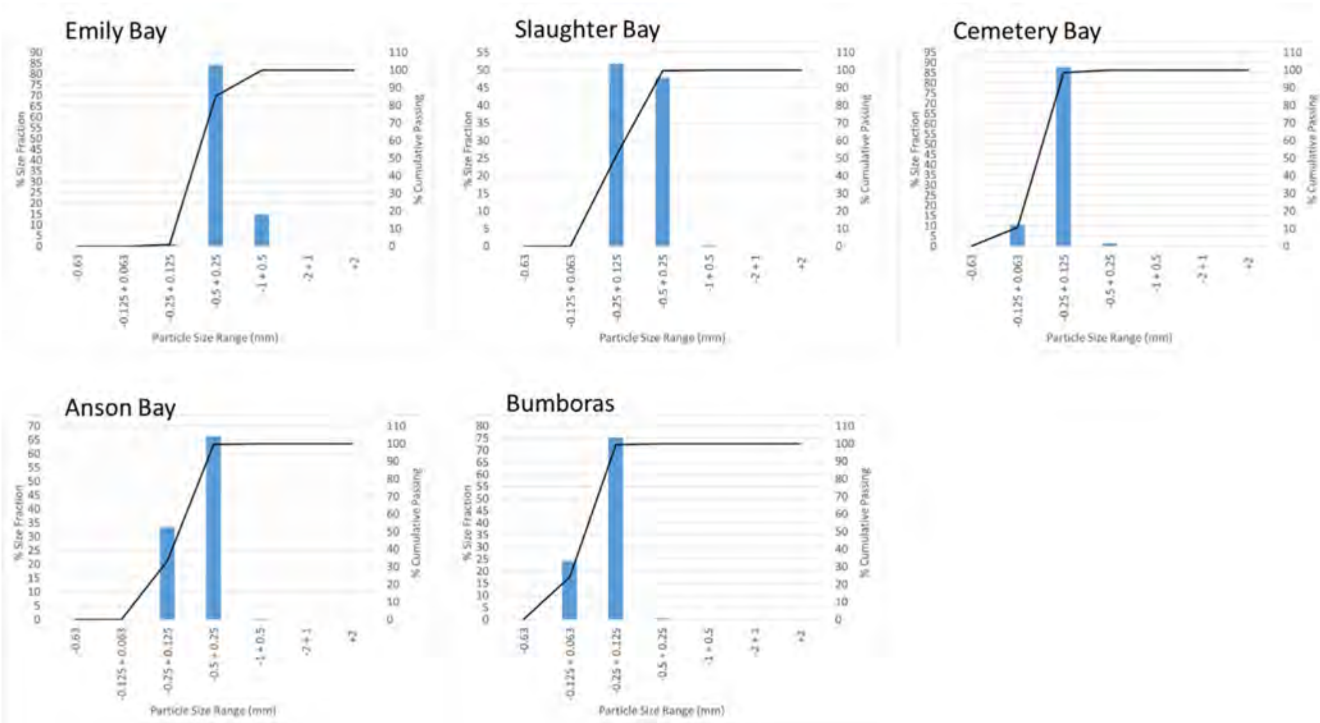


Figure 1.13: Particle size distribution of beach sand for Emily Bay, Slaughter Bay, Cemetery Bay, Anson Bay and Bumboras.

Emily Bay has a very well sorted profile with most particles (~85 %) in the range of 0.125 – 0.25 mm, with some slightly larger (0.5 – 1 mm). Organic matter was determined by "loss-on-ignition" (LOI) by placing 1 g of sand in a crucible and then into an oven at 550°C for 16 hours, with the LOI reflecting the organic component of the sample. The organic matter content of Emily Bay beach sand was 3.8 %.

Slaughter Bay has a moderately well sorted profile with 52 % of particles in the range of 0.125 – 0.25 mm and 47 % in the range of 0.5 – 1 mm. The organic matter content of Slaughter Bay beach sand was 5.6 %. The larger sand particle distribution at Slaughter Bay, compared to Emily Bay, indicates that Slaughter Bay experiences greater storm influence (more energy) that effectively removes smaller particle fractions from the beach surface.

Cemetery Bay has a very well sorted profile with most particles (~87 %) in the range of 0.125 – 0.25 mm, with some slightly smaller (0.063 – 0.125 mm). The organic matter content of Cemetery Bay beach sand was 7.5 %. The larger sand particle distribution at Cemetery Bay, compared to Emily Bay, indicates that Slaughter Bay experiences greater storm influence (more energy) that effectively removes smaller particle fractions from the beach surface.

Anson Bay has a moderately well sorted profile with most particles (~67 %) in the range of 0.25 – 0.5 mm, with some (33 %) slightly smaller (0.125 – 0.25 mm). The organic matter content of Anson Bay beach sand was 6.1 %. The larger particle size distribution of Anson Bay indicates a relatively higher energy environment compared to other sites. For example, low energy coastal environments, such as wetlands, typically have smaller size fraction profiles; while high energy environments, such as exposed beaches, typically have larger size fraction profiles.

Bumboras beach has a moderately well sorted profile with most particles (75 %) in the range of 0.125 – 0.25 mm, with some (25 %) slightly smaller (0.063 – 0.125 mm). The organic matter content of Bumboras beach sand was 7.6 %.

Ball Bay and Cascade (refer Figure 1.14) have coastal access however, while public access is allowed, both sites are used for different purposes. Cascade is used as a maritime port for Norfolk Island (unloading and loading goods and produce for local consumption) and Ball Bay is used as port facilities for receiving liquid fuel such as diesel.

Figure 1.14: Ball Bay and Cascade

Ball Bay has no beach but could be described as a "boulder beach" (McKenna, 2005). Little research has been undertaken on boulder beaches partly because morphological response times are too long for consideration in the normal time-frame of academic field programs, and also because very large clasts (boulders) are difficult to characterize (McKenna, 2005). Oak (1984) proposed that boulder beaches demonstrate certain unique sedimentary characteristics that distinguish them as fundamentally different from pebble and cobble beaches. The dominant characteristics of boulder beaches listed by Oak (1984) are:

- A high wave-energy environment, competent to move large clasts;
- Upbeach fining of sediment;
- Abundant breakage of sediment;
- Positively skewed size distributions;
- Upbeach decrease in roundness;
- No shape zonation;
- No sphericity grading;
- Low foreshore slopes, decreasing as particle size increases.

Of all the public accessible coastal sites, Ball Bay is likely to be the most resilient/stable beach to large storm events and climate change.

1.2.8 REEF INTEGRITY

The Emily and Slaughter Bay Lagoon is a major attraction for the Island's tourism market, being voted in the top ten Australian beaches on Trip Advisor in 2017. Protection and preservation of this ecosystem is vital for the Island's economy. However, the impacts from the discharge of large volumes of nutrient rich, turbid stormwater into the lagoon are becoming increasingly evident (Wilson, 2017). Figure 1.15 below provides the locations of several water quality monitoring sites (1 – 5) and Figure 1.16 summarises Faecal Coliform (FC) results provided by NIRC (from October 2017 – August 2020).

Figure 1.15: Sampling sites for Emily Bay

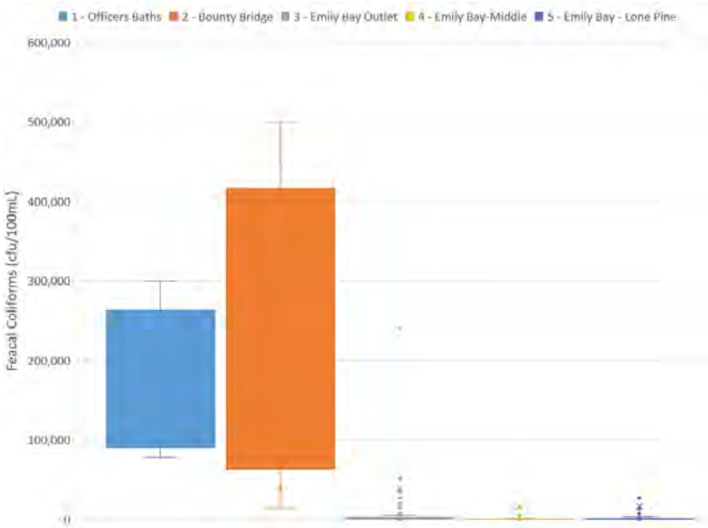


Figure 1.16: Faecal Coliform results

Faecal coliform bacteria are microscopic organisms that live in the intestines of warm-blooded animals and also in the faeces from the intestinal tract; and are commonly used as indicator organisms for faecal contamination in environmental waters. Trigger values from the Australian and New Zealand guidelines for fresh and marine water quality (ANZECC, 2000) with respect to "Recreational Waters – Secondary Contact" (Table 5.2.3 in ANZECC, 2000) indicate 1,000 cfu/100mL (median over 5 sampling events).

Anecdotal evidence from long term Norfolk Island residents suggests that there has been significant degradation of the coral reef from the Town Creek outlet and around the shoreline adjacent to the Salt House (headland between Slaughter and Emily Bays) (Wilson, P.J., 2017). Large areas of sea grass and algae growth are developing on the coral reef and the sea floor. At the same time coral is dying along a transect extending from the creek outlet to Lone Pine (Pendoley, 2015). This is a typical transition for reef systems when nutrient rich-turbid waters prevail.

Footage provided by Mrs Corrine Parsons's shows that the marine ecosystem between the creek discharge point and Middle Beach has been compromised (Wilson, 2017). Figures 1.17 and 1.18 show the coral reef off Salt House point in April 2016 (Wilson, 2017). Rich and luxuriant algal growth on and around the dead coral is evident. The introduction of high levels of phosphorous and nitrogen is known to cause bleaching and death in coral and to enhance algal growth (AIMS 2017, Vega Thurber et al., 2014, D'Angelo and Wiedenmann, 2014).

Figure 1.17: Dense algal growth adjacent the Salt House (source Mrs Corrine Parsons, 2016)

Figure 1.18: Image shows limited coral amongst dense and luxuriant algal and seagrass growth (source Mrs Corrine Parsons, 2016)

The loss of total coral cover and diversity is highlighted in Figures 1.19 – 1.24. Images taken in Emily Bay in 1992 show the reef was characterised by a diverse range of vibrant coral and marine species with limited algae growth (Figure 1.19 and Figure 1.20) (Wilson, 2017). Images from the bay taken in 2016 show a considerable decease in coral cover and diversity and a substantial increase in algal growth relative to 1992 (Figure 1.21). While no quantitative baseline data is available on the fish and invertebrate fauna of the bay, the absence of small fish that were once abundant, and the absence of a rich invertebrate fauna assemblage that is typical of a pristine coral reef environment is obvious to long term users of the bay (Wilson, 2017).

Figure 1.19: Emily Bay Plate Coral 1992 showing high coral cover and rich diversity in coral species and small fish (Source: Mr Jack Marges)

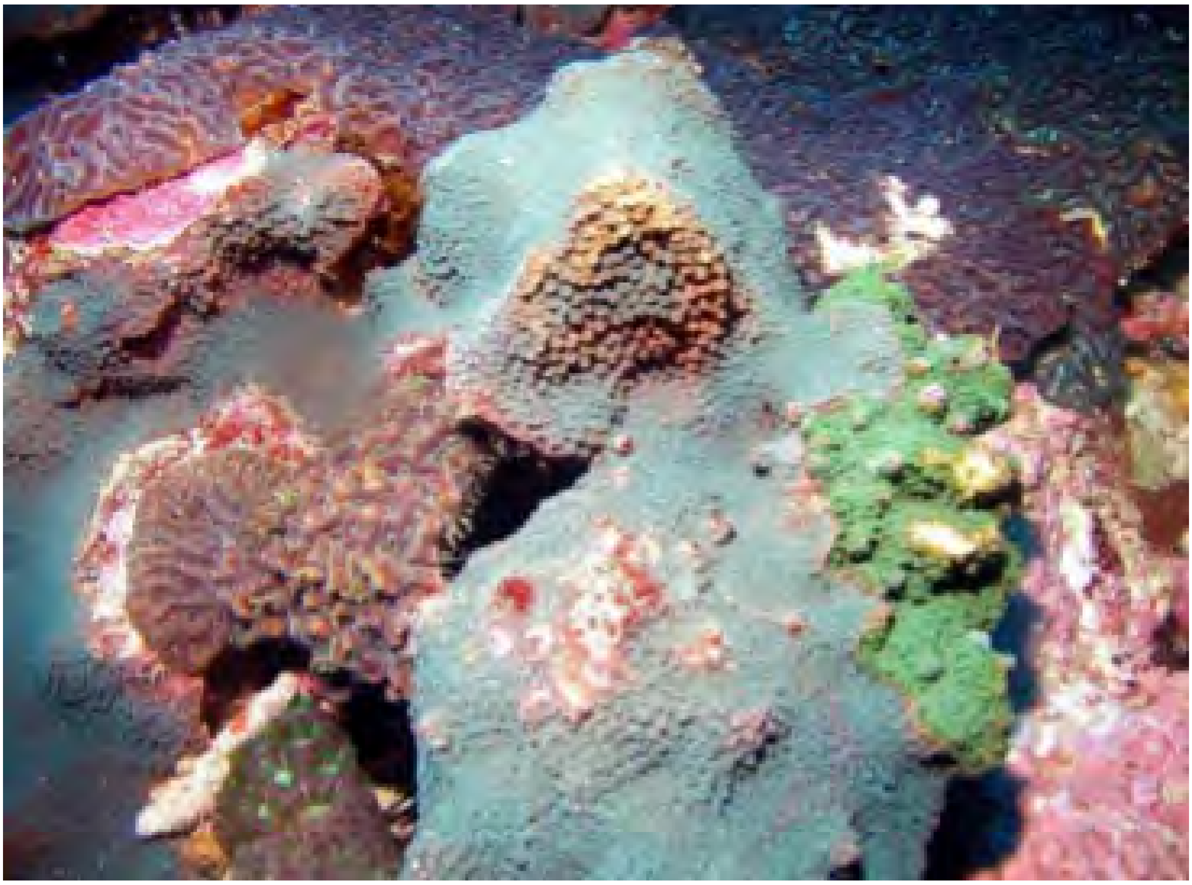


Figure 1.20: Image showing the 100% coral cover with no algal growth (Source: Mr Jack Marges, 1992)

Figure 1.21: Emily Bay plate coral 2016, showing a decline in coral diversity and cover and a complete absence of small fish (source: Mrs Corrine Parsons)

Figure 1.22: Image from 2016 showing dead coral being overgrown by algae (Source: Corrine Parsons 2016)

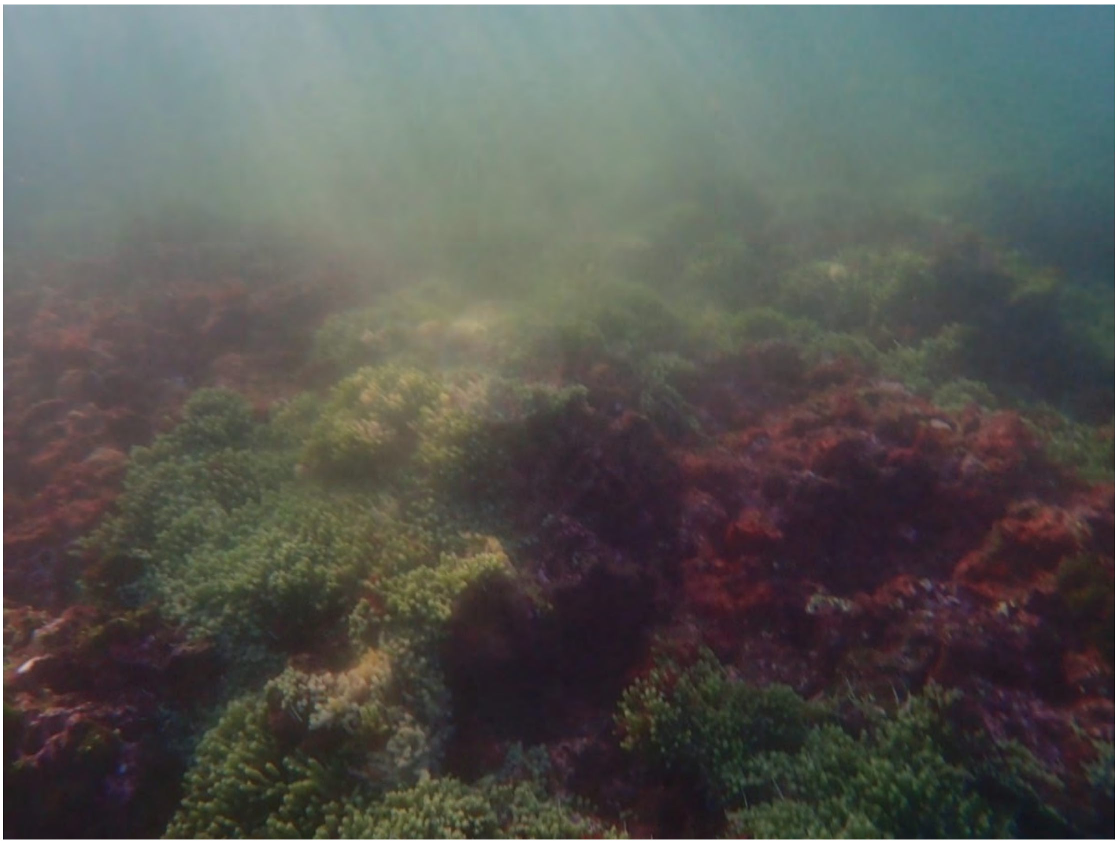


Figure 1.23: Image from 15th May 2021 showing increased growth of Caulerpa lentillifera (Umbido in Japanese, translates to "sea grapes" in English). Excessive nutrients in Emily Bay are the likely cause. (Source: Susan Prior 2021)

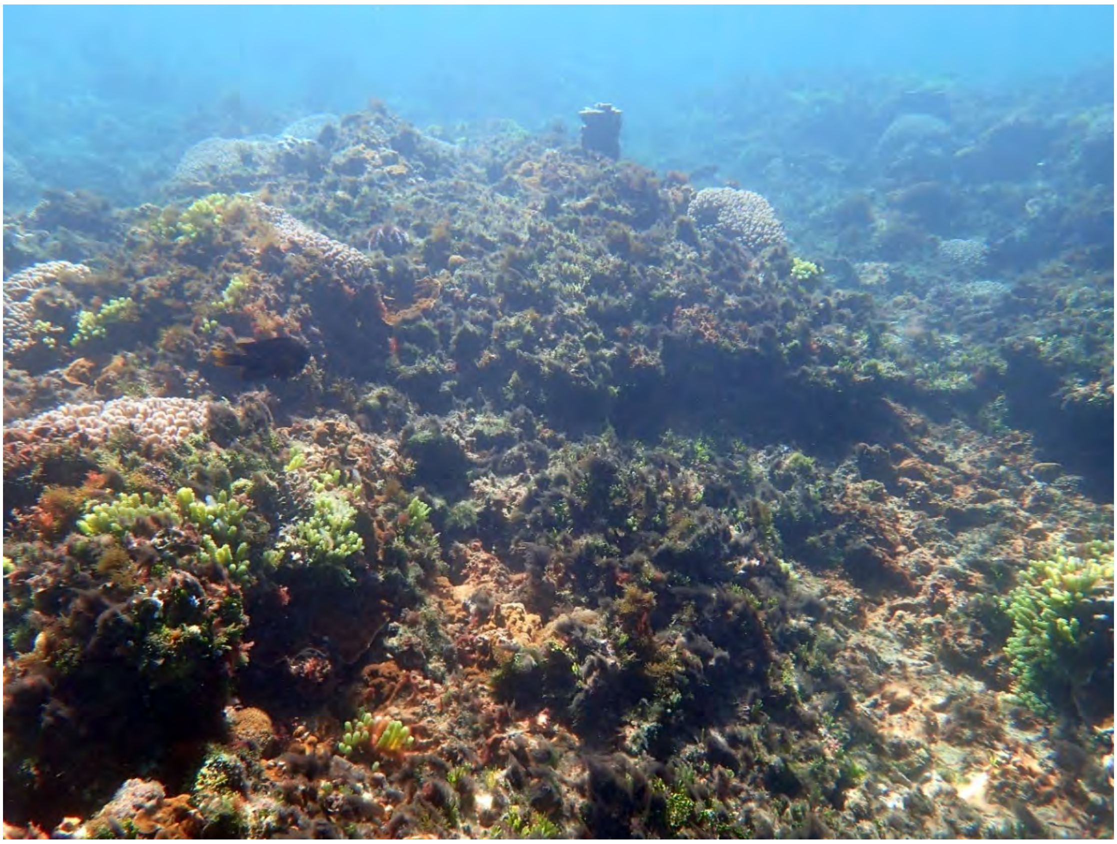


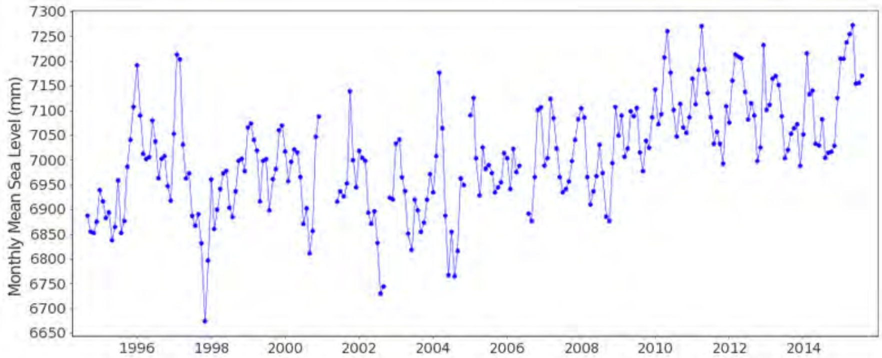
Figure 1.24: Image from 24th April 2021 showing increased algae growth from 2016 (Source: Susan Prior 2021)

The ongoing degradation of the Emily Bay lagoon ecosystem is clearly obvious and based on the rate of coral loss and algal growth in Emily and Slaughter Bay, the entire ecosystem could be lost within 5 – 10 years (Pendoley Environmental, 2015). If 100% of the coral is lost, recovery of the ecosystem will be delayed by the lack of migration of coral spawn from external reef systems (e.g. Lord Howe) due to the isolated nature of Norfolk Island. However, if the discharge of fresh water and nutrients into the bay is stopped soon, the system is expected to show signs of recovery within 1 year (Vega Thurber et al., 2014; Wilson, P.J., 2017).

Reef systems provide many ecosystem services and one of these is shoreline protection. Elliff and Silva (2016) demonstrate how reef systems can act as a first defence to climate change with respect to increasing sea temperature, sea level rise and increasing ocean acidification. Ferrario et al., (2014) identified that, globally, reefs are able to attenuate (on average) 97% of incoming wave energy, as well as reducing (on average) 84% of the height of these waves. Therefore, apart from the tourism benefits, the existing reef system is likely to assist beach preservation in the Emily Bay/Slaughter area in the face of climate change.

1.2.9 MEAN SEA LEVEL VARIATION

Variations in mean sea level are likely to impact on reef systems and beach morphology. Figure 1.25 shows mean monthly sea level on Norfolk Island since 1994. The main observation is an increasing mean sea level trend from 2005. An increasing mean sea level may change the geomorphology of Norfolk Island beaches, particularly on exposed beaches such as Anson Bay, over the next 100 years.



Station Information	
Station ID:	821
Latitude:	-29.058333
Longitude:	167.953611
GLOSS ID:	124
Coastline code:	680
Station code:	91
Country:	NORFOLK ISLAND
Time span of RLR data:	1994 – 2015
RLR completeness (%):	92
Time span of metric data:	1957 – 2015
Metric completeness (%):	47
Date of last update:	28 Sep 2016

Figure 1.25: Mean sea level variation since 1994

1.2.10 SUMMARY

The coastline of Norfolk Island is now protected under the Australian Marine Park and every effort should be made to protect sensitive areas and improve coastal resilience. Chapter 7 in the Norfolk Island Natural Resource Plan (PB, 2009) provides a detailed assessment of coastal issues on Norfolk Island, and it recommended that the Resource Condition Targets and Management Action Targets should be continued. The Norfolk Island Natural Resource Plan (Table 7-2 in PB, 2009) is shown below (Table 1.1). Highlighted areas (in green) summarise contributions from this report to achieving the objectives of the Resource Condition Targets and Management Action Targets. Comprehensive Coastal Management Studies were outside the scope/budget for this project, however the contributions from this report complement existing programs undertaken by Marine Parks and other research/citizen science groups.

Table 1.1: Resource Condition Targets and Management Action Targets (from Table 7-2 in PB (2009)

Aspirational Target: *Sustainable management of the coastline*	
Resource Condition Targets	**Management Action Target**
Complete a comprehensive coastal management study and regularly review the processes and results	• Prepare a comprehensive coastal processes management study and coastal management plan that is implemented as part of the Norfolk Island Plan and regularly updated with the Plan and in accordance with review of the processes and results of the coastal study. • Establish condition benchmarks and indicator species for coastal and marine waters.
Aspirational Target: *Maintenance and enhancement of sandy beaches and dunes*	
Resource Condition Targets	**Management Action Target**
Protect beaches and coastline from erosion	• Develop and implement strategies, to protect the beaches from erosion and retreat to protect the landscape, environment, recreational resources and community assets.
Protect and manage sand resources to maintain landscape, recreational resources and habitats.	• Research sand transport dynamics and options to protect beaches from sand depletion; impacts of sand transport on beach profiles, wave action and possible erosion.
Aspirational Target: *Protection of marine ecosystems and sustainable use of the marine environment and marine resources by the residents and tourists.*	
Resource Condition Targets	**Management Action Target**
Reduce and minimise the human impacts on the marine environment, by ensuring pollution levels in the sea are minimised.	• Prepare a waste and sewage management plan for the Island, incorporating the options outlined in the *Stage 1 Waste Management Audit and Options Study Report, 2000 and Norfolk Island Municipal Waste Stream Feasibility Study*. The plan should consider the following: ▪ Dramatically reduce ocean sewage discharge and dumping of the Island's raw (unburnt) waste into the ocean. ▪ Upgrade waste disposal to ensure floating materials and plastics are not disposed of in the sea as this is a key threatening process for a number of threatened marine species occurring around the Island. ▪ Ensure that discharges to coastal waters are within ecologically sustainable limits, particularly those discharges into Emily Bay. • Develop and implement an educational program which promotes adoption of best management practices to minimise agricultural sources of pollution, including both point and diffuse sources. • A water monitoring program could be implemented to ensure that discharges to coastal waters are within ecologically sustainable limits. Sites to be monitored should include; diffuse sources into the ocean, waterways on the Island and swimming locations around the Island, to try and avoid the risk of contaminated fish passing into the human food chain and pollution risk to exposed humans.

Protect coral reef ecosystem from direct and indirect anthropogenic damage	• A water monitoring program could be implemented to ensure that discharges to coastal waters are within ecologically sustainable limits. Sites to be monitored should include; diffuse sources into the ocean, waterways on the Island and at swimming locations around the Island, to try and avoid the risk of contaminated fish passing into the human food chain and pollution risk to exposed humans. • Develop and implement an educational program for the community and tourists about how to preserve coral reefs.
Identify coastal habitats at risk or of high conservation value	• Prepare a comprehensive coastal processes management study and a coastal management plan that is implemented as part of the Norfolk Island Plan and regularly updated with the Plan and in accordance with review of the processes and results of the coastal study. The study should look at developing strategies that will protect, restore and manage coastal habitats of high conservation value; e.g. plantings to reduce erosion, fence cliff tops to prevent access by cattle.
Sustainable fisheries and maximum community benefit (including domestic consumption, tourist opportunities and economic benefits).	• Limit future fishing licence vessels to those owned and operated by Norfolk Island residents. • Implement agreed bag limits or restrictions on gear (e.g. reduce the no. of lines per person), and educate on catch-and-release techniques, for those fishing in 'the Box'. • Prohibit non-permanent residents from selling fish. • Implement a catch data and fish monitoring program, to ensure fishing remains sustainable. Program should monitor fish populations, any catch or bycatch and the status of the marine environment.
Well understood and conserved marine biodiversity in the Norfolk Island region through integrated management and multiple-use marine protected areas.	• Establish an integrated system of terrestrial and marine protected areas that recognise and protect the cultural and economic importance of people living on Norfolk Island; permit multiple sustainable uses, while protecting biodiversity. • Undertake systematic scientific research on biodiversity and ecological functions and identify significant species, risks and management actions.

1.3 LAND USE CAPABILITY ASSESSMENT – NORFOLK ISLAND SOILS

1.3.1 INTRODUCTION

Norfolk Islands offer a wide diversity of habitats, magnificent native vegetation, and rugged coastlines making it one of New South Wales' favourite island destinations. Evaluating the land-use capability of Norfolk Island is essential for land use planning, agricultural development, waste management, tourism development and sustainable environmental management. The island is unique in terms of geological morphology, land use, ecology and cultural history. Assessment of the land-use capability of the Island - examining landforms, their environmental suitability and the extent that existing use is consistent with environmental sustainability. Norfolk Island Regional Council (NIRC) has well-established soil and vegetation mapping data for the purpose of records and planning; however, due to the continuous changes triggered by the movement of people, commodities, changes in climate and anthropological activities, the soil and vegetation of the Island is frequently changing. Hence, there is a need for continuous real-time monitoring of these variables using spatial data. This section of the report will cover soil and land use data based on desktop study and analytical results from field samples.

1.3.2 BACKGROUND

Landscapes are significant to different people for different reasons such as their scenic beauty, cultural heritage value, environmental qualities, or values associated with the place, such as memories or associations. A coordinated scheme of managing landscape resources is intricate, nevertheless is required for a community/organisation to tackle the foreseeable problems and not just the existing indications.

Most civilisations declined due to water availability, soil degradation and other environmental issues (Diamond, 2005; Gray et al., 2015). The population of Norfolk Island has been declining gradually from 2,601 people in 2001 to 1796 people in 2011 and 1,748 in 2016 (ABS, 2016; Norfolk Island Government Census, 2001; Table 1). While soil is the fundamental need for life to thrive on earth, it is also a non-renewable resource essentially due to the nature of chemical interactions in soil. Soil degradation may lead to lower productivity of plants that affects the ecosystem of a region. Until now, the agricultural lands in Norfolk Island have remained productive with some vulnerable soils around the islands causing soil to erode and degrade. Therefore, it is important to effectively monitor, assess and manage sensitive areas, for the overall longevity and sustainability of life in the islands.

The region has potential to become unique in terms of agricultural produce, if the soils are managed sustainably. For instance, the range of avocado varieties cultivated in one of the farms near Norfolk Island Airport. The most common agricultural produce in the island are Norfolk Island pine seed, Kentia palm seed, cereals, vegetables and fruits; cattle, poultry and pig (Table 1.2). The stability of the natural areas of the island consisting of diverse habitats, interesting native vegetation and rugged coastal areas also requires conservation in terms of soil resources.

While tourism is the main revenue generator for the island, agriculture also has the potential to flourish both due to the productive soils and also tourism related influx of people from all over the world. With over 25 % of land use is for agriculture and around 11.5 % covered by forests (Table 1.2), the land needs to be managed effectively. However, the agricultural population represents only 6 % based on ABS (2016) census data and the population has been on the decline gradually since the first census in 1990 by the Norfolk Island administration.

Table 1.2: Information on social-economic characteristics of Norfolk Island (ABS, 2016).

Parameter	2016	2021 (projected)
Population	1748	1737
Median age	49	?
Population density	46.11 p/km²	45.83 p/km^2
Land use	Crops and pasture – 25 %; Forest – 11.5 %; Other 63.5 %	Need to be evaluated.
Agriculture produce	Norfolk Island pine seed, Kentia palm seed, cereals, vegetables, fruits; cattle, poultry, pig	Need to be determined.
Cattle population	1700 approximately*	Need to be counted.
Poultry	1800 approximately*	Need to be counted
Other domestic animals (sheep, pig, horse, dog, cat)	100 each approximately*	Need to be counted
Agricultural workforce	6% of the total population	-

*Animal Health Surveillance Quarterly (2015)

With the above socio-economic characteristics, there is a need to evaluate the current status of the Island's environment for effective management. To ensure the protection and management of natural and cultural landscapes of the Norfolk Island, this project assessed the status of Norfolk Island soils. The state and properties of the soil determines the stability of the landforms and the vegetation, including agricultural crops. Therefore, effective management of soil is required to produce food for not only the local people but also for visitors. The purpose of this section of the report is to identify landscape suitable for cropping, pasture growth, vegetation cover (forest) and other land use options including waste management, using the assessment of soils data. This section also reports the problem areas such as degraded soils, eroded sites, potential acid sulphate soil, industrial areas and waste disposal sites.

1.3.3 PRELIMINARY INVESTIGATION

The NIRC has well-documented evidence of land use for over 50 years (Abell, 1976; Jones & McDougall, 1973; Abell and Falkland, 1991). This study focussed on evaluating the spatial correctness of previous reports using Google Earth data. In the island, stakeholders and the island community members were consulted before the field work was initiated. This consultation facilitated the understanding of issues related to land resources and apprehensions expressed by the stakeholders. Key problems discussed by the community and stakeholders were soil erosion, native flora and fauna, environmental degradation and agricultural productivity and market related issues. Based on the Google Earth data, previous studies and the community consultations, the representative plots were selected, and the soils were sampled based on different land use systems, soil types and topography (Figure 1.20).

According to Abell (1976), the island was formed from volcanic activity, which might have originated close to Mt Pitt and Mt Bates. Soils have formed from basaltic lava flows and volcanoclastic rocks, and over time have a deeply weathered profile. Basaltic rock formed through this volcanic activity underlies most of the island and is the source of the krasnozem (red soils) and skeletal (thin) soils, which are found throughout the Mt Pitt section of the National Park (Jones & McDougall, 1973; Abell and Falkland, 1991). Skeletal soils are found along the summit ridge from Mt Pitt to Mt Bates, and extend to the northern coastline. The northern coastline consists of a series of cliffs with little soil formation or retention. Krasnozem clays of various classes are found on the eastern and western slopes of this section of the park.

Norfolk Island soils, being basaltic in origin, are nutrient rich and well structured, but they are also friable and porous. They are prone to mass movement such as soil creep, slumps and landslips if vegetation cover has been degraded or lost, or after a period of particularly heavy rain. According to the former NSW Department of the Environment and Heritage (2004), parts of Norfolk Island have been extensively cleared for agriculture and housing.

The report also says that much of Norfolk's landscape has changed from being densely vegetated to mainly pastures bordered by remnant woodland.

Before the original settlement in 1788, the Norfolk Island was densely covered with a subtropical forest of palms, ferns, creepers, flax, and pines, of which a remnant has been preserved around the slopes of Mount Pitt and Mount Bates (Abell, 1976). The densely forested areas still exists in and around Mount Pitt reserve, as a contiguous bushland involving the above two peaks. This can be attributed to the efforts of Norfolk Island Regional Council and the Commonwealth Government of Australia to fence the Mount Pitt area, thereby restricting the influence of domestic cattle on the native vegetation.

Foster et al (2009) summarised the previous environmental studies on Norfolk Island and found that the conditions of soils have been significantly affected by the influence of anthropological activities. In their report prepared to the Norfolk Island administration, they inferred that the combined effects of native vegetation clearing, the hunting of nesting sea birds, running of livestock, subdivision of the most fertile land, poor soil management practices, and poor attention to drainage, the Island's soils are suffering and are subject to erosion, degradation and mass movement. They stressed the importance of effective management to avoid further loss of soil due to soil erosion, sedimentation and slope instability.

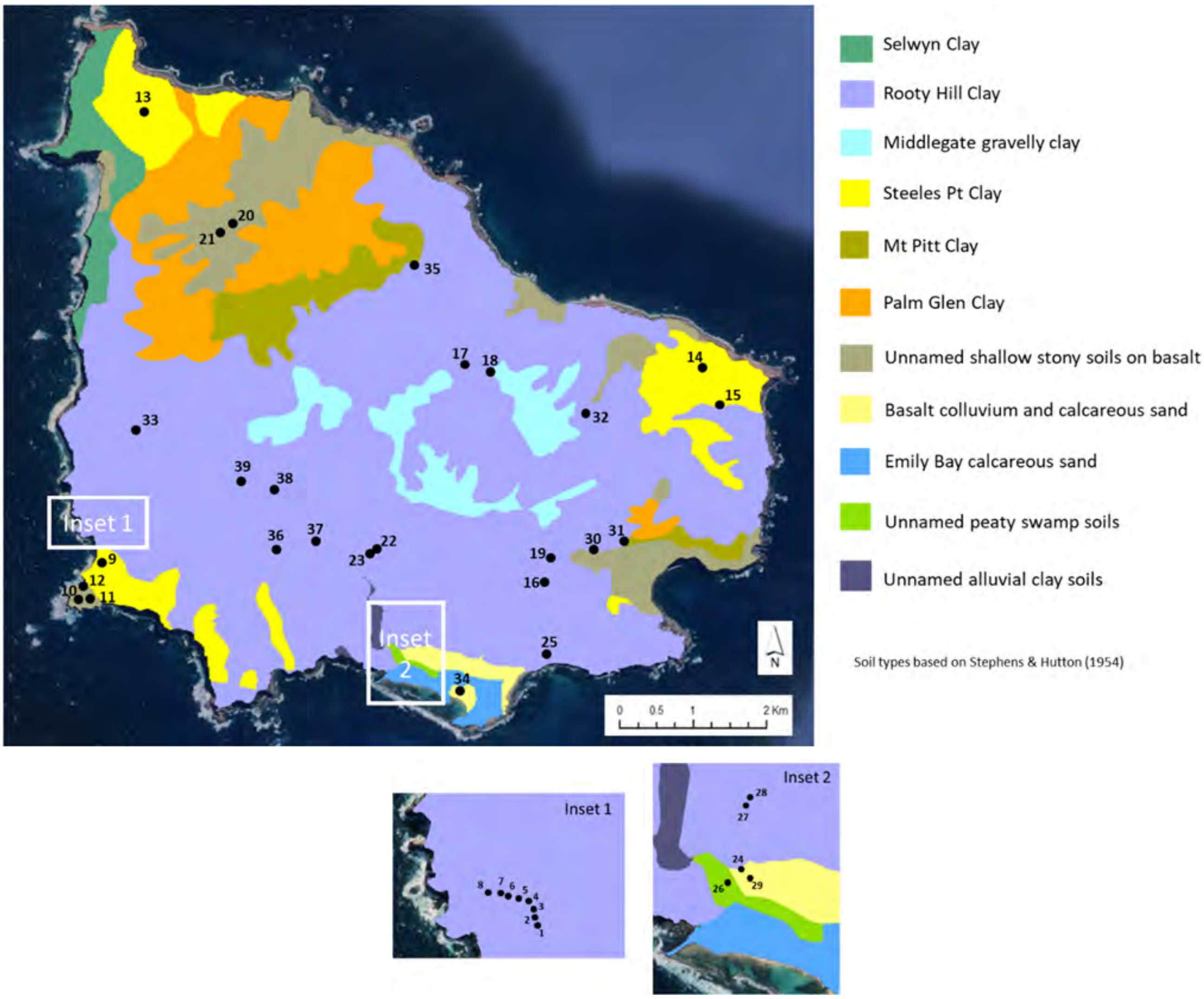


Figure 1.20: Soil sample location

1.3.4 METHODS

Field study

This study involved field collection of existing land use data with reference to past and current land use practices. The field data collection explored issues such as cropping suitability, pastoral suitability, and other land use options (including recreation). Farmers and farm managers were interviewed on grazing, on-farm practices and nutrient/fertiliser management. The factors considered for the study were:

- Biophysical factors – geology, soil, slope, climate, vegetation
- Physical limitations – drainage, flooding, erosion hazard
- Versatility – range of crops
- Productivity – crop yields

These factors supported a better understanding of the environmental/ economic suitability and sustainability of farms on Norfolk Island. The remainder of the investigation included soil sampling in the identified areas and interactions with the Farmers, with the following activities:

- Community consultation including discussions with farmers for understanding land use patterns were conducted.
- Data collection and fieldwork were undertaken over one week period between 16 and 23 September 2019.
- The first day was spent locating and examining all the landscapes on the island, with the help of previously acquired maps and community consultation. The soil sampling equipment were trialled during this and optimised for the sampling.
- Decisions on plot locations at the local level were made in the field, based on locations with large homogeneous areas with a consistent and constant mix of vegetation, slope, relief and soil.
- Point and depth sampling (0-10; 20-30; 30-40 cm) were conducted to study the soil's nutrient status, contaminant status and physical properties.

Soil analysis methods

The collected samples were stored in a cooler esky and transported to mainland for laboratory analysis, to determine and the data was used to compare nutrient status, extent of contamination and spatial variability. These samples aligned with land use patterns in reference to historical data. The samples were sent to the mainland in two parts – one to University of Newcastle (Callaghan, NSW) and the other one to EAL laboratory at Southern Cross University (Lismore, NSW). Soil analysis methods were based on Rayment and Lyons (2011). Presentation of results are shown in Section 8.5 and a summary of major parameters characterising soil productivity are provided in section 8.6.

1.3.5 RESULTS

The soils were analysed for chemical characteristics looking at agronomic traits (pH, nutrients) and contaminants (heavy metals, organics, pesticides). A total of 47 pesticide compounds were analysed in the collected soils and none of the soils showed any presence of pesticides. The soil results are presented based on five categories such as forest soils, drain sites, agricultural soils, weathered sites and polluted sites. The categories were decided based on preliminary investigation using maps and in-person survey. The soils results based on categories are as follows:

Forest soils

The forest soils identified in this study were mostly around Headstone area and Mt Pitt National Reserve. A total of four sites were identified and 12 soil samples were collected and analysed, which included six point samples and six depth samples (around two sites). The soils in the Headstone area were collected from 100 Acres Reserve and Rocky Point (Sample numbers 11 to 17 in Table 1.3). The pH of these soils ranged from 5.1 to 6.4 showing slightly higher pH in 100 Acres Reserve with higher phosphorus and organic carbon levels compared to the latter (Table 1.3). This can attributed to the pine trees in the reserve and the resultant litter. The depth sampling in 100 Acres

Reserve showed higher phosphorus content down the soil profile, which can be attributed to the higher iron content.

The soils associated to Mount Pitt area including Mount Pitt and Red Road (Sample numbers 38-39 and 67-69) show lower phosphorus levels. Iron content was found to be higher in the soil profile as it goes deeper (Table 1.3). While the Mount Pitt soils are not disturbed, Red Road soils were found to be slightly weathered in the eastern boundary of Mount Pitt (Figure 1.21).

Figure 1.21: Exposed soils on the eastern boundary of Mount Pitt

Table 1.3: Soil results for forest areas

Sample numbers		11	12	13	14	15	16	17	38	39	67	68	69
Parameters	Units	100 acres reserve 1 & 2				Rocky Point			Mt Pitt	Mt Pitt	Red Road		
		1	2-D1	2-D2	2-D3	1	2	3	Top	Bottom	D1	D2	D3
pH	-	6.4	6.4	6.1	6	5.3	5.3	5.1	5.7	5.6	6.2	6.1	6.1
EC	dS/m	0.12	0.12	0.13	0.12	0.14	0.14	0.15	0.11	0.12	0.16	0.18	0.18
Organic Carbon	%	4.1	4.1	3.9	3.9	5.1	4.8	4.7	4.3	4.5	5.1	4.7	4.7
Nitrogen	%	0.44	0.41	0.32	0.28	0.56	0.54	0.54	0.49	0.46	0.64	0.62	0.62
Potassium	mg/kg	622	370	327	285	1790	1249	981	<50	<50	174	219	126
Phosphorus	mg/kg	352	385	399	458	585	156	141	5	2	3	2	2
Nitrate N	mg/kg N	28.9	32.9	42	46.1	82.3	44	50.8	0.292	<0.1	1.55	1.64	0.842
Ammonium N	mg/kg N	5.8	6.31	5.29	5.83	7.1	8.98	11.1	7.76	12	4.79	3.2	5.15
Exchangeable Ca	$cmol^+/kg$	5.13	3.48	4.29	2.98	5.13	24.31	23.45	0.22	0.18	5.66	3.54	0.84
Exchangeable Mg	$cmol^+/kg$	7.15	6.00	9.25	8.90	7.83	13.33	17.40	0.46	0.53	2.03	2.07	0.94
Exchangeable K	$cmol^+/kg$	1.19	0.65	0.56	0.53	3.49	2.40	1.98	<0.12	<0.12	0.22	0.47	0.17
Exchangeable Na	$cmol^+/kg$	8.70	8.67	15.56	16.53	5.62	2.32	5.46	1.65	0.42	0.39	0.35	0.23
Exchangeable Al	$cmol^+/kg$	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable H	$cmol^+/kg$	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ECEC	$cmol^+/kg$	22.2	18.8	29.7	28.9	22.1	42.4	48.3	2.3	1.1	8.3	6.4	2.2
Calcium/Magnesium Ratio	-	0.7	0.6	0.5	0.3	0.7	1.8	1.3	0.5	0.3	2.8	1.7	0.9
Zinc	mg/kg	3.3	0.9	0.8	<0.5	2.0	6.4	8.3	<0.5	<0.5	<0.5	<0.5	2.1
Manganese	mg/kg	7.3	6.0	2.7	1.9	4.3	34	41	2.4	2.1	14	<0.1	12
Iron	mg/kg	322	315	337	1512	365	27	63	2.1	1.7	28	1709	15816
Copper	mg/kg	2.4	1.7	1.9	1.5	1.2	2.8	3.3	<0.1	<0.1	0.5	<0.1	1.6
Exchangeable Sodium Percentage (ESP)	%	39.3	46.1	52.5	57.1	25.5	5.5	11.3	71.0	37.1	4.7	5.5	10.6

Note: D1 = 0-10cm, D2 = 10-20cm, D3 = 20-30cm

Drain sites

Significant drain sites around Headstone catchment and Emily bay areas were identified and the soil samples were collected and analysed for nutrient runoff and transport of pesticides. There was no pesticides found in the samples near drain sites (Figure 1.22a and 1.22b).

For the Headstone dam site (Table 1.4), seven soil samples were collected downstream along the creek and the eighth sample was collected in three depths. The site was suspected to have acid drainage problems after a previous rainfall event but the samples were not too acidic while measured in the field and later in the lab. This site needs further investigation by an expert geologist for the potential of acid drainage.

At Emily Bay, samples were taken along Taylor's Rd and in the KAVHA (refer to Figure 1.20) and results are shown in Table 1.5..

Figure 1.22a: Drainage line to Headstone dam

Figure 1.22b: Drainage line to the Bloody Bridge

Table 1.4: Soil results for drain sites – Headstone catchment

Sample numbers		1	2	3	4	5	6	7	8	9	10
Parameters	Units	Dam 1	Dam 2	Dam 3	Dam 4	Dam 5	Dam 6	Dam 7	Dam 8-D1	Dam 8-D2	Dam 8-D3
pH	-	6.3	6.1	6.1	6.4	6.1	6.2	5.9	6	5.9	5.8
EC	dS/m	0.23	0.23	0.23	0.23	0.25	0.25	0.25	0.22	0.23	0.27
Organic Carbon	%	4.6	4.6	4.7	4.6	4.8	4.9	4.7	5.1	4.8	4.7
Nitrogen	%	0.49	0.49	0.49	0.51	0.53	0.53	0.54	0.56	0.54	0.54
Potassium	mg/kg	530	212	315	357	864	1680	400	139	120	144
Phosphorus	mg/kg	12	41	28	28	64	108	9	37	16	50
Nitrate N	mg/kg N	5.56	0.751	0.754	67.5	52.2	54.3	2.43	2.66	0.856	0.193
Ammonium N	mg/kg N	13.5	24.5	112	18.9	13	12	3.77	17.5	12.8	9.79
Exchangeable Ca	cmol⁺/kg	6.91	2.23	0.73	1.36	4.97	8.99	2.47	1.05	2.13	3.86
Exchangeable Mg	cmol⁺/kg	7.76	1.47	1.23	1.42	5.00	7.24	2.62	0.89	2.04	4.74
Exchangeable K	cmol⁺/kg	1.13	0.37	0.67	0.78	1.91	3.99	0.92	0.21	<0.12	<0.12
Exchangeable Na	cmol⁺/kg	1.58	1.21	1.84	0.94	1.23	0.36	0.59	0.91	1.31	1.55
Exchangeable Al	cmol⁺/kg	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable H	cmol⁺/kg	<0.01	1.52	6.07	5.64	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ECEC	cmol⁺/kg	17.5	6.8	10.5	10.1	13.1	20.6	6.6	3.1	5.5	10.1
Calcium/Magnesium Ratio	-	0.9	1.5	0.6	1.0	1.0	1.2	0.9	1.2	1.0	0.8
Zinc	mg/kg	3.6	<0.5	<0.5	0.6	0.6	6.3	<0.5	<0.5	9.7	1.9
Manganese	mg/kg	22	2.7	2.4	16	2.0	14	1.0	3.8	13	11
Iron	mg/kg	226	187	251	156	328	362	28	97	703	218
Copper	mg/kg	3.2	0.5	<0.1	<0.1	0.2	5.4	1.0	<0.1	0.9	<0.1
Exchangeable Sodium Percentage (ESP)	%	9.1	17.8	17.5	9.3	9.4	1.7	9.0	29.8	23.9	15.2

Note: D1 = 0-10cm, D2 = 10-20cm, D3 = 20-30cm

Table 1.5. Soil results for drain sites – near Emily Bay

		Taylors Rd Left			Taylors Rd Right			Taylors Road				Kingston & Arthur's Vale Historic site				
Sample numbers		40	41	42	43	44	45	46	47	48	49	66	50	51	52	53
Parameters	Units	D1	D2	D3	D1	D2	D3	Drain 1	Middlegate Rd	Swamp	Drain 2	Emily Bay	D1	D2	D3	Creek
pH	-	7.3	6.8	6.8	7.1	6.9	6.7	6.2	6.7	5.8	5.5	6.7	6.1	5.7	5.9	6.4
EC	dS/m	0.29	0.29	0.28	0.28	0.29	0.29	0.30	0.30	0.31	0.31	0.33	0.32	0.32	0.32	0.33
Organic Carbon	%	4.1	4.1	3.9	3.5	3.5	3.5	4.3	4.5	4.9	5.1	3.7	4.7	4.7	4.9	5.4
Nitrogen	%	0.44	0.41	0.4	0.45	0.44	0.44	0.52	0.57	0.64	0.64	0.56	0.62	0.62	0.64	0.62
Potassium	mg/kg	273	141	152	152	194	160	189	425	236	670	550	364	354	330	419
Phosphorus	mg/kg	9	6	11	7	26	7	7	11	46	186	48	45	56	51	56
Nitrate N	mg/kg N	8.12	1.49	3	1.06	1.93	1.02	0.85	9.74	2.59	6.63	12.8	3.84	8.64	3.4	1.3
Ammonium N	mg/kg N	4.38	2.33	4.63	4.1	7.65	2.83	4.24	4.09	13.6	19.2	9.46	4.43	5.98	4.17	17.9
Exchangeable Ca	cmol⁺/kg	10.01	10.43	11.13	3.20	7.00	7.85	7.06	12.65	29.95	34.55	24.40	3.13	7.26	3.76	4.18
Exchangeable Mg	cmol⁺/kg	1.94	1.33	1.46	2.42	2.34	2.75	1.73	2.25	5.49	14.57	13.90	3.48	4.17	5.07	6.57
Exchangeable K	cmol⁺/kg	0.58	0.21	0.19	0.16	<0.12	<0.12	0.19	0.76	0.34	1.38	0.85	0.72	0.59	0.66	0.81
Exchangeable Na	cmol⁺/kg	1.25	0.63	0.88	0.35	0.58	1.13	0.75	0.68	3.73	9.67	3.30	1.03	1.44	1.85	5.11
Exchangeable Al	cmol⁺/kg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable H	cmol⁺/kg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ECEC	cmol⁺/kg	13.8	12.6	13.7	6.1	9.9	11.7	9.7	16.3	39.5	60.2	42.5	8.4	13.5	11.3	16.7
Calcium/Magnesium Ratio	-	5.2	7.8	7.6	1.3	3.0	2.9	4.1	5.6	5.5	2.4	1.8	0.9	1.7	0.7	0.6
Zinc	mg/kg	<0.5	<0.5	1.5	0.6	<0.5	<0.5	<0.5	1.4	2.5	8.3	14	0.6	3.8	1.5	5.6
Manganese	mg/kg	2.8	0.5	2.9	2.5	24	2.1	7.5	9.1	68	103	31	8.7	11	2.5	17
Iron	mg/kg	3.0	3.1	4.7	15	18	7.3	11	9.8	120	280	145	78	124	46	249
Copper	mg/kg	0.3	0.2	0.7	0.6	1.1	0.3	0.7	1.0	5.3	4.2	3.5	1.0	3.1	3.5	3.9
Exchangeable Sodium Percentage (ESP)	%	9.0	5.0	6.4	5.6	5.8	9.6	7.7	4.2	9.4	16.1	7.8	12.3	10.7	16.3	30.6

Note: D1 = 0-10cm, D2 = 10-20cm, D3 = 20-30cm

Agricultural soils

The agricultural soils were found to be productive supported by the nutrient values and also the optimism showed by the farmers. Interestingly, no pesticide residues were found in the farms around Norfolk Island. The soil sampling and analysis were conducted on three different farms (Figures 1.23a, b and c). "Property 1" was growing multiple crops along with dairy and the productivity was found to be encouraging (Figure 1.23a). "Property 2" had lots of uneven surfaces including steep slopes. The farmer was growing corn, pumpkins, strawberry, tomato and onion along with pigs (Figure 1.23b). The management of this farm is challenging because of the steep slopes and fragmented areas. "Property 3" is managed based on permaculture principles and they grow vegetables and fruit trees with unique varieties of avocadoes.

Figure 1.23a: "Property 1"

Figure 1.23b: "Property 2"

Figure 1.23b: "Property 3"

The overall productivity of the soils in the Norfolk Island is encouraging but the soils need to be better managed to continuing reaping the benefits of the soil resources. The pH of the agricultural soils in Norfolk Island is within the optimum range for most crops.

Table 1.6. Soil results for Farm sites

Sample numbers		18	19	20	21	28	29	30	31	61	62	63	64	65
		Evans Farm1	Evans Farm2			Lyles Farm 1	Lyles Farm 2	Lyles Farm 3			Lyles Farm 5	Lyles Farm 6	Derek Farm 1	Derek Farm 2
Parameters	**Units**		D1	D2	D3			D1	D2	D3				
pH	-	6.9	6.7	6.4	6.3	6.5	6.7	6.4	6.2	6.1	6.6	6.8	6.5	6.7
EC	dS/m	0.27	0.29	0.29	0.29	0.23	0.23	0.23	0.25	0.25	0.25	0.24	0.22	0.22
Organic Carbon	%	5.57	5.73	5.64	5.53	5.52	5.37	5.35	5.52	5.22	5.61	5.58	6.58	6.67
Nitrogen	%	0.49	0.49	0.49	0.51	0.44	0.41	0.4	0.45	0.44	0.44	0.44	0.59	0.47
Potassium	mg/kg	559	301	280	209	399	468	135	86	869	493	383	828	657
Phosphorus	mg/kg	145	108	27	14	22	6	8	10	18	5	5	118	113
Nitrate N	mg/kg N	9.84	5.85	8.42	47.2	35.8	14.9	0.84	1.15	42.8	13.9	12	35.6	23
Ammonium N	mg/kg N	4.32	2.84	2.87	2.57	19.7	5.04	17.7	8.12	7.78	5.28	4.92	13.3	10.2
Exchangeable Ca	cmol$^+$/kg	6.72	3.59	2.60	2.76	9.14	5.18	1.72	2.17	7.95	4.75	5.06	17.83	13.19
Exchangeable Mg	cmol$^+$/kg	3.14	2.46	1.52	1.31	6.37	2.62	1.56	2.40	3.12	2.66	2.56	5.35	5.56
Exchangeable K	cmol$^+$/kg	1.01	0.33	0.32	0.23	0.62	0.84	0.15	<0.12	1.58	0.98	0.68	1.75	1.42
Exchangeable Na	cmol$^+$/kg	0.30	0.51	0.37	0.55	0.23	0.18	1.25	1.65	0.19	0.15	0.17	0.43	0.34
Exchangeable Al	cmol$^+$/kg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable H	cmol$^+$/kg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ECEC	cmol$^+$/kg	11.2	6.9	4.8	4.8	16.3	8.8	4.7	6.2	12.8	8.5	8.5	25.4	20.5
Calcium/Magnesium Ratio	-	2.1	1.5	1.7	2.1	1.4	2.0	1.1	0.9	2.6	1.8	2.0	3.3	2.4
Zinc	mg/kg	6.7	2.0	0.6	0.8	3.6	1.0	<0.5	0.7	0.9	0.6	0.6	12	6.1
Manganese	mg/kg	131	109	41	24	47	25	10	8.1	10	8.3	10	31	22
Iron	mg/kg	149	37	18	12	305	92	67	24	81	121	84	61	45
Copper	mg/kg	8.3	4.6	1.5	0.7	3.2	1.7	0.7	0.8	0.4	0.7	0.5	2.3	1.6
Exchangeable Sodium Percentage (ESP)	%	2.7	7.5	7.8	11.3	1.4	2.1	26.6	26.6	1.5	1.8	2.0	1.7	1.6

Note: D1 = 0-10cm, D2 = 10-20cm, D3 = 20-30cm

Weathered sites

Based on the preliminary investigation and survey, five different sites were identified around the island which includes the sites at Rooty hill road, Harpers road, New Cascade road, Middlegate road and Ball Bay road (Figure 1.20 – sample numbers 24-26; 32-37; 54-56; 60). The sites were physically observed and the soil samples were collected (Figures 1.24a, 1.24b, 1.24c and 1.24d).

Figure 1.24a: Rooty Hill Rd

Figure 1.24b: Middlegate Rd

Figure 1.24c: Ball Bay Rd

Figure 1.24d: New Cascade Rd

These soils are slightly acidic with a pH ranging from 5.4 to 6.2 and the nutrient values are in the lower side as evident from the phosphorus and nitrogen values (Table 1.7). The soils are affected by wind erosion and weathering due to climatic events as discussed in previous investigations (Abell and Falkland, 1991; Foster et al., 2009).

Table 1.7. Soil results for weathered sites

Sample numbers		24	25	26	32	33	34	35	36	37	54	55	56	60
		Rooty Hill Road			Harpers Road			New Cascade Rd			Middlegate Road			Ball Bay
Parameters	Units	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1	D2	D3	D1
pH	-	5.8	5.5	5.4	5.9	6.1	6.2	5.7	5.4	5.4	5.8	5.7	5.7	5.9
EC	dS/m	0.42	0.41	0.41	0.42	0.43	0.43	0.42	0.41	0.41	0.45	0.44	0.44	0.42
Organic Carbon	%	4.4	4.2	4.7	4.9	4.4	3.7	4.21	4.16	4.11	4.05	4	3.95	3.89
Nitrogen	%	0.44	0.44	0.42	0.44	0.32	0.26	0.28	0.26	0.23	0.2	0.17	0.15	0.12
Potassium	mg/kg	266	244	215	613	734	642	504	371	436	477	380	457	459
Phosphorus	mg/kg	4.4	3.1	3.5	3.2	2.6	2.8	3.0	2.1	3.0	8.9	6.1	4.1	3.7
Nitrate N	mg/kg N	3.35	2.21	1.96	11.5	9.35	30.8	13.1	1.98	2.42	0.842	1.58	0.853	1.55
Ammonium N	mg/kg N	5.67	3.74	2.95	8.41	37.7	22.4	10.4	7.33	5.12	3.62	4.41	3.03	4.34
Exchangeable Ca	cmol$^+$/kg	5.36	3.45	3.60	9.32	2.64	1.93	1.12	1.05	3.61	12.76	12.60	5.81	2.47
Exchangeable Mg	cmol$^+$/kg	3.19	1.69	2.27	6.04	2.95	2.21	1.42	1.03	2.96	2.66	2.31	1.56	3.12
Exchangeable K	cmol$^+$/kg	0.44	0.37	0.33	1.29	1.81	1.53	1.06	0.84	0.97	0.91	0.69	0.94	0.55
Exchangeable Na	cmol$^+$/kg	0.31	0.40	0.29	0.20	0.82	0.66	0.41	0.36	0.33	0.50	0.51	0.64	0.45
Exchangeable Al	cmol$^+$/kg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable H	cmol$^+$/kg	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ECEC	cmol$^+$/kg	9.3	5.9	6.5	16.8	8.2	6.3	4.0	3.3	7.9	16.8	16.1	9.0	6.6
Calcium/Magnesium Ratio	-	1.7	2.0	1.6	1.5	0.9	0.9	0.8	1.0	1.2	4.8	5.4	3.7	0.8
Zinc	mg/kg	2.2	<0.5	0.7	0.6	<0.5	<0.5	<0.5	<0.5	1.0	1.0	3.7	<0.5	<0.5
Manganese	mg/kg	2.6	0.4	0.8	6.6	0.8	1.2	0.4	0.3	2.5	3.1	1.9	0.2	<0.1
Iron	mg/kg	57	59	45	24	69	1113	20	19	15	11	5.9	5.0	1318
Copper	mg/kg	0.9	0.2	0.5	0.5	0.1	0.3	<0.1	<0.1	0.2	0.7	0.6	0.4	0.2
Exchangeable Sodium Percentage (ESP)	%	3.3	6.7	4.5	1.2	9.9	10.4	10.3	11.0	4.2	3.0	3.2	7.2	6.8

Note: D1 = 0-10cm, D2 = 10-20cm, D3 = 20-30cm

Industrial sites

These sites were selected based on the potential to be polluted due to industrial and other anthropological activities such as airport and waste management. The selected sites are around Norfolk Island Industries; airport runoff and drain areas; waste treatment site and effluent treatment area. The electrical conductivity of these soils were relatively higher indicating salinity (Table 1.8). Council has stated that most of the current septic tanks and effluent management systems would not meet current standards including buffer zones from waterways and bores, suitable terrain, soil permeability or portion size with many septic tanks on blocks under ¼ of an acre. Copper was found to be high around the effluent treatment site, which may be attributed to the above-mentioned reason. In terms of PFAS, among the selected soils, perfluorobutanoic acid (PFBA) was found in the drain sites in Taylors road. Other PFAs compounds were not detected. Results for all organic analyses are found in Appendix 1, however no trace compounds were detected at any significant level harmful to the environment or human health.

Table 1.8. Soil results for Industrial sites

Sample numbers		57	58	59	70	71	72	73	74
		NI industries			Airport			Waste Treatment	Effluent
Parameters	**Units**	**D1**	**D2**	**D3**	**Drain 1**	**Runoff**	**Drain 2**	**D1**	**D1**
pH	-	5.8	5.5	5.4	6.7	6.9	6.8	6.4	6.7
EC	dS/m	0.62	0.61	0.61	0.54	0.54	0.55	0.63	0.63
Organic Carbon	%	4.4	4.2	4.7	4.6	4.2	4.6	4.4	3.7
Nitrogen	%	0.44	0.44	0.42	0.49	0.49	0.52	0.32	0.26
Potassium	mg/kg	957	472	323	239	183	270	557	188
Phosphorus	mg/kg	13	4	2	5	2	3	10	153
Nitrate N	mg/kg N	9.45	3.01	5.95	5.47	1.22	12.3	9.8	3.88
Ammonium N	mg/kg N	9.56	6.52	6.81	4.46	3.84	5.96	10.2	4.05
Exchangeable Ca	$cmol^+/kg$	16.71	5.50	4.25	14.54	0.94	12.57	18.26	24.92
Exchangeable Mg	$cmol^+/kg$	9.62	2.87	2.29	2.41	0.34	1.37	2.51	1.33
Exchangeable K	$cmol^+/kg$	1.97	0.95	0.64	0.32	0.33	0.48	1.00	0.15
Exchangeable Na	$cmol^+/kg$	1.82	1.18	2.94	0.17	0.34	0.08	0.23	0.19
Exchangeable Al	$cmol^+/kg$	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable H	$cmol^+/kg$	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ECEC	$cmol^+/kg$	30.1	10.5	10.1	17.4	1.9	14.5	22.0	26.6
Calcium/Magnesium Ratio	-	1.7	1.9	1.9	6.0	2.7	9.2	7.3	18.8
Zinc	mg/kg	9.5	<0.5	<0.5	26	<0.5	4.3	5.1	113
Manganese	mg/kg	9.1	0.4	<0.1	3.1	0.4	7.1	3.4	3.2
Iron	mg/kg	32	177	2458	37	409	44	26	69
Copper	mg/kg	1.0	0.2	<0.1	0.4	<0.1	1.3	1.9	141
Exchangeable Sodium Percentage (ESP)	%	6.0	11.2	29.1	1.0	17.3	0.6	1.0	0.7

Note: D1 = 0-10cm, D2 = 10-20cm, D3 = 20-30cm

1.3.6 PARAMETER SUMMARY FOR PRODUCTIVE SOILS

Norfolk Island soils are predominantly of a "clay" type, with low infiltration rates but a high ability to absorb available water. Results have been categorised into different land uses on Norfolk Island, namely "Forest" sites, "Drain" sites (Headstone & Emily Bay), "Farm" sites, "Weathered" sites, and "Industrial" sites.

Forest sites include the National Park and Reserves on Norfolk Island and represent relatively undisturbed soils. Drain sites were selected due to their proximity to major drainage lines on Norfolk Island and represent sites of potential erosion and routes of contaminant export. Farm sites reflect soils that have been agriculturally worked for many decades. Weathered sites reflect areas with eroded landscapes, slope instability, and exposed B-horizons. Industrial sites represent soils in drainage lines around the airport, waste management centre and wastewater treatment plant. The results summary presented characterises these soils in context of existing land use.

Soil pH

All soils ranged between 5.1 and 7.3 (Figure 1.25). Soils on Norfolk Island would typically expect to be in the range of 6 – 8 and this is observed in the data. Lower soil pH in Forest areas may likely be due to the acidity provided by the decomposing needles of the Norfolk Pines, and/or a result of drier conditions prior to soil sampling.

Figure 1.25: Soil pH and range indicator

Source: https://www.qld.gov.au/environment/land/management/soil/soil-properties/ph-levels

Soil EC

Soil EC results show that Forest, Drain and Farm sites are all non-saline (< 0.34 dS/m) and pose no risk to plant growth (Figure 1.25). Weathered and Industrial sites can be described as slightly saline (0.34 – 0.69 dS/m) which may affect some crops at these levels. Interpretation based on tables in Hazelton & Murphy (2011).

Figure 1.25: Soil EC

Organic Carbon

Organic carbon is a measure of the organic matter in the soil (Figure 1.26). It includes un-decomposed plant litter, soil organisms and humus. Soil organic carbon stores important nutrients, stabilises soil structure and feeds soil microbes. If soil organic carbon is declining over time, then consider practices such as green manure crops, minimum tillage, mulching or strategic grazing.

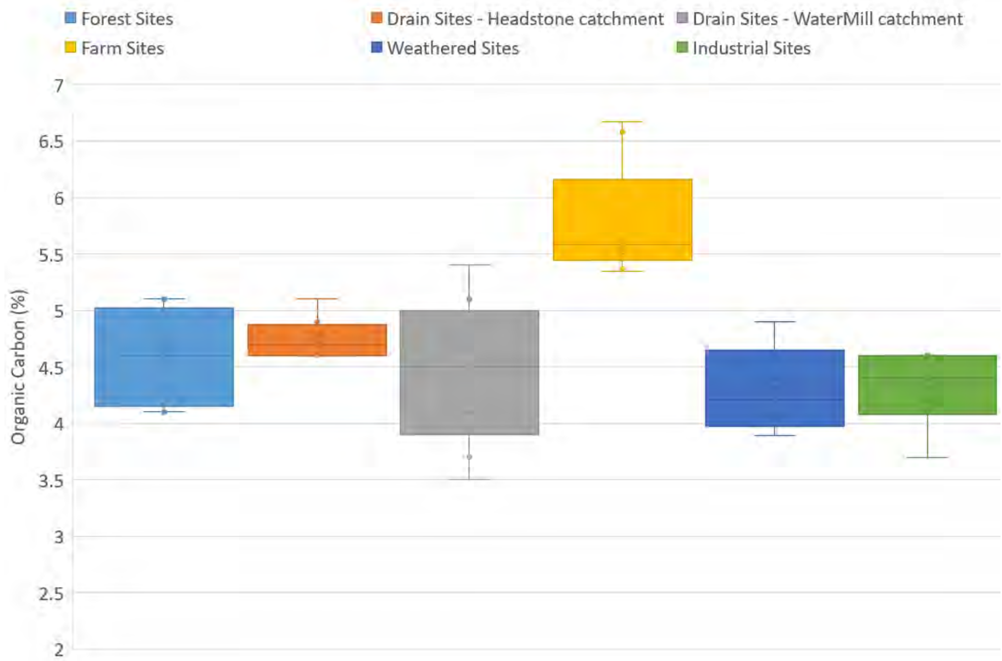


Figure 1.26: Organic Carbon

Soil ECEC

The effective exchangeable cation capacity (ECEC) is a measure of the ability of the soil to hold the nutrients, calcium, magnesium and potassium (Figure 1.27). Good fertile soils with high clay content and moderate to high organic matter levels typically have an ECEC of 10 or higher. Norfolk Island soils can be described as productive and fertile.

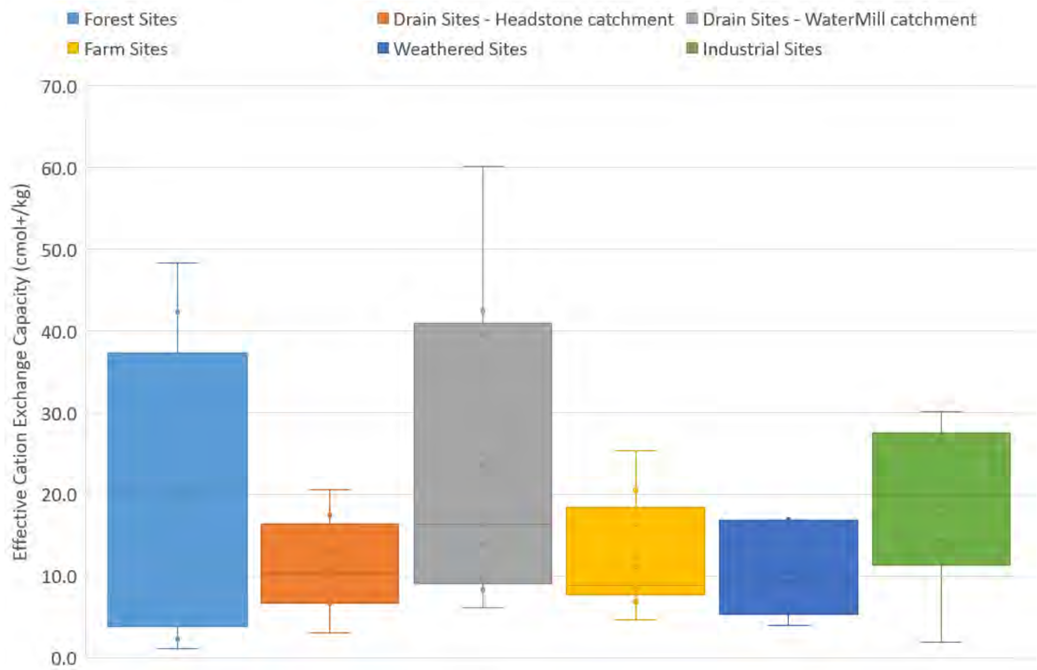


Figure 1.27: Soil ECEC

Soil Nitrogen (%)

Total nitrogen can be described as high to very high (0.25 to > 0.5%, in Figure 1.28) for Forest, Drain and Farm soils; and medium to high for Weathered and Industrial sites. Most nitrogen is bound in organic form and is not available to plants until mineralised to nitrate, but total nitrogen gives some idea of the nitrogen soil store.

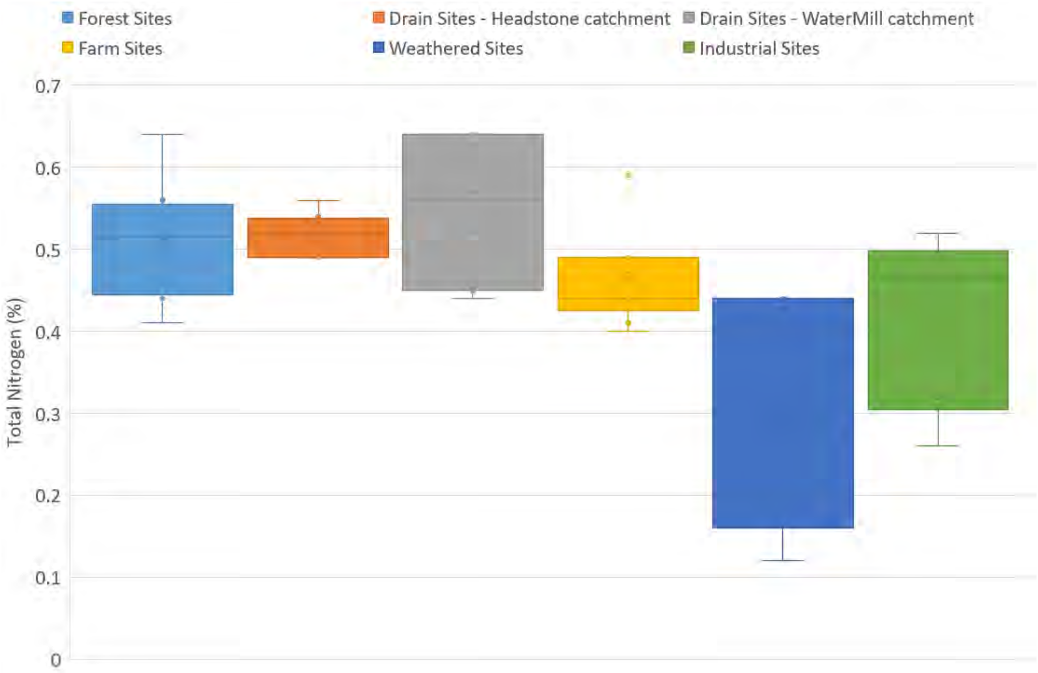


Figure 1.28: Soil Nitrogen

Soil Phosphorous (total)

A significant amount of P is stored in the Forest sites with Farm sites also having higher P store than other sites (Figure 1.29). As expected, Weathered sites are very low in any nutrient, however further evaluation for soil P data is required to interpret any additional fertiliser requirements for a given area/crop.

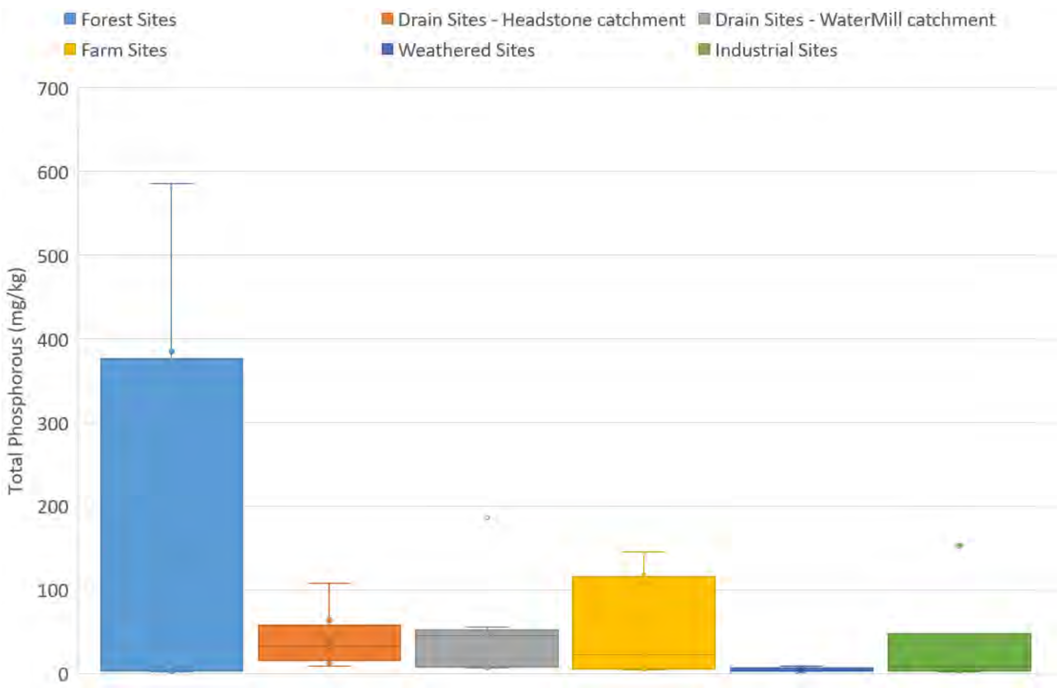


Figure 1.29: Soil Phosphorous

Soil Exchangeable Sodium Percentage (ESP)
Under certain conditions, the presence of excessive amounts of exchangeable sodium can reverse the process of aggregation and causes soil aggregates to disperse into their constituent individual soil particles. The main issue from excessive sodium is soil instability, leading to increased erosion and sediment export during rain events; and this will be described in the next section.

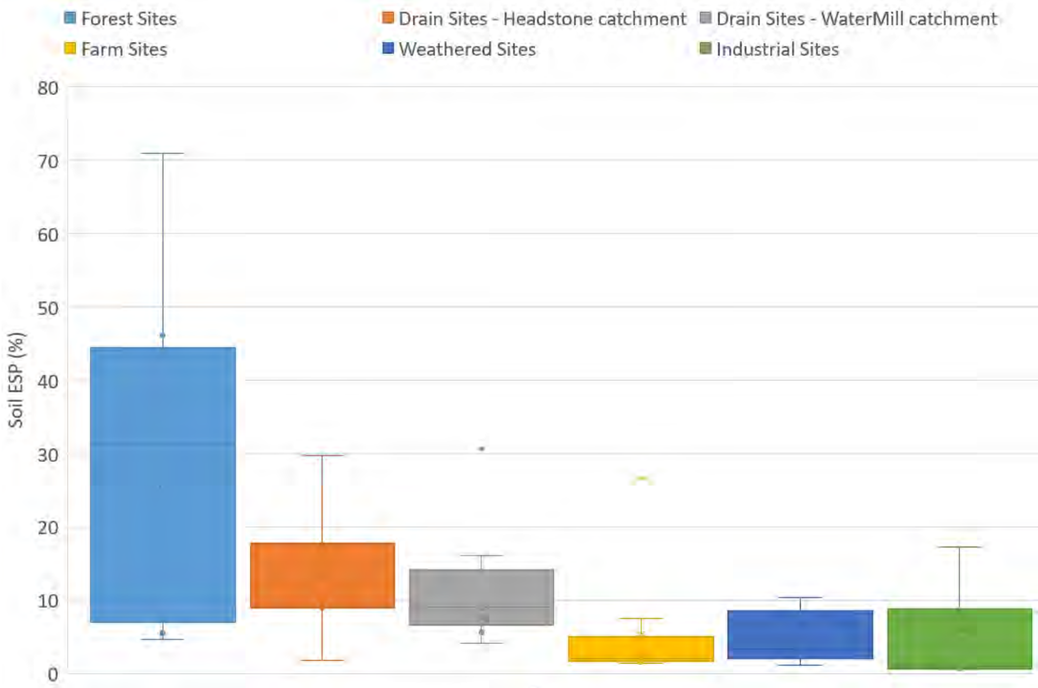


Figure 1.30: Soil ESP

1.3.7 SOIL ESP, PERMEABILITY AND SOIL DISPERSION
Exchangeable sodium is widely determined by soil extraction techniques as outlined in the *Australian Laboratory Handbook of Soil and Water Chemical Methods* (Rayment and Higginson, 1992). The soil exchangeable sodium percentage (ESP) (Equation 1) represents the ratio of exchangeable Na^+ cations to the Cation Exchange Capacity (CEC - the sum of exchangeable Ca^{2+}, Mg^{2+}, Na^+, K^+, Al^{3+} and H^+ in cmol(+)/kg):

$$ESP\% = \frac{[Na^+]}{(CEC)} \times 100 \qquad \text{(Equation 1)}$$

The sodium adsorption ratio (SAR) is a solution equivalent to the ESP using the relative molar proportions of Na^+, Ca^{2+}, and Mg^{2+} (measured in meq/L) in the irrigation waters to be applied (Equation 2):

$$SAR = \frac{[Na^+]}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \qquad \text{(Equation 2)}$$

Because of its high solubility in soil solution, potassium (K^+) is usually neglected as it rarely occupies exchange sites (McBride, 1994). The ESP and SAR are related to the process of cation exchange (Rengasamy and Olsson, 1991; So and Aylmore, 1993; Sumner, 1993). The SAR also describes the probability of Na^+ attaining an exchange site in the receiving soils of a given ESP. The ESP value can be expressed as an SAR equivalent by a number of relationships. These include the equations proposed by (Richards, 1954):

$$ESP = [100(0.0126 + 0.01475 \times SAR)] \div [(1 + (-0.0126 + 0.01475 \times SAR)] \qquad \text{(Equation 3)}$$

and by McBride (1994):

$$\frac{ESP\ \%}{100 - ESP\ \%} = 0.015 \times SAR$$

(Equation 4)

Although there are a number of ESP/SAR relationships available, it has been shown that ESP and SAR values between 0 and 32 are approximately equal (Quirk, 2001). Quirk and Schofield established the qualitative relationship between soil ESP and electrolyte concentration with respect to permeability (cited in Quirk, 2001). They showed that laboratory permeability was a function of the relative proportion of exchangeable sodium or of a related solution parameter, the SAR. In their study, Sawyers 1 soil was subjected to electrolyte solutions (both NaCl and $CaCl_2$) with a range of SAR values.

For each SAR value, the soil was brought to equilibrium in a solution that was sufficiently concentrated to sustain a constant permeability. Electrolyte concentration was then reduced in a step-wise fashion while maintaining a constant SAR value. When permeability decreased by 15 %, Quirk and Schofield (1955) deemed this the C_{TH}, for each SAR value.

Further reductions in the electrolyte concentration of the percolating solution resulted in the appearance of dispersed clay particles (Table 4 in Quirk and Schofield, 1955) and this was designated the C_{TU}. Note that the SAR values used in Equations 5 and 6 are converted ESP values from measured soil analyses and are not the actual electrolyte concentrations of the applied water. The C_{TH}, with respect to SAR values in the range of 0 - 32, is given by Equation 6 (Quirk, 1971):

(C_{TH}) = 0.56 x SAR + 0.6 (SAR 0 - 32) (Equation 5)

The C_{TU}, with respect to SAR values in the range of 0 - 32, is given in Equation 2 (Quirk, 1984):

(C_{TU}) = 0.16 x SAR + 0.2 (SAR 0 - 32) (Equation 6)

Reeve (1958) re-plotted some of Quirk and Schofield's (1955) results, which are provided in a modified form (from Quirk, 2001) in Figure 10. This shows that a series of curves for the same soil can be obtained using permeants of differing electrolyte concentrations. It is important to note that as ESP increases, the electrolyte concentration of the applied solution must also increase to maintain optimum permeability. This may have possible implications for irrigation practices and soil structure/permeability/stability on Norfolk Island.

For example, Davidson and Quirk (1961) demonstrated the impact of changing the electrolyte concentration of irrigation waters, using Riverina clay (60% clay, pH=7.4, ESP=23) near Deniliquin, NSW (similar to Norfolk Island clay soils). The soil was irrigated with waters that had an electrolyte concentration slightly higher than the C_{TH} (point A in Figure 1.31) and later with Murrumbidgee River water, which was approximately half the C_{TU} (point B in Figure 1.31). In the first case, the 7.5 cm of water applied was observed to have permeated completely into the soil after 16 hours (Quirk, 2001). In contrast, large volumes of the Murrumbidgee water remained pooled on the surface after a similar time period.

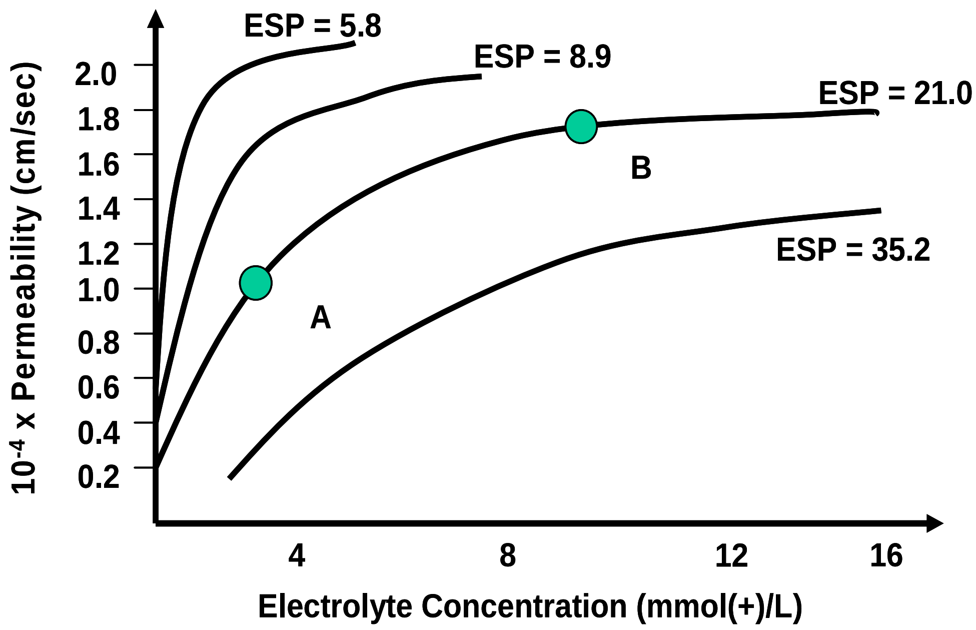


Figure 1.31: Permeability as a function of electrolyte concentration and ESP (after Davidson and Quirk (1961), modified from Quirk, 2001).

Quirk (2001) states that when the irrigation water electrolyte concentration exceeds the C_{TH}, the soil appears granular and dries to a friable state (flocculated). Conversely, when irrigation water electrolyte concentration is less than the C_{TU}, the surface soil appears white (dispersed clay particles) and water remains pooled on the surface for extended periods (Quirk, 2001).

The magnitudes of the C_{TH} and the C_{TU} used in previous studies have been determined for a range of soil textural classes. The C_{TH} and the C_{TU} determined for a non-arid loam (Quirk and Schofield, 1955) are equally applicable to the arid heavy clay used in the study by Davidson and Quirk ((1959) cited in Quirk (2001)). Also, Rengasamy et al., (1984) characterized spontaneous dispersion by defining an empirical linear function relating SAR (as SAR_p) to the electrical conductivity (EC) required for flocculation. The SAR_p is a result of analysing a 1:5 extract (in distilled water) after 1 hour of shaking, then using Equation 2 (Davidson and Quirk, 1961), as opposed to other extraction solutions found in Rayment and Lyons (2011).

Rengasamy et al., (1984) studied a wide range of Australian red-brown earths and obtained an equation, almost identical to Equation 6, to describe the electrolyte concentration at which spontaneous dispersion occurs. They also observed surface turbidity after rainfall (electrolyte concentration $< C_{TU}$), even though the soil was protected by pasture.

Therefore, the C_{TH} and the C_{TU} are significant and are useful in defining dispersion, hence micro-aggregate stability/soil pore structure and relative permeability, over a large range of soil types. Many guidelines based on the C_{TH} concept have been suggested to avoid the adverse effects on water transport in sodic soils (Quirk, 1971; Cass and Sumner, 1982; Rhoades, 1982; Jayawardane, 1992; Jayawardane et al., 2001). However, the C_{TH} concept is not a unique function of SAR and electrical conductivity (EC), but varies with soil type and other factors (Sumner, 1993; Balks et al., 1998). One factor that influences C_{TH} and C_{TU} is the percentage of charged soil particles (clay minerals) present in the soil profile.

Based on the work of Shaw et al (1994), soils containing 40 –50 % clay and mixed mineralogies with limited shrink-swell ability, form the most dense soil matrix and have reduced infiltration and plant available water capacity. Soils of this type appear to be the most difficult to manage and are typical of clay soils on Norfolk Island (% clay up to 65%). As a result, soil behaviour rather than specified ESP level is a better estimate of sodicity effects (Shaw et al., 1994); and soil response to irrigation waters will thus depend on the temporal and spatial presence of solutes.

Mechanisms for cation exchange and displacement will occur within interstitial pore spaces and on the internal/external surfaces of clay minerals. As a result, micro-aggregate/soil pore stability is continually being altered and will impact upon soil permeability over time, particularly when sodium rich waters are consistently applied. The equilibrium of specific cations in the soil solution with a clay surface will be a function of pH, presence of organic matter, and the cations present. Therefore, at one extreme there is a soil profile shown in Figure 1.32, which has a low pH (<< 4.5) and has been leached of accompanying cations.

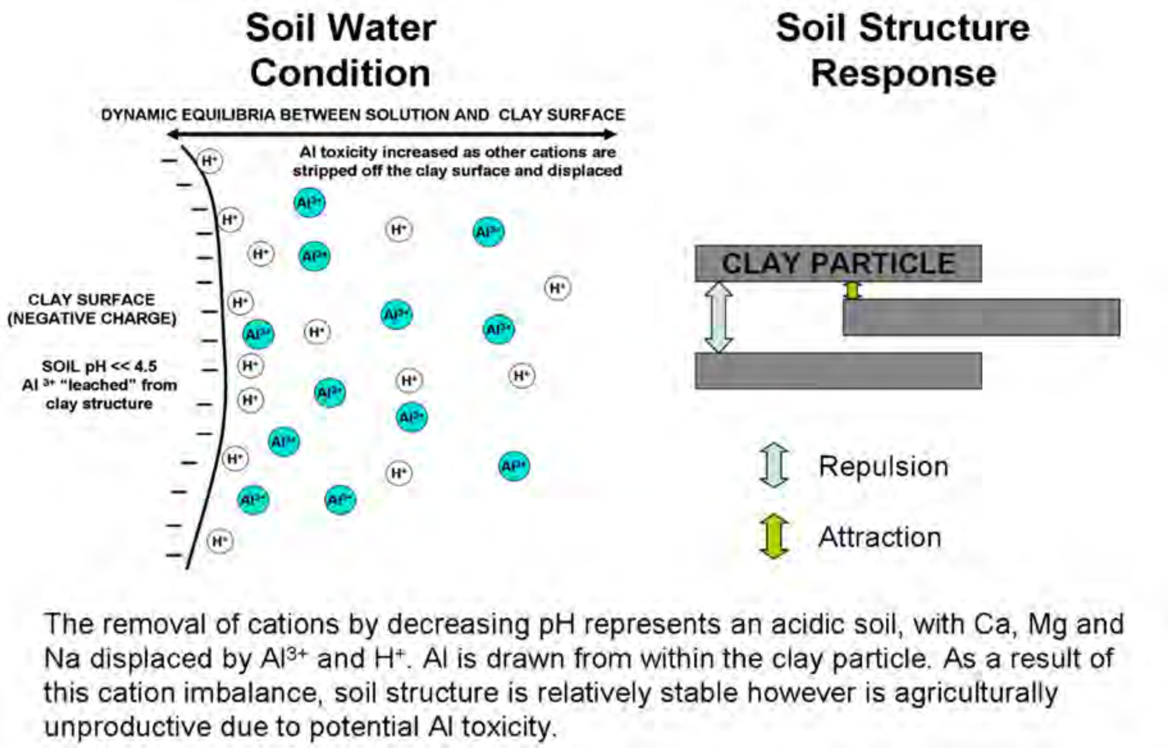
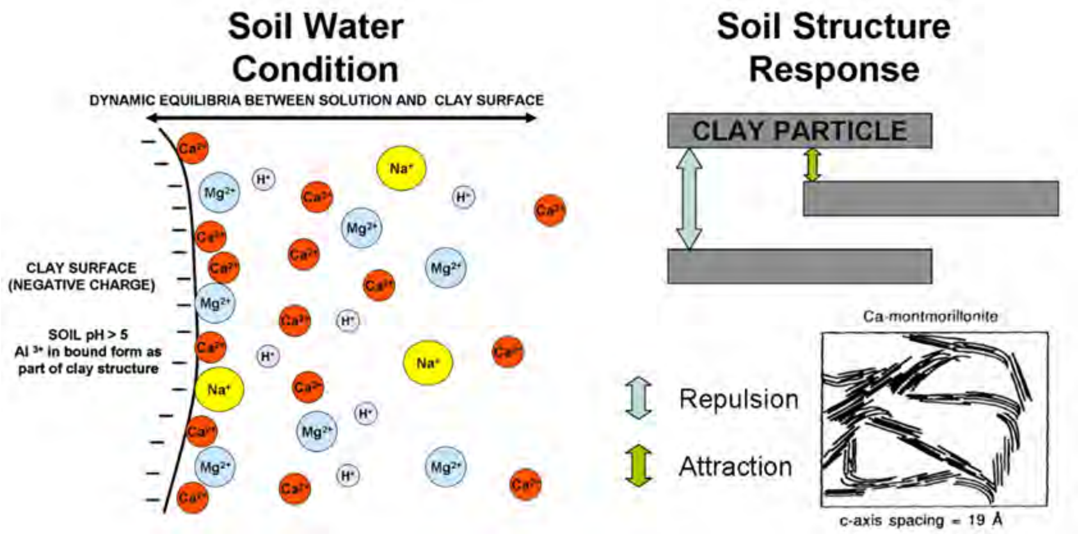


Figure 1.32: A highly acidic soil with leached cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and associated clay particle response

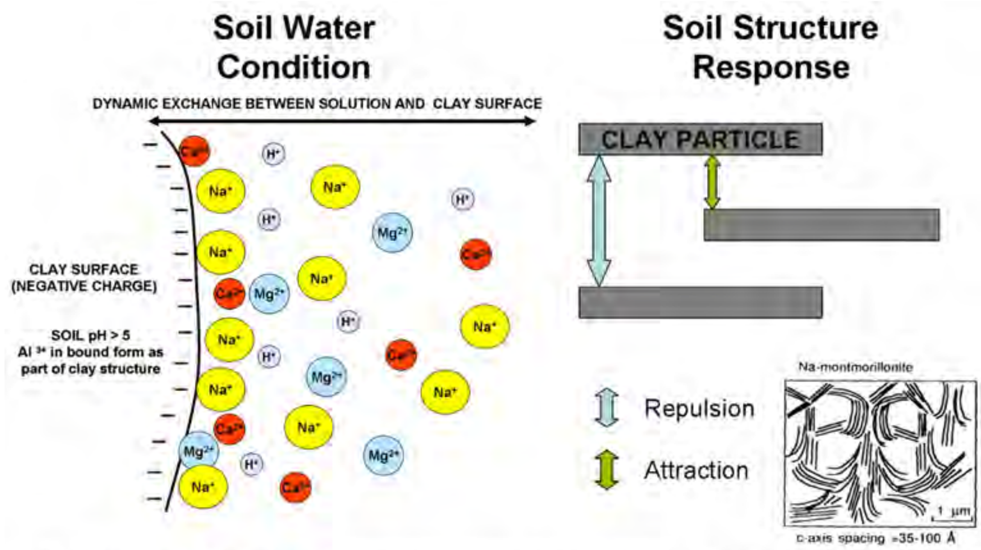
When monovalent and divalent cations occupy clay surfaces, the soil profile may be favourable for plant production. As a result, micro-aggregate/soil pore stability is again altered based on Diffuse Double Layer (DDL) theory however remains stable due to the increased relative presence of Ca^{2+} over Mg^{2+} and Na^{+} (Figure 1.33).



The balance of cations represent a productive soil, with Ca being dominant and Mg and Na in progressively lower concentrations respectively. Al is bound within the clay matrix and will only be released with a major decrease in soil pH (< 4.5). Ca, Mg and Na are constantly competing for soil exchange sites and at soil pH values > 5, these can be conceptualised as the dominant cations potentially involved in altering soil pore structure and optimum permeability. As a result of this cation balance, soil structure is stable and defines optimum transmission of water through the soil profile.

Figure 1.33: An agriculturally "productive" soil with a balance of cations and associated soil response

When sodium accumulates and displaces Ca^{2+} and Mg^{2+}, further alteration to micro-aggregate/soil pore occurs, resulting in a further decrease from optimum permeability. This is predominantly due to the decrease in diameter of soil pores as clay particles expand and reduce effective transmission of water downward through the soil profile (Figure 1.34).



The imbalance of cations shown represents a sodic soil, with Na being dominant and Ca and Mg in significantly lower concentrations. Optimum micro-aggregate/soil pore stability (as with a Ca-dominated clay structure) is reduced because of the change in cationic charge. As a result of excess sodium, soil structure is altered and the transmission of water through the soil profile can be substantially decreased.

Figure 1.34: A sodium-dominated soil profile and subsequent response of clay particles

So what does this mean for clay soils on Norfolk Island? Based on Figure 1.31, and due to the potentially dispersive nature of clay soils on Norfolk Island, there are some potential soil management and land use issues. Figure 1.35 shows soil EC versus soil ESP overlayed with Emerson Aggregate Test (EAT) stability classes. A definition of these classes is also provided. While EAT classes range from 1 – 8, there were no soil samples that were > Class 3a.

Figure 1.35: Emerson Aggregate stability classes and the relationship to soil EC and soil ESP

All soil's had an EC of < 0.64 dS/m however there was a wide range of soil ESP (up to 71%). EAT results of Class 1, Class 2a, and Class 2b indicate potentially dispersive soils (most sites); and several soils were Class 3a (relatively higher EC but low ESP).

"Forest" soils had the largest range of soil ESP (~5 - ~70%) and soil EC was < 0.2 dS/m. EAT Classes 1, 2a, and 2b suggests dispersive soils however these sites are heavily forest, have a lower pH which buffers against dispersion, have a relatively high organic carbon content (4 – 5%) that also buffers against dispersion, and typically have a light to heavy understory and groundcover that protects the soil from raindrop impact. History has shown that removal of forested areas accelerates soil erosion and slope instability as described in Abell & Falkland (1991) so preserving existing "Forest" areas is recommended.

Soil EC and soil ESP for "Drain" site soils (Headstone & Emily Bay) and "Farm" soils ranged from 0.21 – 0.32 dS/m, and 2 – 31% respectively. EAT Classes 1, 2a, and 2b suggests dispersive soils, and since most of these sites have been (to various extents) cleared of forest, there is visual evidence of soil erosion in the past. This is particularly the case for Headstone catchment which is currently having major water quality issues (relating to acidity). Farm sites typically had a groundcover of pasture with scattered trees. There is little doubt that the presence of cattle (in specific areas in some catchments) also exacerbates soil erosion and existing water quality issues.

Soil EC at "Weathered" sites was relatively higher than Forest, Drain, and Farm sites because the A-horizon of these soil profiles has been eroded, taking with it any organic matter, clay and other component that makes a productive soil. These are effectively exposed B-horizons which typically have a higher EC (a "sink" for leached cations from A-horizon in the past). Soil ESP is relatively low for similar reasons, that is, leaching of sodium from the profile (sodium more soluble than Ca or Mg), resulting in a higher % composition of Ca and Mg.

Soil EC at "Industrial" sites was relatively higher than all other sites. This is likely due to the sites sampled having reworked, soil moved around and compacted in the past, and/or cleared of vegetation for extended periods. Soil ESP is relatively low for similar reasons, that is, leaching of sodium from the profile (sodium more soluble than Ca or Mg), resulting in a higher % composition of Ca and Mg.

Note that while the soils on Norfolk Island can be shown to be inherently dispersive, their stability is solely reliant on land use and vegetation cover and the slope of the land where vegetation exists. Primary management options for Norfolk Island soils in improving soil stability should include:

- Maintaining constant ground cover in all areas;
- Improving cattle management such as temporarily fencing off sensitive areas;
- Management/removal of woody weeds.

Catchment Condition and Disturbance Classes are discussed in Chapter 3, as these connect catchment disturbance to reduced land cover and probability of occupancy of species.

1.3.8 GAPS IN IMPLEMENTATION AND FUTURE DIRECTIONS

Current management of the Island's soils and land use seems to be limited. In the past, the Norfolk Island Administration (or its historical equivalent) has commissioned various reports, the aims of which were to provide advice and direction regarding land degradation and conservation strategies.

Stephens and Hutton (1954) provided a number of recommendations including the appointment of an agricultural officer, fertiliser trials and the clearing of weeds. Clive Lucas, Stapleton and Partners Pty Ltd (1988) in their KAVHA Conservation Management Plan recommended a soil study to assess erosion, nutrients and restoration techniques; development of a soil conservation policy with appropriate long term planning; and protection of the most fertile areas by limiting subdivision.

Clifton (1993) also proposed a management plan for KAVHA, which included planting of Kikuyu, judicious planting of trees, and better control of over grazing. Kikuyu is now considered a noxious weed and is not recommended for use as a land use management tool. Watkins Consulting Ltd (1999) recommended studies be completed with regard to catchment management/land use, drainage and slope stability, in relation to climate change impacts.

A report prepared for the Norfolk Island Conservation Society by Mosley (2001) recommended a soil and land use study; development of policies and long term plans to manage soil care, land degradation and rehabilitation; the appointment of supervisory staff; and ongoing monitoring. It is apparent that the recommendations provided in each of these reports echo similar sentiments, and it is therefore suspected that the majority of the actions recommended have not been undertaken or acted upon. Previous environmental assessments have been matched with observations of the Island's soils, where soil erosion, sedimentation and slope instability were observed on a regular basis.

1.4 NORFOLK ISLAND ECOSYSTEMS, BIODIVERSITY AND THE REQUIREMENTS FOR ECOLOGICAL SUSTAINABILITY

1.4.1 INTRODUCTION

The ecological investigations were undertaken based on reflectance of various land and vegetation types from satellite imagery. Drone surveys were also undertaken to demonstrate an innovative approach to assessing land and vegetation types. There are 182 native plant species (of which about 25 per cent are endemic) and a further 370 naturalised species on the Norfolk Island Group (Mills, 2009). 2,192ha of Norfolk Island (total of 3,460ha) classed as moderate to very poor vegetation condition (Class 1 to 3). Higher classes of vegetation condition (less disturbed, Classes 4 to 6) mostly comprise reserve areas and coastal areas with hardwood forests, and the National Park with some small pockets in the east. This area of 633ha of vegetation provides the most significant area of habitat on Norfolk Island.

1.4.2 METHODS & TECHNIQUES

To estimate the ecological condition and risks to the Island we incorporated several techniques. Firstly, using high resolution satellite imagery (4-band panchromatic at 20 cm) we undertook classification and modelling methods to determine the dissimilarities within spectral reflectance that could be used to develop a series of vector files that gave a good representation of the community conditions. Plant Community Type analysis was not within the available budget, so a focus on condition and disturbance were used as proxies for habitat and risk. An innovative and higher resolution approach using a drone survey technique was also employed.

Healthy vegetation is a very good absorber of electromagnetic energy in the visible region. Chlorophyll strongly absorbs light at wavelengths around 0.45 µm (blue) and 0.67 µm (red) and reflects strongly in green light. Healthy plants have a high reflectance in the near-infrared between 0.7 µm and 1.3 µm. This is primarily due to healthy internal structure of plant leaves. Since this internal structure varies amongst different plant species, the near infrared wavelengths can be used to discriminate between different plant species.

Grass has maximum reflectance around 0.8 µm to 1.3 µm up to ~ 55% absorption, by comparison soil peaks at around 1.5 µm - 1.8 µm. Conifers have similar values to grass, and that's why in our analysis there are some correlations with grass and pines. Manmade structures such as buildings and roads, peak around 2.0 µm, but have a much high absorption at 60 %. Bare soil generally has an increasing reflectance, with greater reflectance in near-infrared and shortwave infrared. Some of the factors affecting soil reflectance are: Moisture content

- Soil texture (proportion of sand, silt, and clay)
- Surface roughness
- Presence of iron oxide
- Organic matter content

Three key methods were incorporated to estimate condition and habitat from satellite imagery. Histogram stretches and classification techniques were used to identify areas of manmade and enhanced areas, such as soil adjusted vegetation index, as seen in Figure 1.36 provides good clarity on soils, dirt and erodible areas (the bright red are manmade structures and the mottled red is exposed earth and poor condition lawns with exposed soils. Principal Component Analysis (PCA) is a procedure for reducing the dimensionality of the variable space by representing it with a few orthogonal (uncorrelated) variables that capture most of its variability.

Reducing the dimensions of the feature space is called dimensionality reduction. This results in a dimensionality reduction, thus reducing complexity in a dataset, making it hard to distinguish between the important ones that are relevant to the output and the redundant or not-so important ones.

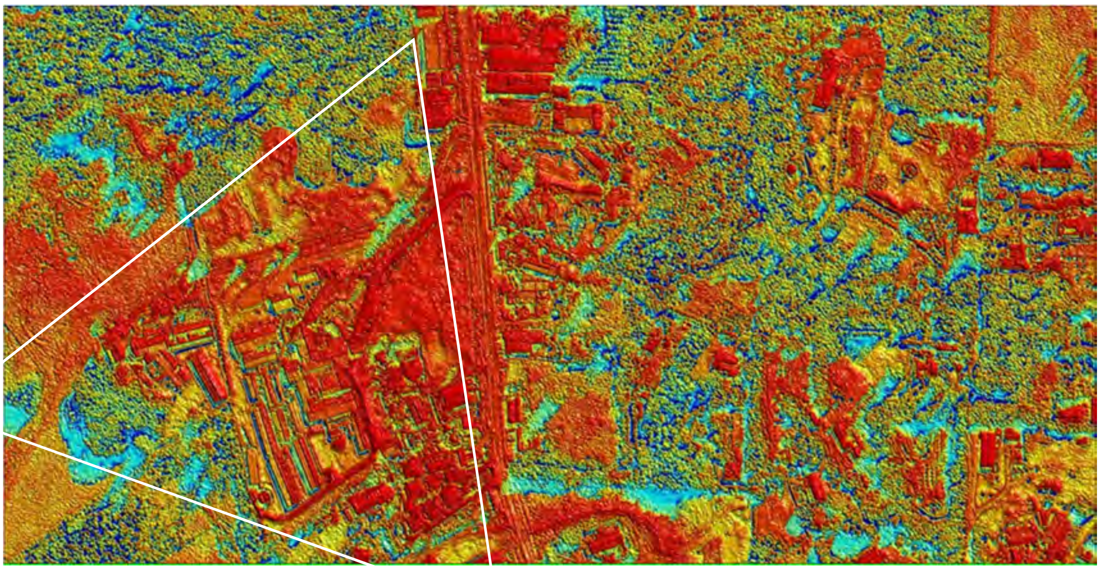


Figure 1.36: Soil adjusted vegetation index image

Figure 1.37 shows the same area as Figure 1.36 following a PCA and stretch procedure. The area within the large triangle now has improved resolution around grass, exposed soils, and native vegetation: Light pink to red - to green respectively. This procedure was useful for separating non-native, native and weed infested creeks.

Figure 1.37: Figure 1 after PCA and stretch procedure

Support Vector Machines (SVM's) are machine learning algorithms that undertake classifications based on set criteria to fit each pixel to this set. This process was effective for distinguishing Norfolk Island Pine from other tree species (rich gold colour) and high chlorophyll evergreen species from lower-level or lower condition areas (Bright yellow gold areas. i.e. Mission Rd vegetation). Refer to Figure 1.38.

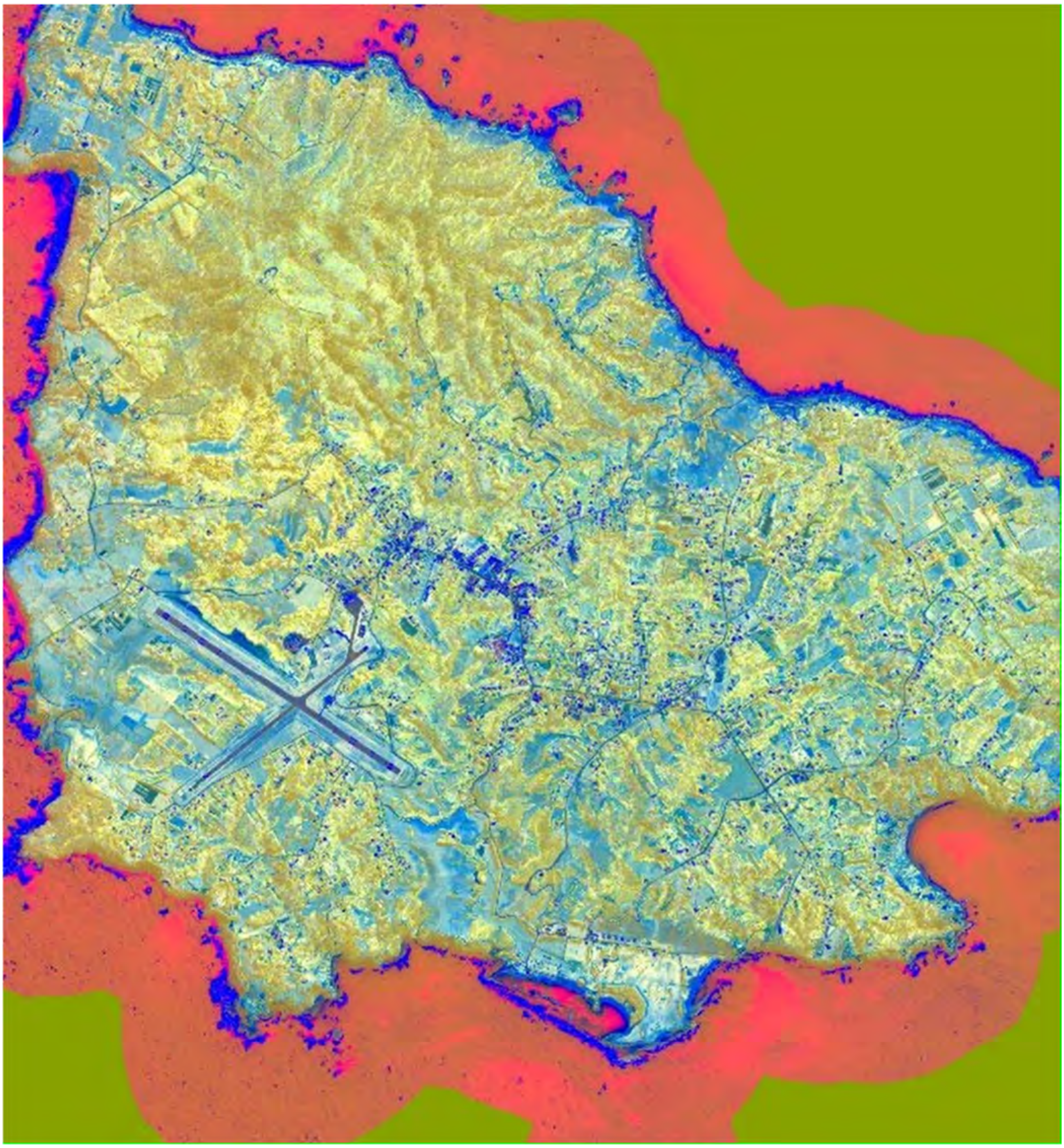


Figure 1.38: SVM classification image for Norfolk Island

In addition to the satellite imagery/interpretation, a Mavic Phantom 4 Pro drone was utilised to survey various parts of Norfolk Island. Resolution was improved from 20 cm (satellite imagery) to approximately 2.3 cm/pixel, and coupled with normalised distribution vegetation index (NDVI, using red/green/near-infrared filters) and elevation data, outputs from drone surveys can be useful soil and land management tools. The case study used in this report is focused on the Headstone catchment and is presented in section 3.5

1.4.3 CLASSIFICATION

1.4.3.1 VEGETATION CONDITION CLASSES

Vegetation community condition is described by applying vegetation condition classes to spectral reflectance classes modelled from satellite imagery (scanned in August 2019). Using a combination of Principal Component Analysis classification and Support Vector Machines (SVM) to separate highly disturbed areas from natural vegetation cover, and Maximum Likelihood Modelling for closely aligned native classes.

To validate the classification outputs, a total of 130 rapid data collection points were randomly surveyed across the Island. At each location data was collected on vegetation structures, weeds, stratums, disturbance types (i.e. grazing, mowing), die- back and erosion. Condition classes for all land areas were vectorised and analysed using GIS. The vegetation units identified during this process were assigned classes based on the characteristics shown in Table 1.9.

Table 1.9: Vegetation Condition

Class number	Class Name	Description
6	**Very Good**	Near natural condition with few weeds. Canopy in good health, little evidence of edge effects. Nearly full range of expected component plants.
5	**Good**	Vegetation in good condition but with some weeds evident and degradation processes evident. Almost full range of expected component species.
4	**Moderate**	Vegetation in reasonable condition with weeds common, evidence of degradation processes common. Some canopy dieback maybe evident. About 40-70% of expected
3	**Poor**	Vegetation in poor condition with weeds common, and evidence of degradation processes common. Canopy dieback of mature trees is often evident. About 20-50% of expected
2	**Very Poor**	Vegetation in a very poor condition with weeds abundant, and evidence of degradation processes widespread. Canopy dieback of mature trees is often common. About
1	**Non- Existent**	Little natural vegetation remains. Few scattered trees and understorey plants remain. Mostly highly disturbed and 75-95% of component species missing.

1.4.3.2 ESTIMATION OF CONDITION CLASSES

Land areas that have low level endemic plant diversity and cover, and areas dominated by weeds at one or more stratums, or there is evidence of activities that lead to land degradation, are all classified as disturbed lands. In some cases, these disturbed areas are devoid of native vegetation (Class 1), or are similar in terms of weed and disturbance yet have a small number of native species present (Class 2), or have one or more native stratums, but are impacted by historical and ongoing disturbances (Class 3).

Modelling shows that these 3 disturbance classes cover 2192 ha of land area on Norfolk Island (Figure 1), or approximately 64% of land area (excluding major roads and shorelines). The worst condition class (class 1) includes open grass areas that are degraded with evidence of sheet and gully erosion. Impacts from trampling, grazing, farming and vegetation management have a strong correlation with this class.

In total, there is 1039ha of this poor-quality habitat on the island (30% of land cover). Figure 3 shows that the distribution of this class is largely related to rural and urban landscapes where there is higher levels of exposed soils and lower chlorophyll reflectance vegetation. Class two also highly correlated with manmade areas and is separated by increased chlorophyll and reduced soil exposure that is related to improvements such as fertilizing and watering. Compared to Class 1 this is a relatively small area (45.5ha) and could, in terms of habitat value, be included with Class 1 but is separated because of its reflectance values.

These first two classes are of limited habitat value and are considered high-risk to catchments and the health of creek lines. They impact on overall Island sustainability outcomes and endemic species diversity. The last disturbed class (Class 3) does provide habitat for endemic species and with care and effort could be improved. Class two has elements of a natural landscape, however, there are elements that impact on its value for restoration.

In total, 1107ha of condition class three is found on the Island, mostly within creek lines and on coastal plains where large lot holdings are located. I.e. Bumboras and Blackmore. This class was difficult to separate from higher quality vegetation on slopes because of shading. The SVM was very good at separating pine areas out, but less successful with native mixed wood forests and rainforests. This will require further work to improve. However, visual inspection was used to build the prior probability estimations for the occupancy of threatened birds. As an example, the following images show the difference in density of rainforest and mixed species trees between low lying valleys in urban areas (Figure 1.39) and upland valley in NP (Figure 1.40). The greater open areas and weeds (more red, brown and less dark green, that is less water) are more obvious in Figure 1.39.

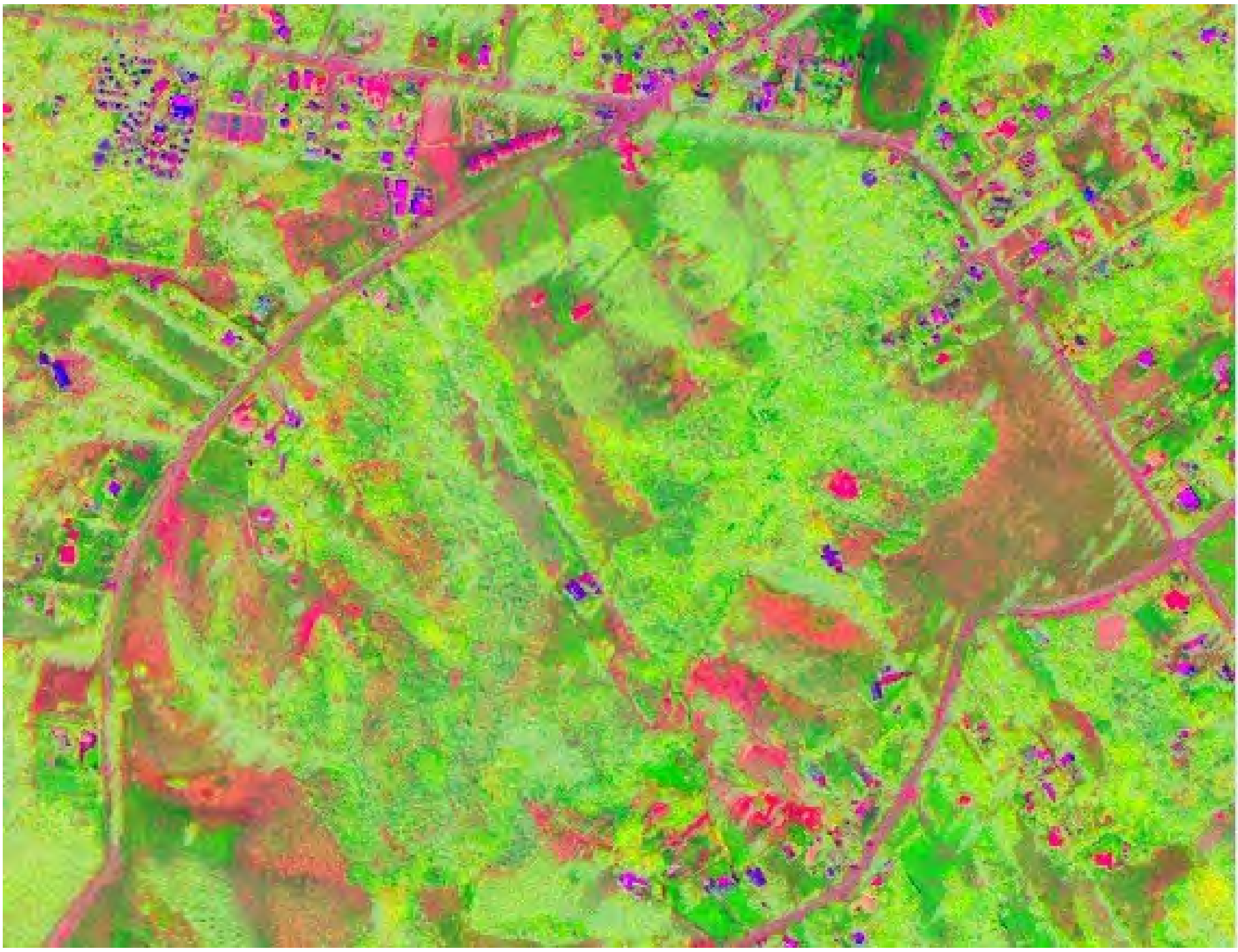


Figure 1.39: Example of extract from SVM separating evergreen trees from grass and shadows, image areas is central east lower elevation valley

Condition Class four includes areas of the Island where native vegetation is dominant, and the structure includes more than two strata levels (area= 336ha). However, when compared to the highest condition recorded onsite there is less cover of endemic vegetation, less stratums and or evidence of increased weeds. Areas dominated by Pine forests or with large emergent Pine overstorys, were more easily separated from this class than coastal lowland rainforest and mixed woodland areas, such as those found in steels point. This condition class requires further work to refine. Refer to Figure 1.36.

The highest quality vegetation recorded on the Island is found largely within the NP and adjoining areas, such as the Botanical Garden. Overall, this class totals 633.ha, and approximately 80% of this class is a single continuous patch.

Figure 1.40: Example of extract from SVM separating evergreen trees from grass and shadows, image areas is from NP central valley slope

1.4.3.3 ESTIMATION OF DISTURBANCE CLASSES

Large-scale clearing occurred during the penal settlement (1788 to 1855), when there were over 1000 convicts on the island at any one time. The Australian Heritage Database reports that about one-third of the island was cleared during the first settlement period (Petheram et al, 2020). It was during this period that the area of cultivated land (rainfed) on the island peaked (481 ha) as the convicts and settlers had to feed themselves from their own manual efforts (Petheram et al, 2020). During the second settlement further clearing occurred as the native pine was extensively harvested for house and ship building, while other areas such as the rising slopes north of the settlement were also cleared to provide unimpeded views of the convict activity (Petheram et al, 2020).

During the Pitcairn Islander's settlement period to World War II, the area of land cleared increased. When the 195 Pitcairn Islanders were resettled on Norfolk Island in 1856 the head of each family was given a 50-acre block (Petheram et al, 2020). The peak period of clearing is unclear but reports indicate that between 1856 and 1960 approximately three-quarters of the island was cleared (Petheram et al, 2020).

In fact, it is likely that over the multi-staged settlement of Norfolk Island, areas of land would have undergone cycles of clearing, regrowth and re-clearing, making it difficult to definitively estimate relative proportions of shallow-rooted and deep-rooted vegetation from historical accounts (Petheram et al, 2020).

Historical and ongoing activities contribute to processes that disturb vegetation and impact on habitat for endemic species. To determine what processes are impacted on the modelled condition classes in the previous sections, 130 rapid data points were established to in part record data on the following:

- Evidence of cattle grazing past and present (waste, tracks, animals).
- Clearing, stumps, fallen timber, absence of native trees.

- Evidence of Fire (burnt trees).
- Evidence of direct human management (slashing, thinning, mowing, spraying)

This data was used to formulate three disturbance classes which were combined with the vegetation conditions classes to generate a Total Disturbance Index (TDI). TDI-1 includes almost all vegetation within urban areas of the Island except for some creek lines and areas in the north east of the Island. In total, there are 1014.ha of TDI-1 on the Island, of which only the higher division (Yellow polygons on Figure 1.41) have the potential for improvement.

TDI-2 includes all areas that have spectral reflectance values that fail to match vegetation classes 1 or 3. This anomaly requires investigation and correction in future works. It is likely that these areas are a combination of maintenance and enhancement that balance the differences between disturbance and improvement.

The process produced better outcome for the areas within TDI-3. These areas are characterised by historical disturbances that have modified native vegetation communities, but original elements remain and could be improved with committed restoration (Yellow areas). That is evidenced at Selwyn Reserve where restoration is benefiting native biota. In total, 531ha of this class is found on the Island (refer to Figure 4).

The final two classes correlate with the higher classes of condition (See Figure 4). Class 4 is mostly made up of reserve areas and coastal areas with hardwood forests. Class 5 is mostly the NP with some small pockets in the east. In all this area of 633ha of vegetation provides the most significant area of habitat on Norfolk.

1.4.3.4 CREEK LINE DISTURBANCE AND RISKS

A linear correlation function comparing catchment wide condition and slope, starting at the headwaters of each catchment and moving stepwise downstream was undertaken to identify catchments and creeks at risk to erosion.

1.4.4 VASCULAR PLANT TAXA

Focusing on indigenous or naturalised vascular plant taxa, Norfolk Island has 556 vascular plants, 181 of which are indigenous (including 57 endemics, 27.5%) and 375 naturalised (76.7% of the total).

In total there are 52 exotic "weed" species on Norfolk. Whilst not all are serious weeds, their contribution to reducing habitat for native biota cannot be underestimated. Based on the suitability of habitats for these colonised weeds on the Island and their broad niches and competitive nature, effective quarantine, detailed mapping and Island wide monitoring is required to limit and control their spread in the future. For example, of the 52 species recorded, 24 have the ability to occupy up to six different habitats. Refer to Table 2.

Approximately 80% of the endemic flora species are threatened under the provisions of the EPBC Act, and one the Norfolk Island Pine is also on the IUCN red list. By comparison, the Hunter Basin in NSW; one of the most developed IBRA regions in Australia has a threatened plant to endemic ratio 25 magnitudes less than that of Norfolk (3.2% of flora threatened in the Hunter IBRA Sub-region).

Interim modelling of the Pre-European distribution of these communities indicates that there have been significant reductions in the distribution of low-lying communities relative to upland communities. This is consistent with clearing practices worldwide.

Table 1.10: Weed species on Norfolk Island and their niches

Species name	Common name	Status	Behaviour	Habitat 1	Habitat 2	Habitat 3	Habitat 4	Habitat 5	Habitat 6	Habitat 7	Habitat 8	Habitat 9
Ageratina adenophora	Crofton weed	Common	aggressive	Watercourses	forest clearings	disturbed	open sites	roadsides	over-grazed pasture			
Ageratum conyzoides	Billy goat weed	Common	Invasive	Pastures	Wasteland	Disturbed sites	Crops	Forests	Woodland	Grassland	Banks of watercourses	Wetlands
Argemone subfusiformis (subspecies)	Prickly poppy			Disturbed soil	Waste lands	Roadsides						
Asparagus aethiopicus	Asparagus fern	Perennial	Supresses growth of other species	Closed canopy of trees	Disturbed understorey	Infertile soils	Shallow	Sandy	Woodlands	Rocky headlands	Coastal areas	
Asparagus plumosus	Asparagus fern, feathered asparagus fern			Fertile soils	Undisturbed	Bushland						
Bidens pilosa	Cobbler's pegs		Invasive	Pastures	Crops	Roadsides	Disturbed	Forests				
Briza minor	Shivery grass, lesser quaking grass			Fertile	Moist	Shady	Disturbed	Roadsides	Wasteland	Grassland	Wetland	Forests
Carduus tenuiflorus	Slender thistle			Pastures	Dry coastal areas	Shrubland	Grassland	Forests	Rocky outcrops			
Cenchrus clandestinus	Kikuyu grass			Lawn	Pasture	Crops	Bushland	Riverbanks				
Cestrum nocturnum	Lady of the night, sweet-scented cestrum			Forests	Stream banks	Shrubland						
Cirsium vulgare	Spear thistle			Pastures	Cropland	Roadsides	Neglected areas	Natural vegetation				
Colocasia esculenta	Taro			Wetlands	Watercourses	Riverbanks	Marshlands					
Cotoneaster glaucophyllus	Cotoneaster, large-leaved cotoneaster		Vigorous and invasive	Woodlands	Grasslands	Coastal	Riverbanks	Roadsides	Waste areas			
Desmodium incanum	Desmodium			Roadsides	Wasteland	Disturbed						
Digitaria ciliaris	Summer grass		Sprawling	Gardens	Lawns	Orchards	Cultivation	Wasteland				
Egeria densa	Dense wasterweed			Nutrient rich, still or slow-moving fresh water	Freshwater ponds	Lakes	Reservoirs	Slow streams				
Eichhornia crassipes	Water hyacinth		Perennial and obstructive	Still or slow-moving fresh water	Dams	Streams	Drains	Irrigation channels				
Eleusine indica	Crab grass, crowsfoot grass	Common	Invasive	Disturbed	Gardnes	Lawns	Pastures	Roadsides	Marshes	Stream banks	Coastal	
Emex australis	Double gee, spiny emex	Annual	Low growing	Sandy, loamy soils	Disturbed	Roadsides	Cropland	Home gardens	Woodlands	Shrublands	Dry creek beds	Grassland
Eragrostis tenuifolia	Elastic grass			Gardens	Lawns	Waste areas	Pastures	Roadsides				
Hakea salicifolia	Willow-leaved hakea		Inhibit growth of other vegetation, seeds germinate rapidly	Bushland	Open hillsides	Coastal						
Ipomoea indica	Purple morning glory, blue morning glory		Quick growth, smother native vegetation	Highly disturbed	Watercourses	Moist forests	Moist, fertile soils					
Lantana camara	Lantana		Forms impenetrable thickets	Disturbed	Rich soils	Well-drained clays	Wasteland	Roadsides	Watercourse banks	Cultivated pastures	Fence lines	
Lantana montevidensis	Creeping lantana		Form dense thicket, take over native bushland	Alluvial, loamy, sandy or shallow stony soils								
Lilium formosanum	Formosan lily		Colonise	Cleared roadsides	Open bushland	Parks	Deep sands	Gravely loams	Fertile loamy soils			
Lolium loliaceum	Stiff ryegrass	Annual	Weed	Roadsides	Crops	Disturbed	Near sea	Salty areas				
Macroptilium atropurpureum	Purple bean		Smothers, forming dense infestations	Sandy clay	Alluvial soil	Watercourses	Coastal	Disturbed	Roadsides	Fences	Urban bushland	Plantation crops
Macrotyloma axillare var. axillare	Axillaris, lime-yellow pea		Weed	Fertile soils	Deep stony, sandy and clay loams	Roadsides	Fences	Disturbed	Open woodlands	Grasslands	Highland pastures	Parks Gardens
Medicago polymorpha	Burr medic	Annual		Flood plains	Valley slopes	Grassland	Dunes	Clay flats	Roadsides	Heavy alkaline soils		
Megathyrsus maximus var. pubiglumis	Green panic grass			Bushlands	Streamside vegetation	Disturbed						
Melilotus indicus	Annual yellow sweet clover		High nitrogen-fixing capacity	Disturbed	Bushland	River and creek beds	Roadsides	Moderately saline coastal areas				
Neonotonia wightii	Glycine		Infest open land	Bushland	Creek banks	Disturbed	Waste areas	Gardens	Fence lines			
Nicandra physalodes	Apple of Peru	Annual	Colonises	Disturbed	Cultivated land	Waste areas	Roadsides					
Ochna serrulate	Ochna	Common		Coastal areas	Disturbed	Paddocks	Roadside	Waste areas	Forest edges close to human habitation			
Olea europaea Subspecies *cuspidata*	African olive			Moderate nutrient level soils	Open woodlands	Parks	Grasslands	Coastal	Disturbed	Wastelands	Roadsides	
Phyllanthus tenellus	Hen and chickens	Annual	Colonises	Disturbed	Rainforests	Vine thickets						
Polygala myrtifolia	Myrtle-leaf milkwort	Common	Weed	Coastal	Grasslands	Watercourses	Sandy or alluvial soils					
Psidium cattleyanum var. cattleyanum	Cherry guava		Invasive, dense thickets that crowd vegetation	Disturbed agricultural areas	Grasslands	Watercourses	Coastal					
Rivina humilis	Coral berry			Closed forests	Forest margins	Streamsides	Disturbed	Waste areas	Urban bushland	Gardens		
Rumex brownii	Swamp dock	Perennial	Colonises	Wet, swampy ground	Woodlands	Forests	Streamsides	Disturbed	Waste areas in full sun			
Salvia coccinea	Red salvia	Perennial		Open woodlands	Banks of watercourses	Disturbed	Waste areas	Roadsides	Gardens			
Salvinia molesta	Salvinia	Perennial	Invasive, forms dense infestations	Lakes	Wetlands	Ditches	Ponds					
Schinus terebinthifolius	Broad-leaf pepper tree		Invasive	Wetlands	Disturbed	Banks of watercourses	Bushland					
Senna septemtrionalis	Cassia, smooth senna	Common		Moist forests	Riverbanks	Open woodland	Disturbed	Waste areas	Roadsides			
Setaria pumila subspecies *subtesselata*	Pale pigeon grass		Weed	Disturbed	Waste ground	Roadsides	Footpaths	Cultivated areas				
Solanum linnaeanum	Apple of Sodom	Perennial		Sandy and calcareous soils	Coastal	Bushland	Pastures	Disturbed	Roadsides			
Solanum mauritianum	Wild tobacco		Supresses growth of other species	Agricultural areas	Coastland	Natural forests	Urban open spaces	Roadsides	Disturbed	Waterways	Waste areas	
Sporobolus africanus	Rat's-tail grass, Parramatta grass	Perennial		Swamps	Lawns	Footpaths	Parks	Roadsides	Disturbed	Waste areas	Grasslands	Open woodland
Trifolium pratense	Red clover	Perennial		Pastures	Cultivated lands	Roadsides	Wastelands					
Trifolium repens	White clover	Perennial		Grey sand, black sand clay and peaty sand	Pastures	Open fields	Garden lawns	Waste ground	Roadsides			

1.4.4.1 VEGETATION CONDITION CLASSES

Vegetation community condition was described by applying vegetation condition classes to spectral reflectance classes modelled from satellite imagery (scanned in August 2019). Using a combination of Principal Component Analysis classification and Support Vector Machines (SVM) to separate highly disturbed areas from natural vegetation cover, and Maximum Likelihood Modelling for closely aligned native classes.

1.4.4.2 ESTIMATION OF CONDITION CLASSES

Land areas that have low level endemic plant diversity and cover, and areas dominated by weeds at one or more stratums, or there is evidence of activities that lead to land degradation, are all classified as disturbed lands. In some cases, these disturbed areas are devoid of native vegetation (Class 1), or are similar in terms of weed and disturbance yet have a small number of native species present (Class 2), or have one or more native stratums, but are impacted by historical and ongoing disturbances (Class 3).

Modelling shows that these 3 disturbance classes cover 2192 ha of land area on Norfolk Island (Figure 6), or approximately 64 % of land area (excluding major roads and shorelines). The worst condition class (Class 1) includes open grass areas that are degraded with evidence of sheet and gully erosion. Impacts from trampling, grazing, farming and vegetation management have a strong correlation with this class.

Figure 1.41 shows the Catchment Condition overview.

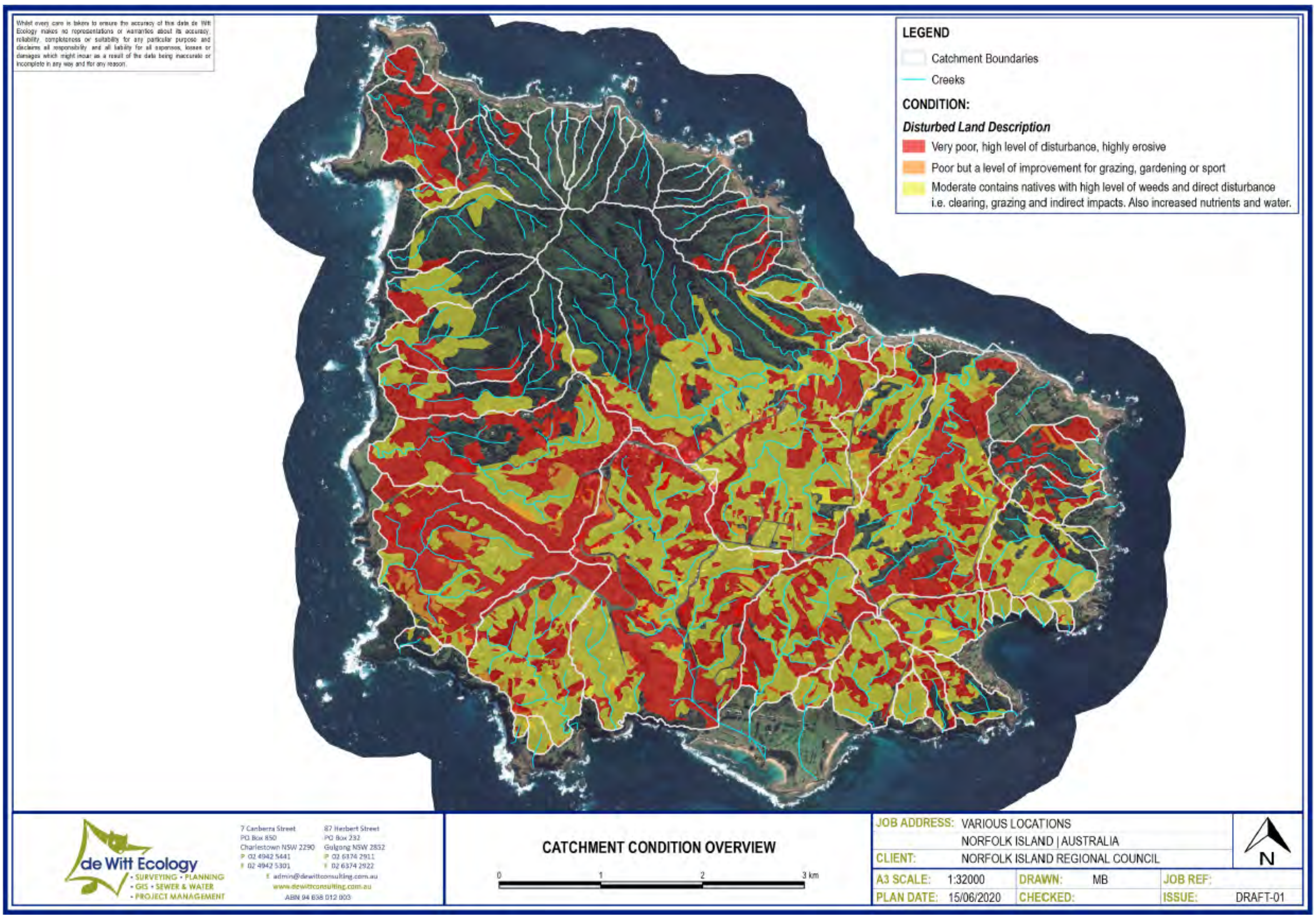


Figure 1.41: Catchment Condition Overview

Figure 1.42 to Figure 1.46 show the catchment conditions on Norfolk Island.

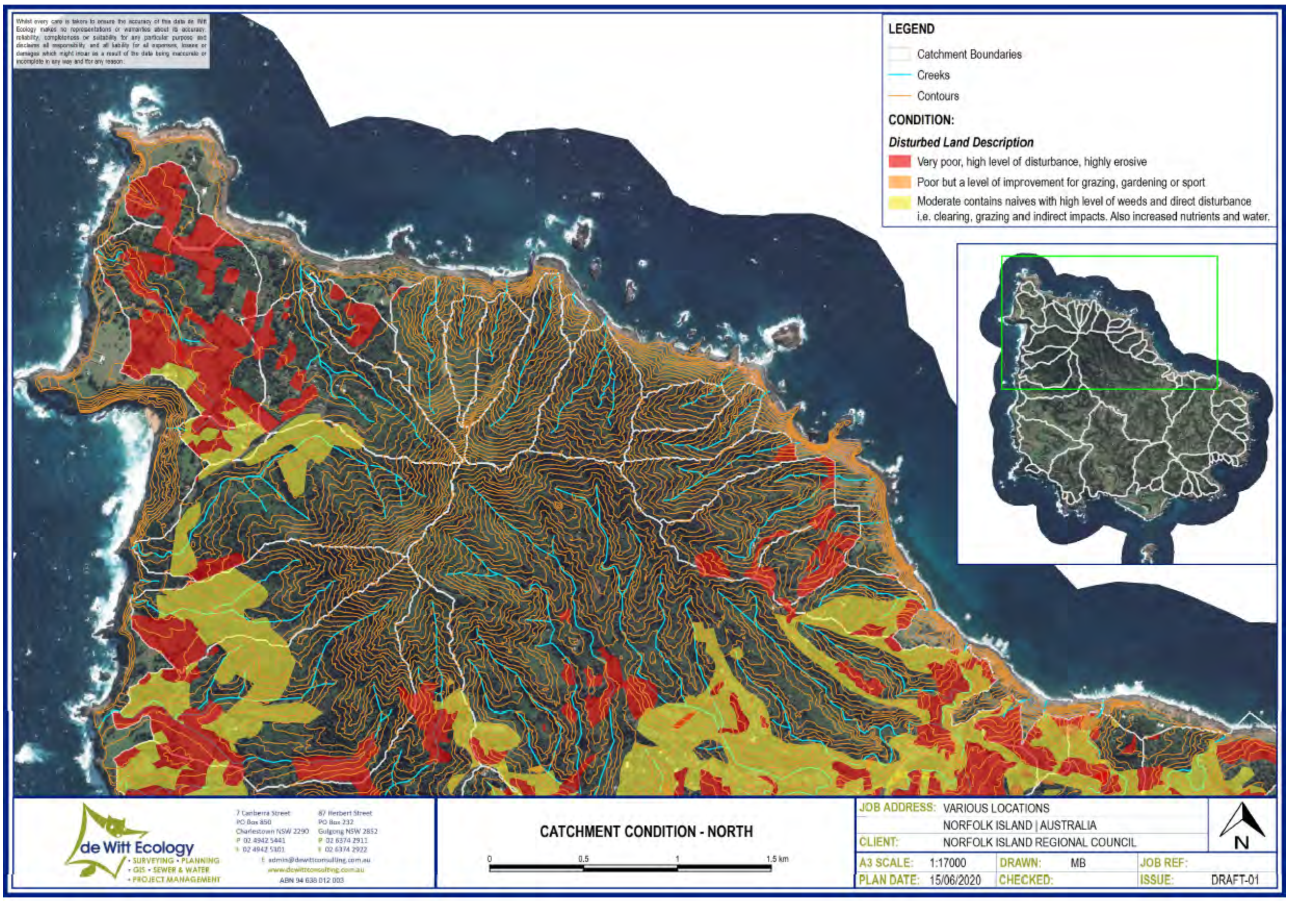


Figure 1.42: Catchment Condition – North

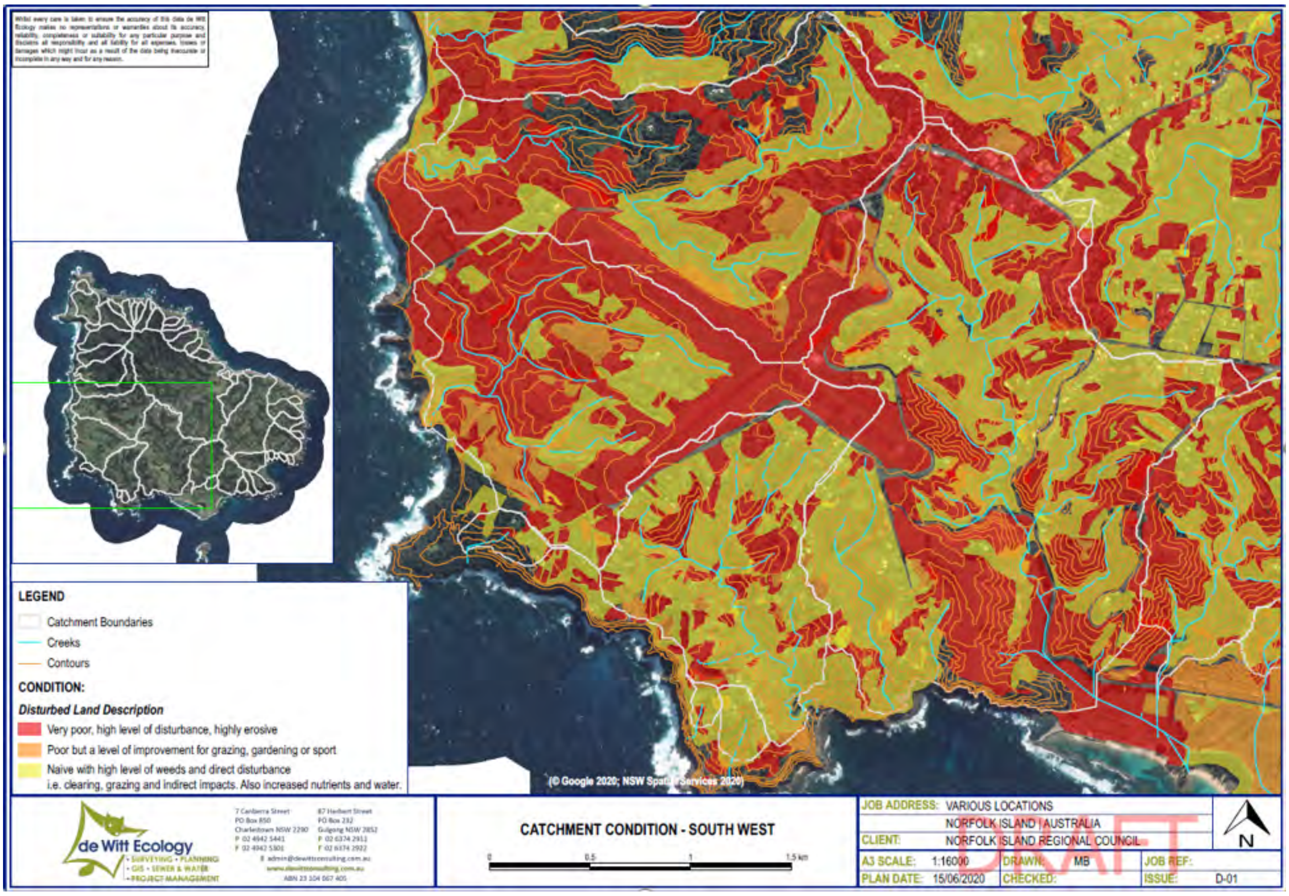


Figure 1.43: Catchment Condition – South-West

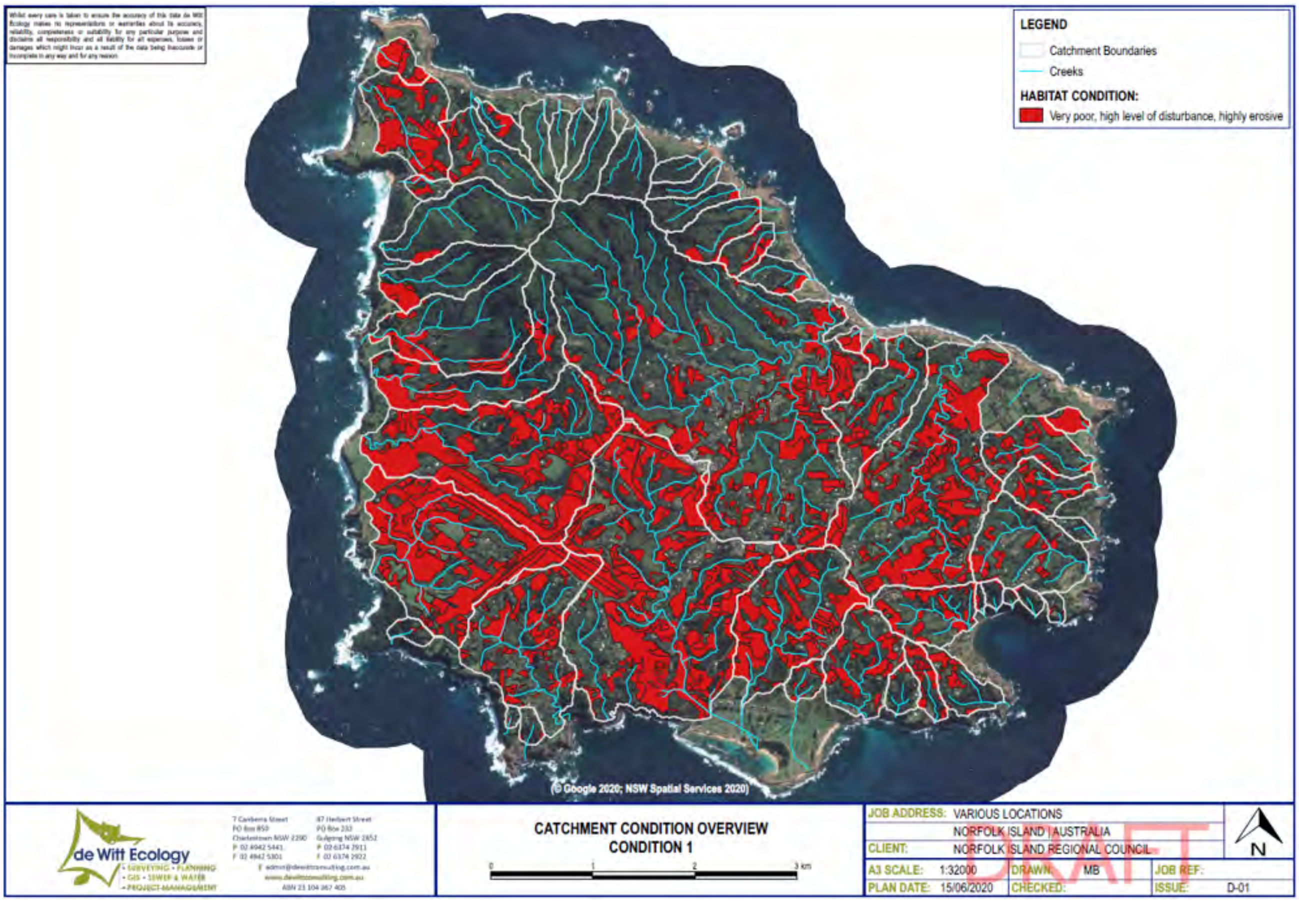


Figure 1.44: Condition 1

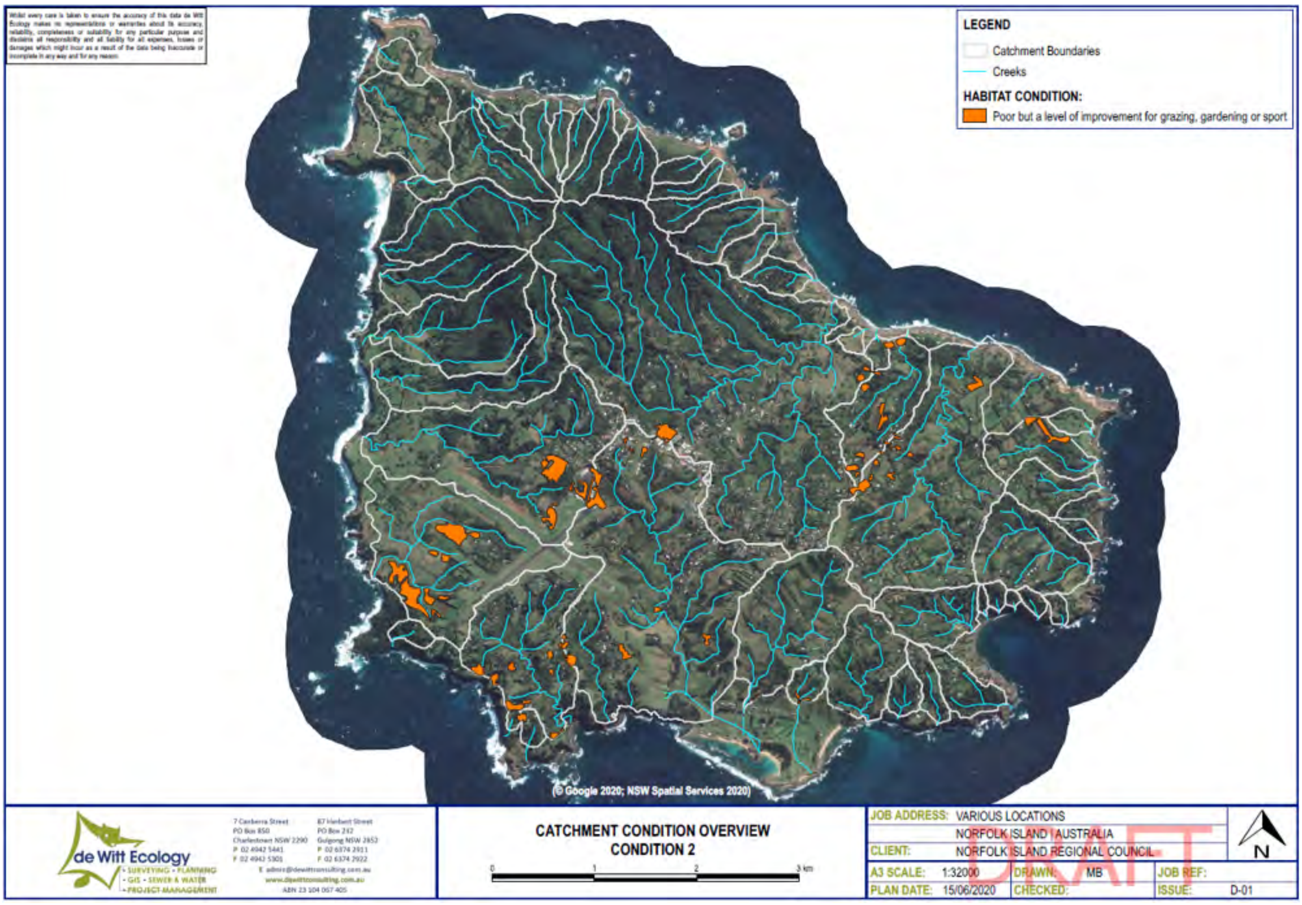


Figure 1.45: Condition 2

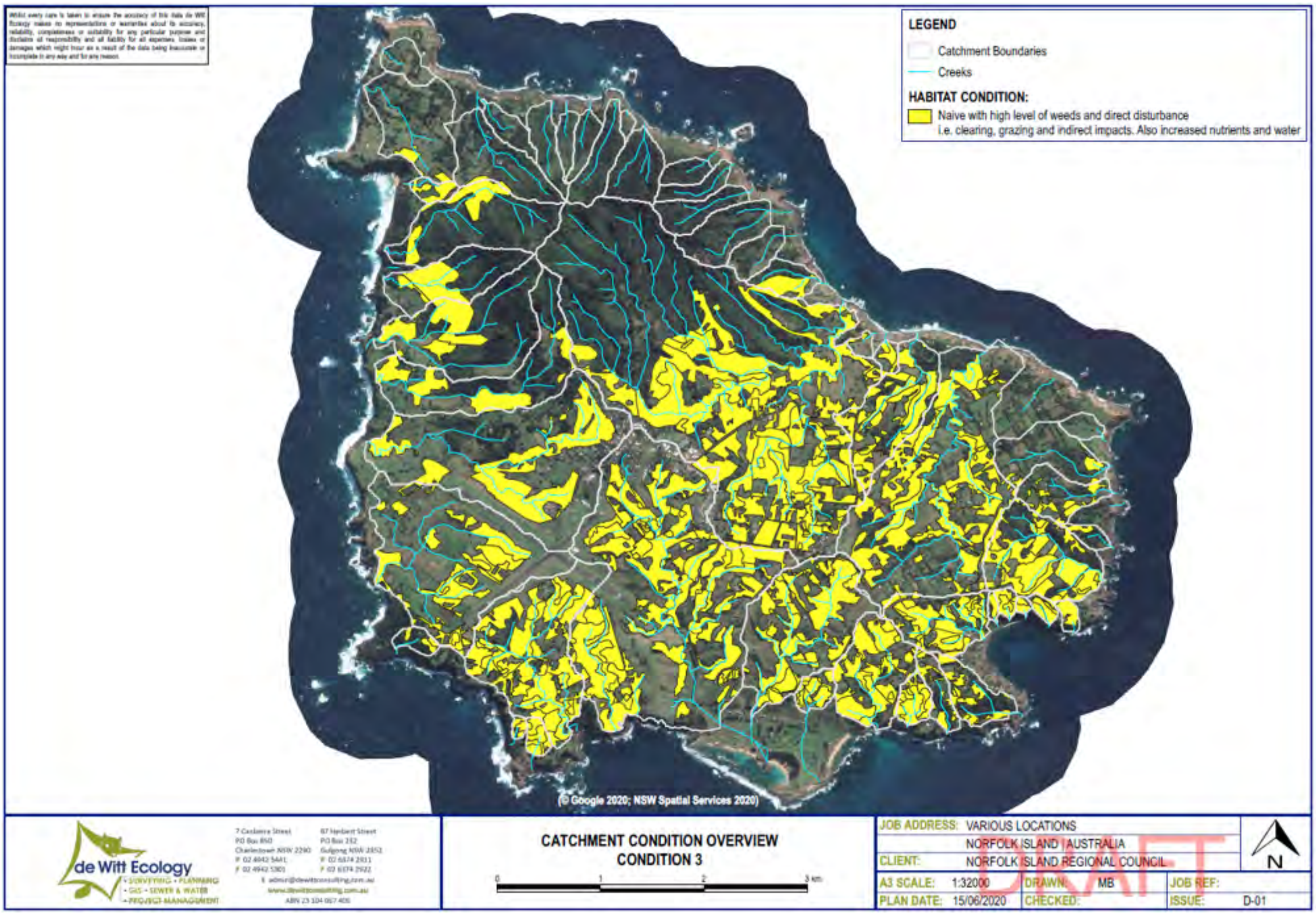


Figure 1.46: Condition 3

1.4.4.3 ESTIMATION OF DISTURBANCE CLASSES

Clearing and disturbance of Norfolk Island vegetation and habitats commenced with the expansion of the Polynesians, where they presumably cultivated food types like plantain. This was followed by several attempts to set up permanent occupancy by the first and second fleet of colonizers. During this time, it is predicted that a quarter of the native vegetation cover was removed. By the 1830's, there was approximately 458 ha of cultivated land, and in 2021 there is only 10 ha (Petheram et al, 2020). The arrival of the Pitcairn Islanders cultivated the cleared land (~458 ha) to produce crops. The generations and influx of main landers has seen further loss of native vegetation cover. Based on the previous estimations, there is only 633 ha of remnant intact Plant Community Types on the Island which is approximately 18 % of the original vegetation. Figures 1.47 to Figure 1.51 show the disturbance classes (1 to 5) on Norfolk Island.

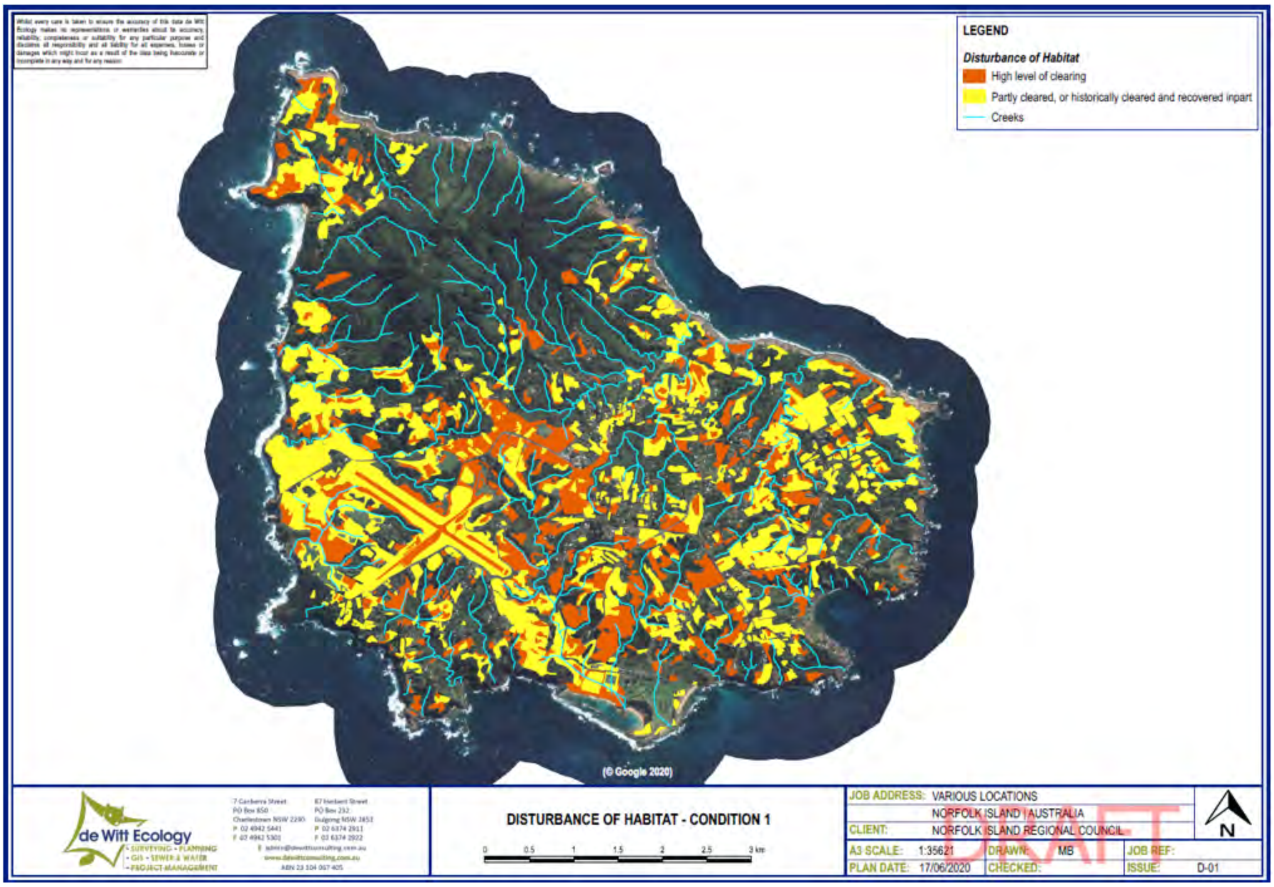


Figure 1.47: Disturbance Class 1 (TDI-1)

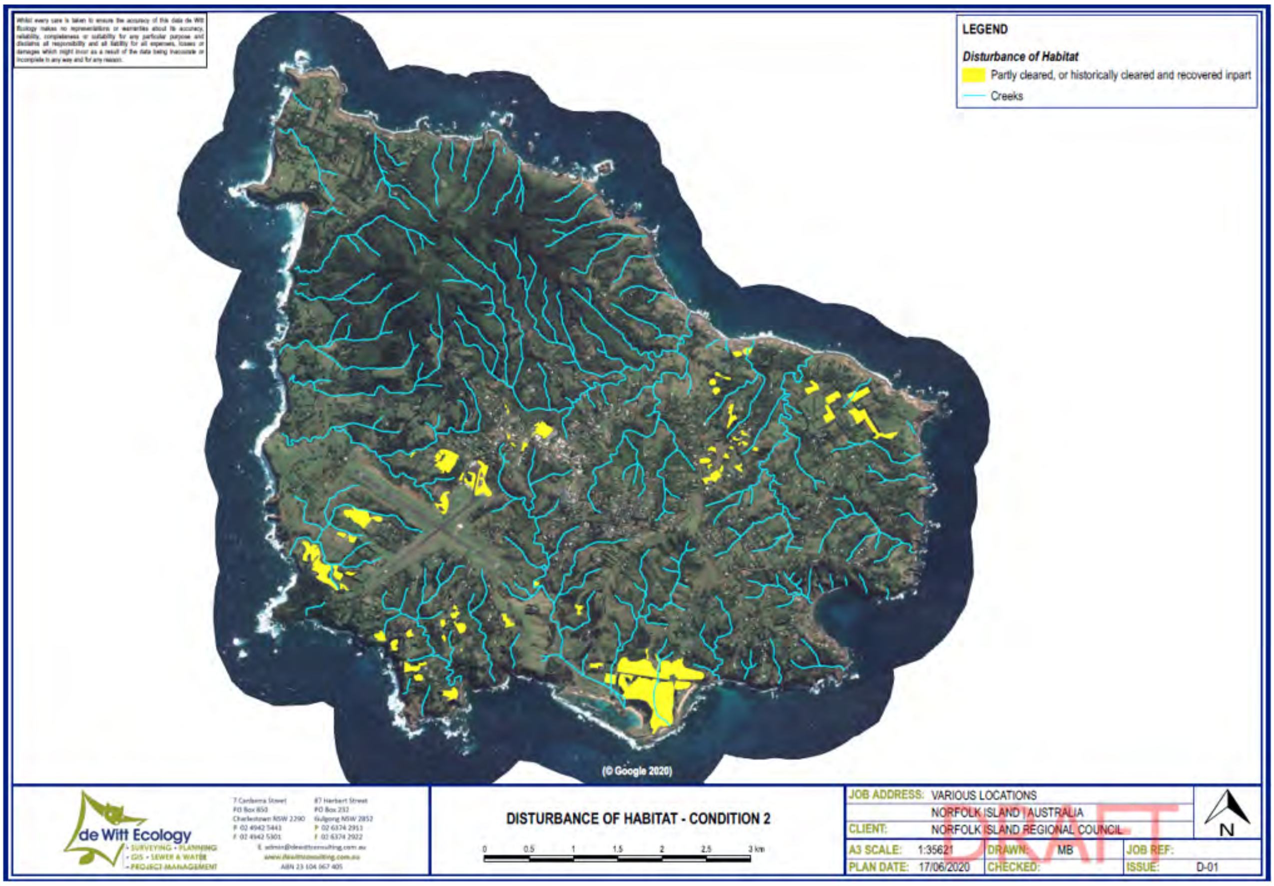


Figure 1.48: Disturbance Class 2 (TDI-2)

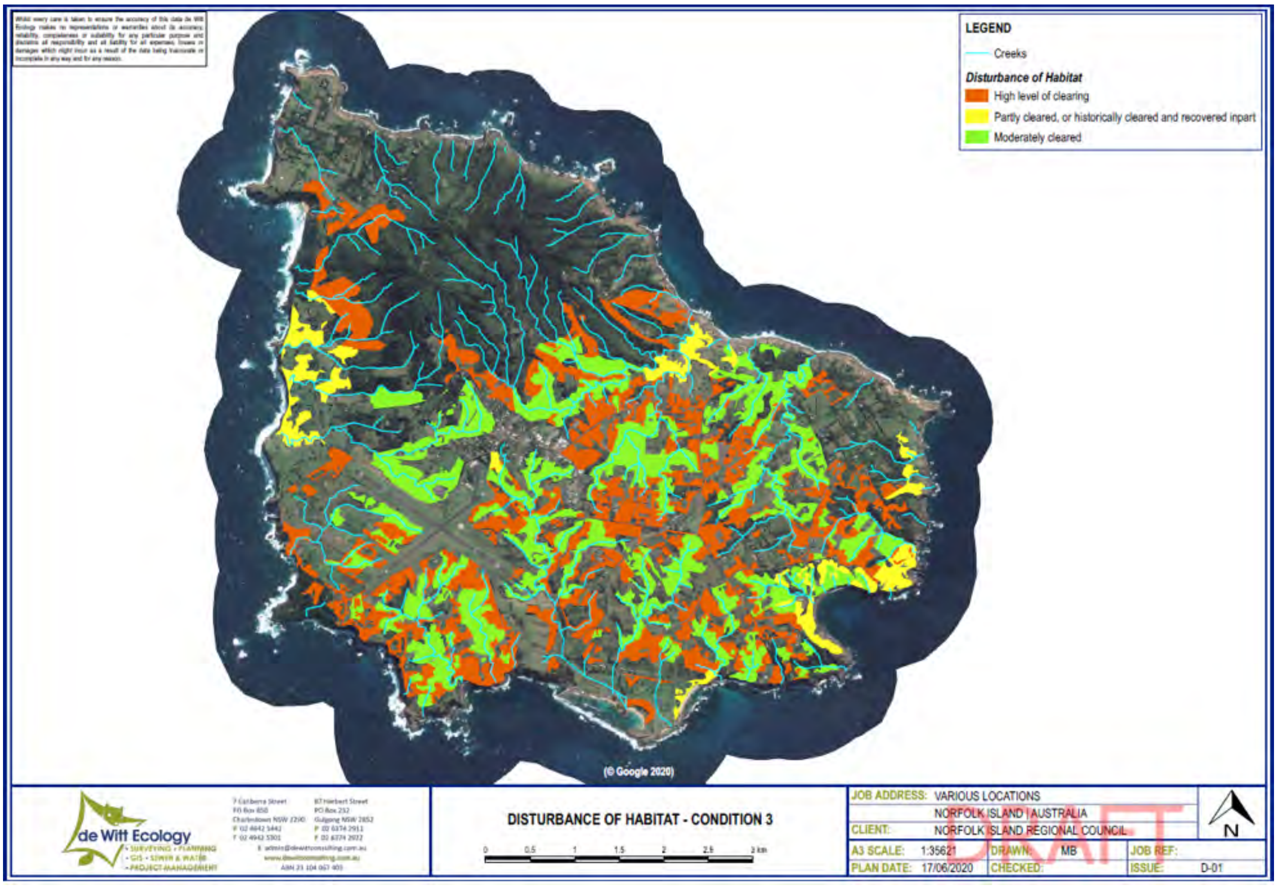


Figure 1.49: Disturbance Class 3(TDI-3)

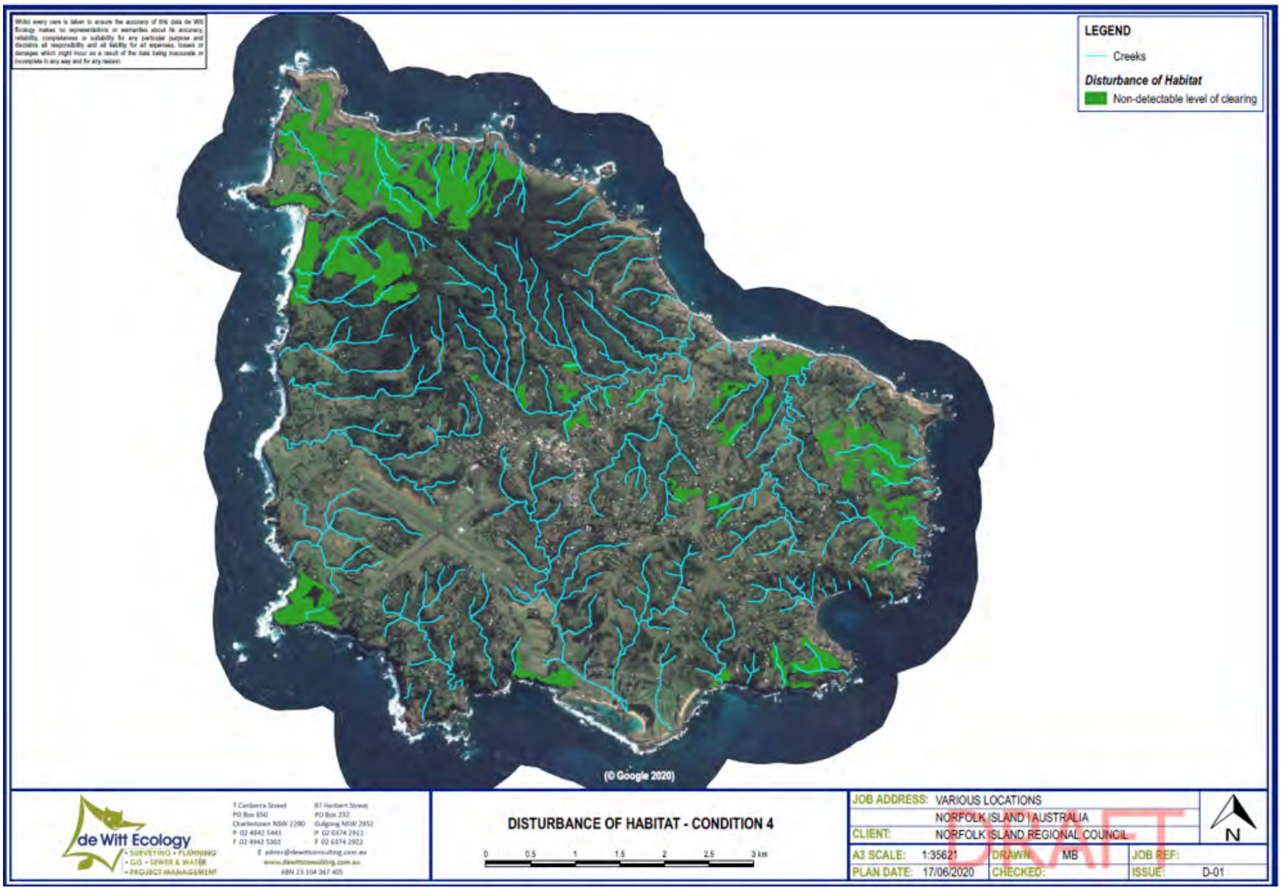


Figure 1.50: Disturbance Class 4 (TDI-4)

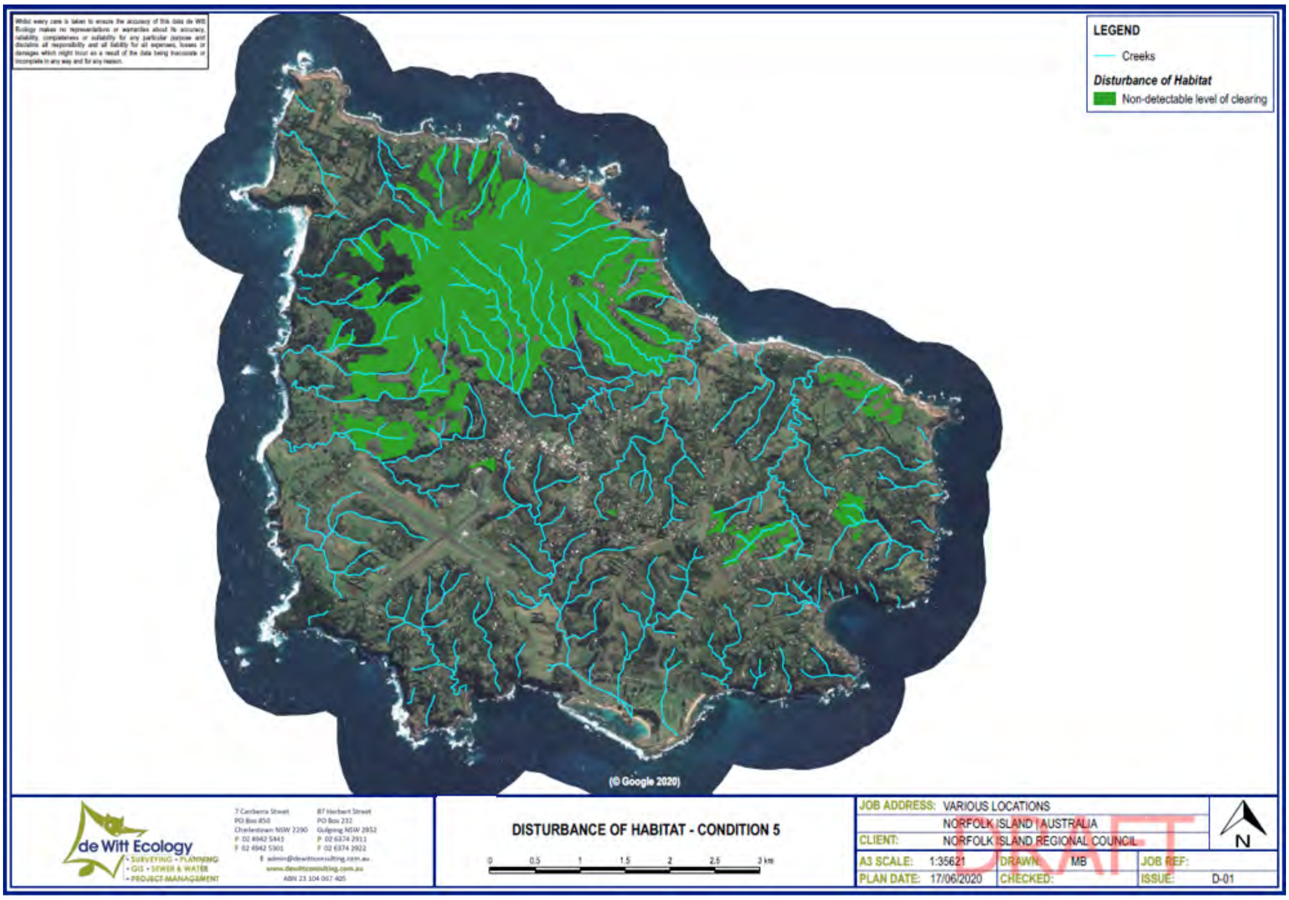


Figure 1.51: Disturbance Class 5 (TDI-5)

1.4.4.4 CREEK LINE DISTURBANCE AND RISKS

A linear correlation function comparing catchment wide condition and slope, starting at the headwaters of each catchment and moving stepwise downstream was undertaken to identify catchments and creeks at risk to erosion. As can be seen in Figure 1.52, there is significant risk in the south east of the Island and high risk in rural areas in the west.

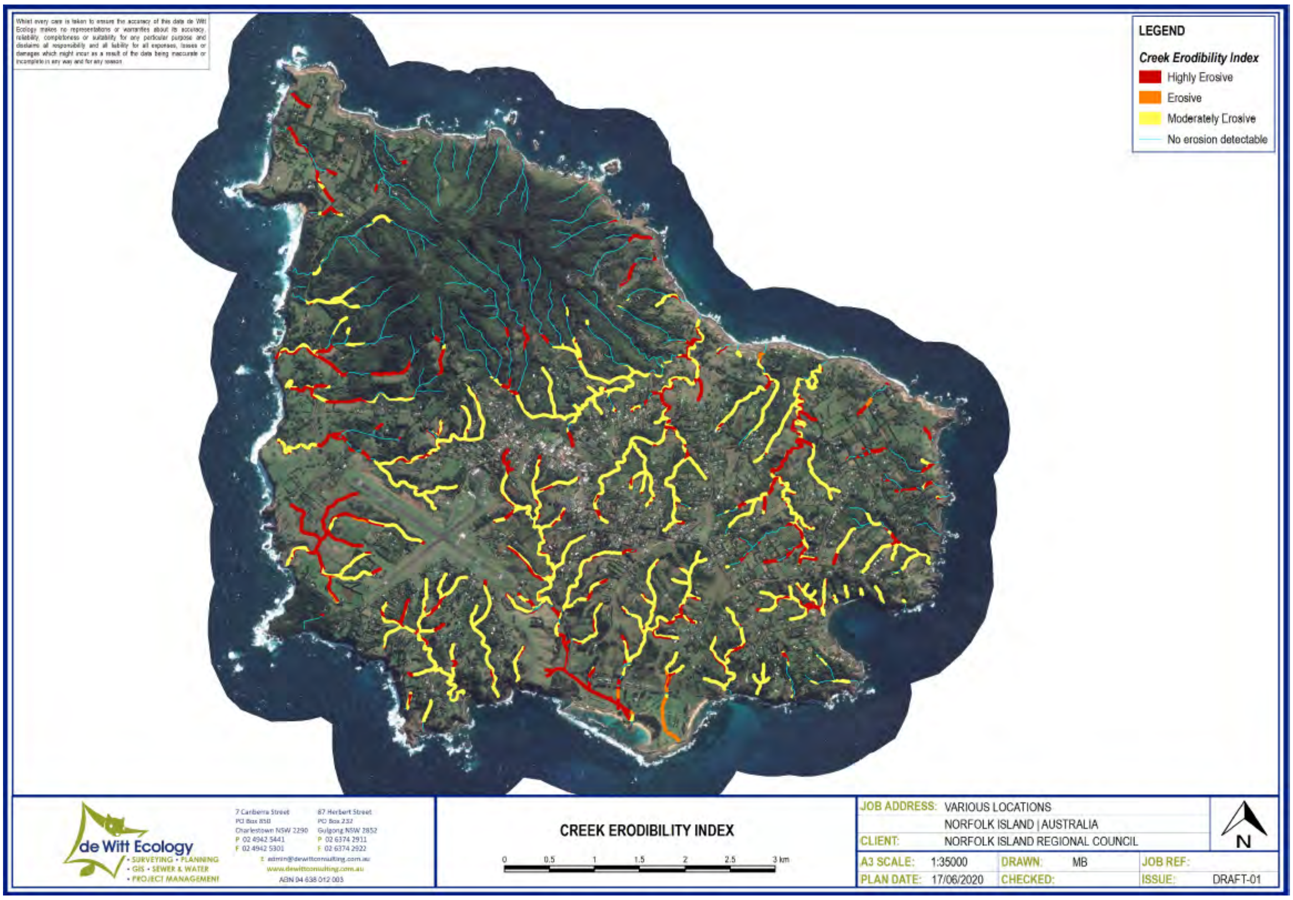


Figure 1.52: Creek Erodibility Index

1.4.5 DRONE SURVEY OUTPUTS (HEADSTONE CATCHMENT)

Drone surveys were undertaken at a number of sites in September 2019. The drone was programmed for an autonomous flight in a survey pattern over Headstone catchment. A third party application, "DroneDeploy", was utilised for this survey and the flight plan/details are shown in Figure 1.53.

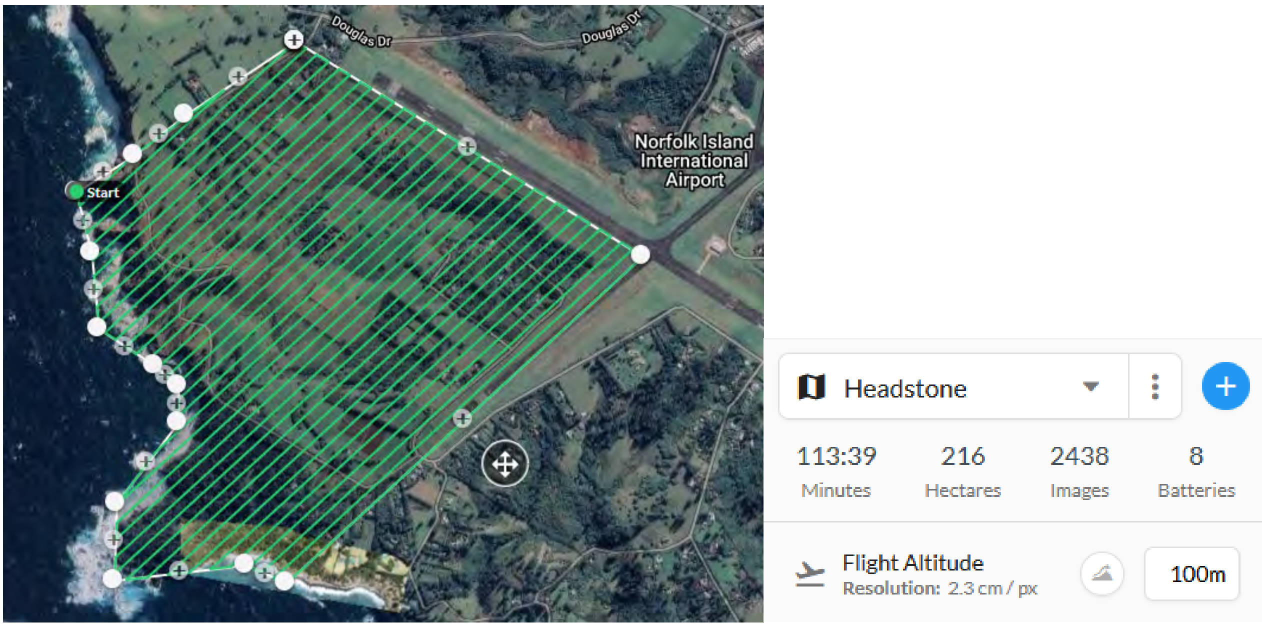


Figure 1.53: Flight plan of Headstone catchment using DroneDeploy

Figure 1.54 shows part of a previously presented satellite image for Headstone catchment. The image is at a resolution of 20cm, appears “grainy”, and very little detail can be observed. The red highlighted region shows Class 1 vegetation and catchment conditions (light blue), which have previous been identified in the satellite imagery analyses. Note the dark blue of the airport runways to the right of the image.

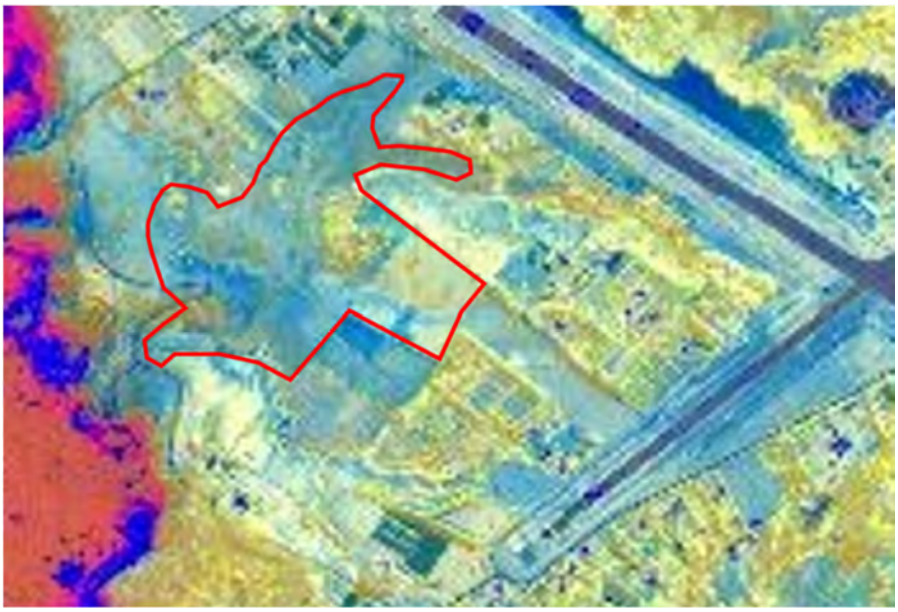


Figure 1.54: Satellite image showing Class 1 and Class 2 vegetation and catchment condition

Figure 1.55 shows the same image but from the drone survey at a resolution of 2.3cm/pixel.

Figure 1.55: Drone survey map view

The much improved resolution shows finer detail and would be much better for evaluating land management practices at this scale. The Class 1 vegetation and catchment condition can be identified by the "browner" areas with minimal groundcover (highlighted in the red area).

The DroneDeploy application takes all the survey images (2,438 in this case) and stitches them together to provide the image shown in Figure 1.55. Each image is geographically set to X, Y, and Z co-ordinates so the images can also provide a digital terrain model (DTM) as shown in Figure 1.56. The Class 1 area is dominated by deep drainage lines and steep slopes, and if left with minimal groundcover, will only get worse over time as water incises deeper into the eroding gullys.

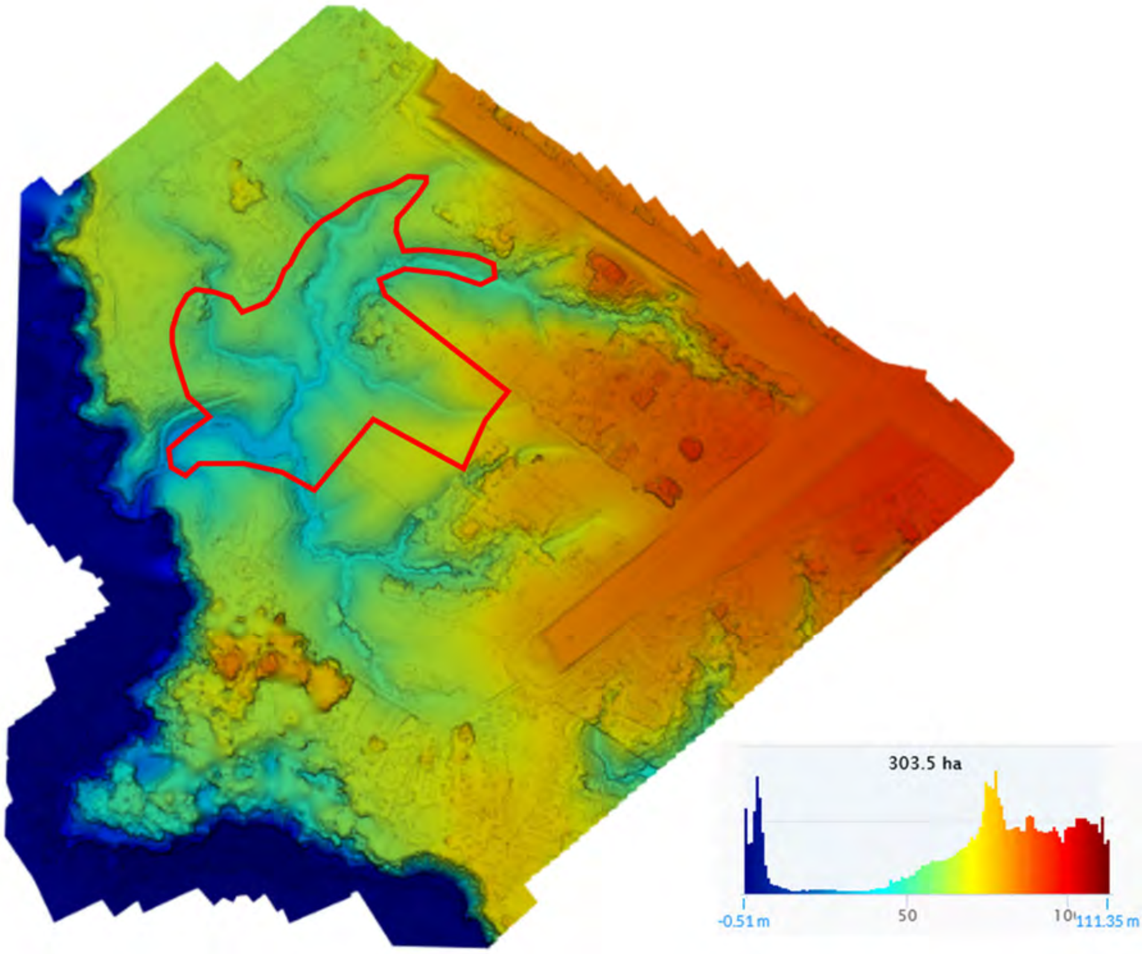


Figure 1.56: Drone survey – DTM view

Figure 1.57 provides another innovative use of drone surveys and the benefits of DroneDeploy. Previously shown satellite imagery and analyses used specific wavelengths, however the Normalised Distribution Vegetation Index (NDVI) is a software algorithm within DroneDeploy that uses a selection of filters. In this case, the red/green/near infra-red filter was used to provide the image in Figure 1.57.

The darker the area, the less "green" is observed. For example, the airport runway, rooftops and ocean are much darker as there is no green light reflected. The dark green areas indicate a strong groundcover while the lighter, red/brown on land indicates poor groundcover. This can be observed in the highlighted area of Class 1 catchment condition.

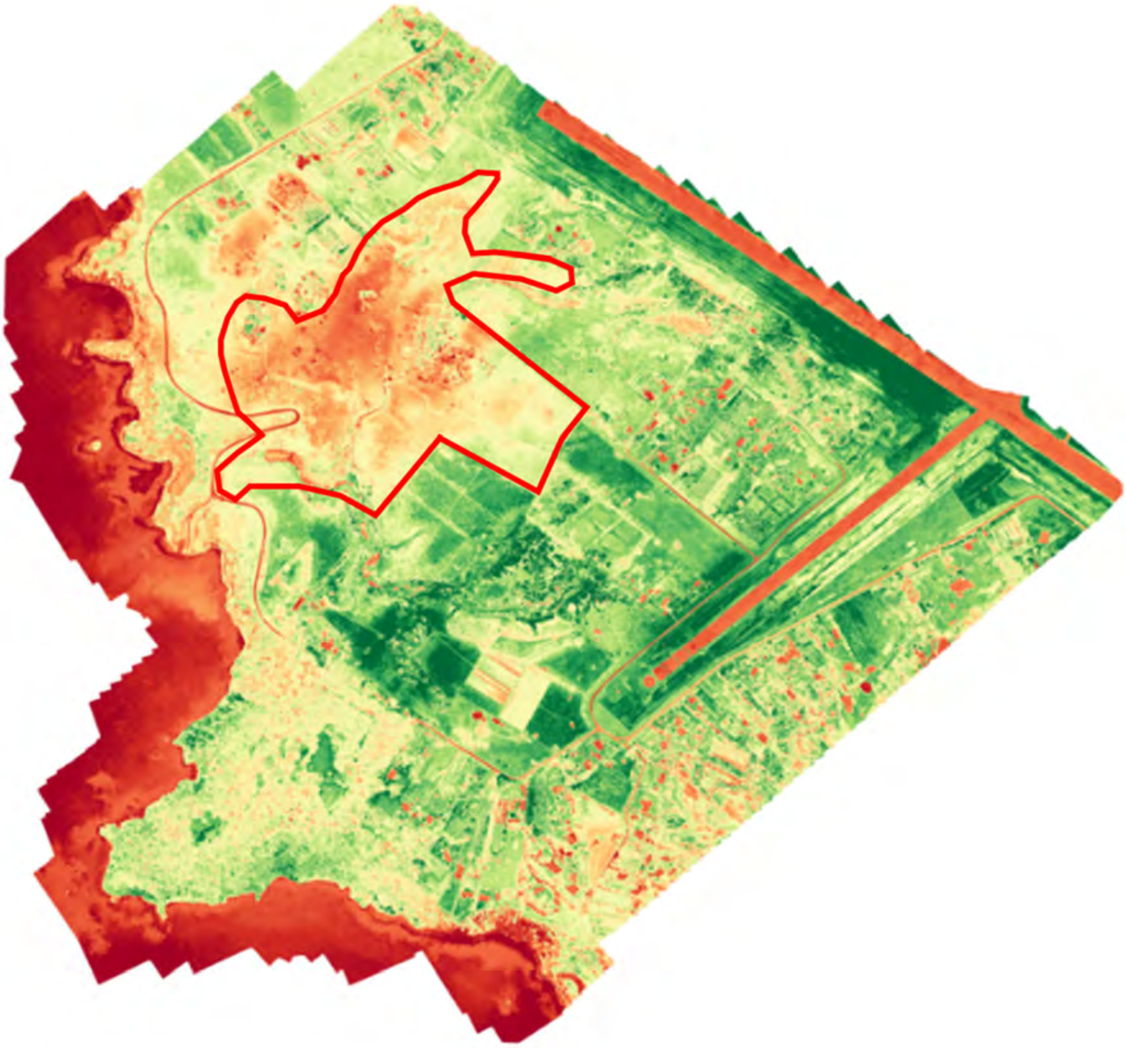


Figure 1.57: Drone survey – Normalised Distributed Vegetation Index (NDVI) using red/green/near infra-red filter

The future of aerial surveys using drones allows an increased capability for Norfolk Island in evaluating and managing different land uses.

1.4.6 BIRD SPECIES CONSERVATION

Given the small scale on this project an approach focusing on establishing a set of prior probabilities for the occupancy of key diurnal forest bird species (Norfolk Island Robin, Green Parrot, Golden whistler, and Slender-billed Silvereye). Further work in the future with local experts will provide more information and more environmental data for probability and mapping models could be developed to assist in conserving these species (Mills, 2018; Naomi Christian Consulting, 2020). Data for this preliminary prior estimate was collected by establishing 34 random plot-based sample sites and surveying species presence and counts of significant species (Refer to Table 1.11). Birds were surveyed across the study area by random transects targeting periods of high bird activity, predominantly between the hours of 6 am and 9 am. As a minimum the surveys followed the following:

1.4.6.1 ESTIMATING THE AREA OF SEARCH

Generally, for smaller patches (<50 hectares) one moves freely throughout the patch in every sample period. In comparison, larger patches (>50 hectares) can be broken into sub-sets and these sampled as independent (i.e. not overlap samples). A variation of methods was used across the study area dependent on patch size. All species are recorded by ear and unknown species are keyed out on site with the use of a digital recorder.

1.4.6.2 INTERVAL TIME

An appropriate interval time ranges from 15 min – 60 min based on patch size and habitat density. Again, this was scaled across the sites.

1.4.6.3 STOPPING RULE

A compound stopping rule in which “surveying was stopped after three sequential periods in which in total two new or fewer species were encountered” was applied.

1.4.6.4 LINE TRANSECTS

In total 6 fixed area transects (400m^2 each) were erected and surveyed on five occasions over a two-week period for a 20 minute survey period at each site (n=6). Surveys were conducted between 0700 and 1000 hours or between 1700 and 1900 hours, windy or rainy days were avoided. Assumptions that were met included, all birds in the transect were detected, that birds do not move before detection, distances are measured accurately, and individual birds are detected independently.

Table 1.11: Sample sites for bird surveys

Site name	Easting	Northing	Description
casbay_1	789,191.00	6,786,023.00	Pine and hibiscus with grass and weeds
casbay_2	789,066.78	6,786,057.46	Pine and hibiscus with some rainforest
coastCliff_1	789,373.00	6,782,204.00	Pine with grassy and weeds
Dev_valley_1	789,373.00	6,782,204.00	Open pine with weedy mid storey and riparian rainforest patches
Coastal_valley_1	789,959.00	6,782,370.00	Tall pine forest and hibiscus with rainforest
Farm_1	790,177.00	6,782,503.00	Orchid with grassy under storey
Reserve_1	790,238.00	6,783,363.00	Open pine with weedy mid storey and some hibiscus
Reserve_2	790,351.00	6,783,197.00	Open pine with weedy mid storey and some hibiscus
Pri_coastal_1	790,814.00	6,783,816.00	Rainforest with open NI Pine and NI hibiscus
Dev_valley_2	790,435.00	6,783,813.00	Open pine with weedy mid storey
Coastflat_1	790,577.00	6,784,629.00	Mixed forest with fern understorey
Coastflat_2	791,175.00	6,784,986.00	Low Mixed forest with no NI Pine
Coastal_valley_2	791,512.00	6,783,900.00	Tall pine forest and hibiscus with rainforest
Reserve_3	791,529.00	6,783,417.00	Open pine with weedy mid storey and some hibiscus
NP_1	786,246.00	6,786,683.00	Rainforest ni Palm
Coastal_valley_2	786,357.00	6,786,956.00	Tall pine forest and mixed wood with rainforest
Dev_valley_3	788,051.00	6,785,440.00	Eucalyptus forest and weeds
Dev_valley_3	788,051.00	6,785,440.00	Weedy creek

Site name	Easting	Northing	Description
NP_1	787,837.00	6,787,012.00	Tall pine forest and mixed wood with rainforest
Selwnres_4	784,689.00	6,786,404.00	Tall pine forest and mixed wood with rainforest
NP_3	785,471.00	6,786,336.00	Guava and whitewood creek line
Coatal_Cliff_2	784,998.00	6,788,830.00	Grass with urban trees
Anson_Pine_coast1	784,808.00	6,787,276.00	Coastal cliff pine forest
Anson_rd_mixed_1	784,794.00	6,786,877.00	Pine forest with mixed wood including Eucalypt
Euc_forest_1	785,006.00	6,786,466.00	Eucalypt plantation
Puppys_pt_1	784,735.00	6,785,979.00	Pine with dense weeds mid storey and disturbed Ck.
Head_st_1	784,414.00	6,784,148.00	Pine plantation and other plantings. Mown and maintained.
Head_st_2	784,477.00	6,783,804.00	Pine plantation and other plantings. Mown and maintained.
100_ac_1	784,760.00	6,783,170.00	Hardwood and pine forest. Healthy, open under storey
100_ac_2	784,483.00	6,782,818.00	Hardwood and pine forest. Healthy, open to moderately closed under storey
Bumb_R_1	786,359.00	6,782,218.00	Hardwood and pine forest. Healthy, open under storey
Bumb_R_2	786,617.00	6,782,117.00	Coastal cliff pine forest
Nrt_cst_NP_1	787,160.00	6,787,634.00	Rainforest creek line
Nrt_cst_NP_2	787,460.00	6,787,508.00	Pine ridge

Figure 3.23 shows the survey sites for each species.

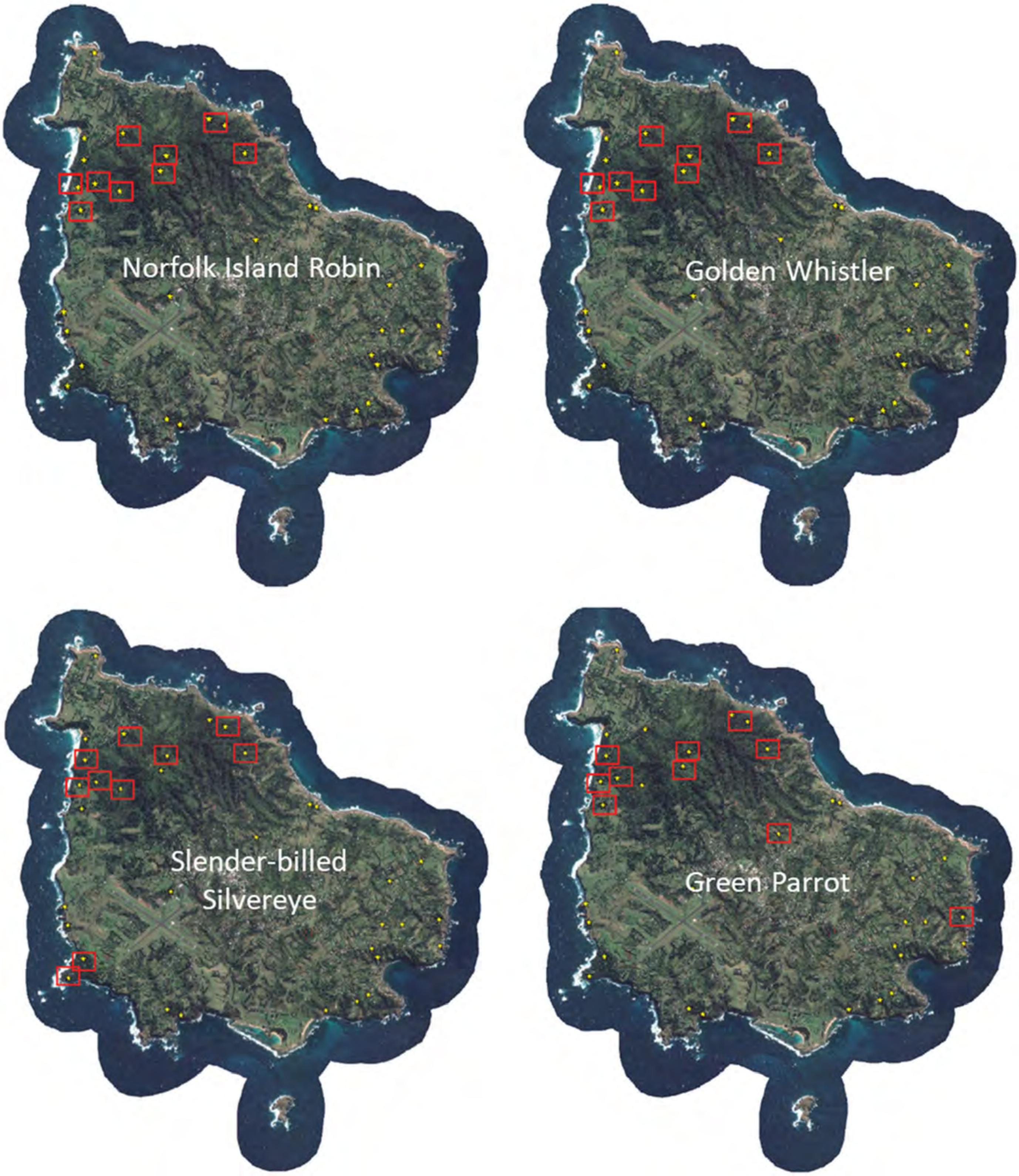


Figure 3.23: Sites for bird surveys

1.4.7 DISTRIBUTION OF SIGNIFICANT BIRD SPECIES

1.4.7.1 NORFOLK ISLAND ROBIN

The Norfolk Island Robin was recorded at all sites within the National Park (NP) (n = 7) and two sites outside; both of which are within 350m of the edge of the NP. Whilst some other sites provided suitable habitat, notably site (100 acre wood sites and sites near Steels Point) these sites are removed from the NP populations by more than 1 km and this may be a barrier to the population establishing in these sites. There are many more factors that could be contributing to this; however, these are beyond the reach of this report.

1.4.7.2 GREEN PARROT

Green Parrot was recorded at 85 % of the NP sites (likely at all sites but detection probability of this species is expected to be only moderate) and at four sites outside of the NP. Family groups were recorded on four occasions and one of these was outside the NP (Sewlyn Reserve). Green Parrot can be found in the urban areas and yards when fruit is available, and the role these resources play in the conservation of the species is worthy of further investigation.

1.4.7.3 GOLDEN WHISTLER

Golden Whistler was recorded at five NP sites and three other sites. This species is likely to use more habitats outside of the NP than Robin but may be limited by structural complexity of the remnants. The locations outside of the NP where it was recorded were the most complex of those sites.

1.4.7.4 SLENDER-BILLED SILVEREYE

Slender-billed Silvereye was recorded at five location in the NP and five outside of the NP. This species is highly mobile and difficult to quantify without considerable monitoring effort over a long period of time. Previous survey sites and methodology undertaken last century should be resampled before any reliable information can be gained on the status of the species.

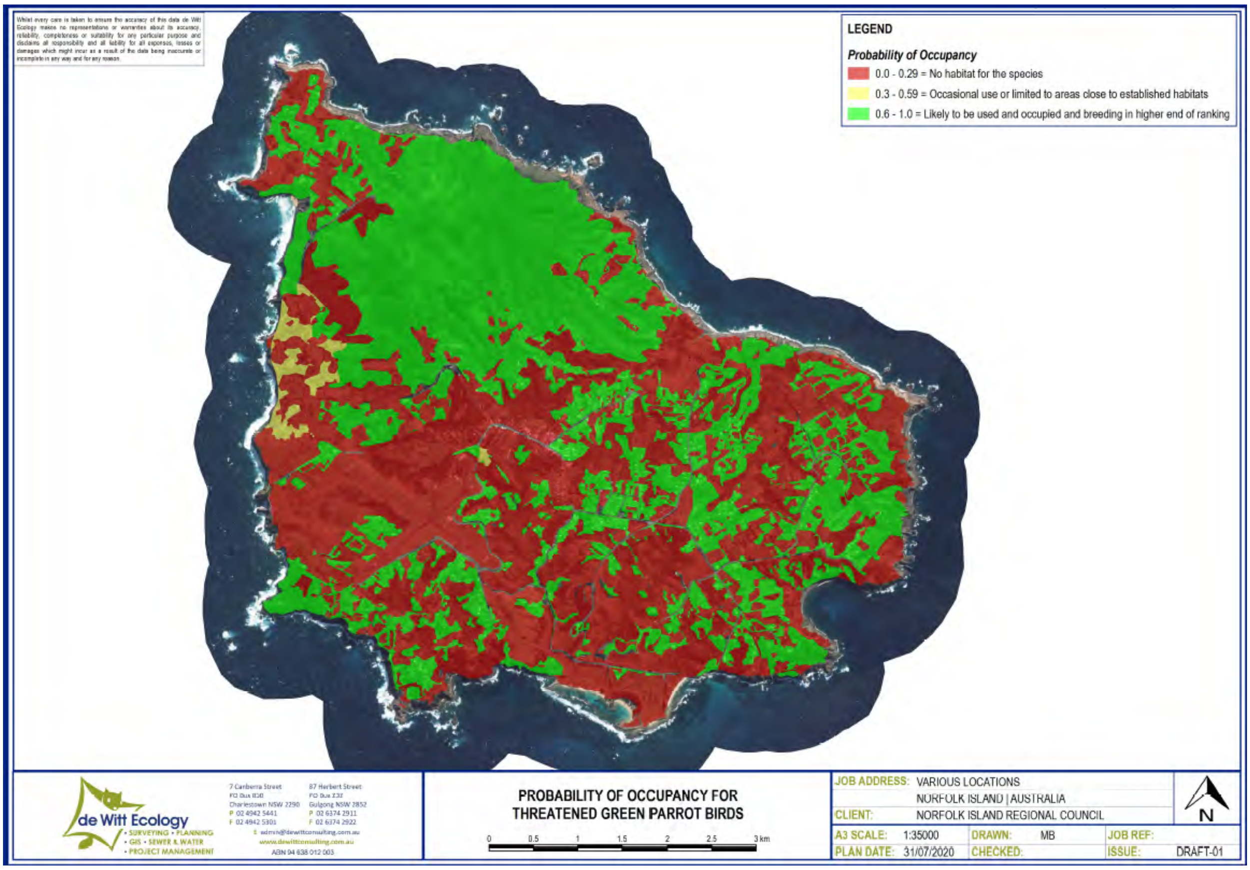


Figure 3.24: Probability of Occupancy for Threatened Green Parrots

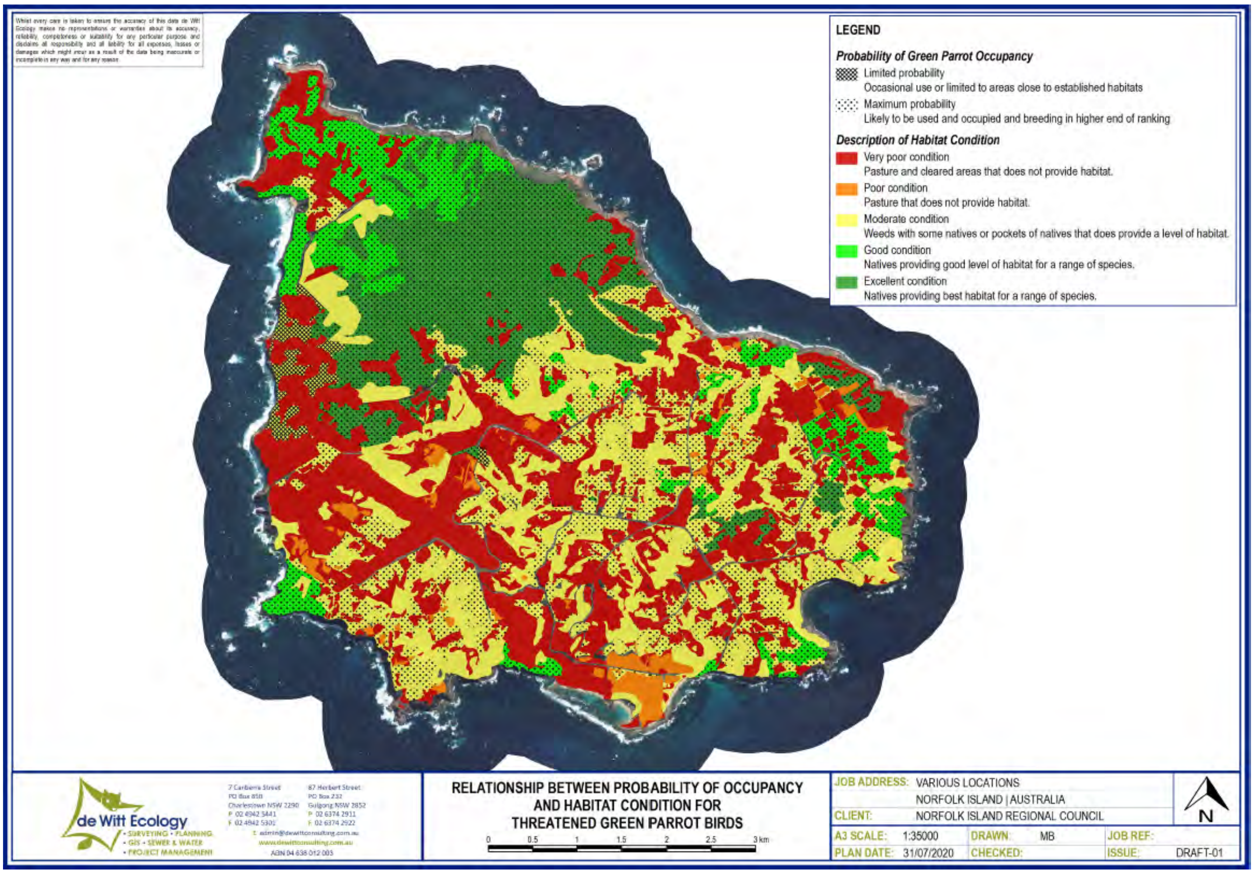


Figure 3.25: Relationship between Probability of Occupancy and Habitat for Threatened Green Parrots

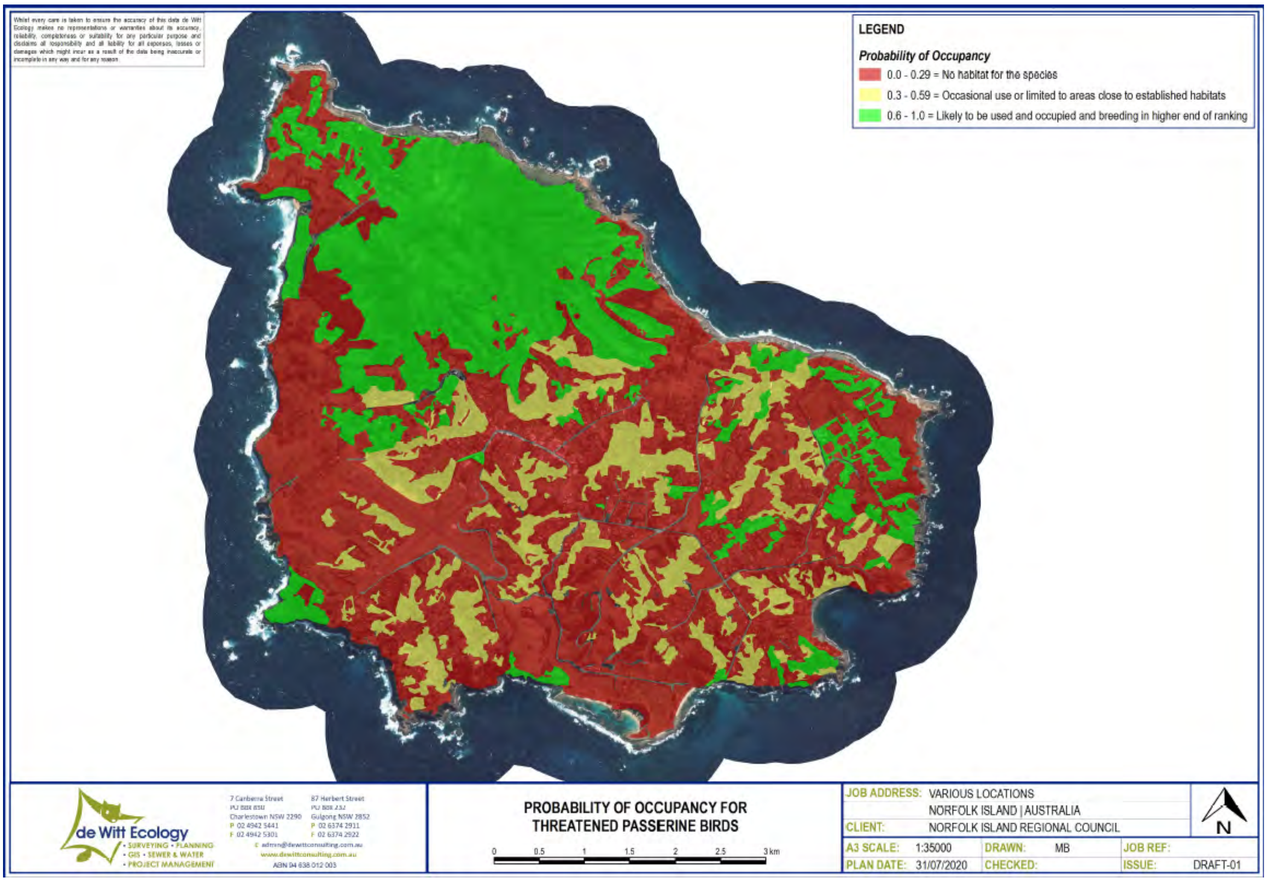


Figure 3.26: Probability of Occupancy for Threatened Passerine Birds

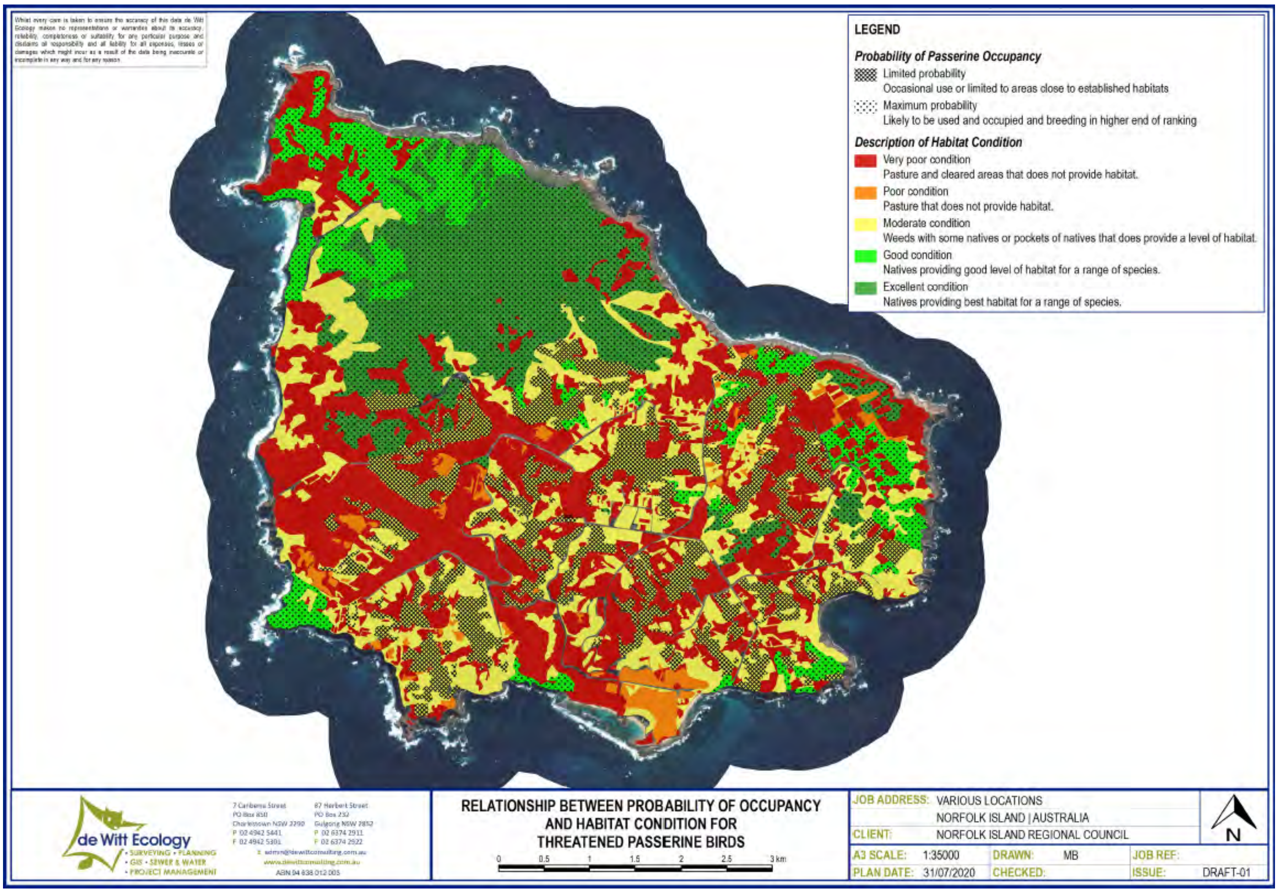


Figure 3.27: Relationship between Probability of Occupancy and Habitat for Threatened Passerine Birds

1.4.8 CONCLUSION

Due to the limited budget for this project only a broad analyses of Vegetation and Catchment condition for Norfolk Island has been provided in assessing the Island's ecosystem, biodiversity, and the requirements for ecological sustainability. Based on satellite imagery and analyses using SVM approaches, Vegetation and Catchment condition maps have been provided. The use of drone surveys improved resolution of images captured and also provided additional information using NDVI and DTM outputs.

Modelling shows that three disturbance classes (Classes 1, 2, and 3) cover 2192 ha of land area on Norfolk Island, or approximately 64% of land area (excluding major roads and shorelines). The worst condition class (Class 1) includes open grass areas that are degraded with evidence of sheet and gully erosion. Impacts from trampling, grazing, farming and vegetation management have a strong correlation with this class.

Probability of occupancy for 4 threatened bird species have been presented based on catchment and vegetation condition. This provides a platform for monitoring changes in bird population, and/or changes in probability of occupancy to future changes in land use.

Existing projects (Mills, 2018; Naomi Christian Consulting, 2020) are addressing the *Norfolk Island Environment Strategy* and will provide a transparent, open-access to vegetation mapping for all of Norfolk Island. Mills (2018) provides a robust way forward:

"The first steps in the mapping project require careful consideration as these are critical to how the project will progress and meet its aims. The following are offered as initial considerations for starting of project in November 2018:

1. Review existing mapping (geology, soils, topography, vegetation) and what use can be made of this.

2. Identify plant community types and those that will be used as mapping units.

3. Test the use of the mapping units on several sites.
4. Finalise mapping units and produce a field guide.
5. Prepare base map (aerial) for mapping purposes.
6. Prepare field maps.
7. Undertake local publicity about the project and encourage participation by the community".

This project is already in progress however, while the authors are unsure of current status, continuation of this project in perpetuity is a recommendation from this report.

Summary/Findings

- Decreasing rainfall, increasing evaporation, and increasing temperatures characterise the future climate of Norfolk Island.
- Rainfall not uniformly distributed over Norfolk Island.
- Increasing sea levels.
- Decline in reef integrity.
- Highly dispersive clay soils (in absence of vegetation cover).
- 2,192ha of Norfolk Island (total of 3,460ha) classed as moderate to very poor catchment condition.
- Higher classes of disturbance condition (less disturbed) mostly comprise reserve areas and coastal areas with hardwood forests, and the National Park with some small pockets in the east. This area of 633ha of vegetation provides the most significant area of habitat on Norfolk Island.
- The relatively high correlation of lower biodiversity with disturbed lands is a common issue, also resulting in land degradation in sensitive areas.
- There are 52 exotic "weed" species on Norfolk Island.
- Approximately 80% of the endemic flora species on Norfolk Island are threatened under the provisions of the EPBC Act, and the Norfolk Island pine (Araucaria heterophylla) is on the International Union for Conservation of Nature Red List of Threatened Species.
- Only 10ha of cultivated land exists in 2020, down from ~460ha in the 1830's.
- Woody weeds dominant on previously cultivated land left unused.

Recommendations

- Improve reef integrity – studies investigating the potential of "re-seeding" existing coral reef systems using a range of artificial reef-based systems.
- Marine surveys – temporal and spatial in various areas within the Norfolk Island Marine Park. Topics may include monitoring reef restoration efficacy, shark movements/numbers and/or studies on other species of interest.
- Coast Watch initiatives involving litter clean-up days and other community activities that promote reef improvement.

- Effective implementation of the *Norfolk Island Coastal Management Plan* (Chapter 7, Table 7-2 in particular).

- Livestock management projects – these may include investigating the use of E-Shepherd collars (these act as "virtual fencing" and significantly reduce the cost of fencing and cattle grids).

- Undertake pest and weed eradication projects.

- Utilise LANDCARE initiatives involving weed removal days and other community activities that promote sustainable living.

- Use of solar pumps to offset livestock watering points in the landscape (reduces soil erosion).

- Develop a strategy/ action plan to improve land cultivation /productivity, applying best practices in regenerative farming and integrated landscape management that focus on resource efficiency, land and ecosystems regeneration, soil organic carbon, agrobiodiversity and crop diversification.

- Develop a strategy to restore "disturbed" environments of low catchment condition, at a small-scale, at first, and include a range of approaches such as planting projects and drainage line restoration to reduce erosion. Satellite imagery or drone images can been used to monitor changes/improvements over time.

- Connect all biodiversity/ecology programs undertaken on island with the Norfolk Island Flora & Fauna Plan, and provide a knowledge-sharing platform for current flora and fauna experts, National Parks & Marine Parks staff and other interested individuals.

- Promote community awareness and education, via e.g. developing online tools, citizen science projects, 4G apps. For example, "iNaturalist" as a global flora and fauna app could support citizen science on Norfolk Island.

CHAPTER 2: HYDROLOGICAL ASSESSMENT AND PRELIMINARY WATER BALANCE

For the assessment of the water balance of Norfolk Island, it is necessary to quantify how much water enters, is used and leaves the island. Water enters Norfolk Island in the form of rain. Rain falls and either is evaporated, recharges the groundwater, runs over the surface finding its way to the sea or is stored for further use.

Water in the island is used in various ways. It is drawn from rain tanks for household or commercial consumption and pumped from surface water ponds and groundwater for livestock drinking, irrigation and human consumption.

Research was conducted in order to estimate and quantify the different fluxes of the water balance for Norfolk Island. These were estimated for the catchments that compose the Island for a better spatially-distributed understanding of the water balance.

2.1 CATCHMENTS OF NORFOLK ISLAND

Available topographic information of the island corresponds to a five meters contours map. A Digital Elevation Map (DEM) was created from the contour lines with a 15 m cell resolution using ArcGIS tools. Both maps are shown in Figure 2.1 below.

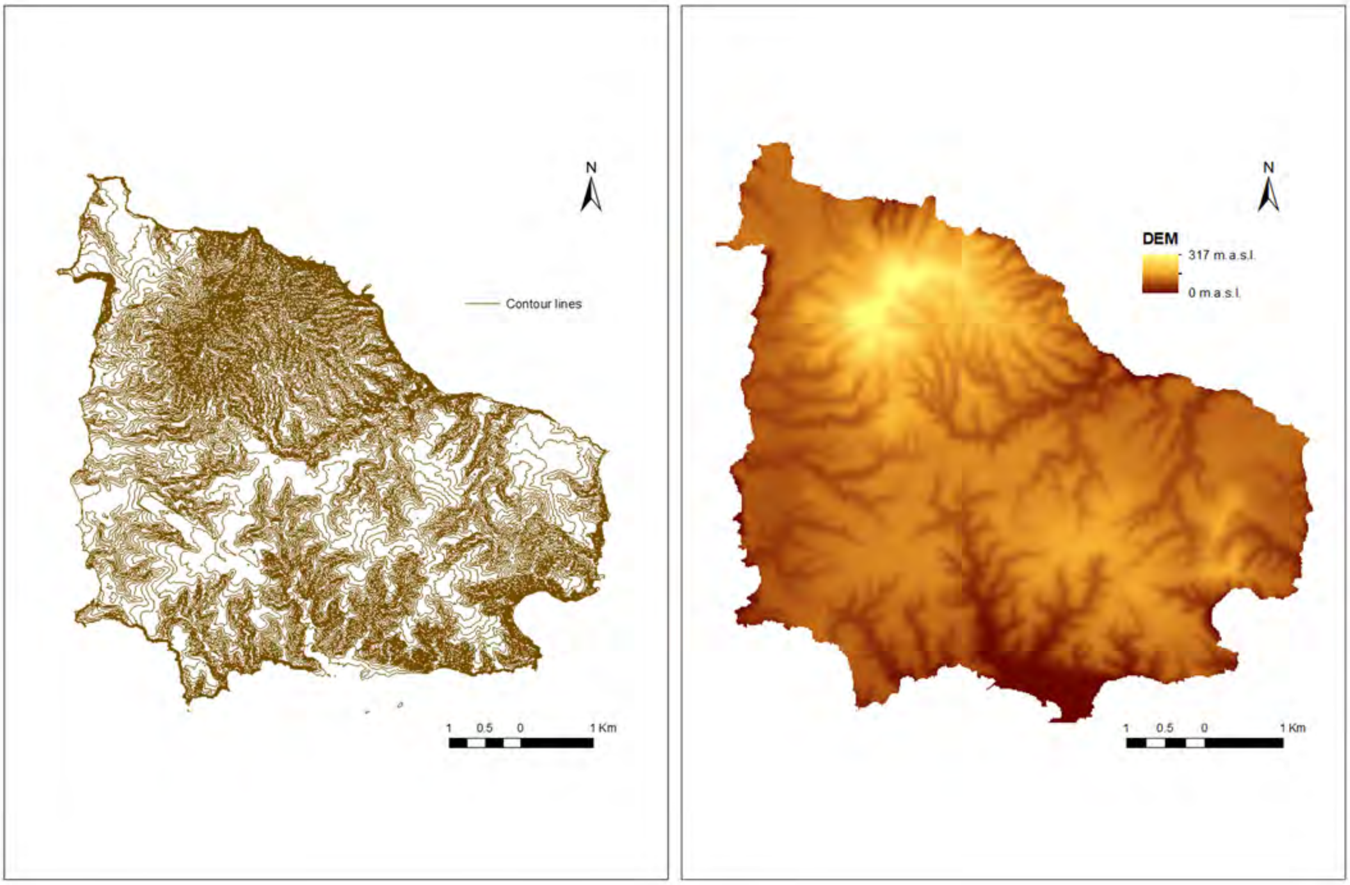


Figure 2.1: 5m-contour line and 15m resolution Digital Elevation Map.

Using the created DEM, 48 catchments were delineated in Norfolk Island. They are presented in Figure 2.2 and Table 2.1.

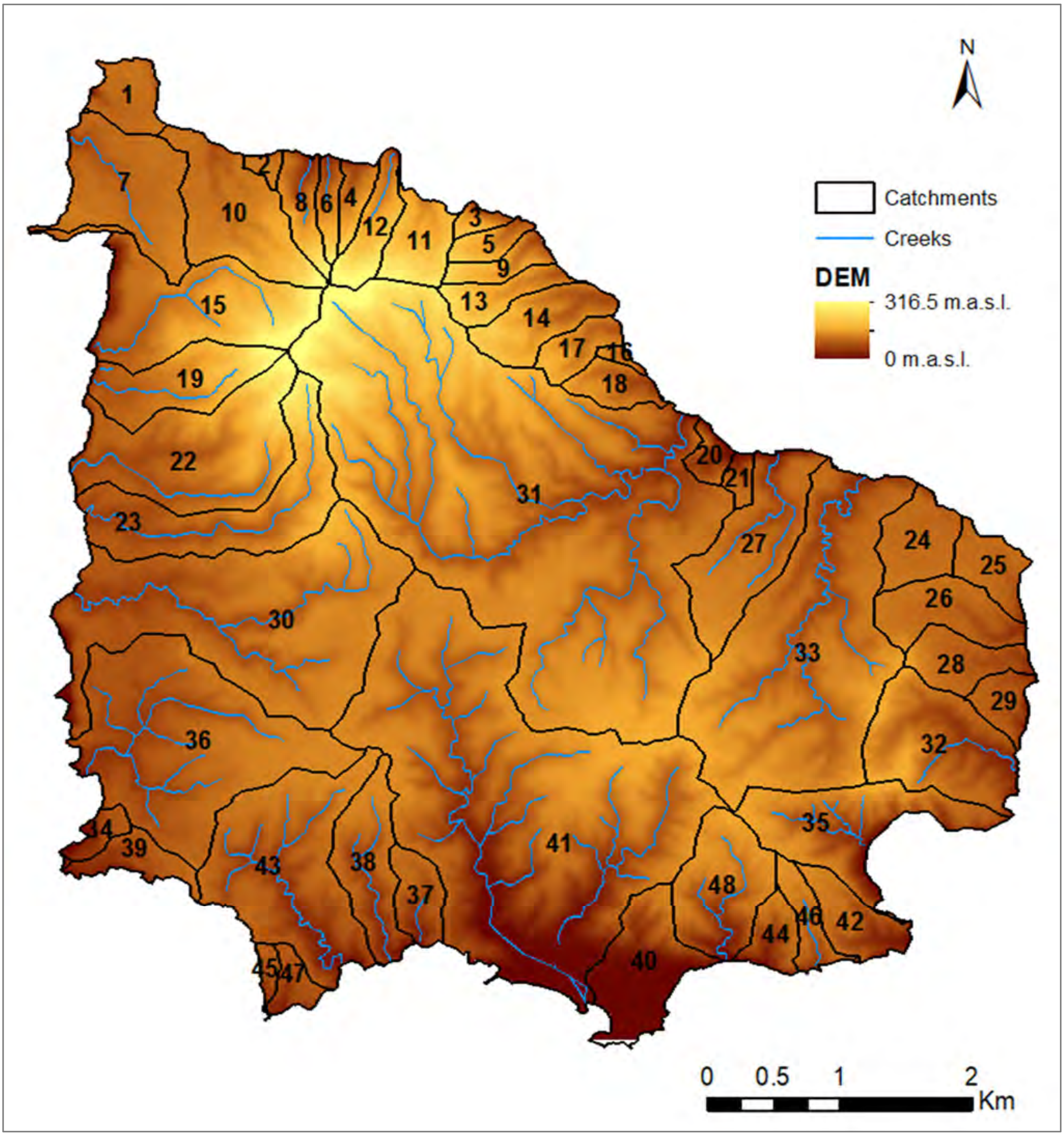


Figure 2.2: Delineated catchments.

Table 2.1: Delimited catchment areas.

Catchment ID	Name	Area (km2)
1		0.239
2		0.048
3		0.066
4		0.129
5		0.122
6		0.120
7		0.808
8		0.214
9		0.155
10		0.724
11		0.299
12		0.260
13		0.219
14		0.378
15		1.070
16		0.034
17		0.188
18		0.185
19		0.539
20		0.105
21		0.073
22		1.178
23		0.979
24		0.344
25		0.238
26		0.420
27		0.767
28		0.299
29		0.173
30	Mission creek	2.492
31	Cascade creek	6.405
32		0.821
33	Stockyard creek	2.578
34		0.106
35		0.791
36	Headstone creek	1.937
37		0.234
38		0.513
39		0.211
40		0.597
41	Watermill creek	4.695
42		0.299
43	Rocky point creek	1.349
44		0.188
45		0.057
46		0.189
47		0.126
48		0.628

2.2 WATER IN: RAINFALL

There are seven meteorological stations with recorded daily rainfall data operated by the Bureau of Meteorology (BOM, 2019) (Figure 2.3, Table 2.2). Only three of them, indicated in green in Figure 2.3, are currently active.

Table 2.2: BOM meteorological stations.

BOM code	Name	Rainfall	Temp.	Latitude	Longitude	Elevation (m)	Status	Start	End
200264	Steels Point	X		-29.0333	167.9833	108	Closed	2000	2018
200288	Airport	X	X	-29.0389	167.9408	112	Active	1890	
200334	Ball Bay	X		-29.0443	167.9798	115	Closed	1999	2019
200367	Duncombe Bay	X		-29.0015	167.9291	90	Closed	2000	2009
200374	Kingston	X		-29.0567	167.9643	12	Active	1998	
200825	Cascade	X		-29.036	167.9708	130	Active	1979	
200849	Comparison	X	X	-29.0428	167.9344	107	Closed	1997	1999

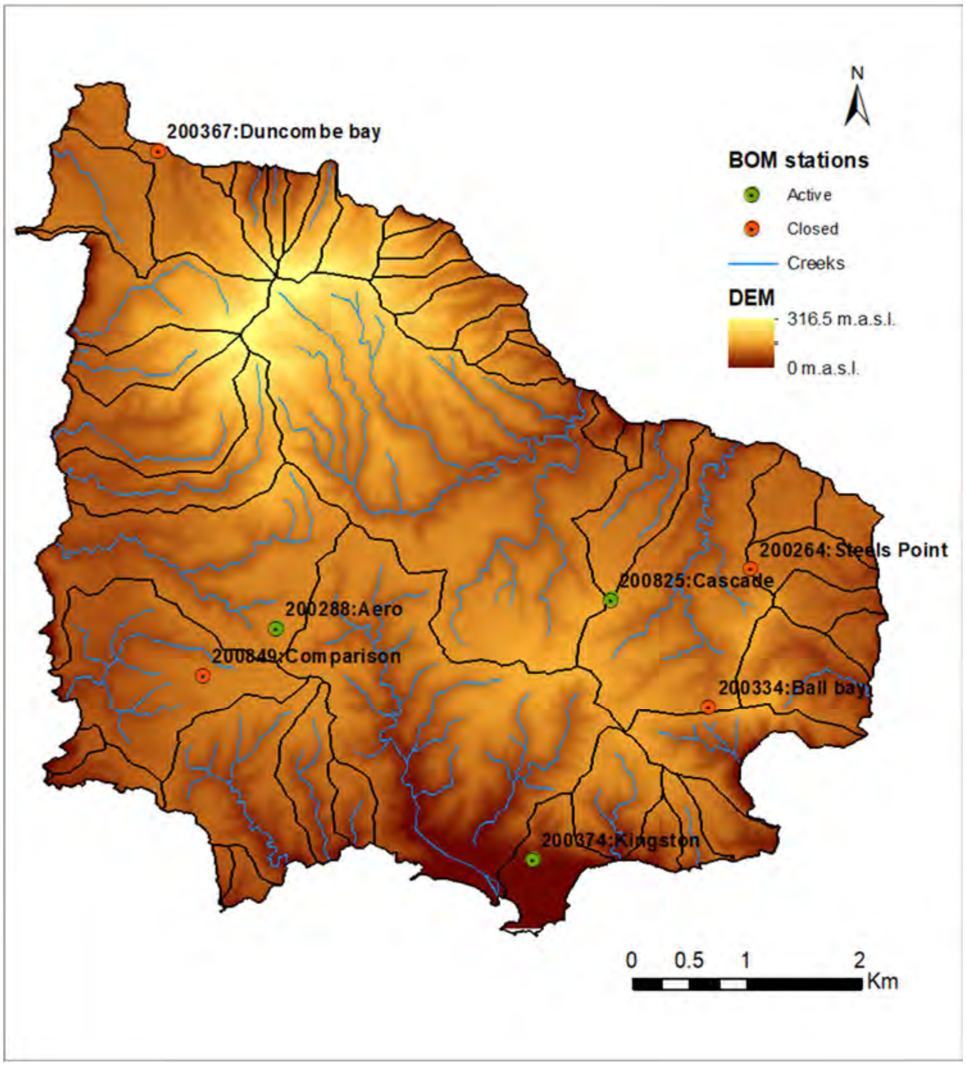


Figure 2.3: BOM meteorological stations.

The number of days with rainfall data are presented in Table 2.3(a) for each year in the period 1999 to 2019. Highlighted in red are those years with less than 350 days data. Table 2.3(b) corresponds to annual rainfall in (mm) for those years (with more than 349 days data).

Table 2.3: (a) Days with rainfall data. (b) Annual rainfall (mm). Period 1999 – 2019.

BOM code	Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
200264	Steels point		366	342	365	365	366	365	365	365	366	365	364	365	366	364	324	365	366	360	304	
200288	Airport	365	366	365	365	365	366	365	365	365	366	365	365	365	366	365	365	365	366	365	365	365
200334	Ball Bay	201	346	341	365	365	366	365	365	365	366	365	365	365	366	363	365	365	364	365	364	181
200367	Duncombe bay		235	170	30	334	121			182	333	119										
200374	Kingston	358	365	362	360	365	366	365	365	364	365	343	361	355	362	364		365	363	364	300	59
200825	Cascade	365	366									213	365	307	306	364	365	365	334	306	365	304
200849	Comparison	120																				

(a)

BOM code	Name	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Average
200264	Steels point		869		1350	1023	867	775	953	1115	1565	965	779	1727	1280	858		862	1244	792			1064
200288	Airport	1304	849	1201	1309	1010	847	822	1063	1198	1580	901	783	1766	1283	997	1101	938	1419	779	1056	923	1101
200334	Ball Bay				1351	1113	903	833	1006	1163	1601	906	816	1799	1380	879	1069	886	1257	765	985		1101
200367	Duncombe bay																						
200374	Kingston	1337	757	1102	1099	957	791	767	1000	1042	1570		607	1497	1092	797		783	1238	696			1008
200825	Cascade	1351	895										838			956	1099	962			1083		1026
200849	Comparison																						

(b)

Station 200288 (Airport) has the most complete record. Stations 200264 (Steels Point), 200334 (Ball Bay) and 200374 (Kingston) have more than 15 years of recorded rainfall for the period 2000 to 2019.

Figure 2.4 shows the comparison of simultaneous daily records for the entire period of available data for the stations located in the north-east of the island: Steels Point; Ball Bay and Cascade. Recorded daily rainfall is fairly consistent among the three locations with those stations located closer to the coast, namely Steels Point and Ball Bay (Figure 2.4a), having the better agreement.

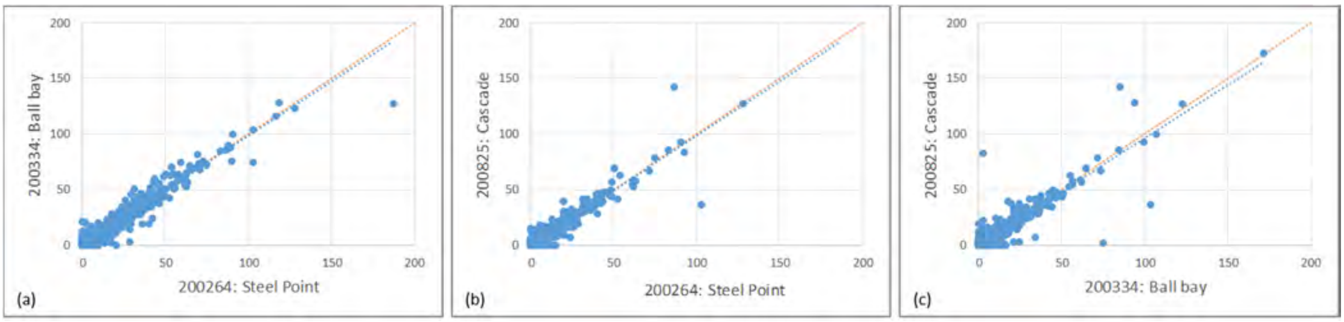


Figure 2.4: Comparison of simultaneously recorded daily rainfall at stations located in the north-east of the island. (a) Steel Point and Ball Bay station; (b) Steel Point and Cascade stations; (c) Ball Bay and Cascade stations.

Figure 2.5 compares recorded daily rainfall at Airport station (200288) with those at the north-east (Steels Point, 200825: Figure 2.5a; Ball Bay, 200334: Figure 2.5b; Cascade, 200825: Figure 2.5c), the north-west of the island (Duncombe Bay, 200367: Figure 2.5d) and at the south-east (Kingston, 200374: Figure 2.5e) of the island.

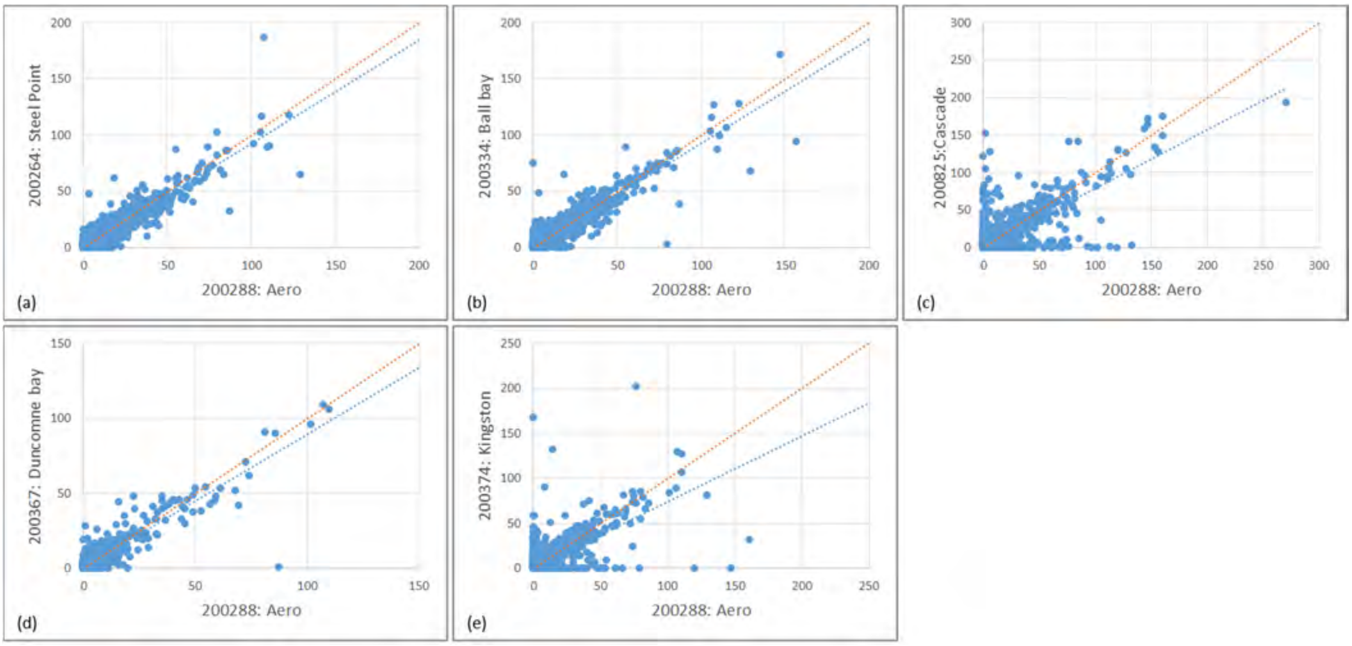


Figure 2.5: Comparison of simultaneously recorded daily rainfall between Airport station and (a) Steel Point; (b) Ball Bay, (c) Cascade, (d), Duncombe Bay and (e) Kingston stations.

From Figure 2.5 it is seen that daily rainfall measured at Airport station has a better agreement with that measured at Steels Point (Figure 2.5a), Ball Bay (Figure 2.5b) and Duncombe Bay (Figure 2.5d) than with rainfall measured at Cascade and Kingston stations (Figure 2.5c and 2.5d respectively), for the days that recorded at both compared stations. Daily rainfall at Airport station appears to be higher than at the other locations, this difference being larger for Kingston station (Figure 2.5e).

Stations Airport, Ball Bay and Kingston stations have the more complete data for the period 1999 to 2019 and are considered representative of rainfall over Norfolk Island. Missing data were filled in using measurements in near stations with the best correlation.

Selected stations were allocated to the delineated catchments based on their proximity to the centroid of each catchment. Correspondences are presented in Table 2.4 and Figure 2.6.

Table 2.4: Delineated catchments and their corresponding stations.

Catchment	Corresponding Meteo Station
1 - 19, 22, 23, 30, 31, 34, 36, 38, 39, 43, 45, 47	Airport (200288)
20, 21, 24 - 29, 32, 33, 35, 42, 46	Ball Bay (200334)
37, 40, 41, 44, 48	Kingston (200374)

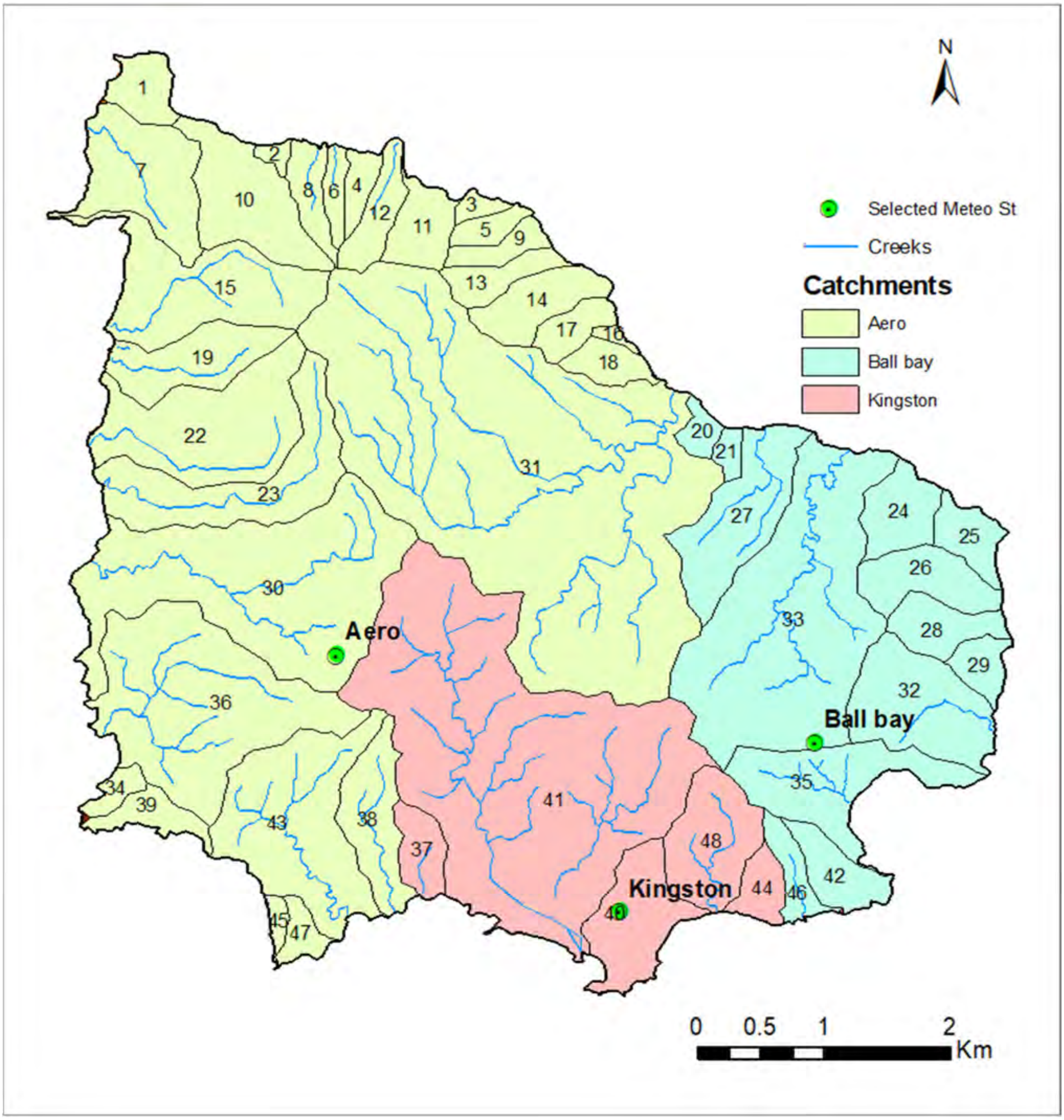


Figure 2.6: Defined areas of influence of selected Meteorological Stations.

Average rainfall years for the period 1999-2019 for the three selected stations: Airport, Ball Bay and Kingston and the representative rainfall for the island are presented in Table 2.5 and Figure 2.7. Appendix 1 presents the average rainfall per catchment for the period 1999-2019 in kL.

Table 2.5: Annual and Monthly Average rainfall. Period 1999-2019.

Rainfall (mm)	1	2	3	4	5	6	7	8	9	10	11	12	Year
Airport (200288)	92	103	101	89	106	118	114	101	73	50	67	87	1101
Ball Bay (200334)	88	102	95	89	106	117	116	103	79	52	66	85	1098
Kingston (200374)	76	95	83	81	96	106	108	98	68	47	62	79	999
Norfolk Island	88	101	96	88	104	115	113	101	73	50	66	85	1080

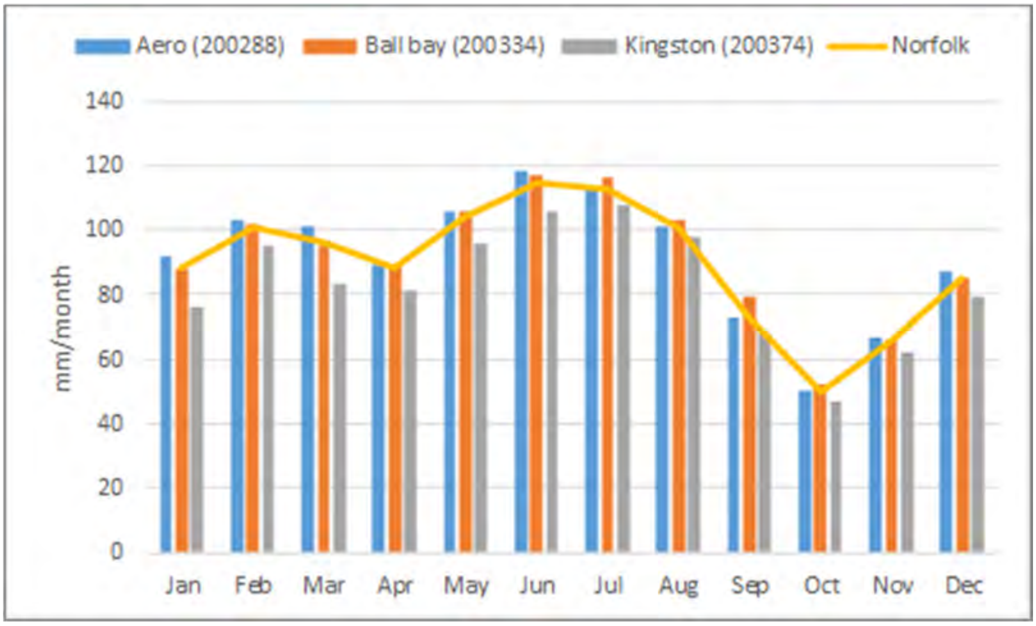


Figure 2.7: Average rainfall years for the Meteorological stations Airport, Ball Bay and Kingston. Period 1999-2019.

2.3 WATER USE (WU)

2.3.1 HOUSEHOLD WATER USE

To distribute household demand and consumption throughout the catchments, visible dwellings using available aerial photographs were counted. These results were adjusted using data from the 2016 census that reported 1080 private dwellings (ABS, 2019). Table 2.6 shows the distribution of households throughout the delimited catchments.

Table 2.6: Number of houses per delimitated catchments.

Catchment ID	Name	Number dwellings
1		3
2		1
3		0
4		0
5		0
6		0
7		15
8		0
9		1
10		16
11		0
12		0
13		1
14		7
15		4
16		3
17		5
18		4
19		1
20		0
21		1
22		5
23		15
24		20
25		10
26		22
27		35
28		22
29		8
30	Mission creek	69
31	Cascade creek	206
32		66
33	Stockyard creek	132
34		0
35		29
36	Headstone creek	40
37		9
38		36
39		10
40		7
41	Watermill creek	135
42		14
43	Rocky point creek	51
44		14
45		5
46		15
47		5

48		38
Total		1080

The Australian Bureau of Statistics reports 1,748 people living in Norfolk Island according to the 2016 census (ABS, 2019). Dividing the total number of people with the number of dwellings, we obtain an average number of people per household of 1.6. In NSW, the average water consumption per capita is 201 L/d. Based on that value, household water demand per catchment was calculated according to the number of households per catchment and the days per month, assuming it is constant throughout the year. Results are presented in Appendix 2, and Table 2.7 below presents total water demand for the island.

Table 2.7: Monthly household water demand in Norfolk Island (kL).

Total dwellings	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1080	10,772	9,723	10,772	10,422	10,772	10,422	10,772	10,772	10,422	10,772	10,422	10,772

Minimum rainwater storage capacity requirements in Norfolk Island are set as a storage of 44,000 L and a roof area of 150 m^2 for a household up to four bedrooms (DCP No2, 2011). Using the stated assumptions, an average household was defined as having 1.6 people living in it, a rain water tank of 44,000 L and a roof area of 150 m^2. The water storage of an average household was calculated assuming the three rainfall time series from Airport, Ball Bay and Kingston meteorological stations. Results are presented in Figure 2.8.

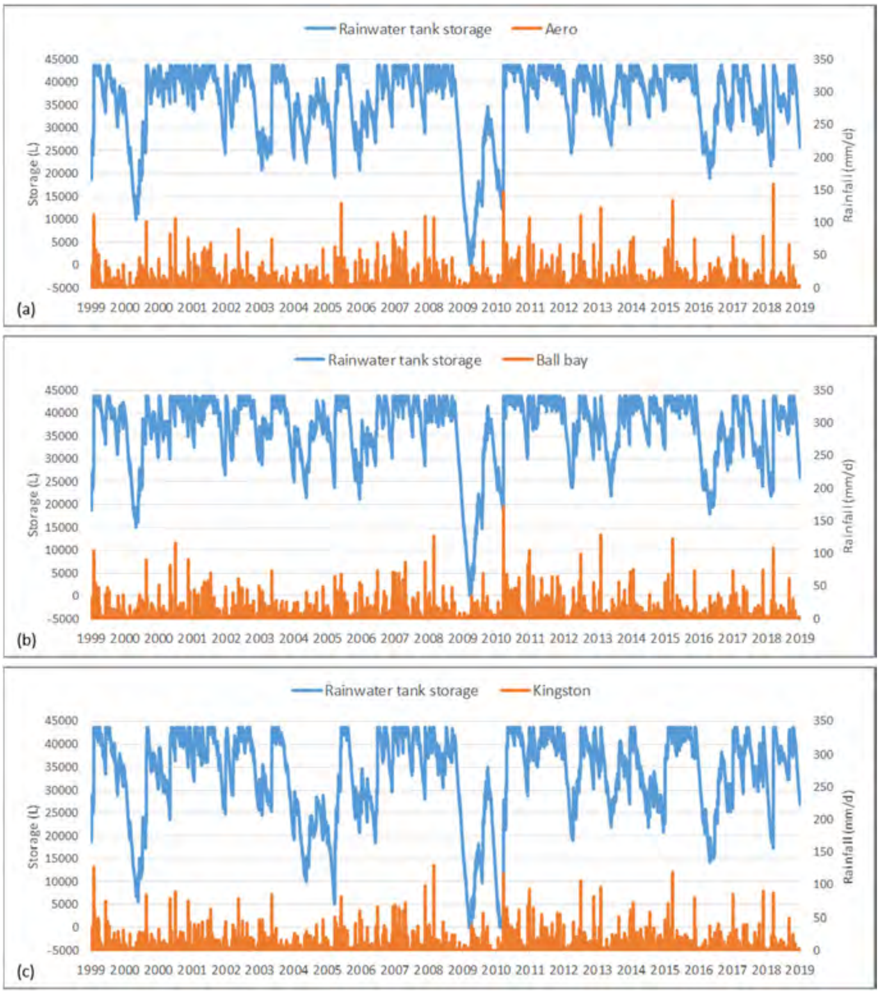


Figure 2.8: Rainwater tank storage daily simulation for an average household. Period 1999-2019. (a) Airport meteorological station rainfall, (b) Ball Bay meteorological station rainfall, and (c) Kingston meteorological station rainfall.

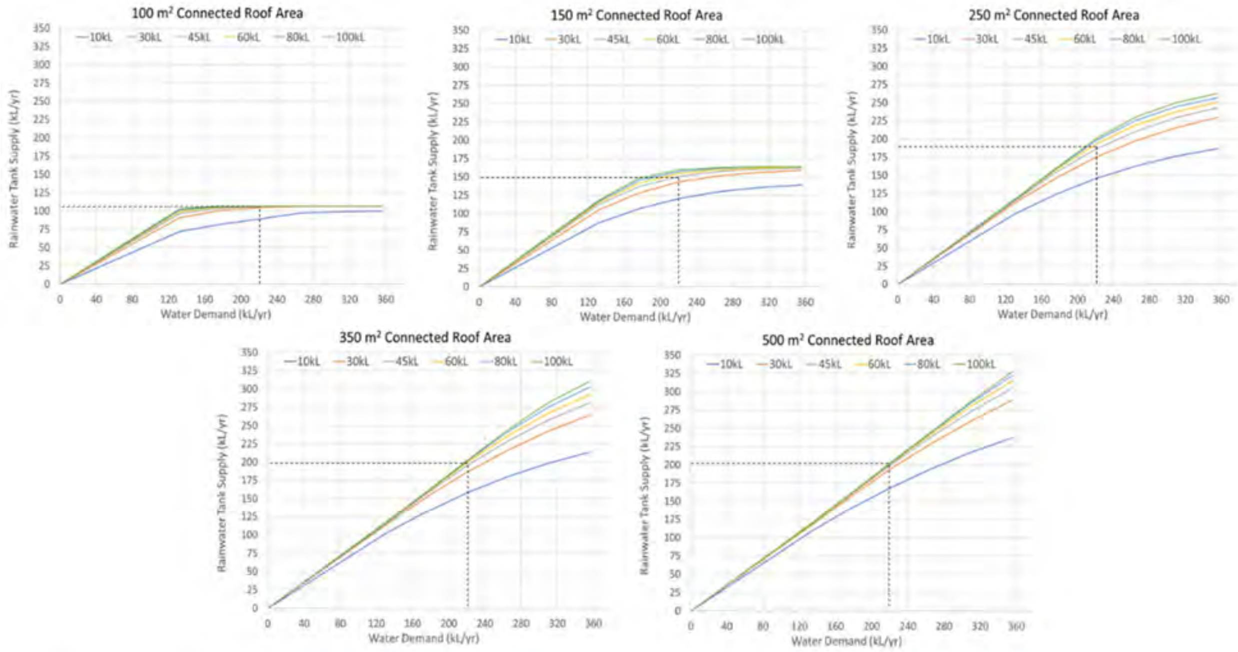
Figure 2.8 shows that in dry summers, as those of 2010 and 2011, rainwater tanks become empty. Those months' water demand is not fully satisfied going down to 70% in the south west of the island. These calculations are only representative for the assumed average household (1.6 people, 150 m^2 of roof area and a rainfall storage capacity of 44,000 L).

Household water consumption per catchment was calculated using the consumption of an average household and the number of households per catchment and it is considered as the water that effectively enters household rainwater storage in each catchment. Results per catchment are presented in Table A.3 and Table A.4 in (kL) and equivalent (mm) over the island respectively in Appendix 1, and in Table 4.3 below for the island.

Table 2.8: Total household water simulated consumption in Norfolk Island and rainfall percent for average year. Period 1999-2019.

Month	(kL)	(mm)	% island rainfall
Jan	10,009	0.29	0.33
Feb	8,686	0.25	0.25
Mar	11,832	0.34	0.35
Apr	10,878	0.31	0.35
May	11,898	0.34	0.33
Jun	13,069	0.38	0.33
Jul	11,927	0.34	0.3
Ago	12,123	0.35	0.35
Sep	9,627	0.28	0.38
Oct	7,659	0.22	0.44
Nov	9,208	0.27	0.41
Dec	9,973	0.29	0.34
Annual	126,908	3.66	0.34

To investigate the relationship between Norfolk Island rainfall depth/patterns, roof area, tank volume, and water demand over time, the Probabilistic Urban Rainwater and wastewater Reuse Simulator (PURRS) was used to continuously simulate rainwater harvesting systems. PURRS was developed by Dr Peter Coombes of Urban Water Cycle Solutions (UWCS, 2019) and is a robust model used in water system research. Rainfall input data was at 6-minute timesteps from the 1/1/1949 to the 31/12/2018 and was sourced from Norfolk Island Airport. Roof areas simulated included 100 m^2, 150 m^2, 250 m^2, 350 m^2, and 500 m^2. Tank volumes simulated included 10 kL, 30 kL, 45 kL, 60 kL, 80 kL, and 100 kL. In the absence of actual water meter data, water demand used in the simulation were estimated on an increasing household water demand (presented as kL/yr, L/person/day and number of people at the bottom of Figure 2.9). Figure 2.9 summarises the results from these simulations.



Water demand input data used in PURRS

Water Demand (kL/yr)	131.9	176.6	221.3	266.1	310.9	355.6
L/person/day	361.3	242.0	202.1	182.3	170.3	162.4
Number of People	1	2	3	4	5	6

Figure 2.9: Summary of PURRS results indicating rainwater efficiency based on input rainfall, connected roof areas, tank volume and water demand

The black dotted line represents a "water demand" of 220 kL/yr (x-axis) and where it joins with a tank volume of 45 kL, and the rainwater yield (y-axis); and it can be observed that as roof area gets larger so does rainwater yield for the given demand. An optimised rainwater harvesting system will lie somewhere on one of these graphs depending on water demand from the dwelling.

There are several key observations from Figure 2.9:

- Smaller roof areas (< 150 m^2) are catchment limited, indicating that roof area is more significant than tank volume in providing household water demand;
- Larger roof areas (> 250 m^2) are water demand limited and tank volume can vary;
- Knowledge of water demand will drive the optimisation of both connected roof area and tank volume
- Knowing the water demand from any water source depends on reliable and accurate monitoring of water use and water metering on Norfolk Island is a recommendation.

2.3.2 VISITOR ACCOMMODATIONS

Each month more than 2,000 visitors arrive to Norfolk Island and they stay an average of 7 days. Thus, on any given day there are approximately 600 visitors adding to the 1,748 residents of the island. Therefore, water consumption related to tourism is important for the island water balance.

For a better understanding of the distribution of tourism water demand, existing tourist accommodations were assigned to catchments according to their location. Accommodations considered are those of the Registered Tourist Accommodation Properties document (NIRC, 2019a). Table 4.4 presents the accommodation distribution per catchment, and Table A.5 in Appendix 1 presents detailed data for each accommodation property. Roof areas and rainwater storages were obtained from surveys of available water sources for operating accommodations completed in January 2002. These results were considered currently valid, and extensions or new developments (considered as those properties listed in the Registered Tourist Accommodation properties but not surveyed in 2002) were added as having the minimum rainwater storage requirements (DCD No2, 2011). Minimum rainwater storage capacity requirements are 32,500 L per bedroom for new developments and extensions, and 80 m^2 and 50 m^2 per bedroom for new developments and extensions respectively. A bedroom was considered as having two beds.

Table 2.9: Accommodation distribution per catchment.

Catchment	Number of Beds	Total Roof Area (m2)	Total Storage(L)
10	38	960	247,386
15	4	160	65,000
23	22	637	272,265
24	24	1,064	474,384
27	10	400	162,500
30	101	4,055	1,526,700
31	724	23,821	7,300,369
32	34	1,424	503,550
33	62	1,342	736,072.5
36	7	240	97,500
38	45	1,760	715,000
41	529	18,320	6,120,740
43	24	1,005	357,755
44	55	1,794	571,680
46	6	240	97,500
48	46	1,260	289,552.5
Location not identified	24	880	357,500
TOTAL	1,755	59,362	19,895,454

2.3.3 WATER DEMAND

The water demand of visitors was determined by using official data about the arrival of visitors into Norfolk Island each month since 2000 to 2016 (NIRC, 2019b). Missing months and years were filled in with average values. According to these data, the visitors normally stay 7 days in the island, therefore the official records of number of visitors per month were evenly distributed into each week. Figure 2.10 presents the number of visitors in an average year, representing the period 1999 – 2019.

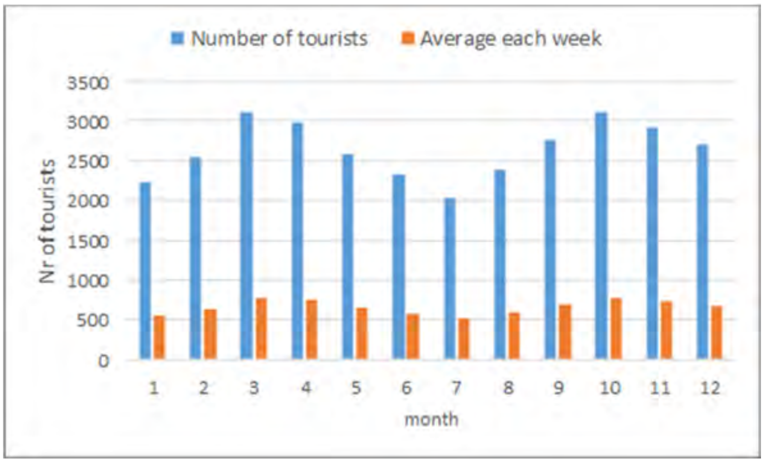


Figure 2.10: Monthly arrival of visitors to Norfolk Island in an average year (Data for period 1999 – 2019).

Assuming all visitors stay in tourist accommodations, and because the preference of visitors for choosing accommodation cannot be controlled, the number visitors were proportionally distributed into the available accommodation properties using Eq. 1. Results for an average year per catchment are presented in Table 4.5. Accommodations that could not be located were excluded from the distribution.

$$Avg. nr. tourists\ at\ any\ point\ in\ time\ in\ the\ catchment = \frac{Nr\ of\ beds\ in\ catchment}{Total\ nr\ of\ beds\ available} \times \frac{Monthly\ tourists}{4} \quad \text{(Eq.1)}$$

Table 2.10: Assumed monthly distribution of visitors per catchment. Using data period 1999 – 2019.

	Nr. visitors	558	637	779	745	648	580	510	596	692	780	729	678
Catch.	Nr. beds	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10	38	12	14	17	16	14	13	11	13	15	17	16	15
15	4	1	1	2	2	1	1	1	1	2	2	2	2
23	22	7	8	10	9	8	7	6	8	9	10	9	9
24	24	8	9	11	10	9	8	7	8	10	11	10	9
27	10	3	4	5	4	4	3	3	3	4	5	4	4
30	101	33	37	45	43	38	34	30	35	40	46	43	40
31	724	233	266	326	312	271	243	213	249	289	326	305	284
32	34	11	13	15	15	13	11	10	12	14	15	14	13
33	62	20	23	28	27	23	21	18	21	25	28	26	24
36	7	2	3	3	3	3	2	2	2	3	3	3	3
38	45	15	17	20	19	17	15	13	15	18	20	19	18
41	529	171	195	238	228	198	177	156	182	211	238	223	207
43	24	8	9	11	10	9	8	7	8	10	11	10	9
44	55	18	20	25	24	21	18	16	19	22	25	23	22
46	6	2	2	3	3	2	2	2	2	2	3	3	2
48	46	15	17	21	20	17	15	14	16	18	21	19	18

From Table 2.10, tourist accommodations are concentrated in Cascade creek catchment (31) and Watermill catchment (41). The average water consumption per guest night in Australia is 313 L/d (Moore, 2015). Using this value the water demand in kL per catchment was calculated and is presented in Table 2.11.

Table 2.11: Visitors' average monthly water demand per catchment (kL). Using data period 2000-2016.

Catch.	Number of Beds	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
10	38	117	126	169	151	140	120	108	126	142	170	148	145	1,661
15	4	11	12	19	17	13	12	11	12	16	18	16	16	172
23	22	69	72	96	89	80	68	62	71	83	96	89	84	958
24	24	75	80	105	95	88	76	68	80	91	106	96	91	1,050
27	10	31	34	46	39	37	30	29	32	37	45	40	38	439
30	101	316	334	441	399	368	321	288	339	382	443	396	383	4,409
31	724	2,264	2,384	3,158	2,905	2,649	2,278	2,060	2,422	2,727	3,173	2,861	2,757	31,636
32	34	107	112	153	137	122	104	99	112	123	153	138	125	1,484
33	62	195	205	271	246	228	193	176	207	233	273	246	234	2,705
36	7	22	24	30	28	27	22	20	22	27	30	29	26	305
38	45	143	149	195	179	166	141	128	153	170	196	179	173	1,970
41	529	1,656	1,748	2,312	2,113	1,942	1,668	1,513	1,764	1,990	2,321	2,097	2,014	23,139
43	24	72	77	105	98	86	76	69	79	91	106	93	92	1,041
44	55	172	181	239	220	200	172	155	184	207	241	220	208	2,399
46	6	19	19	27	25	21	18	18	20	22	27	25	22	261
48	46	144	152	202	184	169	143	134	154	171	202	181	175	2,010
Total	1,731	5,412	5,710	7,565	6,924	6,335	5,441	4,935	5,776	6,512	7,598	6,852	6,582	75,639

2.3.4 WATER CONSUMPTION

Similarly to household water use, water consumed by the visitors was simulated daily for the period 1999 to 2019 per catchment considering the total roof area and storage capacity of the accommodations located in each catchment. As for household consumption, and per the water balance, tourist rainwater consumption was considered as the rain water effectively entering the storage tanks. Results are presented in Table 2.12 in (kL) and in equivalent (mm) over the island for an average year for the period 1999-2019 (Table A.6 in Appendix 1) for the catchments with tourist accommodations.

Table 2.12: Rainwater consumed by tourist accommodations per catchment (kL) and equivalent (mm) for Norfolk Island. Average year for period 1999-2019.

Month	(kL)	(mm)	% island rainfall
Jan	4,866	0.14	0.16
Feb	4,975	0.14	0.14
Mar	5,009	0.14	0.15
Apr	4,735	0.14	0.16
May	5,920	0.17	0.16
Jun	6,332	0.18	0.16
Jul	6,274	0.18	0.16
Ago	5,362	0.16	0.16
Sep	3,985	0.12	0.16
Oct	2,870	0.08	0.16
Nov	3,814	0.11	0.17
Dec	4,846	0.14	0.16
Annual	58,990	1.7	0.16

The pattern of rainfall is different than that of tourist water demand, rainwater stored in tourist accommodation tanks is consumed at a different rate than the filling up of the same tanks. Table 2.13 summarizes these simulation results, it presents water demand, rainwater collected rainwater actually consumed (used from the rainwater storage tank), and remaining water demand (not fulfilled with stored rainwater) for tourist accommodations in the island for an average year, period 1999-2019. Table A.7 in Appendix 1 presents results per rainwater actually consumed by tourist accommodations and remaining water demand for the catchments with tourist accommodations.

Table 2.13: Summary of simulated results for tourist accommodations in Norfolk Island. Average year for period 1999-2019.

Month	Water demand	Rainwater collected	rainwater consumed	Remaining water demand	% satisfied water demand
Jan	5,412	4,866	4,316	1,096	80
Feb	5,710	4,975	4,174	1,536	73
Mar	7,565	5,009	5,319	2,246	70
Apr	6,924	4,735	4,900	2,023	71
May	6,335	5,920	5,344	991	84
Jun	5,441	6,332	5,148	293	95
Jul	4,935	6,274	4,785	150	97
Ago	5,776	5,362	5,380	395	93
Sep	6,512	3,985	5,971	540	92
Oct	7,598	2,870	5,950	1,648	78
Nov	6,852	3,814	4,050	2,801	59
Dec	6,582	4,846	4,130	2,451	63
Year	75,639	58,990	59,469	16,170	79

Simulated results presented in Table 4.8 show that tourist accommodation's water demand is not fully satisfied by rainwater storage. This is especially the case from November to April. According to the survey of 2002, more than half of tourist accommodations have a bore or a well. Therefore, it is estimated that the remaining water demand is satisfied with groundwater extraction.

Figure 2.11 summarizes simulated results of an average year for the period 1999-2019 for Norfolk Island. Figure A.1 in Appendix 1 presents simulated tourist accommodation's results per catchment.

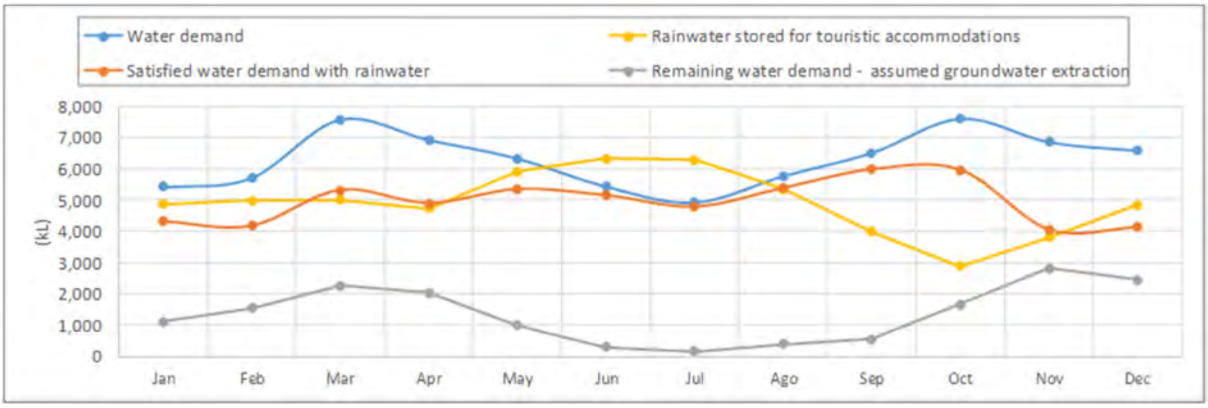


Figure 2.11: Simulated results for tourist accommodations. Average year period 1999 – 2019.

2.4 LIVESTOCK WATER CONSUMPTION

GHD (2016) estimated the total cattle number to be between 1,200 and 1,500 head in 2016, which is a sum of cattle head in public land and cattle head in private properties. NIRC has a registration of cows in public land since 1993 (Table 2.14) but not in private properties. The average total cattle head for the period 1999 – 2019 was assumed to be 1,350.

Table 2.14 – Cattle head in public land in Norfolk Island from 1999 to 2019

Year	Cattle Head in public land (from NIRC)
1999	246
2000	251
2001	264
2002	272
2003	252
2004	259
2005	275
2006	274
2007	253
2008	276
2009	285
2010	282
2011	282
2012	277
2013	277
2014	261
2015	240
2016	221
2017	195
2018	211
2019	209
Average	255

The public land available for grazing is indicated in red in Figure 2.12.

Figure 2.12: Public land for grazing in red. Source: NIRC.

According to GHD (2016), the effective area of common grazing land is 183.5 ha. Combining this information with Figure 2.12, we located public land in the corresponding catchment, resulting in Table 2.15.

Table 2.15: Public grazing land in catchments

Catchment	Name	Public grazing area (ha)
20		15.5
22		14.8
29		1.2
30	Mission creek	3.3
31	Cascade creek	22
33	Stockyard creek	6.2
35		42.7
36	Watermill creek	9.5
40		12.7
41		55.7
Total		183.6

From Table 2.15, the average number of cattle head grazing on public land for the period 1999 to 2019 is 255. The remaining 1,095 (1,350-255) cattle head were then distributed evenly through the catchments in areas zoned as rural and rural residential, according to the Norfolk lots polygon provided by NIRC. The distribution results are presented in Table 2.16.

Table 2.16: Distribution of cattle heads in Norfolk Island catchments

Catchment	Private land	Public land	Total cattle head
1	11		11
2	2		2
7	33		33
9	2		2
10	24		24
13	2		2
14	12		12
15	4		4
16	2		2
17	9		9
18	9		9
19	4		4
20	0	22	22
21	1		1
22	27	21	48
23	41		41
24	16		16
25	12		12
26	19		19
27	35		35
28	14		14
29	5	1	6
30	79	5	84
31	175	30	205
32	36		36
33	116	8	124
35	21	59	80
36	67	13	80
37	11		11
38	21		21
39	6		6
40	10	18	28
41	147	78	225
42	14		14
43	57		57
44	9		9
45	2		2
46	9		9
47	3		3
48	28		28
Total	1,095	255	1,350

The calculations of average water consumption per cow are based on DPI (2014) suggested rates of ~ 70L/Day, and that consumption of water in summer is ~40% higher than in winter (as animals use more water for evaporative cooling in hot weather and pasture is generally drier). Using these data and considering higher consumption of water from the summer months, December to February, we obtain the results for an average year presented in Table 2.17 for the island and in Table A.8 and Table A.9 in (kL) and (mm) respectively for each catchment in Appendix 2.

Table 2.17: Water consumption of cattle heads in Norfolk Island in (kL), (mm) and rainfall percentage (average year)

Month	Water consumed (kL)	Water consumed (mm)	% Rainfall
Jan	4,099	0.12	0.14
Feb	3,703	0.11	0.11
Mar	2,932	0.08	0.08
Apr	2,834	0.08	0.09
May	2,932	0.08	0.08
Jun	2,834	0.08	0.07

Jul	2,932	0.08	0.07
Aug	2,932	0.08	0.08
Sep	2,834	0.08	0.11
Oct	2,932	0.08	0.16
Nov	2,834	0.08	0.12
Dec	4,099	0.12	0.14
Annual	37,897	1.1	0.1

2.5 EVAPORATION AND EVAPOTRANSPIRATION

Evaporation is the process of turning from liquid to vapour and will be considered here as coming from water that is intercepted by vegetative surfaces (canopy interception) and made available for evaporation. Depending on the type of vegetation, this could be a significant loss. Evapotranspiration considers evaporation from the soil and transpiration from plants. Other sources of evaporation, from open water and depression storage, are assumed to be negligible.

2.5.1 LAND COVER CLASSIFICATION

To estimate both evaporation and evapotranspiration losses in the catchments of Norfolk Island, vegetation needs to be identified. Abell and Falkland (1991) described the vegetation of the island as originally being a dense subtropical forest, of which since settlement extensive areas have been cleared for cultivation and grazing. For this project, a broad classification of the different land covers was done based on the aerial photos provided.

Five different land covers were identified, consisting of forest, shrub/bush, urban, crop and grass/pasture. As mentioned, this classification was done by visual inspection of aerial photos, assuming the following:

- Forest is identified by the deep green with protruding areas in the map;
- Bushes are identified by the light green with slightly protruding areas in the map;
- Urban areas are identified as built areas and roads in the map;
- Crops are identified by the regular and flat areas with yellow and light green areas in the map.

Results in percentages are presented in Table 2.18.

Table 2.18: Estimated land cover classification per catchment (%).

Catchment	Forest	Bush	Urban	Crop	Pasture
1	0	13	2.4	11.4	73.2
2	0	0	3.6	6	90.4
3	23.8	0	0	0	76.2
4	38.7	43.7	0	0	17.6
5	83.2	0	0	0	16.8
6	0	84.9	0	0	15.1
7	5.8	13.7	3.6	11.4	65.5
8	5.8	73.9	0	0	20.3
9	71.6	0	0	0	28.4
10	24.1	31.5	3.5	3.3	37.6
11	74.9	13.1	0	0	12
12	47.7	44.6	0	0	7.7
13	64.6	0	0	0	35.4
14	48.9	0	0	0	51.1
15	52.5	0	0.2	1.8	45.5
16	0	0	2	0	98
17	0	23.7	3	0	73.3
18	0	42.6	0.6	0	56.8
19	82.3	0	0	1.5	16.2
20	0	0	0	0	100
21	0	0	1.6	0.7	97.7
22	46	7.1	0.7	7.2	39

23	25.5	15.4	2.6	1.3	55.2
24	13.2	0	3.2	10.9	72.7
25	13.9	0	0.9	0	85.2
26	14.6	21.4	1.9	7.8	54.3
27	19.1	4	8.1	1.2	67.6
28	14	13.8	3.9	4.1	64.2
29	33.1	0	1.8	2.6	62.5
30	24.3	15.9	4.8	0.4	54.6
31	14.4	10.3	5.7	0.2	69.4
32	7.5	28.1	7.9	0.3	56.2
33	0	17.5	10.7	0.7	71.1
34	66.6	0	0	0	33.4
35	14.1	4.3	5	0	76.6
36	0	6.5	4	3.8	85.7
37	17.5	0	3.2	0	79.3
38	5.6	40.6	8	0.7	45.1
39	48.1	0	7	0	44.9
40	0	5.3	3.3	1.8	89.6
41	0	9.8	7.1	3.9	79.2
42	24.7	0	1.6	0.5	73.2
43	6.5	25	7.9	1.1	59.5
44	43.7	0	14.9	0	41.4
45	0	24.6	0	0	75.4
46	18.1	0	4.6	3.4	73.9
47	0	37.3	0	0	62.7
48	6.1	33.4	10.6	0	49.9
Total	16.3	13.2	5.1	2	63.4

According to Table 4.13, 16.3% of the island corresponds to forest, 13.2% to shrubs, 5.1% to impervious areas, 2% to areas used for agriculture and 63.4% as pasture. It is important to stress that these results are only indicative, and the only estimation that could be compared was the percentage of forest that according to CIA (2011) is 11.5% in Norfolk Island.

2.5.2 INTERCEPTION BY VEGETATION: EVAPORATION LOSSES

A proportion of the rain falling on to vegetation canopy is intercepted and evaporates back to the atmosphere. The influence of the canopy in intercepting rainfall is a function of the density of the plant and the morphology of the plant species.

The percentage of rainfall intercepted is larger in forested areas than in grasslands. Only intercepted rainfall by forested areas will be considered in this work. Rainfall interception percentages were estimated using reference values from literature. East Australian eucalyptus intercepts between 10-20% and pine trees 20-30% of annual precipitation (Abell and Falkland, 1991, after Bell (1987)). Wallace et al. (2013) report interception loss as percentages of rainfall for four locations in Australia; two rainforests in Queensland, and two jarrah forests in Western Australia varying from 15% to 33%, on the higher end of the scale are the rainforests and on the lower end the jarrah forests, corresponding to eucalypti.

A value of 20% rainfall intercepted was considered appropriate for forested areas in Norfolk Island. Results using this value are presented in Table 2.19 for Norfolk Island and in Table A.10 in (kL) and Table A.11 in (mm) in Appendix 1 for all catchments for an average year of the period 1999-2019.

Table 2.19: Estimated intercepted rainfall by forest in (kL) and (mm). Results for entire Norfolk Island. Period 1999-2019

Month	Intercepted rainfall (kL)	Intercepted rainfall (mm)	% Rainfall
Jan	102,709	2.97	3.4
Feb	115,157	3.33	3.3
Mar	112,221	3.24	3.4
Apr	99,954	2.89	3.28
May	118,836	3.44	3.31
Jun	132,044	3.82	3.32
Jul	128,383	3.71	3.28
Aug	114,227	3.3	3.27
Sep	82,674	2.39	3.27
Oct	56,686	1.64	3.28
Nov	75,363	2.18	3.3
Dec	97,722	2.83	3.33
Annual	1,235,977	35.74	3.31

Table 2.19 shows that the volumes of intercepted rainfall by vegetation are an important component of the water balance. Due to the uncertainties in the estimation of different land use areas, only interception by forest was considered, but other vegetation types also intercept rainfall and, if considered, they would increase the amount of rainfall intercepted. Therefore, values presented in Table 2.19 are only indicative and are presumed to be underestimated.

2.5.3 EVAPOTRANSPIRATION (ET)

Evapotranspiration is the combination of soil evaporation and plant transpiration. Evapotranspiration rates depends on meteorological conditions, vegetation characteristics and environment and management conditions. The FAO56 method (Allen et al., 1998) estimates evapotranspiration based on the evapotranspiration of a reference crop.

Reference evapotranspiration (ET_0) is defined as the amount of water evapotranspired by a short green crop, completely shading the ground, of uniform height and never short of water (Penman, 1956). ET_0 is calculated using weather data; there are a number of different relationships available that require more or less data. For this work, the pan evaporation method was selected because it only requires evaporation data as input that is measured at the Airport meteorological Station.

To estimate the potential evapotranspiration (PET) or water demand of a vegetation cover other than the reference crop, ET_0 is multiplied by the crop coefficient (Kc). Management and environmental conditions, such as presence of pests and diseases, soil salinity, low soil fertility, water shortage or waterlogging, affect the actual volumes of water evapotranspired.

To calculate ET_0 from measured evaporation, evaporation is multiplied by the pan coefficient (Kp). This coefficient depends on the evaporation pan type and its surroundings. According to the Norfolk Island Airport station metadata, the evaporation pan is type A and surrounded mostly with grass. Climate statistics for the station report that the average wind speed is 4.7 m/s and the average relative humidity is 73.5% (BOM, 2020). For the stated conditions, the pan coefficient (Kp) is assumed as 0.8 (Table 5, Allen et al., 1998). Table 2.20 presents monthly measured evaporation and calculated reference evapotranspiration values (mm) for an average year for the period 1999-2019.

Table 2.20: Measured evaporation (mm) in Airport meteorological Station and calculated reference evapotranspiration (mm) for Norfolk Island. Period 1999-2019

Month	Average evaporation (mm)	Reference evapotranspiration (mm)
Jan	182	146
Feb	152	121
Mar	155	124
Apr	128	102
May	111	89
Jun	94	75
Jul	96	77
Aug	108	86
Sep	121	97
Oct	150	120
Nov	166	133
Dec	172	138
Annual	1,635	1,308

Table 3.16 shows potential evapotranspiration in Norfolk Island is high compared to average rainfall – annual reference evapotranspiration is 1,308 mm and average rainfall is 1,080 mm. Potential evapotranspiration for the different land covers identified in Norfolk Island is calculated using a crop/vegetation coefficient (Kc). Land covers identified in Norfolk Island correspond to forest, bush, crop and pasture. Kc for these land covers were estimated from literature. Kc vary throughout the year linked with the life cycle of the plant, however generally in this work they are considered constant. Potential evapotranspiration estimated this way is highly uncertain and values should be regarded with care. The following crop coefficients were used:

Crops: There are a few main producers of fruits and vegetables in the island, with fields fragmented throughout the island. The rest are personal orchids in small tracts of land producing fruit, vegetable and flowers. Fruit and vegetables produced in the island are tomatoes, lettuce, capsicum, cucumber, pineapples, avocados, etc. The crop coefficient selected for representing crops is **1.05**, corresponding to small vegetables in FAO 56 guidelines (Allen et al., 1998).

Pasture: Corresponding to coarse kikuyu grass (Abell and Falkland, 1991). The crop coefficient for kikuyu grass is **0.85**, reported by Green Building Council of Australia (2014).

Shrubs: Considered to be the secondary growth after the clearing of the original forest is composed by olives, guava, wild tobacco and lantana thicket as described by Allen and Falkland (1991). The representative crop coefficient for this land cover is the combination of the crop coefficients of the species listed above and resulted in **0.76**.

Forest: Forest in Norfolk Island corresponds to palm forest and hardwood subtropical rainforest (Director of the National Parks, 2010). Abell and Falkland (1991) described the forest as composed of palms, ferns, creepers, flax, Norfolk Island pines and eucalyptus. A representative crop factor of **0.73** was calculated with the combination of the crop coefficient from the different species.

Using these crop coefficients, the potential evapotranspiration was calculated. Results in (kL) and (mm) for the island are presented in Table 2.21. Results for all catchments are presented in Table A.12 in (mm) and Table A.13 in (kL) in Appendix 1.

Table 2.21: Potential evapotranspiration or vegetation water demand for Norfolk Island in an average year, in (kL) and (mm). Period 1999-2019

Month	Potential evapotranspiration (kL)	Potential evapotranspiration (mm)
Jan	3,929,220	114
Feb	3,268,161	94
Mar	3,328,873	96

Apr	2,760,639	80
May	2,381,235	69
Jun	2,028,317	59
Jul	2,061,839	60
Aug	2,314,895	67
Sep	2,606,741	75
Oct	3,235,343	94
Nov	3,582,634	104
Dec	3,714,610	107
Annual	**35,212,507**	**1,019**

As stated before, actual evapotranspiration (ET) or water actually used by the vegetation is affected by several factors that could limit plant development and reduce their actual evapotranspiration. These factors include available soil moisture, soil salinity, poor land fertility, presence of hard or impenetrable soil horizons, diseases and pests, etc. Because there is not information available to estimate actual evapotranspiration, it will be estimated trough a simple water balance. Results are presented in Section 4.

2.6 STREAMFLOW AND SURFACE RUNOFF (SR)

Historically, streamflow is not monitored in Norfolk Island. Currently CSIRO is monitoring several creeks in the island, but that information is not yet available. When available, the estimations presented in this section can be updated. The only available information regarding streamflow measurements in the island corresponds to the study by Abell and Falkland (1991), when they monitored eight creeks from May 1981 to June 1984. With the data collected, they calculated the percentage runoff of each of the creeks. Their results are presented in Table 2.22. Values of percentage runoff here presented were used to estimate streamflow for the water balance. A value of 8.9%, calculated from Table 2.22 was used for as representative of the island.

Table 2.22: Summary of streamflow data (5/5/1981-6/6/1984). Abell and Falkland (1991).

Creek	Catchment Area (ha)	Daily flow (l/s)			% Runoff
		Max	Min	Mean	
Cascade	628	600	1.4	15	6.3
Broken Bridge (sub-catchment of Cascade)	393	280	0.5	5.8	4.7
Stockyard	249	315	0	5.8	5.5
Town (*)	133	212	4.5	10	22.7
Watermill (*)	305	605	0.2	11.4	11.9
Rocky Point	124	265	0.4	4.7	14
Headstone	197	1110	0	5.1	6.6
Mission	237	523	0	5.6	5.4

(*) In the present work, Watermill creek catchment considers Town creek as well.

2.7 GROUNDWATER RECHARGE

Chloride was also analysed for estimating groundwater recharge using the chloride mass balance (CMB) method. Healy (2010) offers a comprehensive explanation of the method, which requires knowledge of (i) long-term rainfall volume, (ii) atmospheric wet and dry chloride deposition, and groundwater chloride concentration. The CMB method was applied to Norfolk Island using: (i) average rainfall volume from Meteorological Stations as per Figure 6 and Table 5; (ii) atmospheric wet and dry chloride deposition at the bore location from the equation suggested by Hutton et al. (1976) for SE Australia, in the absence of specific data for Norfolk Island; and, (iii) chloride concentrations from the collected 22 groundwater samples – the groundwater sampling campaign is discussed in detail is Section 2.10 (Groundwater and Surface water quality).

Table 2.23 shows a statistical summary for the chloride concentrations in the samples, which do not represent risk for human, animal or environmental health. An anomalous high concentration of 970 mg/L was found in a bore, which can be related to a saltier local aquifer, or to a localised source of chloride, although more information is needed to support such assumptions. It is expected that CSIRO's report will discuss this bore's hydrochemistry further. This concentration contrasts with the second highest concentration of 280 mg/L. As such, Table 2.23 also shows statistics excluding the 970 mg/L sample. Table 2.23 also shows surface water chloride samples for comparison - they are not used in the recharge calculations.

Groundwater recharge rates applying the CMB method for the areas identified in Figure 6 are: 220 mm/year for the Kingston area, 242 mm/year for the Airport area and 242 mm/year for the Ball Bay area. This corresponds to 22% of rainfall. Abell and Falkland (1991) calculated recharge rates of 29% of rainfall (34% for grassed land and 19% for the forested land) based on a water balance method. Preliminary results from CSIRO indicate lower recharge rates of ~10% of rainfall – the reader is referred to CSIRO's report for details. It is worth noting recharge is a difficult component of the water balance to calculate, and is usually associated with high degrees of uncertainty and disagreement between different estimation methods (Healy 2010). Furthermore, uncertainty in CMB recharge estimates is typically related to uncertainty in atmospheric chloride deposition, and can also be affected by factors such as variable vegetation cover (which can complicate even more atmospheric chloride deposition), and depth to the water table and depth of bores slotted section (which can complicate identifying the recharge zones) (Ordens et al., 2012).

Table 2.23: Cl concentrations in the collected water samples (mg/L)

	N	Min	Max	Mean	Median	Standard Deviation
Groundwater	22	51	970	168	100	187
Groundwater - excluding highest value	21	51	280	130	99	67
Surface Water	3	140	340	210	150	92

2.8 WATER BALANCE CALCULATIONS

The water balance can be summarized as follow:

$$PP = ET + SR + GR + WU + \Delta S$$ (Equation 2)

where: *PP* is rainfall (mm); *ET* is actual evapotranspiration (mm), accounting for evaporation from surfaces, as canopy, and evapotranspiration of the vegetation; *SR* is surface runoff (mm); *GR* is groundwater recharge (mm); *WU* is water used in the island (household, accommodation, cattle, etc.) (mm); and, Δ*S* is changes in water storage, considered equal to zero due to the large time period considered.

As previously stated, the lack of monitoring data prevents the estimation of an accurate water balance for the island and its catchments. Therefore in this section we summarized the estimations of the different components of the water balance for the island and the catchments that represent the 55% of the island area and are those with more households and tourist accommodations are located, namely; Mission creek, Cascade creek, Stockyard creek, Headstone creek, Watermill creek and Rocky Point creek.

2.8.1 NORFOLK ISLAND

Table 2.24 and Figure 2.13 summarize results for the island. Water Use (WU) corresponds to the sum of columns of Household, Tourism and Cattle. The term ET in the water balance equation corresponds to the sum of the interception and the actual evapotranspiration from vegetation and it is obtained as closing the water balance. The term GR1 corresponds to the groundwater recharge considered to be 22% of the rainfall (our predictions) and GR2 to the groundwater recharge considered to be 10% of the rainfall (lower recharge limit as we expected will be proposed by CSIRO). Then, ET1 corresponds to the value obtained when using GR1 and ET2 when using GR2. SR is calculated as 8.9% of the rainfall according to values calculated by Abell and Falkland (1991).

Table 2.24: Water balance components Norfolk Island (mm). Average year, period 1999-2019.

Month	PP	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
Jan	88	0.29	0.14	0.12	0.55	2.97	114					
Feb	101	0.25	0.14	0.11	0.50	3.33	94					
Mar	96	0.34	0.14	0.08	0.56	3.24	96					
Apr	88	0.31	0.14	0.08	0.53	2.89	80					
May	104	0.34	0.17	0.08	0.59	3.44	69					
Jun	115	0.38	0.18	0.08	0.64	3.82	59					
Jul	113	0.34	0.18	0.08	0.60	3.71	60					
Aug	101	0.35	0.16	0.08	0.59	3.3	67					
Sep	73	0.28	0.12	0.08	0.48	2.39	75					
Oct	50	0.22	0.08	0.08	0.38	1.64	94					
Nov	66	0.27	0.11	0.08	0.46	2.18	104					
Dec	85	0.29	0.14	0.12	0.55	2.83	107					
Annual	1080	4	2	1	6	36	1019	96	238	740	108	870
% rainfall		0.3	0.2	0.1	0.6	3.3	94.4	8.9	22	68.5	10	80.6

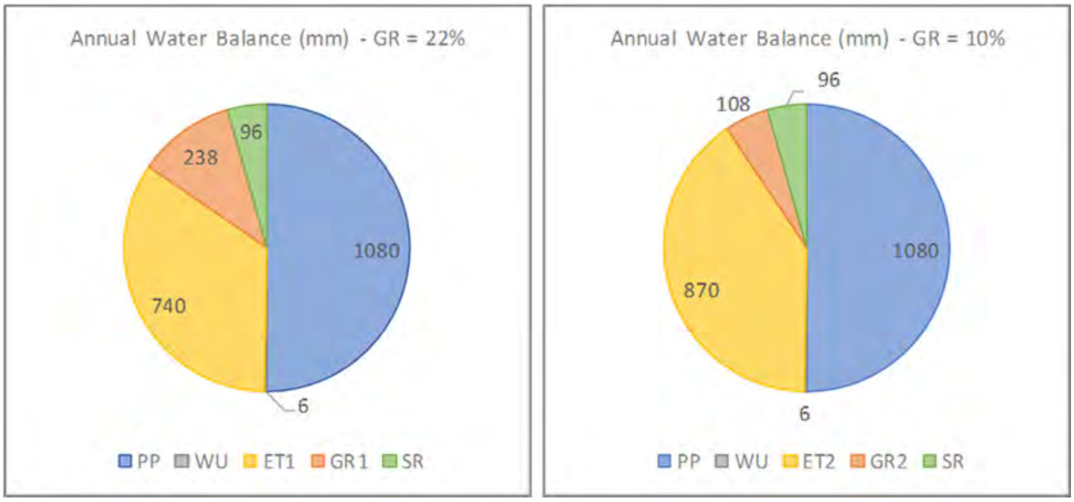


Figure 2.13: Water balance components for Norfolk Island (mm). Average year period 1999-2019.

Groundwater recharge varies from 108 to 238 (mm/year) under different estimations. Correspondingly, evapotranspiration varies from 870 to 740 (mm/year). The value of ET in both cases contain the estimated 36 (mm/year) intercepted by vegetation. Estimated water use in Norfolk Island only accounts for the 0.6% of the rainfall, being the most important water balance component the evapotranspiration.

2.8.2 MISSION CREEK CATCHMENT

Similarly, results for Mission creek catchment are presented in Table 2.25 and Figure 2.14.

Table 2.25: Water balance components Mission creek catchment (mm). Average year, period 1999-2019.

Month	PP	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
Jan	92	0.25	0.14	0.10	0.49	4.48	112					
Feb	103	0.23	0.12	0.09	0.44	4.99	93					
Mar	101	0.31	0.14	0.07	0.52	4.91	95					
Apr	89	0.28	0.13	0.07	0.48	4.33	79					
May	106	0.3	0.17	0.07	0.54	5.15	68					
Jun	118	0.33	0.17	0.07	0.57	5.73	58					
Jul	114	0.3	0.17	0.07	0.54	5.55	59					
Aug	101	0.31	0.14	0.07	0.52	4.93	66					
Sep	73	0.24	0.11	0.07	0.42	3.54	74					
Oct	50	0.2	0.08	0.07	0.35	2.44	92					
Nov	67	0.24	0.11	0.07	0.42	3.27	102					
Dec	87	0.26	0.13	0.10	0.49	4.24	106					
Annual	1101	3	2	1	6	54	1004	59	242	794	110	926

% rainfall		0.3	0.2	0.1	0.5	4.9	91.2	5.4	22	72.1	10	84.1

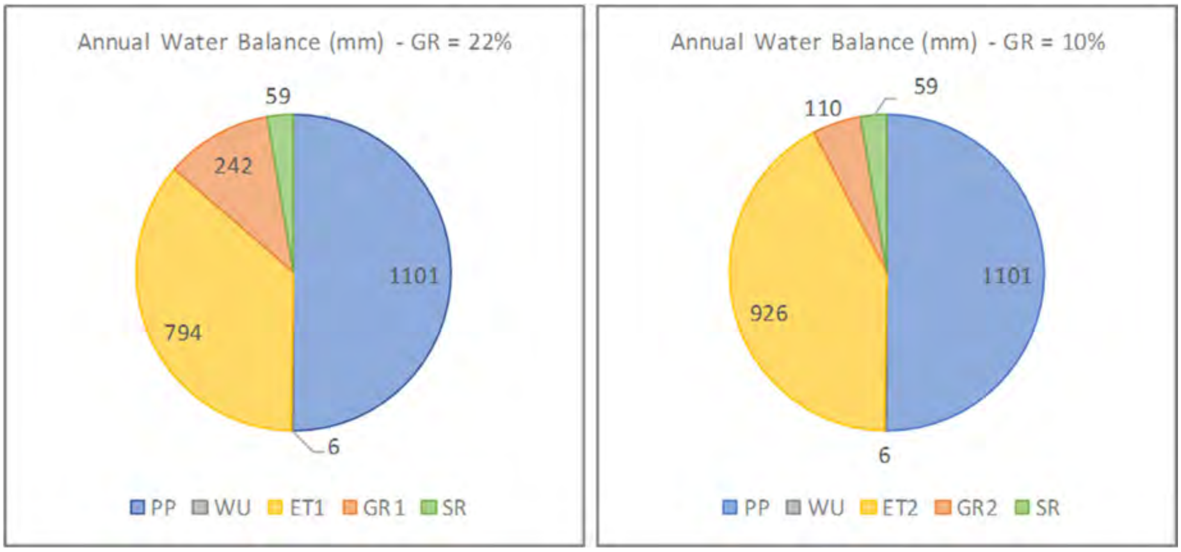


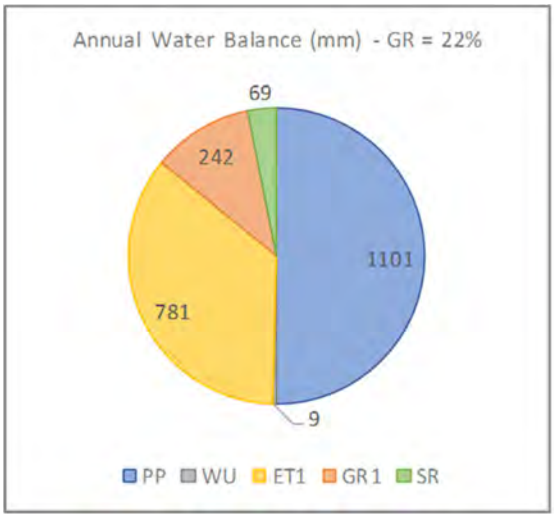
Figure 2.14: Water balance components for Mission creek catchment (mm). Average year period 1999-2019.

2.8.3 CASCADE CREEK CATCHMENT

Results for Cascade creek catchment are presented in Table 2.26 and Figure 2.15.

Table 2.26: Water balance components Cascade creek catchment (mm). Average year, period 1999-2019.

Month	PP	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
Jan	92	0.29	0.33	0.10	0.72	2.65	113					
Feb	103	0.27	0.34	0.09	0.70	2.95	94					
Mar	101	0.36	0.34	0.07	0.77	2.9	96					
Apr	89	0.33	0.31	0.07	0.71	2.56	79					
May	106	0.35	0.39	0.07	0.81	3.04	68					
Jun	118	0.39	0.42	0.07	0.88	3.38	58					
Jul	114	0.35	0.41	0.07	0.83	3.28	59					
Aug	101	0.36	0.35	0.07	0.78	2.91	67					
Sep	73	0.28	0.26	0.07	0.61	2.1	75					
Oct	50	0.23	0.19	0.07	0.49	1.44	93					
Nov	67	0.28	0.25	0.07	0.60	1.93	103					
Dec	87	0.3	0.32	0.10	0.72	2.51	107					
Annual	1101	4	4	1	9	32	1012	69	242	781	110	913
% rainfall		0.4	0.4	0.1	0.8	2.9	91.9	6.3	22	70.9	10	82.9



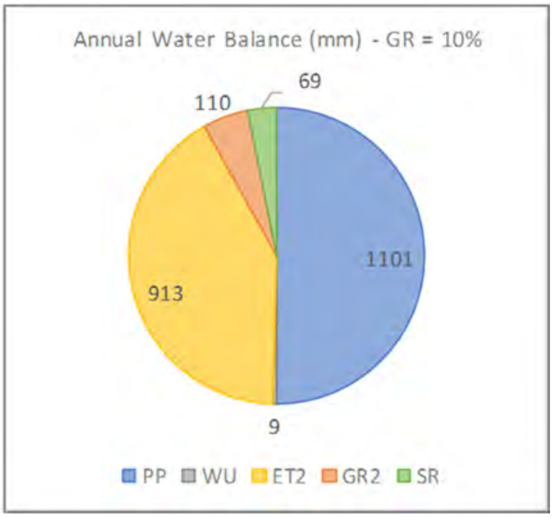


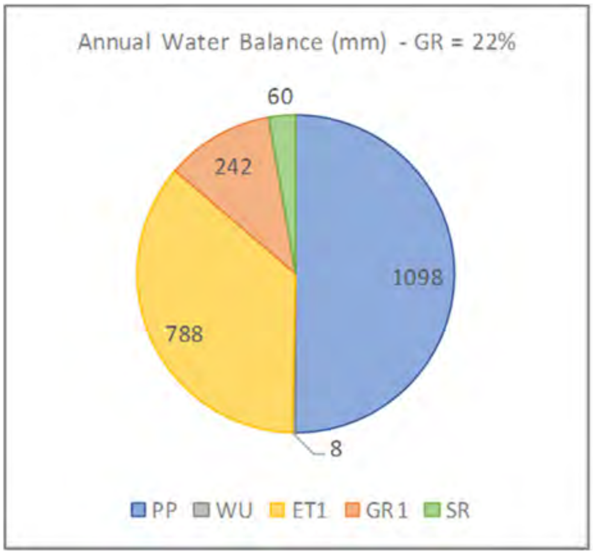
Figure 2.15: Water balance components for Cascade creek catchment (mm). Average year period 1999-2019.

2.8.4 STOCKYARD CREEK CATCHMENT

Results for Stockyard creek catchment are presented in Table 2.27 and Figure 2.25.

Table 2.27: Water balance components Stockyard creek catchment (mm). Average year, period 1999-2019.

Month	PP	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
Jan	88	0.49	0.05	0.15	0.69	0	109					
Feb	102	0.41	0.05	0.13	0.59	0	90					
Mar	95	0.55	0.05	0.10	0.70	0	92					
Apr	89	0.51	0.05	0.10	0.66	0	76					
May	106	0.56	0.06	0.10	0.72	0	66					
Jun	117	0.61	0.06	0.10	0.77	0	56					
Jul	116	0.56	0.06	0.10	0.72	0	57					
Aug	103	0.57	0.05	0.10	0.72	0	64					
Sep	79	0.46	0.04	0.10	0.60	0	72					
Oct	52	0.37	0.03	0.10	0.50	0	89					
Nov	66	0.44	0.03	0.10	0.57	0	99					
Dec	85	0.47	0.04	0.15	0.66	0	103					
Annual	1098	6	1	1	8	0	973	60	242	788	110	920
% rainfall		0.5	0.1	0.1	0.7	0	88.6	5.5	22	71.8	10	83.8



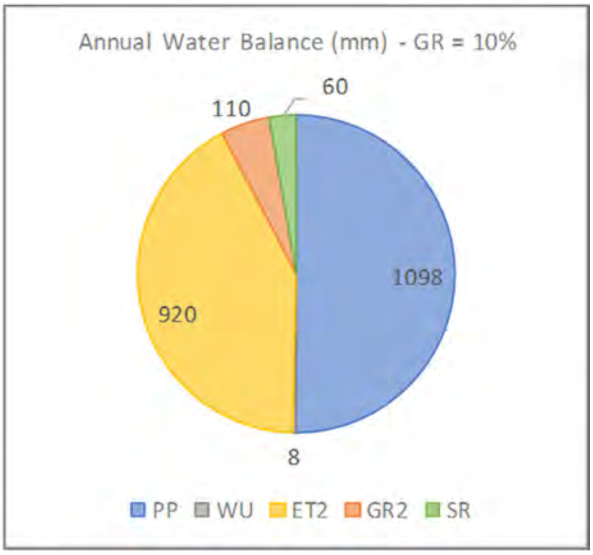


Figure 2.25: Water balance components for Stockyard creek catchment (mm). Average year period 1999-2019.

2.8.5 HEADSTONE CREEK CATCHMENT

Results for Headstone creek catchment are presented in Table 2.28 and Figure 2.26.

Table 2.28: Water balance components Headstone creek catchment (mm). Average year, period 1999-2019.

Month	PP	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
Jan	92	0.19	0.01	0.13	0.33	0	119					
Feb	103	0.17	0.01	0.11	0.29	0	99					
Mar	101	0.23	0.01	0.09	0.33	0	101					
Apr	89	0.21	0.01	0.09	0.31	0	84					
May	106	0.22	0.01	0.09	0.32	0	72					
Jun	118	0.25	0.01	0.09	0.35	0	62					
Jul	114	0.23	0.01	0.09	0.33	0	63					
Aug	101	0.23	0.01	0.09	0.33	0	70					
Sep	73	0.18	0.01	0.09	0.28	0	79					
Oct	50	0.15	0.01	0.09	0.25	0	98					
Nov	67	0.18	0.01	0.09	0.28	0	109					
Dec	87	0.19	0.01	0.13	0.33	0	113					
Annual	1101	2	0	1	4	0	1069	73	242	782	110	914
% rainfall		0.2	0	0.1	0.4	0	97.1	6.6	22	71	10	83

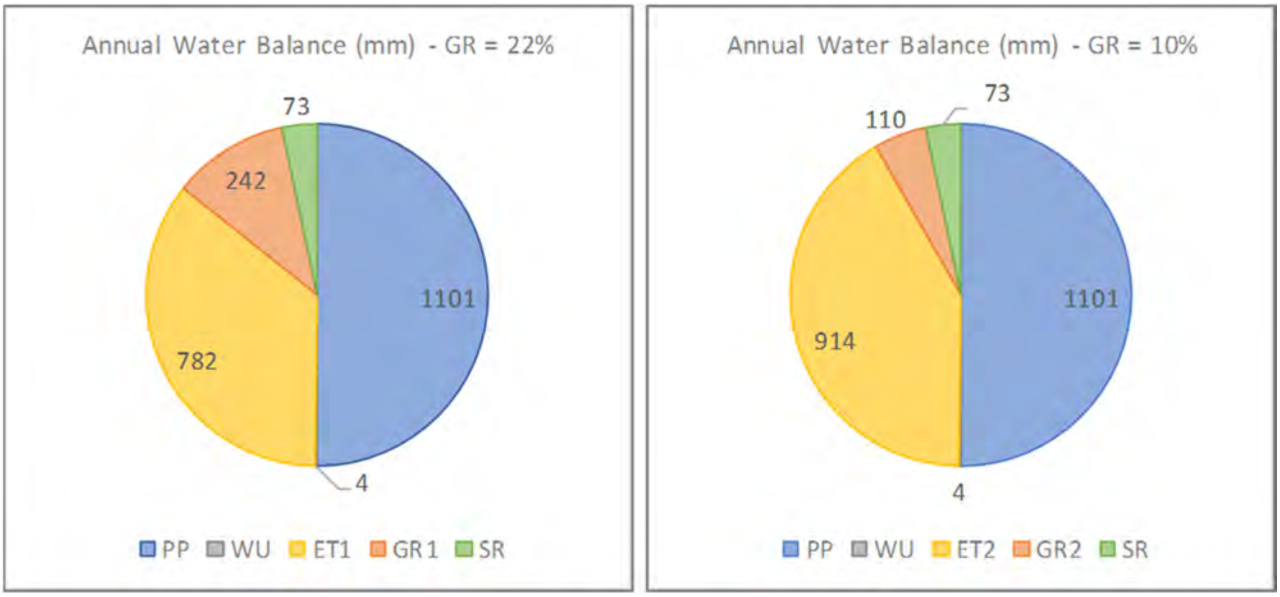


Figure 2.26: Water balance components for Headstone creek catchment (mm). Average year period 1999-2019.

2.8.6 WATERMILL CREEK CATCHMENT

Results for Watermill creek catchment are presented in Table 2.29 and Figure 2.27.

Table 2.29: Water balance components Watermill creek catchment (mm). Average year, period 1999-2019.

Month	PP	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
Jan	76	0.26	0.3	0.15	0.71	0	115					
Feb	95	0.22	0.32	0.13	0.67	0	96					
Mar	83	0.29	0.3	0.10	0.69	0	97					
Apr	81	0.29	0.3	0.10	0.69	0	81					
May	96	0.33	0.37	0.10	0.80	0	70					
Jun	106	0.36	0.41	0.10	0.87	0	59					
Jul	108	0.33	0.41	0.10	0.84	0	60					
Aug	98	0.33	0.35	0.10	0.78	0	68					
Sep	68	0.26	0.26	0.10	0.62	0	76					
Oct	47	0.19	0.18	0.10	0.47	0	95					
Nov	62	0.23	0.24	0.10	0.57	0	105					
Dec	79	0.27	0.31	0.15	0.73	0	109					

Annual	999	3	4	1	8	0	1031	152	220	619	100	739
% rainfall		0.3	0.4	0.1	0.8	0	103.2	15.2	22	62	10	74

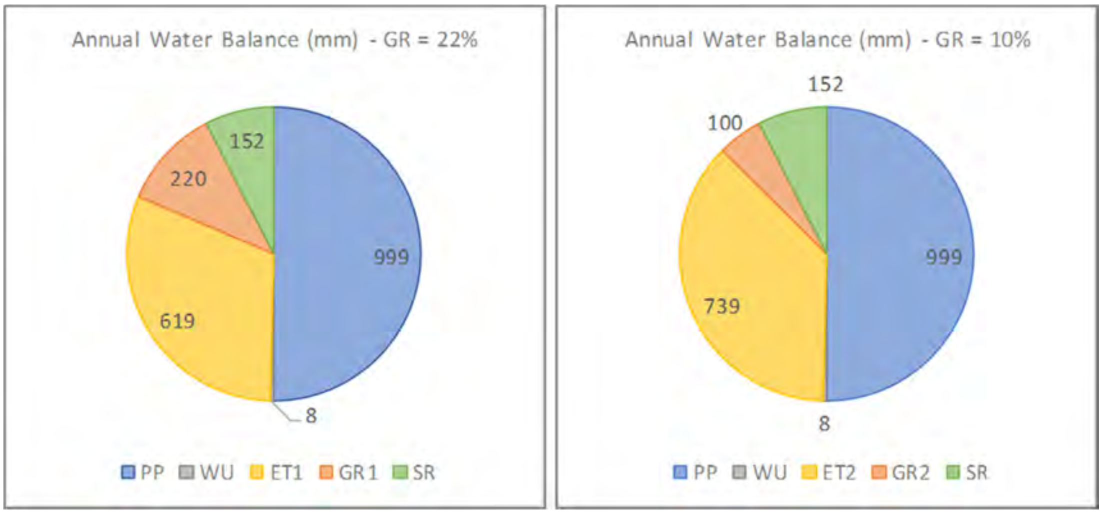


Figure 2.27: Water balance components for Watermill creek catchment (mm). Average year period 1999-2019.

2.8.7 ROCKY POINT CREEK CATCHMENT

Results for Rocky Point creek catchment are presented in Table 2.30 and Figure 2.28.

Table 2.30: Water balance components Rocky Point creek catchment (mm). Average year, period 1999-2019.

Month	PP	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
Jan	92	0.34	0.06	0.13	0.53	1.2	110					
Feb	103	0.31	0.05	0.12	0.48	1.33	91					
Mar	101	0.43	0.07	0.09	0.59	1.31	93					
Apr	89	0.38	0.06	0.09	0.53	1.16	77					
May	106	0.41	0.07	0.09	0.57	1.38	67					
Jun	118	0.46	0.08	0.09	0.63	1.53	57					
Jul	114	0.41	0.07	0.09	0.57	1.48	58					
Aug	101	0.42	0.06	0.09	0.57	1.32	65					
Sep	73	0.33	0.05	0.09	0.47	0.95	73					
Oct	50	0.27	0.04	0.09	0.40	0.65	91					
Nov	67	0.33	0.05	0.09	0.47	0.87	100					
Dec	87	0.35	0.06	0.13	0.54	1.13	104					
Annual	1101	4	1	1	6	14	986	154	242	699	110	831
% rainfall		0.4	0.1	0.1	0.5	1.3	89.6	14	22	63.5	10	75.5

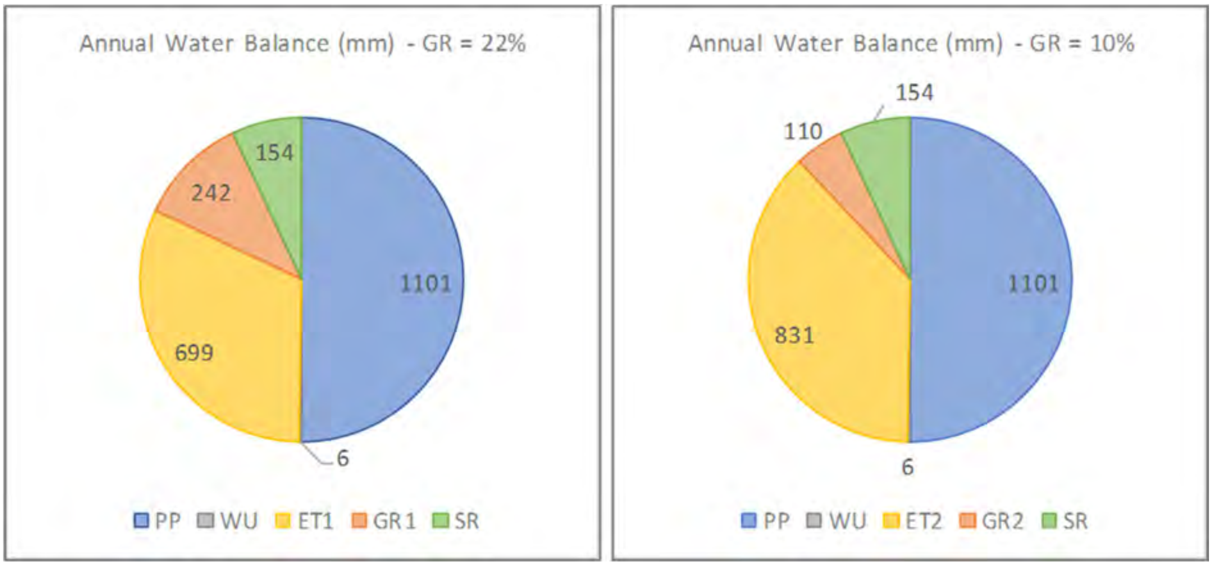


Figure 2.28: Water balance components for Rocky Point creek catchment (mm). Average year period 1999-2019.

Annual water balance components for all catchments are presented in Table A.14 in mm and in Table A.15 in % rainfall in Appendix 2.

Even if the estimated values for the water balance components are highly uncertain, especially for estimations of evapotranspiration, groundwater recharge and surface runoff, the results indicate that the major use of water in the island is the vegetation evapotranspiration.

The water balance components presented were estimated with the available information. The lack of monitoring data of the water balance components in Norfolk Island make the estimation of evapotranspiration, surface runoff and groundwater recharge especially uncertain. It is expected that more accurate information related to the water balance will become available when CSIRO finish their study. At that point, it is recommended to revisit the estimations presented here and adjust if necessary.

2.9 GROUNDWATER AND SURFACE WATER QUALITY

2.9.1 METHOD

A groundwater and surface water sampling campaign for assessing contamination was conducted from 24 to 29 September 2019. This was carried out in partnership with the CSIRO team who is conducting a parallel project on the Hydrology of the Norfolk Island. For the sake of effective resource management it was decided not to analyse compounds that CSIRO was going to analyse (i.e. major and minor ions, metals, isotopes). CSIRO provided a detailed description of groundwater and surface water chemistry in their report. As such, PFOA, PFHxS and PFOS, and pesticides were analysed for the samples collected by the UQ team. During the sampling campaign, a bore was identified as possibly contaminated by petroleum-related compounds due to intense smell, which was sampled for benzene, toluene, ethylbenzene and xylene (BTEX), Total Petroleum Hydrocarbons (TPH) and Polycyclic Aromatic Hydrocarbons (PAH). It is worth noting this bore is not the same as the one showing high chloride concentration (Section 2.6 Groundwater recharge).

The sampling locations were chosen in collaboration with CSIRO colleagues based on achieving a representative spatial cover, landowner agreements for sampling, and prior information (e.g. bore construction details, geology and existent historical chemical data). 27 samples were collected including 22 groundwater and 5 surface water samples. Samples from all locations were analysed for pesticides and chloride, except for Mission Creek and WWII Dam. Samples for PFOA, PFHxS and PFOS were only collected in catchments with drainage lines from the Airport, because this is the only area where this type of contamination is probable. The groundwater samples were collected after the bores were purged for approximately 3 volumes, and after the physicochemical parameters were stable. The surface water samples were collected in running water as far as possible.

2.9.2 RESULTS

The vast majority of the landowners did not allow for the identification of the sampling locations nor for the data to be shared outside the project team. As such, no private bores or wells are identified in this report.

All samples showed concentrations below the detection limit for all analysed pesticides (Table 2.31). Table 2.31 shows the concentrations detected in water samples, and the reference values, for PFOA, Sum of PFHxS and PFOS. The guidelines typically provide guidance values for different protection levels for species in the water, which are normally classified as 80%, 90%, 95% and 99%. In this report, the 99% protection level is used. Table 2.32 shows the PFOA concentrations in the Airport bore tank, Mission Creek, WWII Dam and Bumbora Creek are below the reference values for recreational water and fresh water. PFOA concentrations in the Airport bore tank and WWII Dam exceed the reference values for drinking water. The sum of PFOS and PFHxS concentrations significantly exceed the reference values for drinking and recreational water, except for the Bombora Creek. It is worth noting there is no reference value for the sum of PFHxS and PFOS for fresh water. The bore sampled for petroleum-related compounds showed BTEX and PAH below detection limit. TPH concentrations in groundwater are shown in Table 2.33 with available guidelines thresholds in Table 2.34.

Table 2.31: Analysed pesticides and detection limit (µg/L or ppb)

Compound	Detection limit	Compound	Detection limit
Alpha BHC	<0.1	o,p'-DDT	<0.1
Hexachlorobenzene (HCB)	<0.1	p,p'-DDT	<0.1
Beta BHC	<0.1	Endrin ketone	<0.1
Lindane (gamma BHC)	<0.1	Methoxychlor	<0.1
Delta BHC	<0.1	trans-Nonachlor	<0.1
Heptachlor	<0.1	Endrin aldehyde	<0.1
Aldrin	<0.1	Isodrin	<0.1
Heptachlor epoxide	<0.1	Mirex	<0.1
Gamma Chlordane	<0.1	Dichlorvos	<0.5
Alpha Chlordane	<0.1	Dimethoate	<0.5
Alpha Endosulfan	<0.1	Diazinon (Dimpylate)	<0.5
o,p'-DDE	<0.1	Fenitrothion	<0.2
p,p'-DDE	<0.1	Malathion	<0.2
Dieldrin	<0.1	Chlorpyrifos (Chlorpyrifos Ethyl)	<0.2
Endrin	<0.1	Parathion-ethyl (Parathion)	<0.2
Beta Endosulfan	<0.1	Bromophos Ethyl	<0.2
o,p'-DDD	<0.1	Methidathion	<0.5
p,p'-DDD	<0.1	Ethion	<0.2
Endosulfan sulphate	<0.1	Azinphos-methyl	<0.2

Table 2.32: PFOA, Sum of PFHxS and PFOS concentrations (µg/L or ppb) in the collected surface water samples, including the relevant water-quality reference values.

Location	PFOA	Sum of PFHxS and PFOS
Airport bore (tank)	0.74	17
Mission Creek	0.29	6.8
WWII Dam	0.84	28
Bumbora Creek	<0.0005	0.0004
Reference values		
Drinking Water (FSANZ, 2019)	0.56	0.07
Recreational water (FSANZ, 2019)	10	2
Fresh water (HEPA, 2019)	19	0.00023 (only PFOS)

Table 2.33: TPH concentrations in the collected surface water samples

Compound	C6-C9 Fraction (volatile) (mg/L)	C10-C14 Fraction (mg/L)	C15-C28 Fraction (mg/L)	C29-C36 Fraction (mg/L)	C10-C16 Fraction (mg/L)	C10-C16 - Naphthalene Fraction (mg/L)	C16-C34 Fraction (mg/L)	C34-C40 Fraction (mg/L)	Sum of C10-C36 (mg/L)
Groundwater concentration	<0.04	0.066	<0.20	<0.20	0.065	0.065	<0.50	<0.50	<0.45

In the absence of trigger value guidelines for TPH's, the values provided below are groundwater acceptance criteria based on "Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand – Module 5: Tier 1 groundwater acceptance criteria" (1999). There is little information on trigger values for TPH concerning ecosystem health however all values are considered low and of minimal concern.

Table 2.34: TPH guideline threshold based on "Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand – Module 5: Tier 1 groundwater acceptance criteria" (1999)

Contaminant	Tier 1 Groundwater Acceptance Criteria		
	Potable	Irrigation(3)	Stock(3)
Napthalene	-	0.8	0.16
C7 - C9	18(4)	> S(2)	> S(2)
C10 - C14	> S(2)	> S(2)	> S(2)
C15 - C36	> S(2)	> S(2)	> S(2)

NOTE:

1. Refer to Tables 5.9 and 5.10 for Tier 1 groundwater acceptance criteria based on volatilisation.
2. >S denotes calculated limit exceeds solubility limit given TPH criteria based on aliphatic component only. Separate consideration is given to the aromatic component.
3. Values uncertain, based on cross-media transfer estimates.
4. Exceeds solubility limit for aliphatic components; aromatic components will be limited by criteria for BTEX compounds. Therefore, comparison of measured concentrations with criteria for BTEX, will also be protective against adverse effects associated with aliphatic component.

2.9.3 CASE STUDY EXAMPLE: RUNOFF WATER QUALITY IN THE WATERMILL CREEK CATCHMENT

Recent water quality reports have highlighted the negative impacts of runoff water quality in the Watermill Creek catchment (URS, 2013; The Administration of Norfolk Island, 2014; GHD, 2016; Wilson, 2017; AECOM, 2017). Runoff during large rain events enters the Watermill Creek catchment and flows to Emily Bay. Results indicate elevated nutrient levels (nitrogen and phosphorous), increased turbidity, and elevated faecal contamination (*E.Coli*) (Wilson, 2017; AECOM, 2017). Elevated nutrients and turbidity impact upon reef integrity and resilience, and elevated faecal contamination causes closure of Emily Bay for swimming and other recreational activities (Wilson, 2017; AECOM, 2017).

The Norfolk Island Regional Council (NIRC) will be investigating landscape works (such as leaky weirs) to reduce both flow and contaminant loads to Emily Bay, as improving this issue is a major priority in the Norfolk Island Environmental Strategy (NIRC, 2018). To conceptualise runoff water quality in a catchment, a common tool used in the stormwater industry in Australia is the Model for Urban Stormwater Improvement Conceptualisation (MUSIC v6) (eWater, 2016). MUSIC v6 allows catchment and climate attributes to be entered into a continuous simulation. Components of the catchment can be replaced with "treatment nodes" such as ponds, wetlands, swales and other water sensitive design structures, used to decrease flow and contaminant loads. MUSIC v6 was used to conceptualise runoff water quality in the Watermill Creek catchment. The link to the MUSIC v6 User Guide is shown below:

https://wiki.ewater.org.au/display/MD6/MUSIC+Version+6+Documentation+and+Help+Home

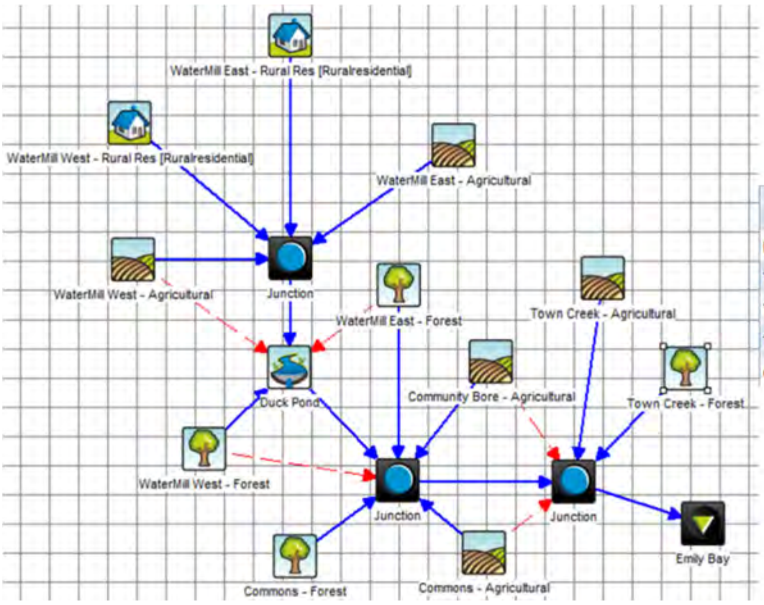
The Watermill Creek catchment is approximately 487 ha and comprises various land uses, including rural/residential, agriculture and forests. The Watermill Creek Catchment and Sub-catchments showing location, land use, and area (ha) are provided in Figure 2.29.

Location	Land Use	Area (ha)
Watermill Sub-catchment West	Rural Residential	105
Watermill Sub-catchment West	Agricultural	45
Watermill Sub-catchment West	Forest	28
Watermill Sub-catchment East	Rural Residential	20
Watermill Sub-catchment East	Agricultural	21.7
Watermill Sub-catchment East	Forest	20
Kingston Commons Sub-catchment	Forest	45.1
Kingston Commons Sub-catchment	Agriculture	40
Community Well Sub-catchment	Agriculture	23.6
Town Creek Sub-catchment	Agriculture	80
Town Creek Sub-catchment	Forest	59
Watermill Creek Catchment Total Area (ha)		487.4

Source: AECOM (2017) Emily Bay and Upper Cascade Creek Catchments Norfolk Island Water Quality Study, Prepared by AECOM Australia for Norfolk Island Regional Council (REF: 60531847)

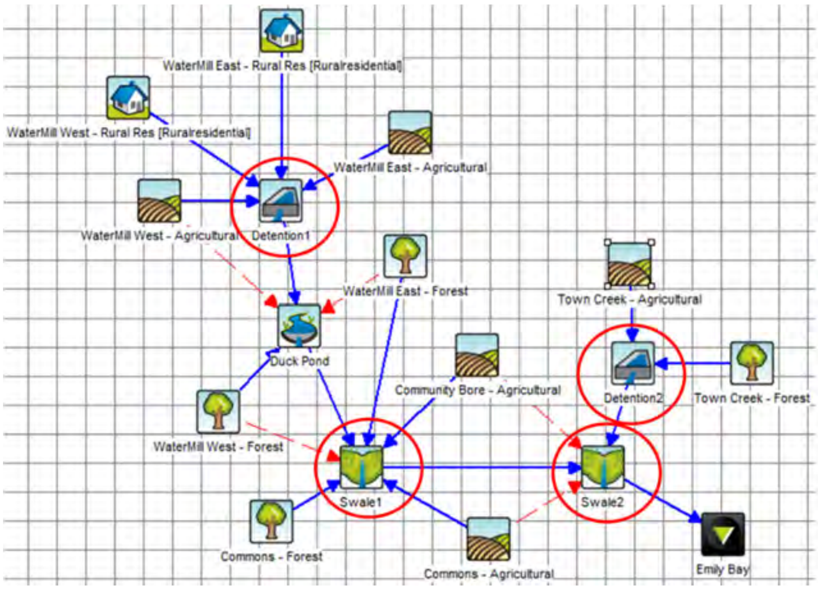
Figure 2.29: Watermill Creek Catchment and Sub-catchments showing location, land use and area (ha)

The rainfall and evaporation input data from 1990 – 2018 (at 6-minute timesteps) was used in MUSIC v6, and was sourced from the Australian Bureau of Meteorology (BOM, 2019). Figure 2.30 shows the existing Watermill Creek sub-catchment attributes as assigned in MUSIC v6, including results (sources, residual loads and % reduction). Figure 2.31 shows the Watermill Creek sub-catchment attributes with inclusion of treatment nodes (highlighted in red circles), including results (sources, residual loads and % reduction). Figure 2.32 summarises treatment node inputs used in MUSIC v6.



	Sources	Residual Load	% Reduction
Flow (ML/yr)	1370	1360	0.4
Total Suspended Solids (kg/yr)	144000	125000	12.9
Total Phosphorus (kg/yr)	367	338	7.9
Total Nitrogen (kg/yr)	2950	2860	2.9
Gross Pollutants (kg/yr)	21300	5440	74.5

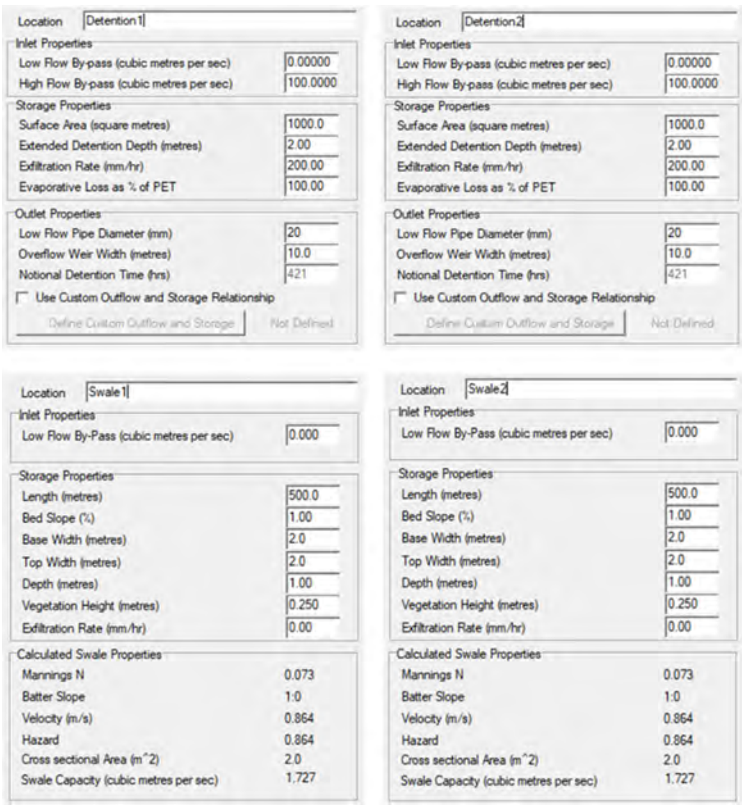
Figure 2.30: Existing Watermill Creek sub-catchment attributes



	Sources	Residual Load	% Reduction
Flow (ML/yr)	1350	744	44.9
Total Suspended Solids (kg/yr)	137000	57100	58.3
Total Phosphorus (kg/yr)	354	177	50
Total Nitrogen (kg/yr)	2870	1690	41.2
Gross Pollutants (kg/yr)	20100	0	100

Figure 2.31: Watermill Creek sub-catchment attributes with inclusion of treatment nodes

The use of 4,000 m^3 of detention/retention and 1,000 m of swales in the Watermill catchment would significantly reduce nutrient loads and peak flows to Emily Bay. For example, MUSIC v6 results show that flow to Emily Bay would be reduced by 44.9 % compared to the existing condition; and this directly relates to the decreases in total suspended solids (58.3 %), total phosphorous (50 %), and total nitrogen (41.2 %). The exact placement of treatment structures within the Watermill catchment is yet to be determined, however it has been demonstrated that significant improvements in runoff water quality can be achieved. Coupled with improved livestock management and wastewater treatment (from septic tanks), runoff water quality is likely to be further improved.



Location	Detention1	Location	Detention2
Inlet Properties		**Inlet Properties**	
Low Flow By-pass (cubic metres per sec)	0.00000	Low Flow By-pass (cubic metres per sec)	0.00000
High Flow By-pass (cubic metres per sec)	100.0000	High Flow By-pass (cubic metres per sec)	100.0000
Storage Properties		**Storage Properties**	
Surface Area (square metres)	1000.0	Surface Area (square metres)	1000.0
Extended Detention Depth (metres)	2.00	Extended Detention Depth (metres)	2.00
Exfiltration Rate (mm/hr)	200.00	Exfiltration Rate (mm/hr)	200.00
Evaporative Loss as % of PET	100.00	Evaporative Loss as % of PET	100.00
Outlet Properties		**Outlet Properties**	
Low Flow Pipe Diameter (mm)	20	Low Flow Pipe Diameter (mm)	20
Overflow Weir Width (metres)	10.0	Overflow Weir Width (metres)	10.0
Notional Detention Time (hrs)	421	Notional Detention Time (hrs)	421
Use Custom Outflow and Storage Relationship		Use Custom Outflow and Storage Relationship	
Define Custom Outflow and Storage	Not Defined	Define Custom Outflow and Storage	Not Defined

Location	Swale1	Location	Swale2
Inlet Properties		**Inlet Properties**	
Low Flow By-Pass (cubic metres per sec)	0.000	Low Flow By-Pass (cubic metres per sec)	0.000
Storage Properties		**Storage Properties**	
Length (metres)	500.0	Length (metres)	500.0
Bed Slope (%)	1.00	Bed Slope (%)	1.00
Base Width (metres)	2.0	Base Width (metres)	2.0
Top Width (metres)	2.0	Top Width (metres)	2.0
Depth (metres)	1.00	Depth (metres)	1.00
Vegetation Height (metres)	0.250	Vegetation Height (metres)	0.250
Exfiltration Rate (mm/hr)	0.00	Exfiltration Rate (mm/hr)	0.00
Calculated Swale Properties		**Calculated Swale Properties**	
Mannings N	0.073	Mannings N	0.073
Batter Slope	1:0	Batter Slope	1:0
Velocity (m/s)	0.864	Velocity (m/s)	0.864
Hazard	0.864	Hazard	0.864
Cross sectional Area (m^2)	2.0	Cross sectional Area (m^2)	2.0
Swale Capacity (cubic metres per sec)	1.727	Swale Capacity (cubic metres per sec)	1.727

Figure 2.32: Treatment node inputs used in MUSIC v6

2.10 WASTEWATER MANAGEMENT

The Water Assurance Scheme (WAS) is the Norfolk Island sewerage system that connects approximately 230 dwellings to the sewer network, including some of the larger accommodation premises. The network consists of seven pump stations and over 100km of pipes directing sewage to the wastewater treatment plant (WWTP). The remaining dwellings on Norfolk Island (~ 520) utilise septic tank systems to treat their household wastewater. Note that the ABS 2016 Census states that there are an additional 255 homes that are unoccupied.

Council engaged Balmoral Group and NSW Public Advisory to develop a business case for the upgrade of the wastewater treatment plant and to provide options for beneficial reuse of recycled effluent. Please refer to this document during discussion of this section (BGA & PWA, 2019). The proposal for the wastewater treatment plant upgrade was developed in consultation with Norfolk Island Regional Council and the Community in response to the following business needs:

- Existing plant determined to have a high risk of failure within the next 5 years
- Environmental risks from effluent discharge to the Norfolk Island Marine Park (to meet its requirement under the *Temperate East Commonwealth Marine Reserves Network Management Plan)*
- Increasing water security risk affecting the Community due to climate change
- Public health risks from household septic tanks contamination surface water and beaches

Assessments of appropriate treatment technologies for the replacement of the Norfolk Island wWastewater Treatment Plant included:

- Capital and installation costs for the appropriate technology
- Identify ongoing operational costs
- Options for beneficial reuse of treated effluent
- Provisions for the management/reuse of sludge
- Take into account the isolation of Norfolk Island and limited availably of technical assistance and supplies
- Allow for future expansion
- Inbuilt redundancy to allow for system failures and maintenance work to be carried out.
- Expansion of current sewer network, allowing more developments to connect, especially in higher density development areas close to the Water Assurance Scheme.

The Community were mainly consulted on the end use as opposed to the treatment plant type, and ultimately the end use determined the type of technology. There was a clear indication from the community that they were keen to have the effluent reused in some capacity however direct aquifer recharge should not be considered due to the lack of understanding of the Island's groundwater systems. The Community were interested in aquifer recharge by passive means, direct reuse for agriculture, stock watering, and pasture irrigation.

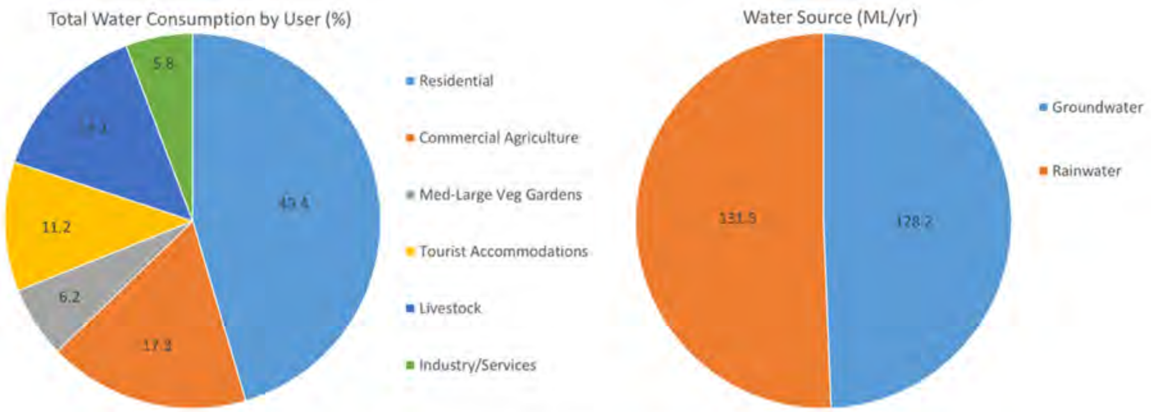
The preferred solution recommended by the Business Case (BGA & PWA, 2019) was to replace the existing plant with a Membrane Aerated Bio-film Reactor (MABR) treatment plant and pipework which will supply recycled wastewater to agricultural areas of Norfolk Island. The option allows for 32 priority households and one tourist accommodation to connect to the centralised sewage network via a pressure sewer system. The upgrade will result in approximately 55 ML/yr of highly treated effluent to be reused for agriculture, stock watering and pasture irrigation; and provides a climate-independent water source.

Improving the centralised sewage treatment system is critical to encourage households in high contamination risk areas to join the centralised system, which will have a major impact on surface water and groundwater quality and the condition of popular tourist beaches. Water quality reports indicate the septic tanks contribute to contamination in surface water flows that lead into popular tourist beaches, Emily Bay and Slaughter Bay (URS, 2013; The Administration of Norfolk Island, 2014; GHD, 2016; Wilson, 2017; AECOM, 2017). Failing onsite systems, especially those in close proximity to bores, also present a contamination risk to groundwater systems.

2.11 IMPROVING WATER SECURITY, EMERGENCY MANAGEMENT, & FOOD PRODUCTION

Norfolk Island has undergone severe water shortages since 2019. Some rainwater tanks were critically low and groundwater levels were showing a decreasing trend. Since all water use on Norfolk Island is sourced from rainwater or groundwater an alternative source was required. In 2020, a desalination plant producing 20 kL/day (7.3 ML/yr) was provided to Norfolk Island by the Australian Government, primarily for the re-surfacing work on the Airport (~$45 million for this work). This desalination plant was left on Island for emergency water supply.

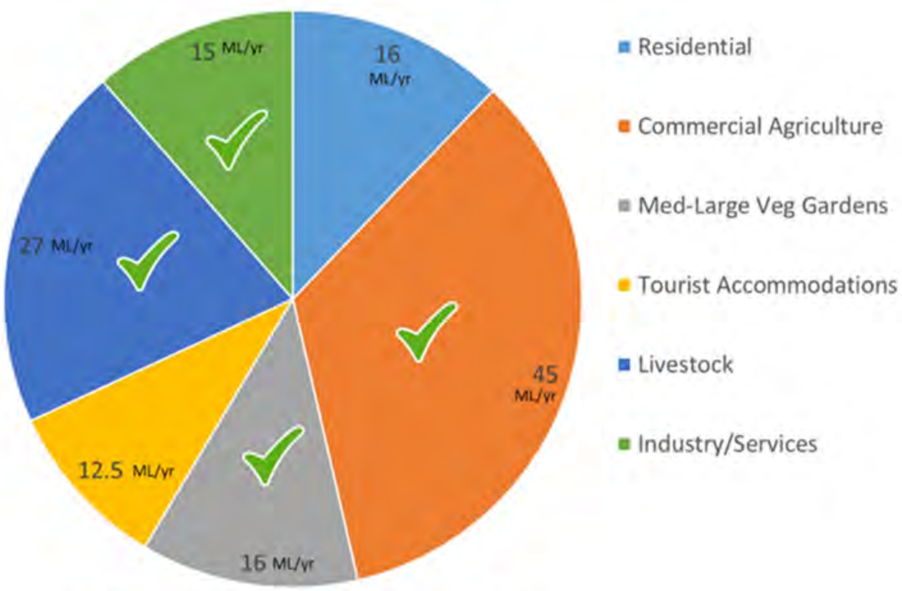
Core components of a sustainable community are a secure water supply and the ability to manage foreseeable emergency risks, and produce fresh and nutritious food. Minimal water results in negligible food production and this was the Norfolk Island condition in 2019/20. Figure 2.32 shows the major water users on Norfolk Island and the relative use of rainwater and groundwater sources.



Data Source: CSIRO NIWRA Report (2021)

Figure 2.32: Major water users on Norfolk Island

Due to the uncertainty in groundwater recharge rates, one main objective is to reduce reliance on groundwater extraction. Figure 2.33 shows the distribution of users relying on groundwater extraction. The green "tick marks" indicate users that would benefit from an alternative water source such as recycled wastewater.



Data Source: CSIRO NIWRA Report (2021)

Figure 2.33: Distribution of Users based on Groundwater demand

Norfolk Island water security is under threat due to the historical reduction in rainfall and increasing temperatures (since 1970's) (BOM, pers. comm.). The implications of a reduction in water security are significant on environmental, social, and economic aspects. A future with limited water security has a direct impact upon household supply, food security (from the perspectives of crop irrigation and stock watering), tourism, public health, and commercial businesses. In fact, no aspect of Norfolk Island life will remain unaffected by this risk. The Emergency Management Norfolk Island Committee (EMNIC) has recently identified several gaps in Emergency Management Response Plans that sit beneath the Norfolk Island Disaster Plan (NORDISPLAN), namely water security and increased risk of unplanned wildfire given a drier, hotter environment.

Norfolk Island Regional Council (NIRC) has made progress towards the upgrade of the NI Sewerage Treatment Plant by commissioning the Balmoral Report (in 2019), which also canvassed feedback from the Community, and provided several options available to NIRC. The Community and EMNIC strongly supported *"Option 1 - Membrane Aerated Biofilm Reactor with water recycled to agriculture and community standpipe. Reticulated pressure system for priority areas."* An estimated 55 ML/y of recycled Class A water would be made available, which would be used to provide irrigation and stock watering, reducing the demand on rainwater and groundwater.

The proposal for the wastewater treatment plant upgrade was developed in consultation with Norfolk Island Regional Council and the Community in response to the business needs, and assessment of appropriate treatment technologies for the replacement of the Norfolk Island Wastewater Treatment Plant. The total cost for Option 1 was ~$18 million.

In the recent Norfolk Island Environmental Assessment, an “available water” assessment was undertaken. Figure 2.34 highlights the main sources of water used, proposed, or available for Norfolk Island in 2019/20. Figure 2.35 highlights how available water could be better utilised, whilst reducing the need for desalination or increasing groundwater extraction rates. The significant differences from existing water availability (Figure 2.34) and what could be utilised (Figure 2.35) are based on:

- Rainwater harvesting improved by a conservative estimate of 15% by optimising roof area/tank volume on existing dwellings/accommodations.
- Decreased dependency on groundwater extraction (lowers extraction by 55 ML/yr, effectively reducing extraction to pre-1990’s levels) (lubbe side is).
- Desalination and deep groundwater extraction pre-feasibility options only provide 30.8 ML/yr and would be almost ineffective in a “dry” period similar to that experienced by Norfolk Island in 2019/20.
- Recycled water used for ~43% of the Island’s demand (“fit for purpose” users) and is climate independent; **resulting in an additional 103 ML/yr for Island water demand.**

The fact is that Norfolk Island is not short of water, the Island only lacks the infrastructure to provide a sustainable approach to utilising all available sources and increasing water security into the future (refer Figure 2.35). The cost of a new NI Sewerage Treatment Plant alone is ~$9 million. However, to not invest the full amount of $18 million for the additional new connections, reticulated water to “fit-for-purpose users” (commercial growers, services/industry, and livestock, reflecting ~43% of the Island’s water use), and community stand-pipe; would be a significant opportunity missed. For example, ocean discharge would continue to enter the Marine Park at considerable environmental costs and economic losses through fines, septic tanks will still pollute surface and groundwater, and the loss of 103 ML/yr of available water (~38% of existing total water demand). These can all be avoided by investing the full $18 million and providing Norfolk Island the future they deserve.

It is also recognised that Option 1 would provide a reliable supply of water that may be utilised for firefighting purposes which currently do not exist. The increasing risk of fire, especially within the eucalypt plantations of the Norfolk Island National Park (NINP) has been flagged with EMNIC and NINP as a real and emerging threat. There has never been a more compelling argument for water security, improved food production, and emergency management on Norfolk Island. The full WWTP upgrade, connection of additional dwelling/accommodations to the

Water Assurance Scheme, a reticulated network to "fit-for-purpose" users, and stand-pipe for other users; all point to a sustainable water and food future for Norfolk Island.

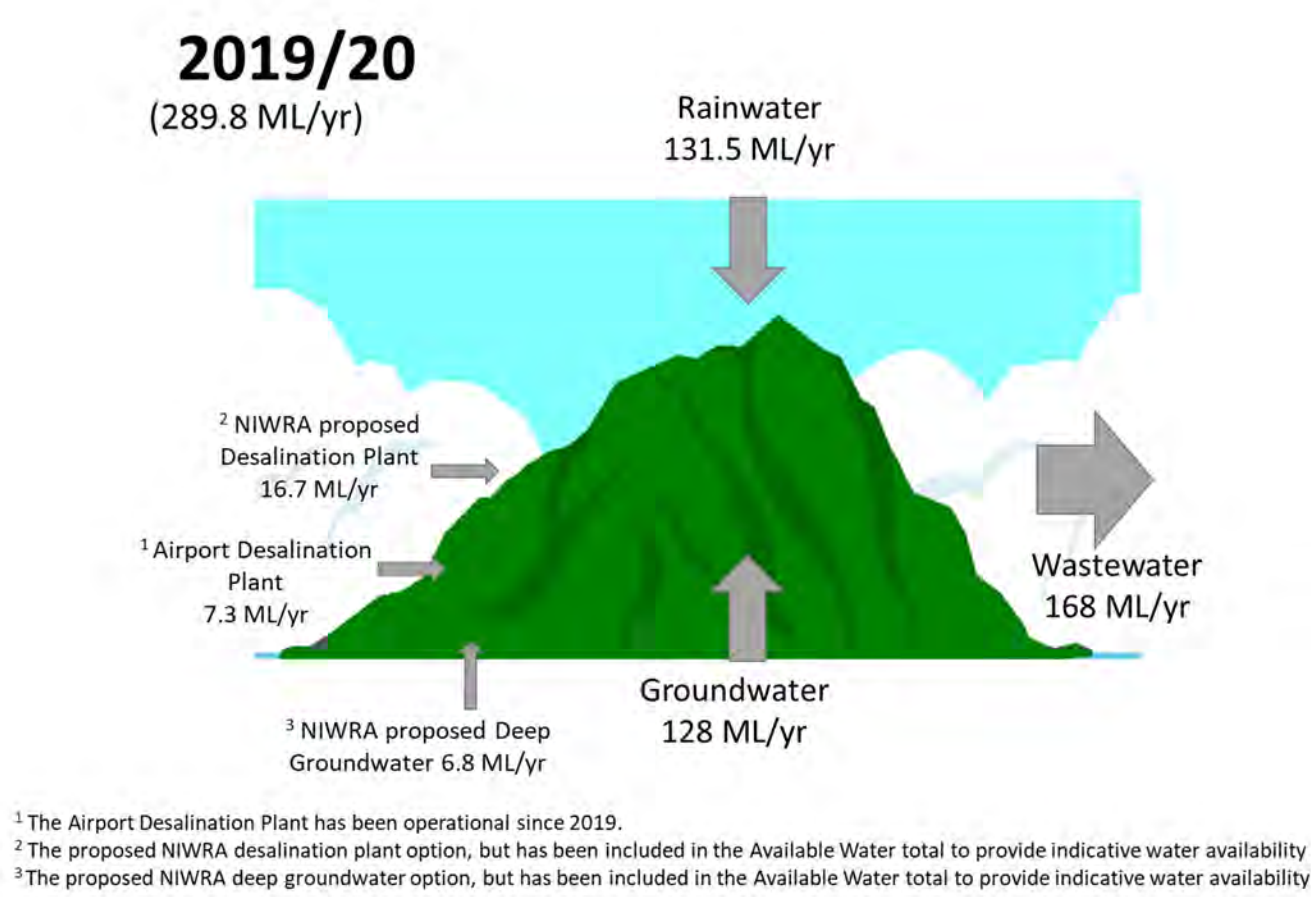


Figure 2.34: Available water on Norfolk Island during 2019/20

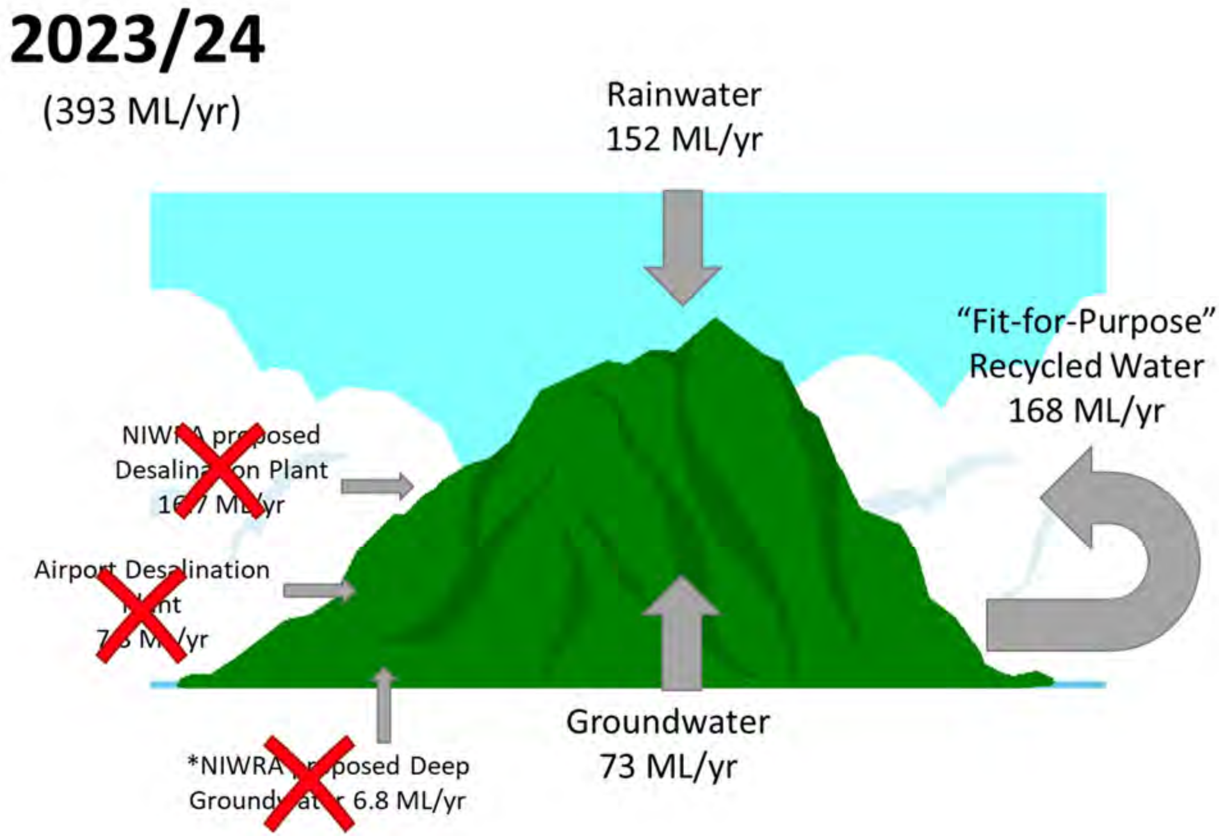


Figure 2.35: Available water on Norfolk Island after the WWTP upgrade and Reuse Option 1 in the Balmoral Report

Summary/Findings

- Norfolk Island water security is under threat due to the reduction in rainfall and increasing temperatures.
- Groundwater levels in 2019/20 at lowest point in recent history and recharge rates remain uncertain.
- Approximately 131 ML/yr of harvested rainwater and 128 ML/yr of groundwater extracted for Island water demand.
- All wastewater discharged via septic tanks across the Island, or treated through the Water Assurance Scheme before discharged to the ocean.
- Attributed to livestock and non-sewered areas (septic tanks), surface water quality in major creeks often exceed ANZECC guidelines after heavy rain, sometimes causing closure of Emily Bay (as a human health hazard).
- Poor monitoring and metering of water use across Norfolk Island.
- Up to 65% of buildings do not have optimised roof/tank volume for increasing rainwater yields.

Recommendations

- Investigate ways to mitigate the effects of climate change, drought, and seasonal water shortages, such as alternative sources of water for irrigation. Option 1 in the Balmoral Report provides a climate dependent source of recycled wastewater into the future.

- Alleviate pressure on groundwater extraction by utilising wastewater discharged to the ocean, thus also eliminating nutrient loads on the Marine Park.

- Investigate approaches to decreasing runoff, such as leaky weirs, and other retention/detention devices in the landscape.

- Digitise location of existing septic tanks and improve operational processes, such as initiating a septic tank inspection program to reduce poorly performing systems contributing to surface and groundwater quality issues.

- Incrementally over time, connect dwellings to the Water Assurance Scheme, further securing "fit-for-purpose" water into the future.

- Optimise roof area/tanks volume on up to 65% of dwellings to improve rainwater harvesting yields.

- Initiate water-metering projects to determine demand and diurnal water use patterns for a range of sites (hospital, school, residential, commercial, tourist accommodations and industrial sites). The use of water meters has proven useful for leak detection in water systems and the use of "smartmeters" can incorporate a citizen science approach to Norfolk Island water management.

- Continued monitoring of surface water discharge throughout the island using stations installed by CSIRO.

- Monitor of groundwater levels and rainwater tank levels at appropriate sites.

- Update Development Application (DA) standards for new dwellings (in progress)

CHAPTER 3: NORFOLK ISLAND'S WASTE MANAGEMENT SYSTEM

EXECUTIVE SUMMARY

Norfolk Island Regional Council (NIRC) is uniquely challenged in developing a modern waste management system protective of the marine park in which they exist and equivalent to mainland Australian Councils. NIRC lacks the resource base that mainland Australian Councils have and has waste management costs that are magnitudes higher due to a current reliance on exporting wastes back to Australia. This comes at great cost through reliable air freight or infrequent shipping often limited to breakbulk operations.

Port Macquarie Council for example has total waste management revenue of $20.5 million per annum from a population of 85,000 from a revenue base (2019) of $213 million (48% from rates), which includes $31.6 million in grants from the NSW and Australian Governments[1]. Waste management costs for Port Macquarie-Hastings Council therefore consumes 9.6% of its total budget while total per capita waste management costs are an economical $241 per annum due to modest disposal costs.

Norfolk Islands reported collecting total waste management revenue of $793,492 from a population of 1748 from a revenue base (2019) of $41.70 million (7.8% from rates), which includes $20.4 million in grants from the Australian Government [2]. Waste management costs for Norfolk Island Regional Council is therefore equivalent to only 2.3% of its total budget with grants or 4.5% without, while total per capita waste management costs for NIRC was $454 per annum, approximately double the Port Macquarie per capita costs due to high export and disposal costs (comparable to the $500 charged per person on Lord Howe Island).

Unique to remote locations the economics of waste management in Norfolk Island are extreme and closer to the situation in Antarctica than a mainland council in Australia. For comparison the costs of disposing of a cubic metre (to landfill) for 1 tonne of mixed household waste to landfill in Port Macquarie[3] is approximately $240, while for Norfolk Island disposal of the same waste to landfill costs approximately 5 to 10 times this cost with sea freight and disposal being $1,169 and air freight and disposal costing $2,288 based on costs incurred by NIRC in 2020/2021[4].

This quantity of exported waste is also likely to increase both as NIRC reduces the amounts of waste being disposed of at headstone and with increased consumption if regular shipping is introduced through construction of a temporary groyne at Cascades Pier which eliminates break bulk cargoes and permits full shipping containers to be unloaded.

Conversely there is also a prospect of lowering shipping costs from the $6,500 charged by Boral for a 20 FCL to be reduced to approaching costs around $2,500 to $3,500 which similar to that experienced by similar locations in the Pacific (Tuvalu, Kiribati, Niue, Nauru) through negotiating a regular backloading rate which would significantly reduce export and disposal costs by sea freight though still remaining at estimated costs of $708 for residual waste and $344.06 for recyclables per tonne.

However, the clear gap in available funding versus costs in pursuing higher levels of waste management to protect the unique environment Norfolk Island is not easily answered. The suitability of thermal treatment systems such as incineration, pyrolysis or gasification on paper are an appealing proposition. However, based on international, regional and Australian experience these are still speculative propositions for Norfolk Island.

Uncertainty about the viability of thermal treatment systems for Norfolk Island based on high costs and risks were raised in two assessments already conducted by Norfolk Island Administration in 2009 and 2015. In contradiction to Circular Economy principles, these systems would be significant emitters of greenhouse gases and a major source of air pollution and ash.

[1] Port Macquarie – Hastings Council Annual Report, 2019/2020.
[2] Norfolk Island Regional Council Annual Report, 2018/2019.
[3] https://www.pmhc.nsw.gov.au/Services/Waste/Waste-facility-location/Waste-fees-charges
[4] Norfolk Island Regional Council Waste Management team.

Better results and a reduction in expensive waste exports might be achieved through a greater emphasis of Circular Economy principles through fast tracking and better resourcing of programmes, equipment and human resourcing to ensure waste such as glass and cardboard (which together make up 53% of all commercial and household municipal wastes) are processed and utilised on Norfolk Island as soon as possible.

Though cardboard utilisation as 'renewable' material as part of the biomass load in the energy sector is a possibility either as cogeneration with timber trash and woody wastes such as occurs in Fiji at the sugar and timber mills or as part of biogas generation. Further information on this is provided in the energy section of the report.

Partnering with plastic packaging companies is an option to convert residual waste bales, which currently contain 60% to 70% plastic, from a quarantine waste to plastic bales through concentrating the plastics and addressing contamination. Food and hygiene products could be diverted to the HotRot system through potentially piloting biobased nappies and feminine hygiene products.

Clean plastic bales could potentially be used in new Circular Economy applications now being developed. This could be done through leveraging packaging brand audits conducted under this project and linking with new initiatives, such as the ANZPAC Plastic Pact and the Commonwealth's new projects working in the same space.

Further engagement with the private sector is needed to move toward packaging free and low packaging products following the example of the Prinke store and commitments made by the private sector in Australia, with the aim of reducing the flow of waste materials into Norfolk Islands that add to the waste management problem.

The Waste Management Centre and its staff should be recognised for the great strides in improved waste management that have occurred since 2015. However, its services are not fully utilised by the entire population as shown in the survey results and the persistence of damaging practices of waste burning, burial and dumping (via Headstone).

Many individuals choose to use the Waste Management Centre to dispose of only certain waste streams that they cannot easily burn on their properties such as glass. Others opt to boycott the Waste Management Centre entirely due to the required fees and misinformation about what is done with their waste once deposited at the centre.

This should be addressed through properly formulated Community-Based Social Marketing which has been successfully used in identifying barriers and benefits and developing targeted projects to change normative behaviours which would be needed to gain full partnership from the community.

Nonetheless, whether residents utilise the Waste Management Centre or dispose of their waste by other means, the sheer volume of waste on the island remains a key challenge. It is therefore critical that Norfolk Island moves towards a system that focuses on reduction and reuse, and that the accessibility and processes of the current Waste Management Centre are improved.

Acronyms

APCO	Australian Packaging Covenant
CDL	Container Deposit Legislation
CDS	Container Deposit Schemes
EPR	Extended Producer Responsibility
FOGO	Food and Green Waste
MPS	Marine Plastic Solutions
NIRC	Norfolk Island Regional Council

SIDS	Small Island Developing States
SUP	Single Use Plastic
WMC	Waste Management Centre

1. INTRODUCTION

1.1 BACKGROUND

Norfolk Island is an oceanic island located in the Pacific Ocean, approximately 1400 km from the Eastern Seaboard of Australia and 800 km from the nearest land mass. Norfolk Island is a mountain top remnant of an elongated shield volcano and consists primarily of a large, elevated plateau, formed from horizontal sheets of basalt. The island has an area of approximately 3855 ha and is home to a variety of endemic species including 43 plants, 15 birds, and an unknown number of invertebrates.

Norfolk Island has a small population of just 1,748 people[5]. At the time of the 2016 Census, the population was comprised of 46.8% males and 53.2% females. The median age of people in Norfolk Island in the 2016 Census was 49 years. Children aged 0–14 years made up 16.9 % of the population and people aged 65 years and over made up 23.8 % of the population. There were 1,080 private dwellings recorded on the island at the time, and an average of 2.2 persons in each household.

Each year Norfolk Island accommodates approximately 27,565 visitors, the majority of whom come from Australia and New Zealand[6]. Tourism is key pillar of the economy for Norfolk Island which markets itself as a ‘natural paradise’ hosting a long list of pristine natural settings to be enjoyed such as beaches, rolling green hills, and pine forests. However, rates of tourism have been steadily declining since 2002 due to changes in market demographics, traveller trends, increased competition from other holiday destinations and the world financial economy. Likewise, COVID-19 has had an extremely detrimental effect on the Norfolk Island economy with tourist entry being either restricted completely or limited to certain Australian citizens at different times during 2020.

According to Norfolk Island Tourism Strategic Plan 2013-2023, there are plans to boost tourism through the improvement and promotion of niche market attractions such as unique flora and fauna, a commitment to sustainability, and unique homegrown/locally made products. However, the effective management of waste produced by both locals and tourists remains a challenge. Thus, tackling the Norfolk Island waste management challenges are an important step in addressing improved tourism, sustainability, and quality of life for its residents.

Marine Plastic Solutions (MPS) presents this review of the Norfolk Waste Management System in response to changes in strategic and administrative circumstances in recent years since the Island’s last waste management review in 2015.

Issues addressed in this report highlight the impacts of such change but also the opportunities available to the Island’s capacity to manage waste. Domestic changes in logistical shipping chains, the relationship with the Australian commonwealth, destination status from domestic to international between Australia, and disrupted international recycling flows due to waste bans in countries such as China all pose challenges for waste regulatory frameworks. Additionally, there have been considerable improvements, propagation, and participation in the strategic use of bans, container deposit schemes (CDS) and Extended Producer Responsibility/Product Stewardship since 2015.

In recent years, an increasing number of waste management activities are being performed in other small island developing states with specific reference to the Pacific context. These present case studies for island waste

[5] Australian Bureau of Statistics, 2016.
[6] Norfolk Island Regional Council, 2018.

management practices that could be considered for Norfolk Island. There have also been many changes by governing and regulatory bodies such as the introduction of the *Recycling and Waste Reduction Act 2020* which establishes a framework to regulate the export of waste materials, in line with the Council of Australian Government 2020 agreement to ban the export of waste plastic, paper, glass and tyres. Importantly, this Act also targets product stewardship, with manufacturers, importers, distributors and other persons being encouraged or required to take responsibility for their products. The Australian Packaging Covenant has also rolled out its new ANZPAC Plastics Pact which functions across Australia, New Zealand, and the Pacific Islands to work with businesses, governments, and NGOs from across the plastics value chain towards a circular economy for plastic.

Norfolk Island has shifted from 'international destination' to becoming 'part of Australia' as a result of the *Norfolk Island Legislation Amendment Act 2015* and related Acts, which allowed the Australian Government to assume responsibility for funding and delivering national and state level services. These reforms have had a number of significant consequences including changes to biosecurity regulations, waste exports, and the governing of and funding for waste management on Norfolk Island.

In the waste sector, common waste disposal behaviours and practices performed in larger land masses are not always feasible for small islands, for an Island as geologically isolated and ecologically unique as Norfolk Island it is not exempt from these challenges. Limited by land space and reliant on groundwater for domestic use, which lies an average of 1 meter below the surface, it has previously been said that the construction of an on-island landfill is not a viable from an environmental, economic or human health perspective due to concerns of contamination[7]. Thus, common practice for Norfolk Island waste management has been to eliminate the majority of wastes by open pit burning and depositing the residues, burnt and partially burnt, into the ocean off Headstone cliffside. This practice has been criticised for its pollution impact on air and water quality, the negative visual impact of floating wastes, and the negative environmental consequences impacting the island's highly valued fishing and tourism sectors[8].

1.2 BASIS OF THIS STUDY

Marine Plastic Solutions Pty Ltd has been commissioned to undertake this study in preparing this report the MPS team travelled to Norfolk Island where they:

- Reviewed current waste management services and systems,
- Conducted a household waste audit,
- Conducted three marine litter surveys on Emily Bay, Bumbora Beach, and Anson Bay, and
- Carried out a brand audit.

The MPS team found that while Norfolk Island Regional Council and its Waste Management Team has made impressive improvements to their management of waste since 2015 it is struggling to effectively manage their waste using current systems and funding and the ongoing pressure to continue to improve. Currently, contaminating and harmful methods of waste disposal such as burning, backyard burial and disposal at sea are reducing but still regularly practiced. These burning, burial, and dumping practices are problematic as they have detrimental impacts on the environment, water quality and human health[9].

[7] The Administration of Norfolk Island, 2009.
[8] The Administration of Norfolk Island, 2009; 2018, Norfolk Island Regional Council.
[9] Norfolk Island Regional Council, 2018.

2. NORFOLK ISLAND CONTEXT

2.1 SMALL ISLAND EXPERIENCE

The MPS team has extensive experience working in island waste management throughout 15 Pacific Islands (e.g., Kiribati, Samoa, Solomon Islands, Vanuatu, Tuvalu), six Caribbean small island developing states (SIDS), the Maldives in the Indian Ocean as well as in Australia with additional experience in Asia, Europe and Africa. Since 2013, the MPS team has worked across a variety of waste related issues including, solid waste, hazardous waste, healthcare waste, e-waste, shipping waste, and plastic in order to help tailor solutions to specific needs to facilitate transformation to the circular economy and a sustainable future.

Recent projects include:

- Implementing private sector waste development projects in the Solomon Islands targeting plastic waste, organic waste, other recyclables, affordable collection systems (pay as you throw) and reform of the business enabling environment (treaties, tax and fostering support of global packaging companies,
- The Mid-Term Review of the Kiribati Solid Waste Management Program (funded by the Ministry of Foreign Affairs and Trade, New Zealand),
- The development of a Market Systems Assessment (MSA) to identify specific waste markets and value chains for the Strongim Bisnis programme in the Solomon Islands (funded by the Australian Department of Foreign Affairs and Trade),
- The development of the Vanuatu National Plastic Strategy (funded by the Department for International Development), and
- An ongoing marine plastics debris deep dive study at national and regional levels for the Eastern Caribbean (funded by World Bank PROBLUE multi-donor trust fund).

MPS is also involved in private sector initiatives such as marine plastic recovery programmes. MPS is currently collaborating with Banana Hands, an Australian/Solomon Islands company producing socially responsible coconut based cosmetic and personal care products, on their Clean Oceans Project to assist in the removal of marine plastic from the Solomon Islands outer islands through training and equipping locals. MPS is a member of the ANZPAC Plastic Pact and working with them to expand marine plastic recovery activities across the Pacific Region.

Throughout our work, MPS has identified a number of common challenges affecting small islands including, insufficient budget, lack of staff and resources, inadequate ongoing external technical support, and an engrained culture of ad hoc approaches to waste management through methods such as burial, burning and dumping. In order to tackle these issues, the approach to waste management must be comprehensive and inclusive so as to avoid the trap of reverting back to haphazard approaches over time.

2.2 KEY CHALLENGES FOR NORFOLK ISLAND

Norfolk Island faces many challenges in relation to waste management. The remoteness of the island itself significantly impacts sustainable waste management practices. Since the island has no harbours, access is restricted with all sea-bound goods and materials transported to jetties via traditional long boats. Unpredictable weather conditions, combined with a lack of regular shipping to New Zealand and no direct shipping to Australia, further contribute to the costs and logistics of exporting waste. Such factors can also negatively affect the procurement of equipment and parts necessary for the efficient management of waste on the island. Furthermore, the economic realities of exporting materials to markets for recovered resources affects the feasibility of moving materials from Norfolk Island.

Incoming sea freight in 2017–18 was about 18,000 revenue tonnes[10]. It is expected this will drop to about 15,000 tonnes in 2018–19 as the 2017–18 year included one-off freight deliveries for the recently completed upgrade of the Cascade Pier. Outgoing sea freight is minimal and includes kentia seeds, empty beer kegs, personal effects,

[10] Norfolk Island Regional Council, 2018.

waste metals and rubber for recycling. Outgoing sea freight is also expected to increase, due to plans to develop a temporary groyne at cascades, which will increase incoming sea freight and hence overall consumption. This will increase waste exports for offshore disposal and recycling.

A lack of recurrent funding can adversely impact effective operation of the waste management system. Purchase of capital equipment along with maintenance and repair of existing infrastructure and equipment is dependent upon limited available funding under Norfolk Island Regional Council (NIRC). A shortage of personnel with technical skills and expertise in the waste management sector, as well as those with the ability and experience to perform mechanical maintenance and repair, can also present real challenges for waste management on the island.

The small size of the island means that landfill is not a feasible option and the population depend upon limited infrastructure and services. Diverse waste streams including hazardous waste and solid waste (organic, recyclable and residual) require effective, low per-unit cost management. There is no household bin collection service, and the community relies instead upon a waste management centre. Households and businesses sort and deposit their own waste into glass, paper and cardboard, aluminium, steel, plastic, and residuals. In addition, there are smaller receptacles for the collection of food waste, batteries, and aerosol cans. Such a system requires education and awareness raising and relies upon the continued participation and commitment of the community in order to operate efficiently and effectively.

The position of Norfolk Island within a marine park presents some unique challenges for the management of waste. The Park itself not only supports an abundance of diverse temperate and tropical marine life but provides for a rich source of recreational water activities including swimming, snorkelling, diving, outrigging, surfing, wind surfing, paddle boarding, jet skiing and fishing enjoyed by locals and tourists alike. Threats to the marine ecosystem include the discharge of surface water with high nutrient and coliform levels, dumping of waste into the ocean and effluent discharge from the Sewage Treatment Plant. A formal program of marine water testing would be required to determine the types and levels of impacts from such discharges.

Finally, the views and opinions of local inhabitants regarding waste treatment and disposal within their small island community must also be given special consideration. Attitudes and expectations around issues of self-determination and governance can affect social cohesion which is especially crucial for the well-being of the community as a whole.

2.3 NORFOLK ISLAND REFORM

The Norfolk Island Legislation Amendment Act and related Acts, which came into effect in May 2015, allowed the Commonwealth to assume responsibility for funding and delivering national and state level services. This Act was introduced in order address issues of sustainability which arose from the model of governance requiring Norfolk Island to deliver local, state and federal functions from 1979. Since 2016 mainland taxation, social security, immigration, biosecurity, customs and health arrangements, including Medicare and the Pharmaceutical Benefits Scheme, have been extended to Norfolk Island. The Department of Infrastructure, Transport, Cities and Regional Development is working to further extend remaining Commonwealth legislation to the island in order to ensure that laws are consistent with contemporary Australian laws.

As a result of these reforms, Norfolk Island has shifted from being an ‘international destination’ to becoming ‘part of Australia’. Consequentially, Norfolk Island Regional Council is now in charge of waste management and have adopted the Waste Management Strategic Plan (WMSP) to guide operations to better address the Norfolk Island waste related challenges.

According to the Norfolk Island Environment Strategy 2018–2023, waste generated from packaging of imported goods contributes significantly to the volume of waste managed on the island. Additionally, waste and recycling exports have also been affected due to Norfolk Island now being subject to country import bans on Australian exported waste such as the bans imposed by China in 2018.

Despite becoming ‘part of Australia’, Norfolk Island is not considered to be part of any particular State or Territory of Australia and as such is ineligible for State or Territory grants. As a result, Norfolk Island is only able to access funding programs specifically developed to assist Councils on key environmental actions. Without extra assistance Council is currently unable to generate a strong surplus budget for operations due to a variety of factors including small ratepayer base, high cost of living, remote location and limited growth and development on the island. As things currently stand, the environment division of Council lacks the resources to fully deliver the environmental objectives set out in the Community Strategic Plan 2016-2026.

2.4 POSITION WITHIN A MARINE PARK

The Norfolk Commonwealth Marine Reserve, managed by Parks Australia, is one of eight marine parks that make up the Temperate East Network off the coast of New South Wales and Queensland. The reserves of the Temperate East Network were established to protect and maintain marine biodiversity, contribute to the National Representative System of Marine Protected Areas (NRSMPA) and to help ensure the long-term ecological viability of Australia's marine ecosystems.

The Temperate East Commonwealth Marine Reserves Network Management Plan 2014-2024, prepared under the Environment Protection and Biodiversity Conservation Act 1999, is the primary tool for the conservation and management of the Temperate East Network and sets out which activities are allowed without authorisation, allowable with authorisation and not allowed.

The Norfolk Island Marine Park (NIMP) covers 188 443 km2 of marine area surrounding Norfolk Island. The reserve includes three zoning types:

- National Park Zone (International Union for Conservation of Nature, IUCN, Category II)
- Habitat Protection Zone (International Union for Conservation of Nature, IUCN, Category IV)
- Special Purpose Zone (Norfolk) (International Union for Conservation of Nature, IUCN, VI)

Norfolk Island itself is contained within the Special Purpose Zone which is designated as IUCN category VI; a protected area with sustainable use of natural resources. The primary objective of this category is *to protect natural ecosystems and use natural resources sustainably, when conservation and sustainable use can be mutually beneficial*[11]. Other objectives for this category are as follows:

- To promote sustainable use of natural resources, considering ecological, economic and social dimensions;
- To promote social and economic benefits to local communities where relevant;
- To facilitate inter-generational security for local communities' livelihoods – therefore ensuring that such livelihoods are sustainable;
- To integrate other cultural approaches, belief systems and world views within a range of social and economic approaches to nature conservation;
- To contribute to developing and/or maintaining a more balanced relationship between humans and the rest of nature;

o To contribute to sustainable development at national, regional and local level (in the last case mainly to local communities and/or indigenous peoples depending on the protected natural resources);

o To facilitate scientific research and environmental monitoring, mainly related to the conservation and sustainable use of natural resources;

o To collaborate in the delivery of benefits to people, mostly local communities, living in or near to the designated protected area; and

o To facilitate recreation and appropriate small-scale tourism.

[11] Director of National Parks, 2013.

Some of the current methods of discharge and disposal of certain materials in the Norfolk Island waste stream into the ocean are not consistent with the objectives for the Marine Park. Parks Australia has allowed the current methods of discharge and disposal to continue on the understanding that NIRC is actively seeking solutions and investigating alternative methods of waste disposal and is committed to ceasing the current practices as soon as practicable.

3. TECHNICAL CONSIDERATIONS

3.1 NORFOLK ISLAND WASTE MANAGEMENT CENTRE

The Norfolk Island Waste Management Centre (WMC) opened in October 2003 and is comprised of the Main Shed with a drop off zone, revolve area and processing area. As there is no waste collection service on the Island residents and businesses are responsible for dropping off sorted waste to the WMC. Solid waste is received, sorted and where possible, processed at the Centre. A shredder for processing green waste also operates at land adjacent to the WMC Shed. The WMC Shed currently houses the following equipment and machinery:

- Receptacles and bays for sorting and storing processed waste
- Multi-purpose baler and mini sort line for processing general waste, carboard, plastic, aluminium and steel cans
- Bobcat and trucks for shifting and transporting waste
- A glass crushing mill (currently not operating)
- Loader
- Shredder for processing tyres, hard plastics, cardboard and paper
- Office and staff amenities.

During the visit by MPS waste delivered to the WMC was sorted and processed during as follows:

- Cardboard and 'uncompactable' mixed household wastes (mattresses, bric a brac[12], furniture, old toys, etc.) were transported to the Headstone Waste Disposal Facility on the southwest coast of the Island where it was burnt in an open area at the cliff edge.
- The burnt remains and residual ash are then disposed of via an adjacent chute to the ocean (Norfolk Marine Park) though some metal scrap is reportedly recovered and sent to the bailer.
- Glass (mostly bottles), butcher's waste and deceased animals (e.g., cattle, horses) were being deposited directly into the ocean at Headstone Waste Disposal Facility via the chute with no processing or treatment (to be diverted to the HotRot system).
- The majority of the residual/general waste is baled and exported to be processed/recycled/disposed in Australia or New Zealand. Since the MPS audit cardboard as also been compacted and exported.
- A HotRot composting plant has been commissioned and awaiting full scale operations.
- A car crusher has been commissioned and has been used to crush cars, metals and white goods in preparation of future export.

[12] Miscellaneous objects and ornaments of little value.

Norfolk Island has identified a need to not only change the behaviour of end-of-life waste management but also to develop a better system where less waste is produced on the island, recycling or reusing is enhanced and the accessibility and processes of the current WMC are constantly improved to meet this need.

3.1.1 WASTE DROP OFF AREA

General waste collection/disposal including plastics

The current method of solid waste collection/disposal for both residents and commercial premises is for solid and other wastes to be dropped off at the waste management centre (WMC) between the hours of 7am to 3pm Tuesday and Saturday, and 7am to 1pm Wednesday to Friday. No curb-side collection takes place on the island.

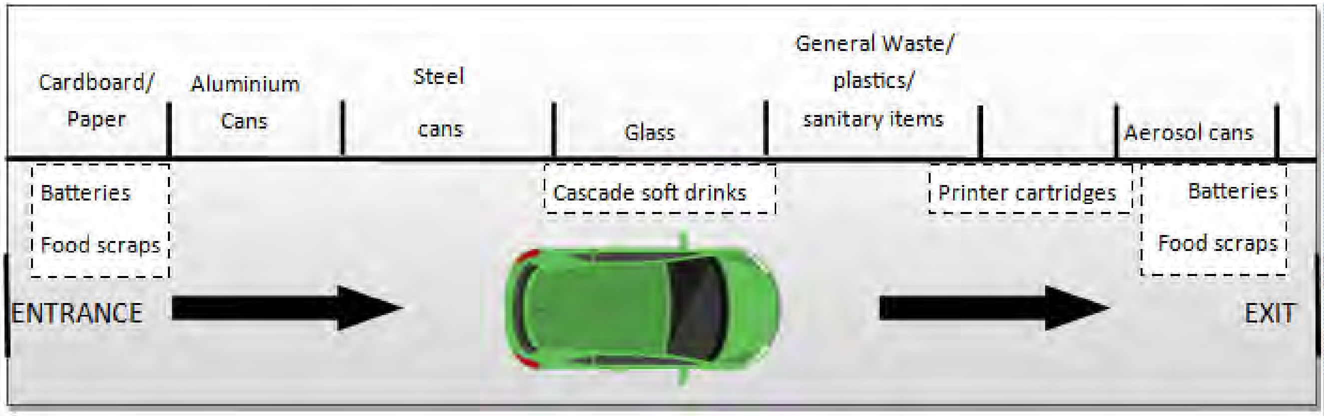


Figure 3.1 Norfolk Island WMC Sorting Guide 2020

Residents are encouraged to separate recyclable materials including glass, aluminium and steel food cans, batteries, and general rubbish into labelled chutes within the WMC as shown in Figure 3.1 above and Figure 3.2 below.

Figure 3.2: Norfolk Island WMC waste drop off area and disposal chutes 2020

The waste streams are then stored on the floor of the WMC for removal by the staff. Recyclables, residual and hazardous wastes are exported off the island and uncompactable waste is transported to the Headstone Disposal Centre, where it is burnt and metal is recovered and returned to the centre for compaction with white goods and cars, while ash and other incombustible parts of the burned wastes are disposed of into the ocean.

3.1.2 WASTE SEGREGATION

Recyclable materials are deposited into the labelled chutes for carboard, aluminium cans, steel food cans, glass, and clean plastic in the first half of the drive though drop off with a separate chute for general garbage near the exit

Larger vehicles are directed to the lower level of the WMC where they discharge their loads and return through the same entry door. The delivered waste is then periodically lifted by bobcat into one of two areas allocated on the floor for the storage of general waste.

The waste is then loaded by bobcat onto the conveyor of the multi-purpose baler and mini sort line where recyclables are periodically compacted and baled, and general wastes are sorted to divert any remaining recyclable materials out before the residual wastes are compacted and baled for export as shown in Figure 3.3.

Figure 3.3:. Multi-Purpose Baler and Mini Sort Line used for aluminium, steel, plastic and residual wastes at the WMC

Wastes that are not to be baled (cardboard, glass and uncompactable mixed wastes) are loaded by the bobcat into a tipper for transport by WMC staff to Headstone for burning, subject to prevailing wind conditions, prior to ocean dumping. Though it is noted here that baling of cardboard for export has now also commenced. The main WMC receival and processing area has the following equipment: 2x bobcats, forklift with rotating forks, forklift with clamps, front end loader (currently being repaired), 2 small tipper trucks and a Brentwood Shredder AZ50HD capable of shredding cardboard, small tyres, food, mixed plastics, mixed MSW, timber and light grade sheet metal. To promote reuse within the community an area to the right just prior to exiting the drive through drop off is an area where the public can place useful household goods which they no longer need but are still useable by other Norfolk Islanders.

3.1.3 CARDBOARD

The MPS waste audit found that cardboard is the largest single municipal waste stream in Norfolk Islands making up 30% of the municipal waste stream from combined commercial and domestic sources. MPS estimates 177 tonnes of carboard waste is being produced each year from commercial and domestic sources. The MPS online waste behaviour survey in section indicated that 83% of all cardboard waste is disposed of to the WMC and the remaining 17% offsite through burning, burying, disposal to Headstone and composting.

The commercial sector was found to be the largest contributor as shown in Table 3.11 and Figure 3.20 producing an estimated 83% of cardboard waste. During the MPS audit in December 2020 all cardboard waste collected at the WMC (as shown in Figure 3.4) was taken to Headstone, where it was burnt with 'uncompactable' wastes and ash being disposed of at sea.

Figure 3.4: Norfolk Island WMC Cardboard Bay

It was planned that cardboard waste would be completely reprocessed via the HotRot system after being processed through the cardboard shredder as shown in Figure 3.5. Though concerns exist regarding how much cardboard the HotRot system can absorb, how to control any issues related to plastic tapes, adhesives and labels that are attached to cardboard (which could build up in soil over time), and other impacts from synthetic inks and chemical residues.

Figure 3.5: Cardboard shredder at the WMC

The WMC has started baling and exporting cardboard to Australia to avoid harmful burning practices and disposal of ash to the sea. However, recent sea freight costs of $804.59 and air freight costs of $1,958.18 per tonne (without disposal costs) means that the potential export costs to Australia would be between $142,412 and $346,598 per annum to freight the estimated 177 tonnes of cardboard waste produced. A study conducted by the University of Queensland for the EU funded PacWaste Project investigated emissions from cardboard briquettes compared to commercial barbecue briquettes and found they were comparable[13].

Given the unsustainably high costs to bale and export cardboard and the concerns in open burning at Headstone and sea dumping the ashes it would be useful to determine if that emissions from combusting clean cardboard in Norfolk may be comparable to the burning green waste or forestry trash to determine if there are other acceptable options.

Though cardboard utilisation as 'renewable' material as part of the biomass load in the energy sector is a possibility either as cogeneration with timber trash and woody wastes such as occurs in Fiji at the sugar and timber mills or as part of biogas generation. Further information on this is provided in the energy section of the report.

3.1.4 RESIDUAL WASTE

The MPS waste audit found that residual waste is the second largest component of municipal waste in Norfolk Island, making up 25% of the waste stream. Approximately 60% is generated from commercial sources and 40% coming from households as shown in Table 3.1 and Figure 3.20.

Figure 3.6: Norfolk Island WMC Residual Waste Bay

The MPS waste audit estimated 151 tonnes is being produced per annum, which is compacted after general garbage is collected from the waste bay by bobcat and is loaded onto the mini sort line conveyor belt where recyclables are removed and diverted to the relevant bays.

[13] https://www.sprep.org/attachments/pacwaste/PacWaste_Technical_Report_Briquettes.pdf

The MPS online waste behaviour survey in section 4.1.4 indicated that 90% of all residual waste is disposed of to the WMC and the remaining 10% offsite through burning, burying, disposal to Headstone from households and business.

Bales of residual waste are transported by air or sea freight for disposal to landfill by deep burial as quarantine waste at considerable cost. With recent transport and disposal costs per tonne of $1,169 for sea freight and $2,288 for air freight (including disposal costs) this would translate into potential costs of between $176,519 and $345,488 per annum to freight the estimated 151 tonnes of residual waste produced.

MPS waste characterisation study of the residual waste composition as shown in section 4.2.2 shows that the residual bale, after organic contamination (32% food waste/6.8% green waste), is plastics which makes up 30.8% of the total weight, including 12.9% plastic film, 12.7% hygiene (nappies/feminine hygiene products made up of plastic/paper blends), 6.9 % single use plastics (SUPs), 4% plastic composite, 2% plastic container and 0.6% polystyrene.

Plastic content could possibly be as high as 50.8 % as textiles (which make up 12.7% of the bale) are often made up of polyesters and other plastics. Paper makes up 10.3% of the bale by weight. Given the high costs of residual waste export and disposal there is the potential to reduce the number of residual bales by at least 50% through diverting more of this plastic into new waste bay to produce plastic bales free from food and green waste (FOGO) contamination, paper and hygiene products. These could be sent as a recyclable rather than as residual waste and avoid disposal costs and could be supported through plastic packaging initiatives. Likewise pilot projects supporting compostable hygiene products could see these diverted to the HotRot system and further education provided to the public and commercial sectors on not including waste food in garbage.

Efforts to reduce food and green waste should be directed through education and outreach to the residential and commercial sectors as a primary control but as a secondary measure the staff operating the mini sort line could also target FOGO and divert this to a dedicated skip bin as they already do for recyclables.

Support for island wide use of compostable nappies compatible with the HotRot system should be considered through a cost benefit analysis as the potential savings from eliminating ‘plastic nappies’ and enabling residual bales to possibly be recycled in Australia and not be sent to quarantine waste would be high.

3.1.5 GLASS

The MPS waste audit found that glass is one of the four major municipal waste streams in Norfolk Island, making up 23% of this waste stream. Primarily this is from households which produce over 85% of glass waste (Figure 3.7), as shown in Table 3.1 and Figure 3.20, resulting in an estimated 136 tonnes being produced each year.

Glass was previously being crushed using an imported USA Glass Aggregates Systems crusher unit, as shown in Figure 3.8. However, WMC staff advise that glass crushing was very labour intensive as bottles are loaded onto the incline belt and crushed one at a time. A surge hopper retrofitted to the existing crusher in 2018 was meant to allow for automated and regulated feed of glass into the system.

The MPS online waste behaviour survey in section 4.1.4 indicated that 88% of all glass waste is disposed of to the WMC and the remaining 12% offsite through burying and disposal to Headstone. During the MPS surveys in December 2020 all glass bottles were disposed of at Headstone into the sea. The result of this sea dumping is that marine litter surveys conducted by MPS found large amounts of sea glass at Bumbora Beach while plastic bottle labels, lids and plastic inserts were found at Anson’s Bay Beach.

Figure 3.7: Norfolk Island WMC Glass Bay

Figure 3.8: Glass Aggregate Systems glass crusher

However, this does not appear to have addressed the previous problems. While problems with Argentine ants, attracted to the sugar residue in the bottles were also at risk of being spread via the crushed glass.

Alternate systems are currently being considered that deliver a premium glass aggregate but with low labour and should be considered as a priority considering the impacts sea dumping of glass bottles with their plastic component are having as shown by marine litter surveys. Recycling of the glass with quality equipment would also substitute for builders' sand that is currently being quarried in the World Heritage Area.

3.1.6 ALUMINIUM

The MPS survey found that aluminium cans are a minor waste stream making up only 2% of the municipal waste stream with an estimated 10.4 tonnes being produced each year equally from commercial and domestic sources as shown in Table 3.1 and Figure 3.9.

Figure 3.9: Norfolk Island WMC Aluminium Cans Bay

The MPS online waste behaviour survey in section 4.1.4 indicated that 90% of all aluminium waste is disposed of to the WMC and the remaining 10% offsite through burying and disposal to Headstone.

Aluminium is dropped into the bay within the WMC by households and businesses where it is collected from the waste bay by bobcat, loaded onto the conveyor of the mini sort line and compacted into the general-purpose baler. The bales are then periodically exported to Australia via sea freight loaded into shipping containers and diverted to recyclers.

Typical weights in the Pacific from small, dedicated aluminium compactors used in the Pacific standardly achieved 14 tonnes per shipping container, as shown in Figure 3.10 above, which would have a current value of $15,400 on the Australian recyclers market and can also be used for steel cans. Such small compactors quickly recover costs. Based on export data the multipurpose bailer in the WMC appears to only be achieving very low compaction rates at weights of 4.5 to 6 tonnes per shipping container which is very low compaction weight for aluminium cans

Figure 3.10 Tuvalu Compacted Aluminium Cans

The 2020 ship freight costs for a 20-foot container of recyclables (no disposal costs) were calculated at $6,500 while the return for a 6-tonne load of aluminium would be $6,600 based on the Australian recyclers market which should cover costs A 14-tonne load of aluminium however have a value of $15,400 fully covering costs and providing a potential income of $8,900. Better backloading rates would further reduce costs as well overseas export (Korea typically) which pays much higher rates than Australia with little increase in shipping costs.

3.1.7 STEEL

The MPS waste audit estimated 11.4 tonnes of steel cans were being produced each year. The MPS online waste behaviour survey in section 4.1.4 indicated that 96% of all glass waste is disposed of to the WMC and the remaining 4% offsite through burying and disposal to Headstone.

Steel cans are dropped into the bay (Figure 3.11) within the WMC by households and businesses where it is collected from the waste bay by bobcat, loaded onto the conveyor of the mini sort line and compacted into the general-purpose baler. As with aluminium export data shows the multipurpose bailer in the WMC does not achieve high compaction rates for steel cans only achieving weights of 6.5 to 8.2 tonnes per shipping container which is very low compaction weight for steel cans.

Figure 3.11: Norfolk Island WMC Steel Bay

The 2020 ship freight costs for a 20-foot container of recyclables (no disposal costs) were calculated at $6,500 while the return for an 8-tonne load of steel would be $800 based on the Australian recyclers market, resulting in a cost of $5,700. An 18-tonne load of steel however has a value of $1800 which reduces costs further to 4,700. More importantly higher compaction rates can result in twice as much steel being shipped in a single shipping container effectively halving the cost in exporting steel cans. Better backloading rates would further reduce costs.

3.1.8 CLEAN PLASTIC (PET PLASTIC BOTTLES)

The MPS survey found that PET plastic bottles/clean plastic is a minor waste stream in Norfolk Island, making up 1% of the waste stream and with over 89% coming from domestic sources as shown in Table 3.1 and Figure 3.20. This results in an estimate 5.9 tonnes of PET plastic waste being produced each year with the MPS online waste behaviour survey in section 4.1.4 indicated that 86% of all PET plastic waste is disposed of to the WMC and the remaining 14% offsite through burning, burying and disposal to Headstone.

PET plastic bottles (and other plastics) are dropped into the bay within the WMC by households and business where it is collected from the waste bay by bobcat and transported to a dedicated plastic shredder and bailed in separate loads for export (Figure 3.12).

Figure 3.12: Norfolk Island WMC Clean Plastic Bay

Export data for PET plastic shows the baling in the WMC is achieving a wide range of compactions for a 20 FCL from 4.6 tonnes, which is low to 9.6 tonnes which is very good. With the 2020 ship freight costs for a 20-foot container of recyclables (no disposal costs) is calculated at $6,500 with the potential return for a 9.6 tonne load of shredded PET plastic varying from $1,440 to $4,320 (depending on quality and the buyer) based on the Australian recyclers market which are very unstable.

The 2020 cost of airfreight of recyclables was approximately $1958 per tonne for recyclables which would result in total freights costs of $9,007 for 4.6 tonnes to $18,798 for a 9.6 tonne load.

3.1.9 ORGANIC WASTE

In this section 'organic waste' groups together the two separate categories of green waste and food waste, as both will be managed in the same way by NIRC by adding them into the HotRot composting system along with a number of other waste and organic materials (gyprock, animal carcasses, cardboard, paper etc.).

It is also important to note that most green and food waste are not managed at the WMC but offsite as indicated by the MPS online waste behaviour survey in section 4.1.4 which found that 88% of all green waste is managed offsite primarily by burning but also by burying, composting and vermiculture. For food waste the survey found that 61% was managed offsite primarily through being feed to livestock, burying, composting and vermiculture.

The online survey therefore indicated that only 12% of household green waste and 39% of household food waste was disposed of to the WMC. Based on the quantities of green waste and food waste received at the WMC the MPS waste audit estimated a generation rate of 6.3 tonnes of green waste and 58.2 tonnes of food waste.

Given the low rates of disposal of green waste and food waste disposed of at the WMC these estimated generation rates cannot be regarded as representative and specific green waste and food waste audits would need to be conducted which were beyond the resources of the survey.

It should be noted that green waste estimates of approximately 1500 tonnes per annum and food waste estimates of 150 tonnes per annum were provided in the 2015 Norfolk Island Waste Management Strategy.

3.1.10 PLANNED COMPOSTING SYSTEM

In October 2018 a composting system known as 'HotRot', shown in Figure 3.13, and its associated infrastructure was purchased by NIRC and was claimed to be able to manage all the organic waste streams on Norfolk Island including livestock carcasses, food scraps, butchers' waste, cardboard and paper, green waste and untreated timber/pallets, and cooking oil.

Figure 3.13: HotRot Compost System behind the WMC facility

The Norfolk Island Regional Council, 2020, *Composting Facility at Norfolk Island Waste Management Centre Environmental Impact Statement* stated that 'it is expected that this system will process the largest volume of the island's waste stream representing 70% by volume based on estimates of these waste streams in the National Waste Management Strategy prepared in 2015. Inputs to the HotRot composting system are pre-prepared mostly through dedicated shredding systems with green waste being shredded through the Telcor Green Waste Processor shown in Figure 3.14 below.

Figure 3.14: Telcor Green Waste Processor.

Butchers' wastes are processed through the dedicated animal carcass shredder shown in Figure 3.15 below.

Figure 3.15: Organic shredder for large animal food waste

Cardboard wastes are processed through a dedicated shredder and bays that are shown in Figure 5, while other shredders are present in the WMC. That can process untreated timber and pallets.

Figure 3.16: Hotrot Compost receival bays

The HotRot system was commissioned in 2020 and has been successfully producing small quantities of compost with anecdotal information being that it has been of good quality. However full product testing is ongoing with compost products being tested against applicable industry standards through testing in accredited laboratories in Australia.

Scale up to full operations is expected in 2021 while the ratio of different organic and inorganic waste inputs is trialled to ensure a quality product is produced. What ability the system has to absorb all the cardboard and timber waste will need to be determined based both on optimum waste inputs as well as considerations on plastic and other contaminants present in these wastes and to what degree they can be screened as well as meeting product tolerance limits.

There are potentially limits to using timber in the process as it may be difficult to separate treated and untreated timber which would contaminate the compost and possibly poison the microbes needed in the compost process.

3.1.11 HAZARDOUS AND OTHER WASTE

The waste audit review conducted by MPS did not target hazardous wastes such as chemicals, paints and oils, tyres used batteries and e-wastes and will not cover these components in any detail.

These materials all appear to be adequately collected and stored and are shipped out to Australia as funds and shipping permit. An audit to ensure that hazardous wastes are safely stored according to their classification and that staff are trained and regularly audit and confirm that storage is complaint. Four hazardous or other wastes that MPS provides short comment and recommendations on includes used tyres, used oil, treated timber and asbestos.

Tyres
For used tyres there is the potential, similar to glass, that they are reprocessed into 'crumb' and utilised within NIRC building projects roads, bicycle and walking paths, playgrounds and in parks. The costs and feasibility would need to be investigated versus the very high costs of export and disposal in mainland Australia as would concerns of impacts from microplastics produced by such infrastructure.

Treated timber
Timber treated with CCA (copper chrome arsenate), ACQ (amine copper quaternary) or other timber treatments need to be managed as a hazardous waste as if it is burnt it releases the toxic and carcinogenic metals in the air and resulting ash which is harmful to human and environmental health.

Distinguishing between treated and untreated timber can be difficult without chemical testing as aging results in the identifying colour of the treatment fading. In 2001 the Brightstar Solid Waste and Energy Recycling Facility (SWERF) in Wollongong, Australia had to shut down as it was unable to find a way to economically screen out CCA treated timber for untreated timber and could not control arsenic emissions in its combustion air or waste ash[14].

Treated timber is also problematic if it is shredded and added into a composting system as the toxic chemicals used to treat the wood would also be toxic to the micro-organisms present in the composting system and would also result in the compost being contaminated with toxic heavy metals or other treatment chemicals,

Given that waste timber is burnt at Headstone, as part of the uncompactable waste fraction, a program of monitoring of the timber waste in NIRC is needed to ensure treated timber is not being burnt and toxic ash being exposed to workers, the public or dumped into the environment. This is also needed to screen any waste timber that is intended to be shredded and added to the HotRot system. Handheld XRF devices ca be used to identify timber treated with CCA, ACQ and other metal contaminants and to determine the presence and extent of treated timber in Norfolk Island and if different management methods are needed.

Asbestos
Asbestos is currently collected and exported to Australia for landfill disposal at great cost. Asbestos cement materials (ACM), which mostly includes roofing and cladding materials which were no longer manufactured in Australia or OECD countries after the 1980s are only harmful when the materials are broken and fibres are released.

The primary harm from ACM has been identified as those tradesmen who were occupationally exposed to air born asbestos fibres when they engaged in practices such as cutting ACM without using appropriate PPE. When airborne asbestos can be inhaled where the fibres can lodge in the lung and trigger asbestosis and mesothelioma.

Asbestos however as a natural mineral fibre poses no threat to human health through ingestion via food or water and poses no threat to groundwater as it does not leach. This is why asbestos is disposed of to landfill where it poses no risk. As a legacy issue Norfolk Island has only a finite amount of asbestos waste that can be readily quantified through an asbestos survey as has been conducted in 13 Pacific Island countries under the PacWaste project[15]

Given the costs to collect, transport and dispose of asbestos waste to mainland Australia varies between $1300 for sea freight to almost $3000 for air freight per tonne (including disposal costs) there is a case to consider disposal on Norfolk Island in a dedicated disposal cell purpose built to safely contain all the remaining asbestos in Norfolk.

The costs and feasibility would need to be investigated versus the very high costs of export and disposal in mainland Australia but is likely to be a much more affordable option that offers the same level of protection to human and environmental health and safety.

[14] Brightstar Environmental, Emissions Data from Solid Waste and Energy Recycling Facility (SWERF), 1-2 Mar , 2001.
[15] https://www.sprep.org/pacwaste/resources/reports

4. WASTE CHARACTERISATION

MPS undertook a detailed waste characterisation study of the Norfolk Island Waste Management Centre (WMC) in December 2020 covering a full business week (7-day period). MPS staff completed surveys of waste delivery flows, detailed household waste characterisation, brand surveys and volumetric and visual assessment of waste at Headstone Waste Centre. In addition to these surveys the MPS team undertook three marine litter surveys (standing stock) on the beaches of Norfolk Island. The results of this analysis are provided below.

4.1 NORFOLK ISLAND WASTE CHARACTERISATION STUDY 2020

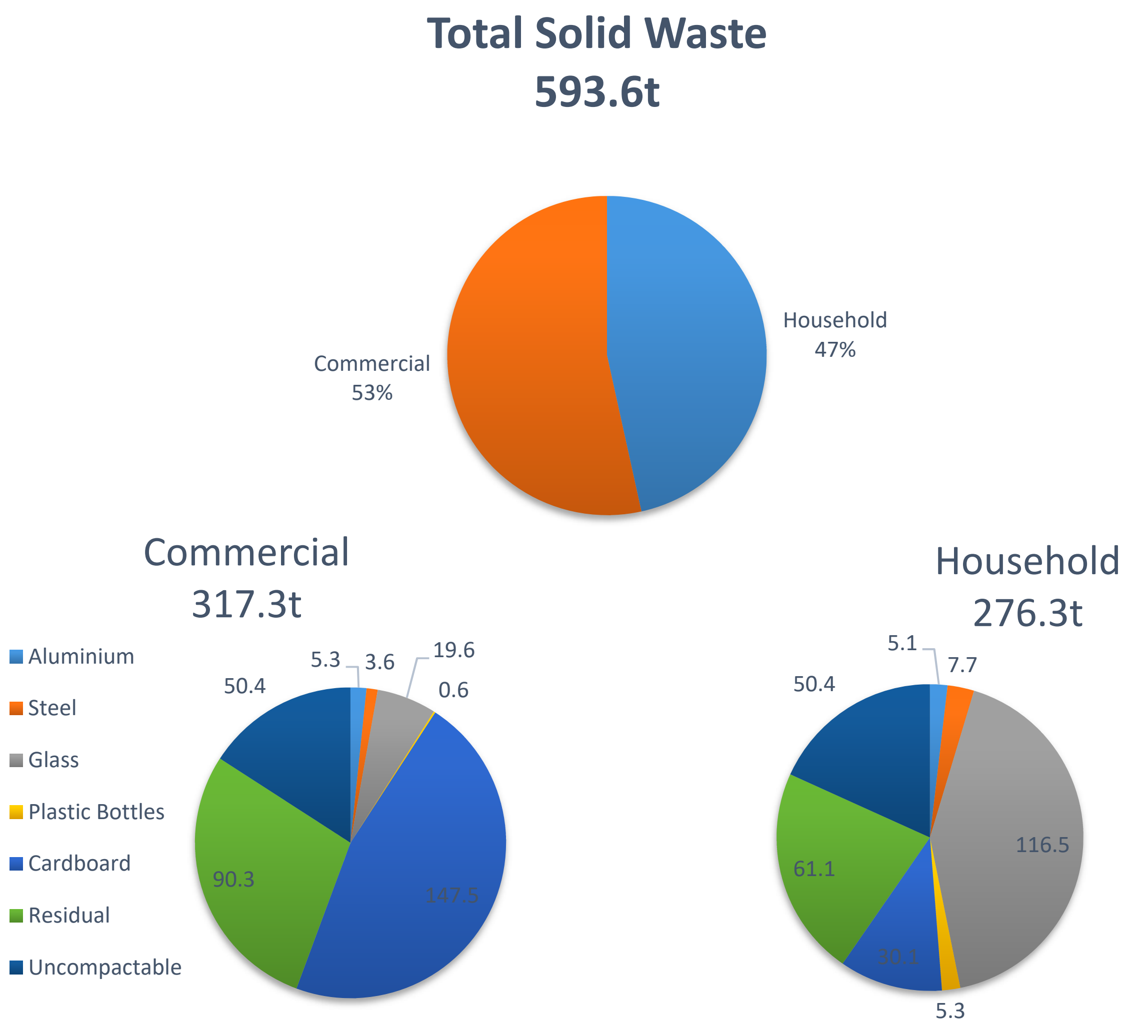


Figure 3.17: Total Estimates for Commercial and Household Sources of Municipal Solid Waste in Norfolk Island

Figure 3.17 above shows that there are an estimated 593.6 tonnes of municipal solid waste generated per annum based on the MPS audit of wastes dropped off by households and the commercial sector at the Norfolk Island Regional Councils (NIRC) Waste Management Centre in December 2020. This data was further augmented by data provided by the NIRC Waste Management Team, particularly related to waste loads exported or sent to Headstone for disposal.

The audit estimated that the commercial sector produced approximately 53% or 317 tonnes of all municipal solid waste as shown in Figure 3.17 and was the dominant producer of cardboard (83%) and residual waste (60%) as shown in Figure 19. Households were estimated to produce the remaining 47% or 276 tonnes of all municipal waste and were the dominant producer of glass (86%) and steel cans (68%) as shown in Figure 3.19. Figure 3.18 above shows that four categories of waste dominate the municipal waste stream including cardboard (30%), residual waste (25%), glass (23%) and 'uncompactable' wastes (17%) making up 95% of the total municipal waste stream, with the remaining categories of steel cans (2%), aluminium cans (2%) and plastic bottles (1%) only making up the remaining 5%.

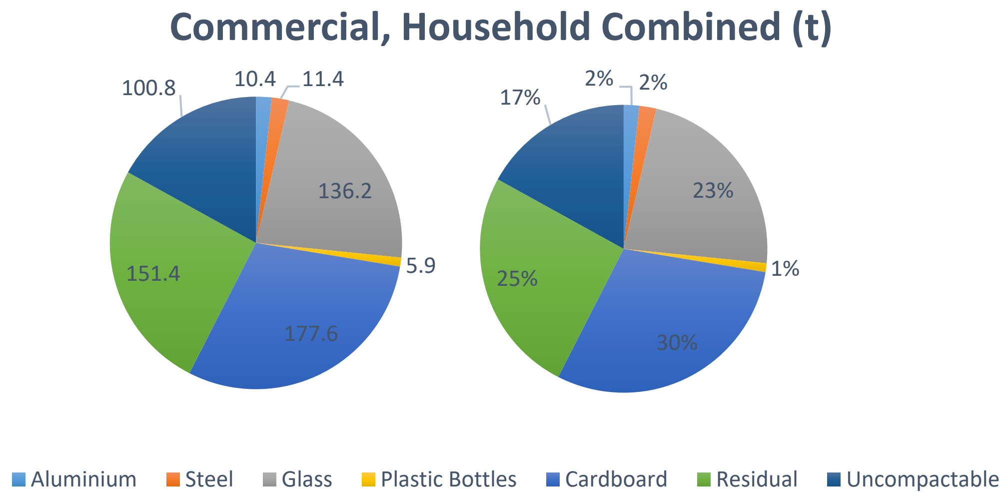


Figure 3.18 Total Estimates for Municipal Solid Waste in Norfolk Island by Waste Category

It is important to note that these estimates exclude bulky waste (cars, white goods), green/food waste (including small amounts disposed of at the WMC) and hazardous wastes (including household hazardous) which have previous estimates provided in the Norfolk Waste Management Strategy 2015 but does include an estimate of other mixed 'uncompactable' wastes (commercial and household bric a brac, construction wastes etc.) disposed of at Headstone.

Affordable and environmentally effective management of these four categories is therefore critical for NIRC to reduce impacts on the marine environment by reducing the wastes that are disposed to headstone which also leave harmful debris. The reuse of these categories within Norfolk Island also needs to be maximised so that high-cost waste exports (such as residual wastes) are reduced.

4.1.1 COMMERCIAL WASTE

Table 3.1 shows that the commercial waste makes up slightly more than half of the waste delivered to the WMC and is the dominant source of cardboard waste and residual waste (mostly plastic wrap), contributes equally to uncompactable and aluminium wastes, half of the steel can waste only minor quantities of glass and PET plastic bottles.

Table 3.1: Annual total tonnage split by household and commercial solid waste delivered to the WMC disposal chutes

Material Type	Household (t/y)	Commercial (t/y)	Annual Total (t)
Aluminium	5.107	5.250	10.358
Steel	7.739	3.634	11.373
Glass*	116.540	19.638	136.179
Plastic Bottles	5.330	0.590	5.920
Cardboard*	30.080	147.514	177.593

Residual	61.074	90.297	151.372
Uncompactable#	50.400	50.400	100.801
Total	**276.271**	**317.325**	**593.596**

Material types marked (*) were calculated from NIRC Export Data (Nov 2020 - Jan 2021) & (#) NIRC Headstone Data

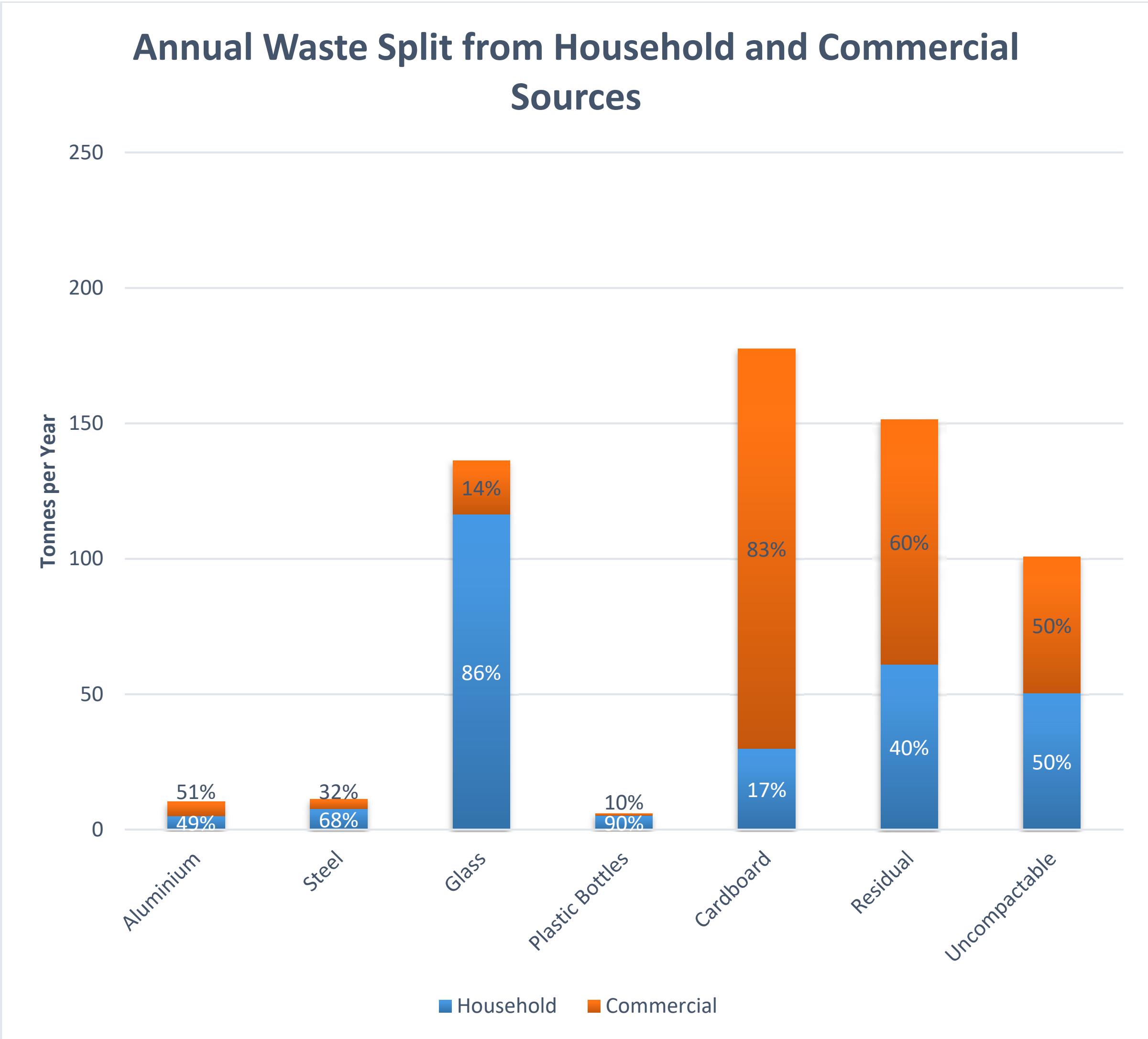


Figure 3.19: The Household/Commercial Waste Contribution by % to different Waste Categories

The similarities and differences between household and commercial waste is best illustrated in Figure 19 above showing that for the major waste streams of residual wastes, cardboard and uncompactable waste they are the major or equal contributor.

Figure 3.20 shows estimates in December 2020 were that 30% (179 tonnes) of all municipal solid waste, made up of residual waste, aluminium cans, steel food cans and PET plastic bottles was being exported (recyclables & residuals) to Australia via air and sea freight.

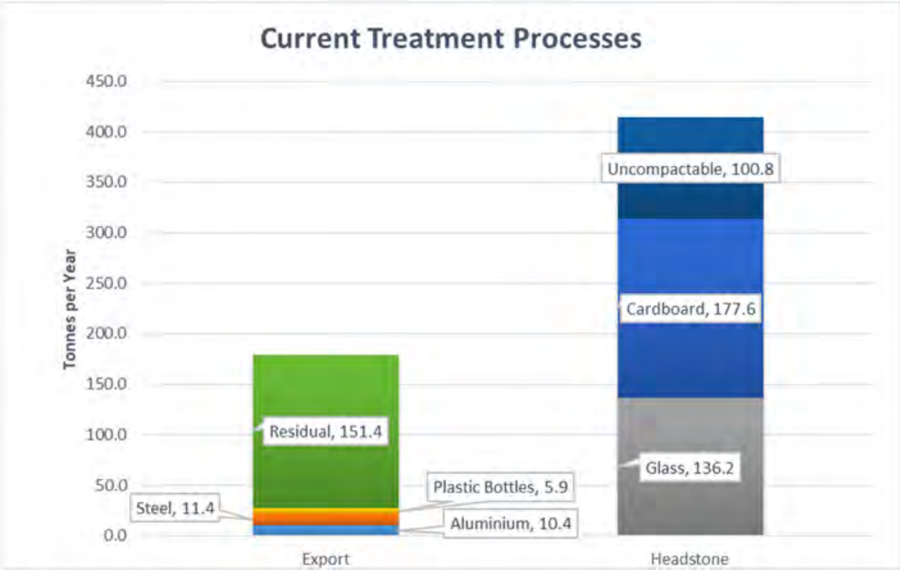


Figure 3.20:December 2020 Municipal Solid Waste Categories Exported and Disposed of at Headstone

While the remaining 70% (414 tonnes) is made up of glass and cardboard, which was not being processed at that time, and mixed uncompactable waste from business and households (including construction wastes) unable to be exported, is transported to the Headstone where it is burnt and an estimated 29% (170 tonnes) of ash and non-combustibles (mostly glass, metal, unburnt residues) remaining is disposed of into the sea.

Figure 3.21 shows volumes of municipal solid waste disposed of at Headstone that could be reduced from December 2020 levels of 70% (414 tonnes) to 17% (100.8 tonnes) using existing equipment or planned upgrades to allow through all cardboard (177 tonnes) and glass (136 tonnes) of to be diverted to the WMC for reprocessing.

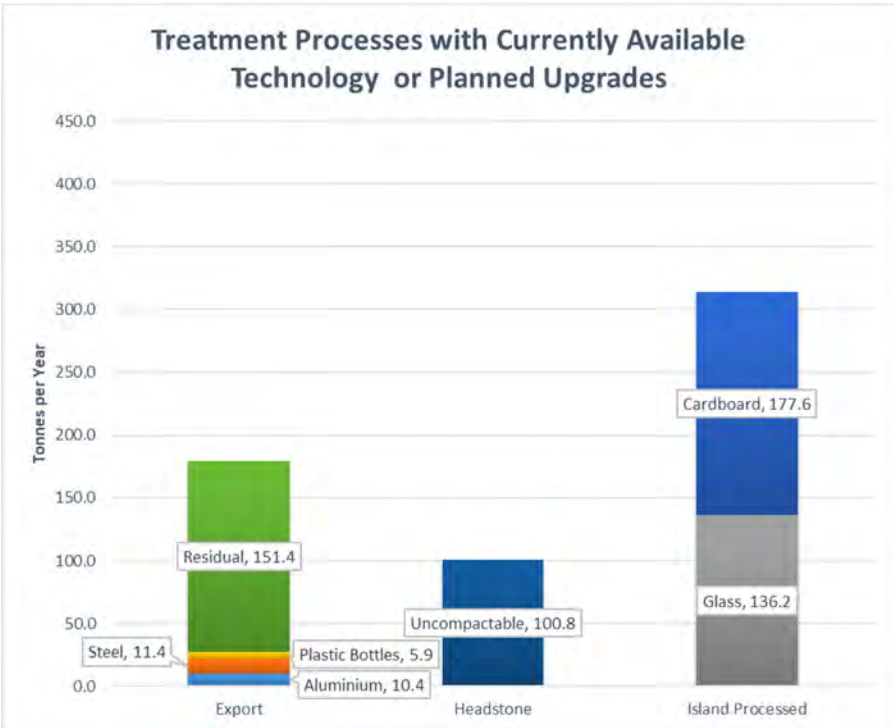


Figure 3.21: Potential Targets for Management of Municipal Solid Waste Categories in 2021

Though this would require the existing glass processing equipment to be upgraded or replaced to be able to effectively process this volume of glass with low labour intensity. Similarly, the HotRot composting system and its supporting equipment (shredders) would also need to be brought to full operational capacity.

4.1.2 WASTE DISPOSAL ACTIVITY

Figure 3.22 shows the frequency of vehicles over a normal working week. Vehicles were separated into two categories representing domestic and commercial, defined by source of generation, i.e., from homes or businesses.

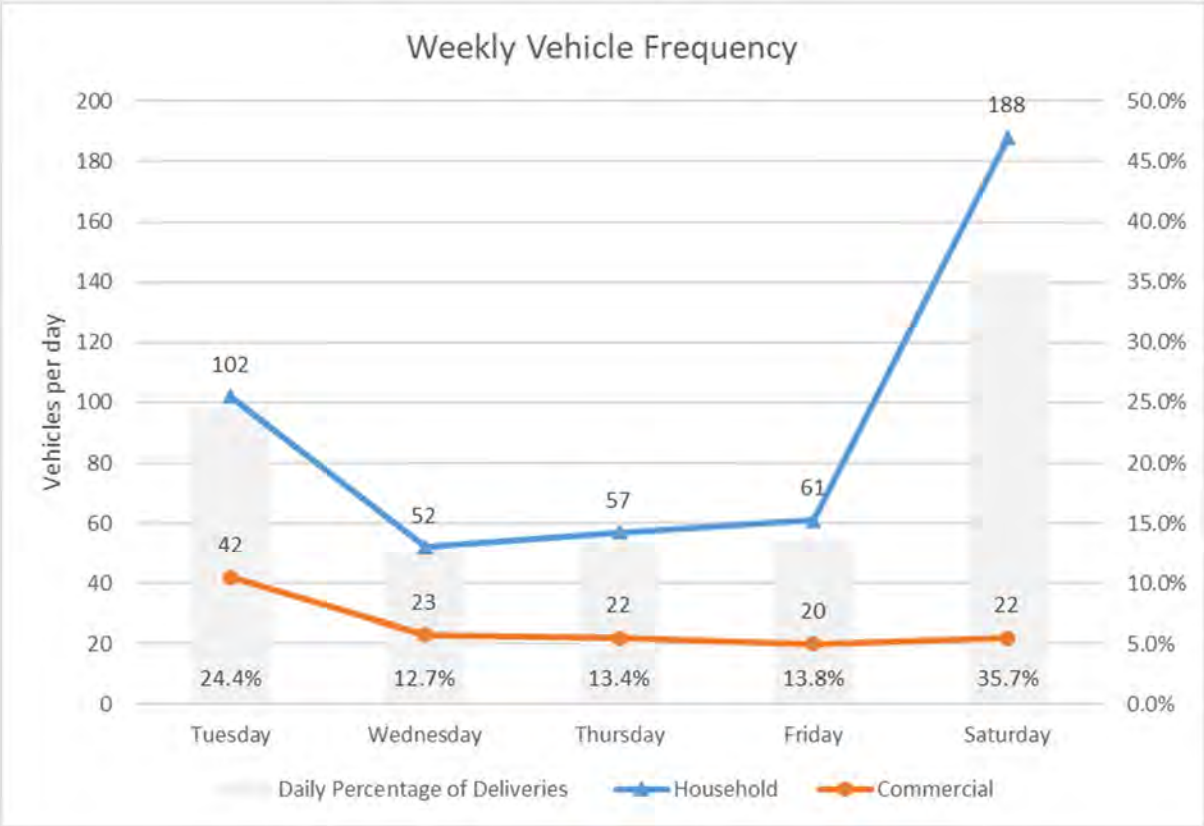


Figure 3.22: Daily Waste Deliveries to WMC by Waste Source

There is a significant increase in deliveries from domestic sources on Tuesdays and Saturdays, 2-fold and 3-fold respectively, compared to Wednesdays, Thursdays and Fridays. The total daily frequency of vehicles for each day are as follows: Tuesday (144), Wednesday (75), Thursday (77), Friday (82), Saturday (210). Table 3.2 shows that commercial deliveries increase 2-fold on Tuesdays compared to the rest of the week and household deliveries increase 2-fold on Tuesdays and close to 4-fold on Saturdays compared to other days.

Table 3.2: Daily delivery ratios split by count of vehicles from domestic and commercial sources

Daily Delivery Ratio	Tuesday	Wednesday	Thursday	Friday	Saturday
% of Household Drop-offs	22%	11%	12%	13%	41%
% of Commercial Drop-offs	33%	18%	17%	16%	17%
% of All Deliveries Total	**24%**	**13%**	**13%**	**14%**	**36%**

In Figure 3.23 domestic drop-offs constituted 78% of all waste deliveries with the remaining 22% from commercial sources. This figure represents vehicles which entered and disposed of waste at the WMC. It does not include vehicles that disposed of waste at Headstone which was not recorded in this study.

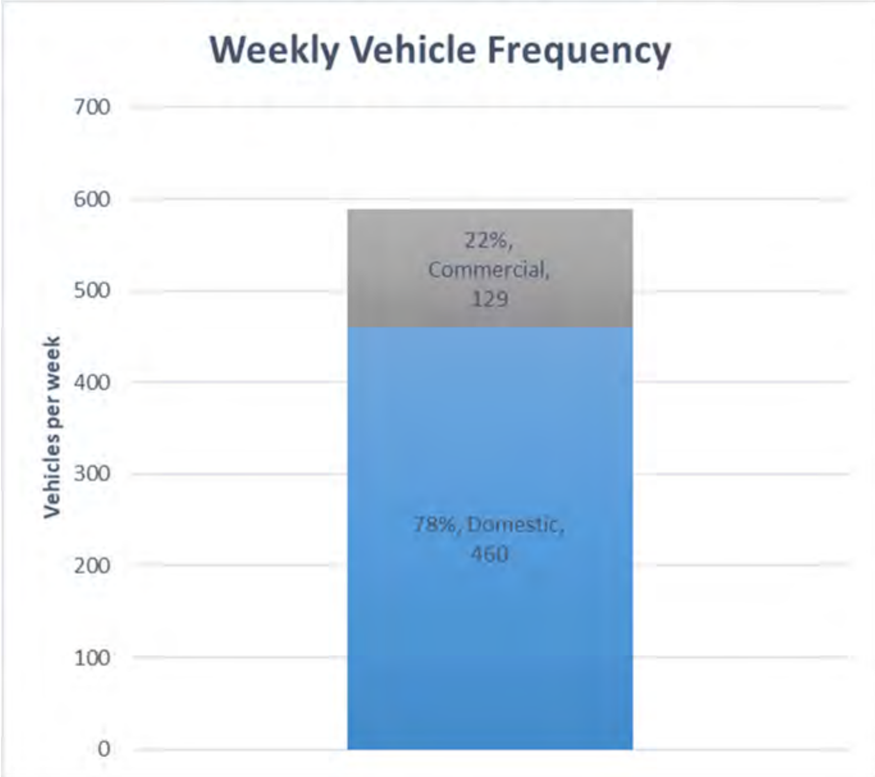


Figure 3.23:Weekly Waste Deliveries by Waste Source

4.1.3 NORFOLK WASTE BEHAVIOUR

Previous studies[16] of domestic disposal behaviours found that up to 84% of residents used the WMC for waste disposal and the remaining 16% disposed of waste by burning at home. This study also indicated that 17% of residents disposed of food waste and 48% of disposed of garden waste at the WMC, too as shown in Table 3.3 below.

Table 3.3: Waste behaviour comparison 2008

Waste Behaviour	2008
Used WMC	84% WMC
	16% Burnt/buried at home
Food waste	17% WMC
	66% Animal feed
	14% Compost/Vermiculture
Garden waste	48% WMC

[16] APC, 2015.

4.1.4 ONLINE WASTE BEHAVIOUR SURVEY

MPS conducted an online waste behaviour survey over the months of February and March 2021. This survey received a total of 49 respondents, where responses were limited to one per house. The sample size of this survey indicates a confidence level of 95% with 15% error as shown in Table 3.4.

Table 3.4: Sample size for survey responses

Confidence Level		0.95			0.9		
Error		5%	10%	**15%**	5%	10%	15%
Population		**Sample Size**					
Occupied Private Dwellings	746	254	86	**41**	200	63	30

The questionnaire was comprised of two sections and allowed respondents to select more than one answer per question, i.e., all that applied to their household. Figure 3.24 asked *"Which of the following waste types do you drop off at the WMC/Headstone/Burn at home/Bury yourself*". Figure 3.25 asked *"How do you dispose of your food/garden waste?*". Figure 3.24 indicates that 100% of survey respondents use the WMC for at least one waste type. Only 22% of respondents use Headstone directly to dispose of waste, which is predominantly from building and demolition sources (20%), with the remainder comprised of organic material (2%) and general waste (4%).

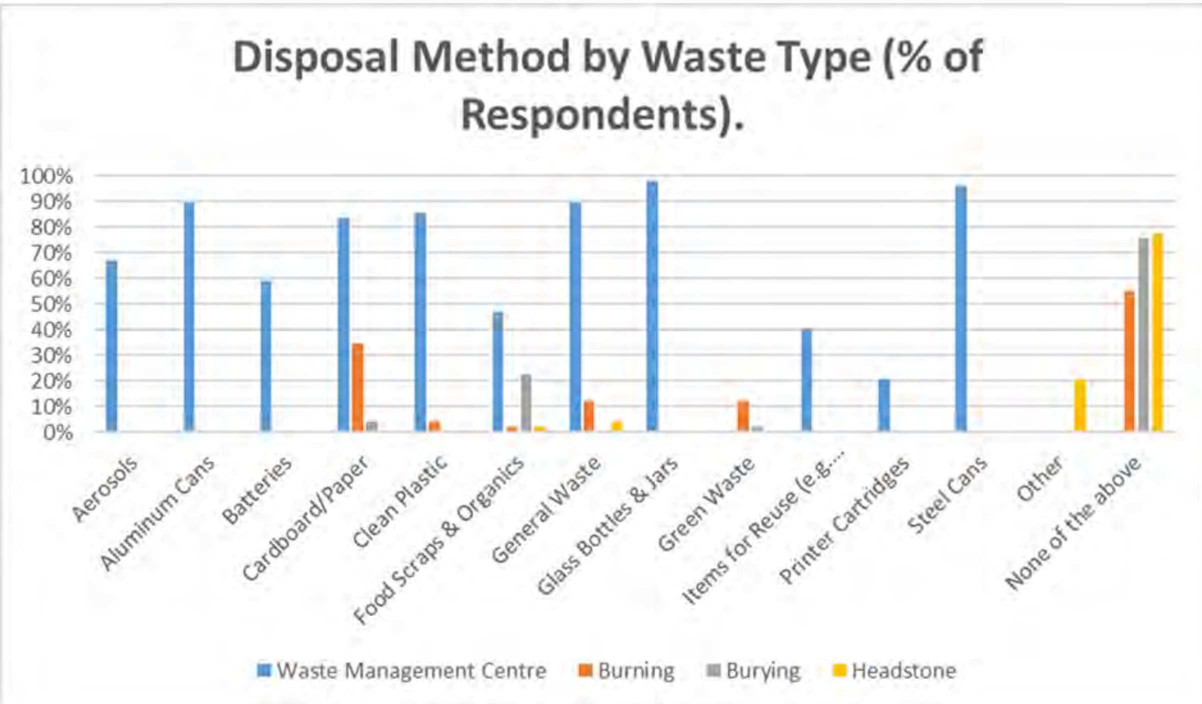


Figure 3.24:Disposal method by waste type as a percentage of respondents. "Select all that apply". One survey per household. (n=49)

At home burning practices are common with 45% of respondents indicating they burn materials such as cardboard/paper (35%), general waste (12%), green waste (12%), clean plastic (4%) and food and organics (2%). Waste burying practices are performed by 24% of respondent where 22% indicated they bury their food scraps and organics, 4% cardboard/paper and 2% green waste.

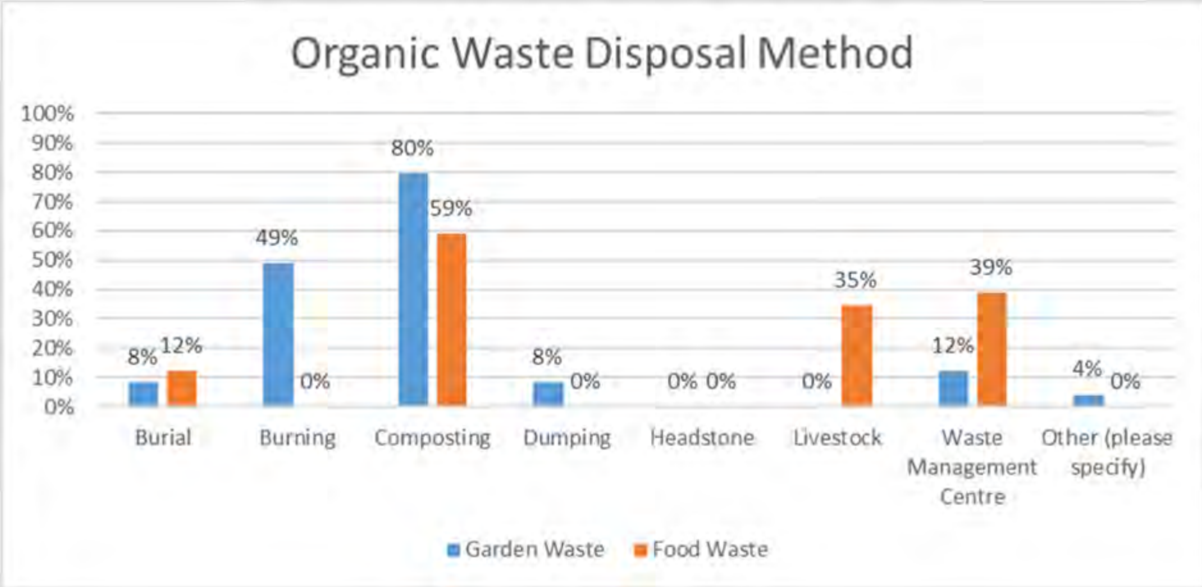


Figure 3.25:Further differentiation of organics into garden and food waste. "Select all that apply". One survey per household. (n=49)

Figure 3.25 provides further granularity into individual management practices for organic materials by treating garden waste and food wastes as separate material types. This questionnaire indicates that the most common practice for both garden waste and food waste is composting, 80% and 59% respectively.

Material burnt at home it is solely garden waste (49%) and not food waste. Garden waste, if not burnt or composted, is taken to the WMC (12%), buried (8%) or dumped (8%). Food waste, on the other hand, is most favourably composted/vermi-composted (59%), given to livestock as feed (35%), disposed of at the WMC (39%), or buried at home (12%).

4.1.5 WASTE MANAGEMENT CENTRE - BAY SAMPLING

The MPS team also developed reference densities for the major waste types as shown in Table 3.5 to be used to determine volume and weight of different wastes under volumetric survey (the bays) and loads of materials transported to headstone.

Table 3.5: Reference Densities for Norfolk Island Waste Materials delivered to the WMC

Material Type	Sub Material	Volume (m^3)	Weight (kg)	Density (kg/m^3)
Aluminium	-	0.12	4.25	35.42
Steel	Small	0.12	10.87	90.58
	Large (>1L)	0.12	6.82	56.83
Glass	-	0.07	20.06	286.57
Plastic	Containers	0.12	4.45	37.08
	Film	0.12	2.53	21.08
	PS	0.12	0.71	5.92
Cardboard*	-	0.79	34.94	44.22

General Waste*	-	0.79	70	88.18

*Cardboard is not compacted with base unit of 10kg

By using the reference densities recorded in Table 3.6 the MPS team was able to record how much waste in both volume and weight was deposited at the WMC over a 1-week period. This in turn was used to estimate the per annum estimates for each waste type produced.

Table 3.6: Estimation of weights from volumes received in Norfolk Island WMC over a 7-day accumulation period

Waste Type	Volume of Material (m^3)	Estimate Weight in Bay (kg)
Aluminium	5.6	199.19
Steel	2.7	218.72
Glass	9.1	2618.8
Plastic	3.1	113.85
Cardboard	77.3	3415.26
General Waste	22.5	1980.32

Conversion weights taken from "Reference Densities for Norfolk Island Waste Materials Delivered to the WMC".

4.2 HOUSEHOLD WASTE CHARACTERIZATION STUDY 2020

MPS staff conducted household waste characterisation study using a combined approach of ASTM D5231 Standard Test Method for Determination of the Composition of Unprocessed Municipal Solid Waste and #BreakFreeFromPlastic's brand surveying methodologies.

Table 3.7 below outlines the minimum number of samples needed for a statistically significant study. According to census data Norfolk Island has 746 occupied private dwellings, therefore a minimum sample size of 86 households for a confidence level of 95% and 10% error was targeted.

Table 3.7: Sample size calculation

Confidence Level		0.95			0.9		
Error		5%	**10%**	15%	5%	10%	15%
Population		**Sample Size**					
Occupied Private Dwellings	746	254	**86**	41	200	63	30

The study collects two series of data with series (I) categorising by waste material by type, and (II) categorising waste packaging materials by brand name and material type. All components of the waste characterization study and brand survey are shown in Figures 3.26, 3.27, 3.28 and 3.29 above. In total MPS processed approximately 1 tonne of waste from 91 households in this study.

Figure 3.26: Household Waste Collection at the WMC

Figure 3.27: Household Waste Assessment

Figure 3.28: MPS Applying ASTM Standard Test Method for Characterisation of Household MSW

Figure 3.29: MPS Sorting Sample for Characterisation

4.2.1 HOUSEHOLD WASTE CHARACTERISATION

The following analysis of this information has then been used to estimate the municipal solid waste generation rate of households, estimated annual waste generation rates, and weight characterisation of the average domestic waste stream disposed of at Norfolk Island WMC. Conducted over a 7-day period, the municipal solid waste generation rate data obtained achieved a 95% confidence interval with 15% error. Table 3.8 indicates that the mean generation rate of a resident of Norfolk Island is 0.467kg/person/day or 3.27 kg/person/per week or 170kg/person/year. This equates to the households of Norfolk Island disposing of 298 tonnes of municipal solid waste (garbage, recyclables) to the WMC annually.

Table 3.8: Population and Domestic Generation Rate.

	Population	Kg/c/day	Kg/day	Kg/week	Tonnes/year
Residents	1,748	0.467	815	5,708	298

* For municipal solid waste only and does not include green waste, bulky waste, food waste not delivered to WMC

It is important to note here that the Table 3.8 estimate of 298 tonnes for household waste generation per annum differs from the Figure 18 estimate of 276 tonnes as Table 3.8 includes estimates for green waste, food waste and household hazardous waste which were excluded from the Figure 3.18 estimate (a total of 71.8 tonnes). This was done as it was not possible in the MPS survey to determine the commercial waste contribution to these waste streams. The other difference is that WMC data to headstone enabled an estimate of 'uncompactable' wastes being disposed to headstone to be calculated (based on truckloads delivered) which was estimated as 100.8 tonnes and 50:50 between commercial and household.

4.2.2 COMPARISON WITH NSW HOUSEHOLD WASTE GENERATION

The Norfolk Island generation rates by comparison with the average NSW resident municipal solid waste generation rate (residual and recyclables) of 4.82 kg/person/per week[17] is only 68% of that value.

NSW residents also generate a further 3.98kg/person per day of green waste and food waste. However, as most Norfolk Island residents do not dispose of these wastes at the WMC and instead do this offsite, MPS was unable to determine per capita rates of generation for these waste types[18].

Domestic waste is divided into waste types aligned with waste disposal groupings at Norfolk Island WMC. Figure 30 shows that glass is the dominant waste item generated from domestic sources, making up 39% of the total weight of the waste stream. The second largest category, residuals, is 21%, with food waste making up 20%, cardboard waste 10%, steel cans 3% and aluminium, plastic bottles, green waste and hazardous waste (batteries mostly) individually making up 2%.

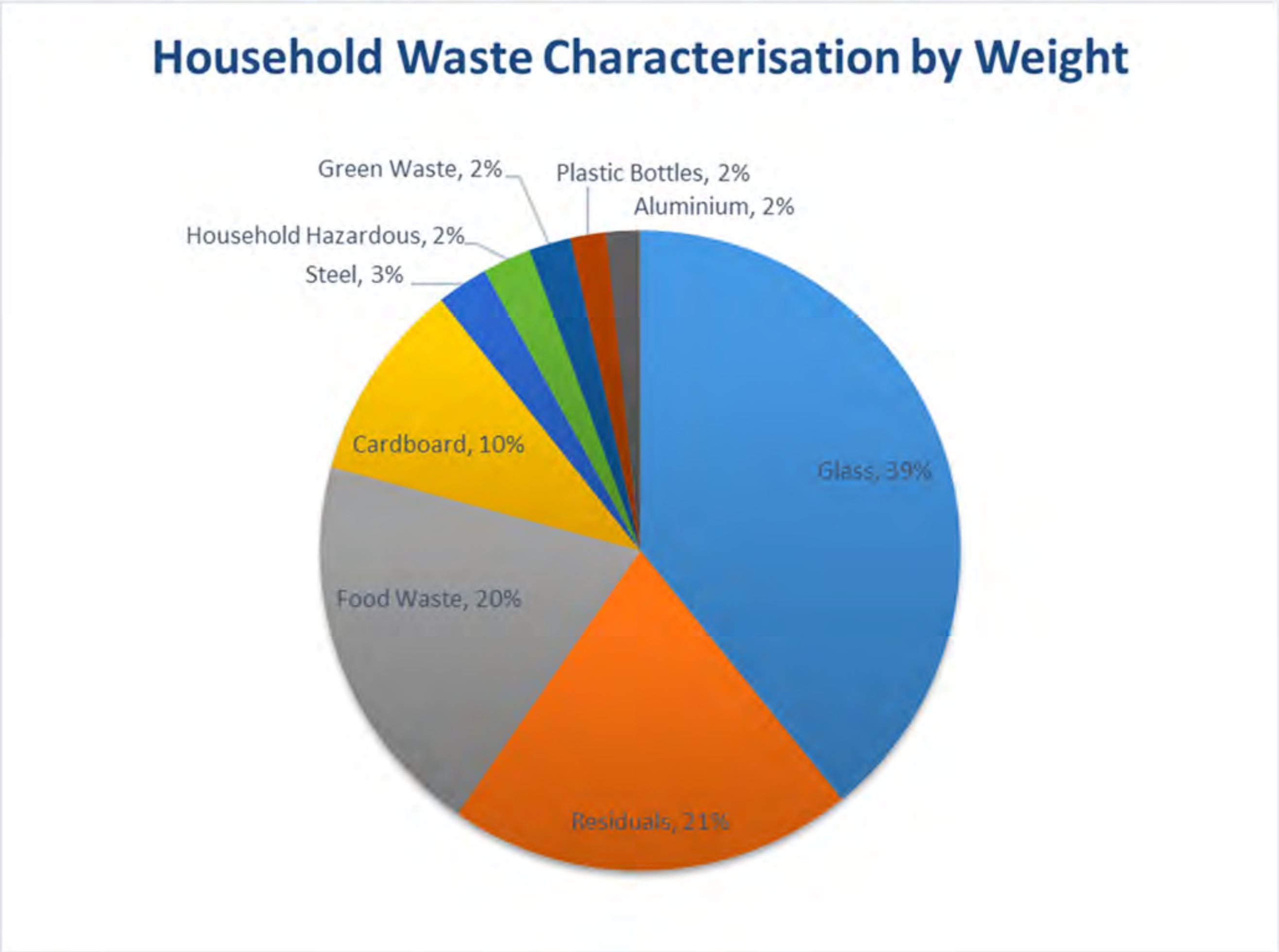


Figure 3.30: Household Waste Characterisation by the ratio of weight of each waste category

[17] https://www.epa.nsw.gov.au/your-environment/waste/local-council-operations/local-council-waste-and-resource-recovery
[18] https://www.epa.nsw.gov.au/your-environment/waste/local-council-operations/local-council-waste-and-resource-recovery

4.2.3 RESIDUAL WASTE CHARACTERISATION

In Figure 3.31 the waste characteristics of residual wastes was investigated. Residual wastes are baled and strapped into cubic metre blocks approximately 450kgs weight and are then exported to Australia via air or sea flight for deep burial as quarantine waste (due to Norfolk Islands designation as an External Territory). The characterisation shows that the residual bales largest component is plastics which makes up 30.8% of the total weight, including 12.9% plastic film, 12.7% hygiene (nappies/feminine hygiene products made up of plastic/paper blends), 6.9 % single use plastics (SUPs), 4% plastic composite, 2% plastic container and 0.6% polystyrene. Plastic content could possibly be as high as 50.8 % as textiles (which make up 12.7% of the bale) are often made up of polyesters and other plastics. Paper makes up 10.3% of the bale by weight. However, 38.8% of the residuals bale by weight was found to be made up of organic contaminants with food waste making up 32% of the bale weight and green waste another 6.8%.

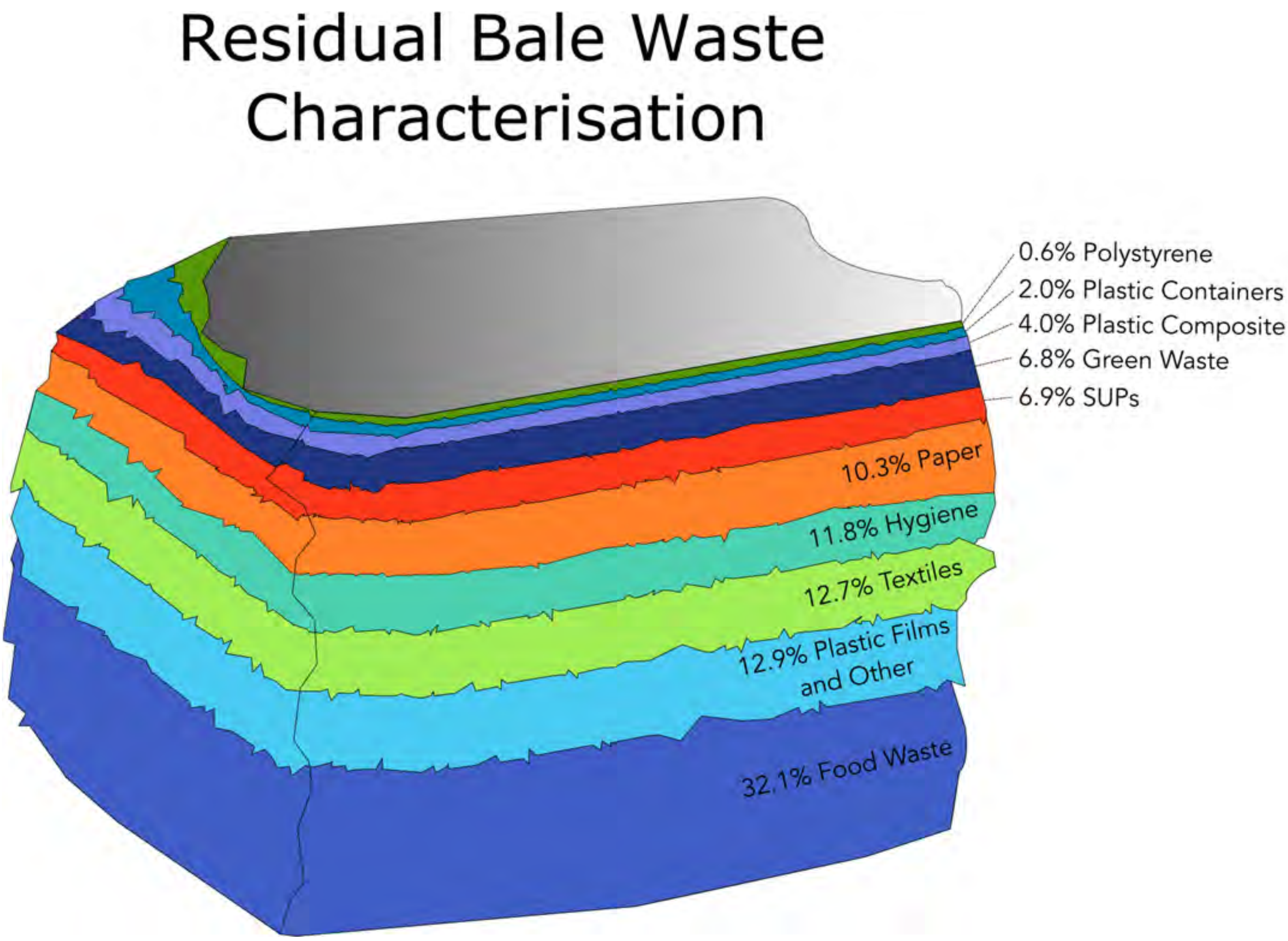


Figure 3.31: Waste Characterisation of baled residual waste by the % of weight of each waste category

4.2.4 HOUSEHOLD MUNICIPAL SOLID WASTE GENERATION

Table3. 8 summarises the daily generation rate of each material type per person is estimated and converted into annual tonnes of each material type.

Table 3.8: Estimation of waste generated from domestic sources

WMC Bay	%	Material Types	%	Kg/c/day	Tonnes/ year	Total Tonnes/ year
Food Waste	20%	Food Waste	9.5%	0.044	28.4	**58.2**
		Food Waste (Res. Bale)	10%	0.047	29.8	
Green Waste	2%	Green Waste (Res. Bale)	2.1%	0.010	6.3	**6.3**
Aluminium	2%	Aluminium	1.6%	0.008	5.1	**5.1**
Steel	3%	Steel	2.6%	0.012	7.7	**7.7**
Glass	39%	Glass	39.2%	0.183	116.5	**116.5**
Plastic Bottles	2%	PET	1.5%	0.007	4.3	**5.3**
		HDPE	0.3%	0.002	1.0	
Cardboard	10%	Cardboard	10.1%	0.047	30.1	**30.1**
Residuals	21%	Plastic Cardboard Composite	1.2%	0.006	3.7	**61.1**
		Paper	3.2%	0.015	9.6	
		Polystyrene	0.2%	0.001	0.6	
		Plastic Containers	0.6%	0.003	1.8	
		Plastic Films	4.0%	0.019	12.0	
		Single Use Plastics	2.1%	0.010	6.4	
		Hygiene, Pharmaceuticals	3.7%	0.017	11.0	
		Textiles, Ceramic, Other	5.4%	0.025	16.0	
Household Hazardous	2%	Batteries	0.5%	0.002	1.5	**7.3**
		E-waste	1.5%	0.007	4.4	
		Hazardous	0.5%	0.002	1.4	
Total	**100%**		**100%**	**0.467**	**297.7**	**297.7 Tonnes**

Table 3.9 shows the estimated domestic generation rate of waste categorised by WMC material type (tonnes/week and tonnes/year) as a function of the island population of 1748 people with a total of 297 tonnes of municipal waste generated per annum.

Table 3.9: Estimation of waste generation for Norfolk Island (1748 individuals)

Material Type	Tonnes/week	Tonnes/Year
Food Waste	1.116	58.167
Green Waste	0.121	6.295
Aluminium	0.097	5.107
Steel	0.148	7.739
Glass	2.235	116.540
Plastic Bottles	0.102	5.330
Cardboard	0.576	30.080
Residuals	1.171	61.074
Household Hazardous	0.140	7.320
Total	**5.708**	**297.7Tonnes**

4.2.5 DISPOSAL OF HOUSEHOLD MUNICIPAL WASTE OUTSIDE OF WMC

Table 3.10 below provides a breakdown of the proportion of different waste streams managed through the WMC or outside of it. The results show that for most green (88%) and food waste (61%) is managed outside of the WMC through burning, composting, vermiculture and burial.

The MPS behaviour survey in Figures 3.23 and 3.24 of this document shows that while most waste generated in households in Norfolk Island is delivered to the WMC for disposal some wastes are disposed of in different locations.

Table 3.10: Percentage of household waste managed and not managed by the WMC according to survey results

Material Type	Managed by WMC (%)	Not Managed by WMC (%)
Food Waste	39%	61%
Green Waste	12%	88%
Aluminium	90%	10%
Steel	96%	4%
Glass	98%	2%
Plastic Bottles	86%	14%
Cardboard	84%	16%
Residuals	90%	10%

Household Hazardous	40%	60%

The survey also indicated that significant amounts of combustible wastes including cardboard (16%), plastic bottles (14%) and garbage/residuals (10%) are disposed of outside of the WMC through burning, burial or disposal to Headstone. Table 3.11 provides a quantification of different waste streams potentially not managed through the WMC with a total estimate that this would include up to 60 tonnes of all municipal solid wastes combined. Most of these wastes would be green and food wastes (and potentially cardboard) which can be suitably managed outside of the WMC. However, it also shows 11.4 tonnes of garbage (residuals) and hazardous wastes and 3.9 tonnes of recyclables which should be managed in the WMC or being disposed of in locations and a manner which will be polluting and harmful to the land and environment of Norfolk Island.

Table 3.11: Household waste potentially not managed by the WMC by material type

Material Type	Not Managed by WMC Factor (%)	Not Managed by WMC Tonnes/week	Not Managed by WMC Tonnes/year
Food Waste	61%	0.683	35.610
Green Waste*	88%	0.106	5.525
Aluminium	10%	0.010	0.521
Steel	4%	0.006	0.310
Glass	2%	0.045	2.331
Plastic Bottles	14%	0.015	0.762
Cardboard	16%	0.094	4.912
Residuals	10%	0.119	6.230
Household Hazardous	60%	0.084	4.392
Total		**1.162**	**60.591**

* Green waste is underestimated as it is not currently received by the WMC

4.2.6 BRAND SURVEY OF WASTE PACKAGING MATERIALS

With packaging companies volunteering or being held responsible for managing their waste streams in accordance with Circular Economy principles conducting ‘Brand Surveys’ is a potential mechanism for NIRC to gain assistance from the private sector.

This can occur bilaterally through self-sourcing connections with interested companies, or through introductions by joining organisations such as the ANZPAC Plastic Pact (launched 18 May 2021) which links up different stakeholders dealing with plastic waste management. This study reports records waste items with branding by waste type and links brands to the highest-level parent companies. The following results indicate the top 10 brands in Norfolk Island waste by material type and overall.

The top 10 brands for Norfolk Island make up 69% of all items recorded from just 7% of the parent companies identified in the study. The remaining 31% of branded items are made up of a further 134 parent companies. The top 3 parent companies were Asahi Group, The Coca-Cola Company, and Kirin Holdings Company, making up 44% of all brands recorded as shown in Figure 3.32 below.

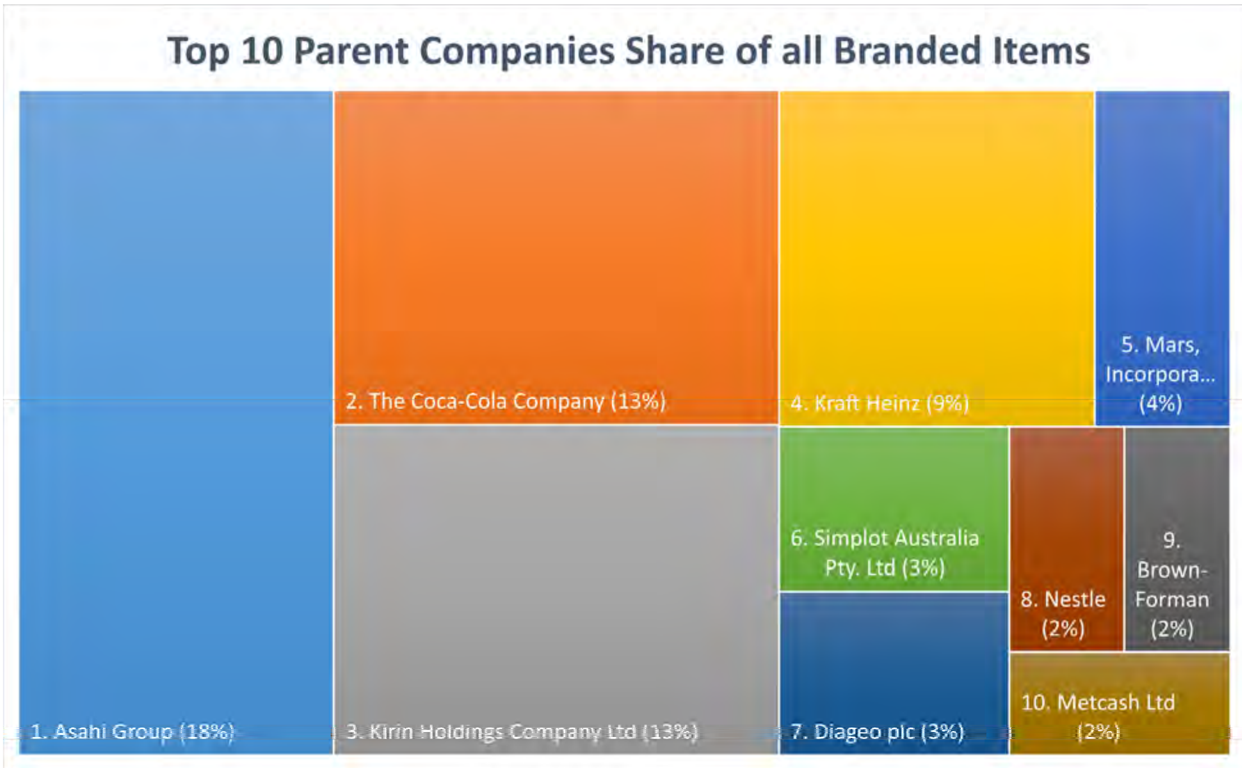


Figure 3.32: The top 10 parent companies of any branded items

Figure 3.33 below shows that the top 10 brands for plastic items account for 62% of all plastic brands from just 15% of the parent companies identified in the study. The remaining 38% of plastic items surveyed are made up of a further 58 parent companies.

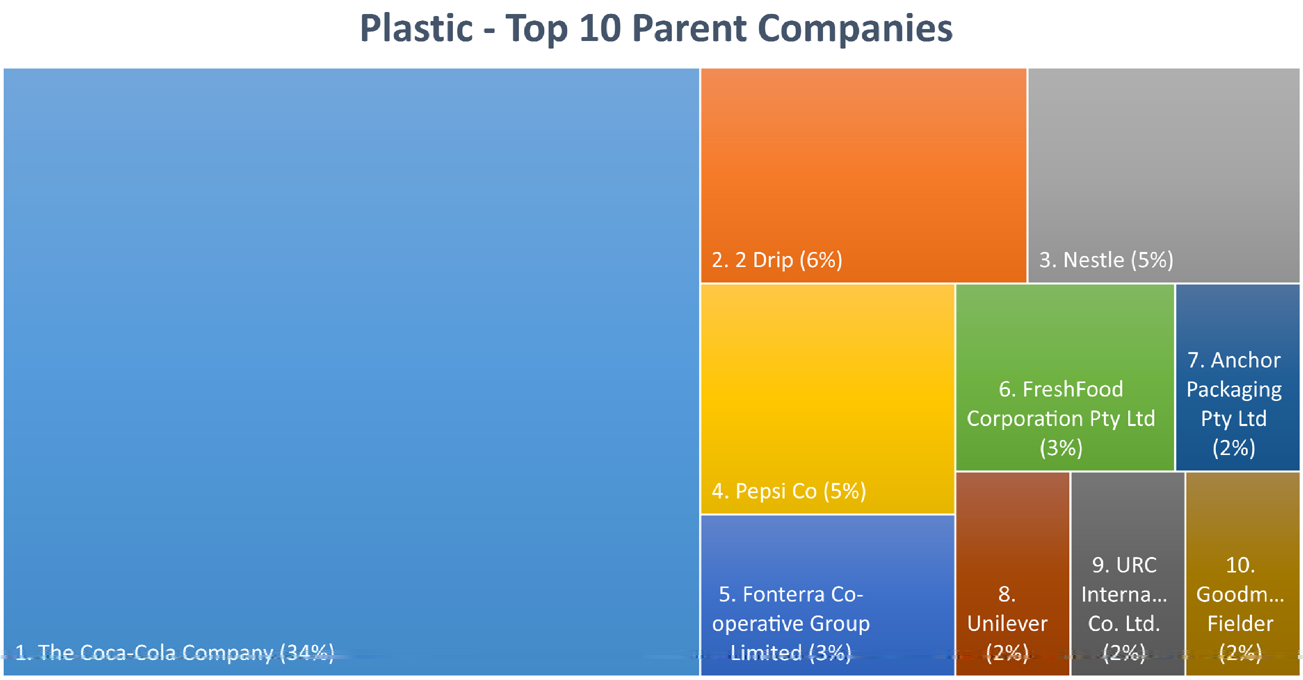


Figure 3.33: The top 10 parent companies of plastic branded items

For branded plastic the top 3 parent companies identified were The Coca-Cola Company, 2 Drip, and Nestle which make up 45% of all plastic brands recorded.

The top 10 brands for aluminium items account for 98% of all aluminium brands from 59% of the parent companies identified in the study. The remaining 2% of aluminium items surveyed are made up of a further 7 parent companies. The top 3 parent companies identified were Asahi Group, Kirin Holdings, and The Coca-Cola Company making up 84% of all aluminium brands recorded as shown in Figure 3.34.

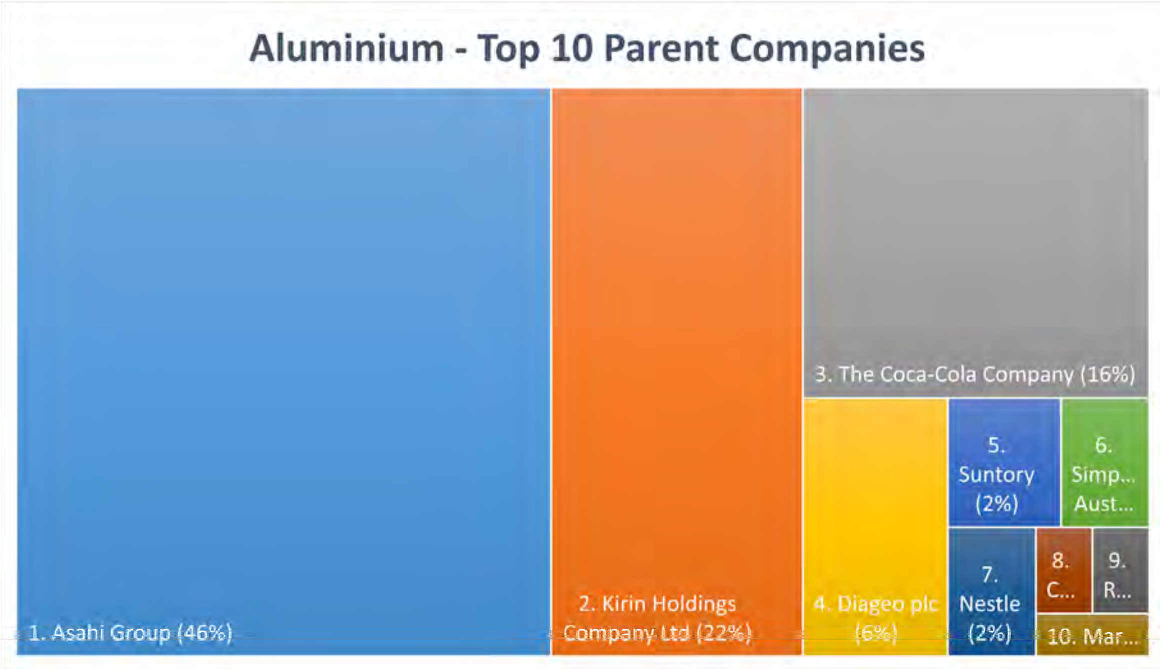


Figure 3.34: The top 10 parent companies of aluminium branded items

The top 10 brands for glass items account for 73% of all glass brands from 22% of the parent companies identified in the study. The remaining 27% of glass items surveyed are made up of a further 36 parent companies. The top 3 parent companies identified were Kirin Holdings, Brown-Forman, and Asahi Group making up 45% of all glass brands recorded as shown in Figure 3.35.

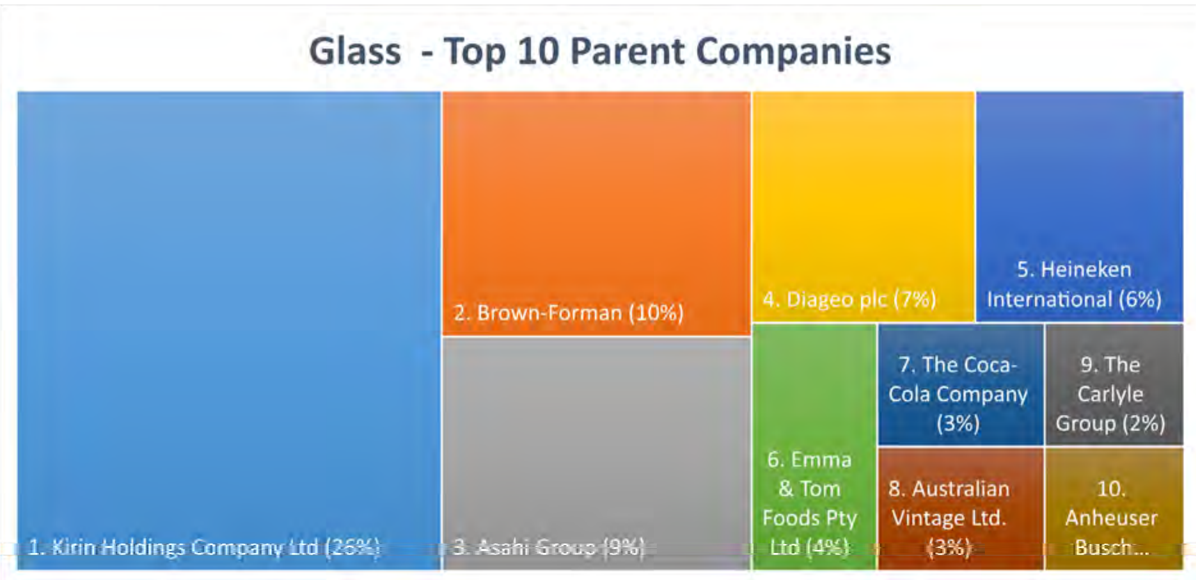


Figure 3.35: The top 10 parent companies of glass branded items

The top 10 brands for steel items account for 83% of all steel brands from 29% of the parent companies identified in the study. The remaining 17% of steel items surveyed are made up of a further 24 parent companies. The top 3 parent companies identified were Kraft-Heinz, Mars Inc, and Simplot Australia making up 57% of all steel brands recorded as shown in Figure 3.36.

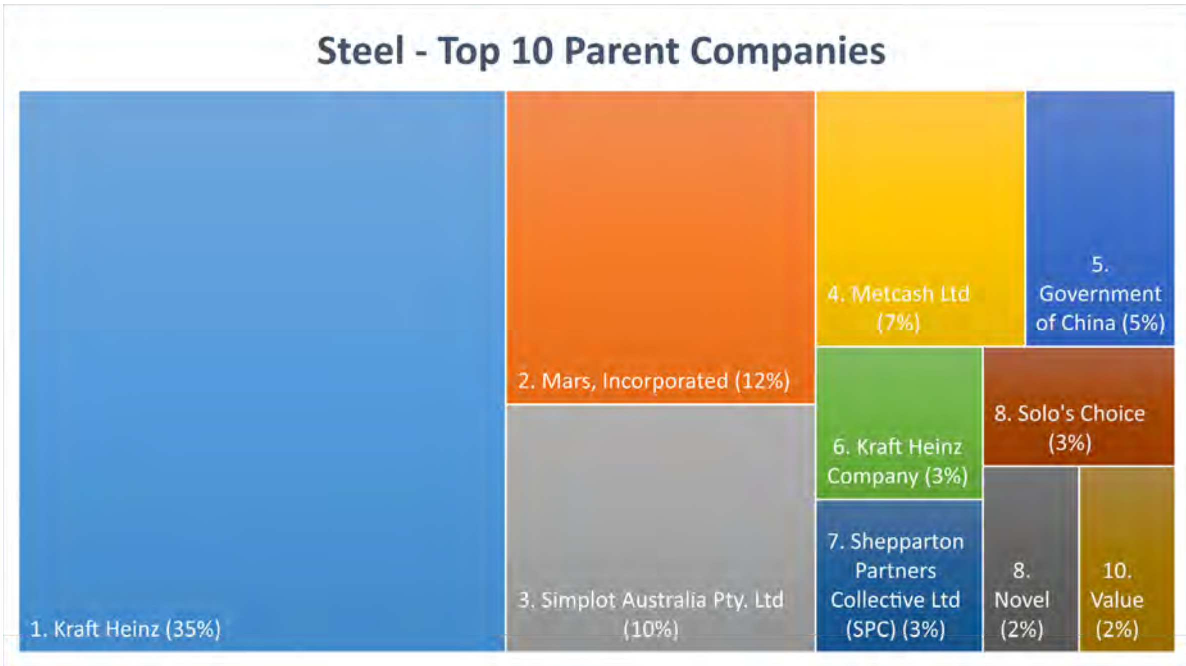


Figure 3.36: The top 10 parent companies of steel branded items

Table 3.12: Brand Survey Number of Companies and Brands

Material Type	Parent Companies Counted	Brands Counted	Items Counted
Plastics (1-7)	68	100	210
Glass	46	73	223
Steel	34	48	305
Cardboard & Paper	24	25	27
Aluminium	17	36	403

Table 3.12 above shows the number of companies associated with different kinds of packaging materials. For plastic over 68 companies associated with 100 brands of plastic packaging were identified, for glass over 46 companies associated with 73 brands of glass packaging were identified and for steel over 34 companies associated with 48 brands of glass packaging were identified.

For cardboard although a full skip bin was surveyed the items were very large and therefore only 27 items were surveyed which showed 25 different brands and 24 different parent companies. But a much larger survey is needed for cardboard due to the high diversity. Aluminium had the lowest number of parent companies with just 17 companies covering over 36 brands.

The Brand Survey found packaging waste for plastics, glass, steel, cardboard/paper and aluminium in Norfolk Island was from 189 different companies with the greatest diversity of companies in plastic packaging and the least in aluminium as shown in Figure 3.37. Many of these companies are members of the Australian Packaging Covenant (APCO) and the Australia, New Zealand, Pacific Plastic Pact (ANZPAC) who have made commitments regarding reducing packaging impacts or even have bilateral arrangements.

Figure 3.37: The Number of Packaging Parent Companies by Material Type

Currently Norfolk Island Regional Council has no benefit from any of these arrangements and bears the full costs of managing the packaging waste from these companies which are imported into Norfolk Island. Being able to present clear information on the packaging means companies product value chains in Norfolk can assist in leveraging support from these companies in managing these waste streams.

4.2.7 HEADSTONE SURVEY

The most recent studies of waste volumes burnt at Headstone were in 2013/2014

Table 3.13: Waste Volumes Burnt at Headstone

Material Type	Weight Burnt 2010/11 (t)	Weight Burnt 2013/14 (t)
General household	710	910
Builder's waste	105	-
Whitegoods	14	-
Food scraps	165	45
Steel cans	-	110
Glass dumped	-	95
Aerosols	-	1
Total tonnes	**994**	**1,161**

Headstone has been the traditional disposal point for waste produced in Norfolk Island for some time, but considerable effort has been made to gradually reduce the types and volumes of waste disposed of in this location due to the severe impacts on the human and environmental health.

All residual waste, which includes almost all of the plastic waste produced on the island is now baled and exported via air or sea freight to mainland Australia where it is disposed of as quarantine waste for deep burial.

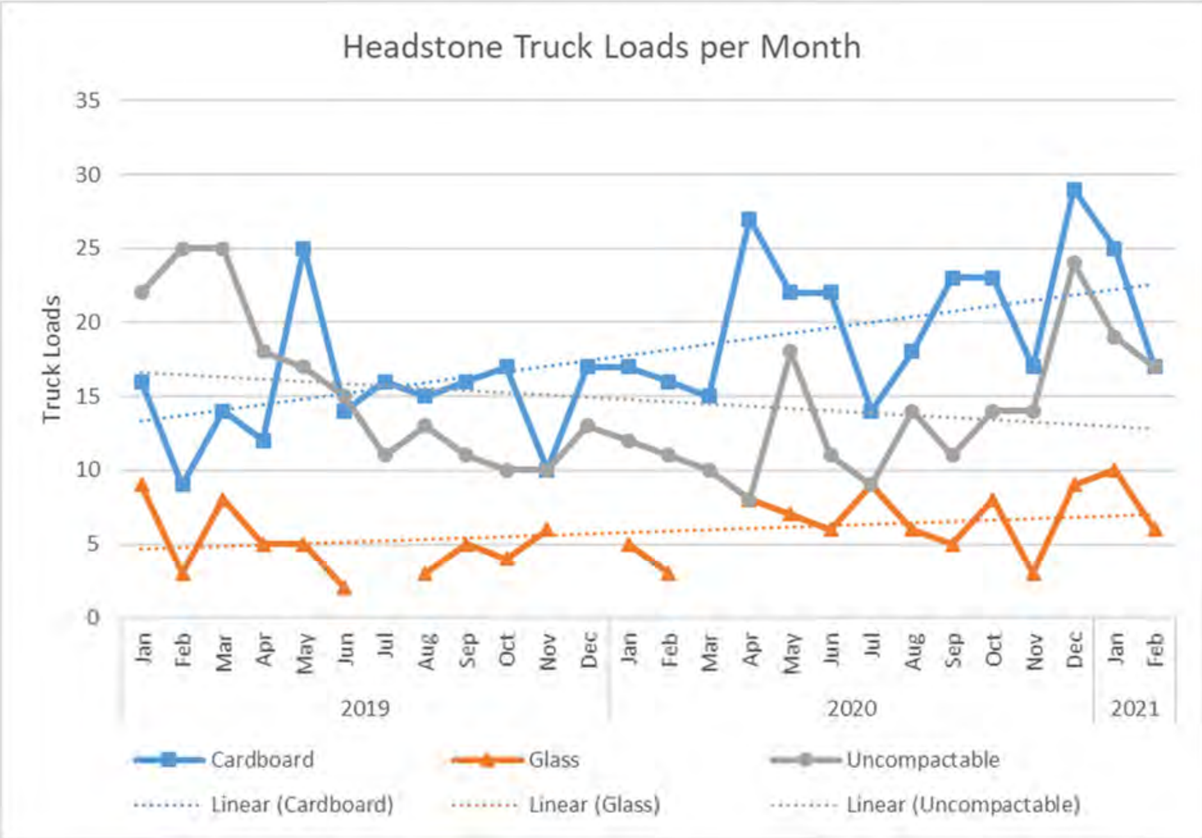


Figure 3.38: Norfolk Island - Waste Delivered to Headstone Point (Period: January 2019- February 2021)

As shown in Figure 3.38 above, trend lines for 'uncompactable' wastes shows the impact recent NIRC waste management initiatives have initially reduced waste that is going to Headstone Point.

However, a return to fuller touristic conditions, and increases in population, shipping and buying that enable fuller consumption has meant that waste components such as glass, cardboard and now uncompactable wastes are steadily increasing.

It should also be noted that the above graph only relates to records taken after baling and export of residual waste reduced waste being disposed of at Headstone by over 150 tonnes per year (equivalent of eighteen 20-foot container loads of waste) plus the cessation of bulky metal wastes (cars, white goods, etc).

Support to NIRC to divert waste from Headstone Point and to produce products such as sand from waste glass, complete the recovery and export of recyclables already started and commence full scale composting which will also use waste cardboard, gypsum (building materials) as well as organic waste is needed to move further into the Circular Economy principles promulgated through recent national legislation, policy and budgeting.

Table 3.14: Conversion of truck loads into volume (m^3).
Cardboard: 14.15m^3/Truck Load, Glass, Uncompactable: 5.4m^3/Truck Load

Period	Cardboard (m^3)	Glass (m^3)	Uncompactable (m^3)	Total (m^3)
2019	**2561.15**	**270**	**1026**	**2273.4**
Jan	226.4	48.6	118.8	253.8
Feb	127.35	16.2	135	199.8
Mar	198.1	43.2	135	253.8

Apr	169.8	27	97.2	189
May	353.75	27	91.8	253.8
Jun	198.1	10.8	81	167.4
Jul	226.4	0	59.4	145.8
Aug	212.25	16.2	70.2	167.4
Sep	226.4	27	59.4	172.8
Oct	240.55	21.6	54	167.4
Nov	141.5	32.4	54	140.4
Dec	240.55	0	70.2	162
2020	**3438.45**	**373**	**842.4**	**2527.2**
Jan	240.55	27	64.8	183.6
Feb	226.4	16.2	59.4	162
Mar	212.25	0	54	135
Apr	382.05	43.2	43.2	232.2
May	311.3	37.8	97.2	253.8
Jun	311.3	32.4	59.4	210.6
Jul	198.1	48.6	48.6	172.8
Aug	254.7	32.4	75.6	205.2
Sep	325.45	27	59.4	210.6
Oct	325.45	43.2	75.6	243
Nov	240.55	16.2	75.6	183.6
Dec	410.35	48.6	129.6	334.8
2021	**594.3**	**86.4**	**194.4**	**507.6**
Jan	353.75	54	102.6	291.6
Feb	240.55	32.4	91.8	216
Grand Total (m^3)	**6593.9**	**729**	**2062.8**	**5308.2**

Suitable shredders able to process the mixed 'uncompactable' wastes (the most difficult to deal with) would enable their volume to be reduced so they could be exported for disposal or recycling (if this is an option). While this study has not considered green wastes, robust shredders are also needed to deal with the large quantities from farms, forestry and households. New equipment would enable NIRC to move to the proposed waste management outcomes illustrated below where no waste is burnt at Headstone Point and none of the resulting residues are pushed into the sea.

4.2.8 NORFOLK ISLAND BEACH LITTER MONITORING 2020

To further illustrate the impacts of current waste management impacts on the marine environment surrounding Norfolk Island marine litter surveys were conducted on three beaches during November and December using the modified OSPAR method.

Figure 3.39: Emily Bay 100m Transect with beach width measured at 20m intervals

MPS undertook environmental litter surveys conducting three standing-stock marine litter surveys to determine the load of litter on the beaches of Norfolk Island. Surveys covered a 100m transect from the water line to the back of the beach (as shown in Figure 3.39 above) of Norfolk's Anson Bay, Bumboras, and Emily Bay beaches and characterised litter materials in accordance with a Norfolk Island adapted version of OSPAR Litter Monitoring Guidelines.

Figure 3.40: Norfolk Island map of beaches surveyed by MPS, the Waste Management Centre and Headstone

Figure 3.40 shows that the surveyed beaches proximity to the primary waste discharge point at Headstone which are the primary accessible beaches available to monitor in accordance with the OSPAR beach litter monitoring method. Table 3.15 shows the distance of the beaches from the WMC and Headstone which is probably the major contributor to the marine beach litter found not discounting materials that may have originated from the open sea.

Table 3.15: Approximate proximity to surveyed beaches and waste disposal facilities. Distance calculated by driving distance for WMC and by straight line coastal distance approximation for Headstone

Survey Site	WMC	Headstone
Anson Bay	5.3km	4.0km
Bumbora Beach	4.9km	4.4km
Emily Bay	6.0km	5.7km

The Norfolk Island average of 787.33 pieces is greater than the average of 300 to 600 reported on Western European beaches as shown in Table 3.16. Differences can probably be attributed to the proximity from Headstone which is the major waste discharge point and the very protected nature of the beach at Emily Bay.

Table 3.16: Total abundance of litter items from a 100m transect of each surveyed beach

Survey Site	Abundance of Litter (Items/100m)
Anson Bay	1393
Bombora Beach	793
Emily bay	176
Average	**787.33**

Emily Bay was found to have only 176 marine litter items on 100 metres of beach as shown in Figure 3.41 above but is sheltered behind the reef which could screen out marine litter items.

Figure 3.41: Marine litter collected from 100m transect of Emily Bay beach

Figure 3.42: Marine litter collected from 100m transect of Anson Bay beach

Anson Bay Beach was found to have 1393 pieces of marine litter, a high number for a remote beach with anecdotal evidence that much larger amount of marine litter occur during certain times of the year necessitating beach clean-ups.

Figure 3.43: Marine litter collected from 100m transect of Bumboras Beach

Bumboras Beach was found to have 793 pieces of marine litter on a 100-metre beach transect dominated by glass which is probably derived from the 136 tonnes which is disposed of into the sea from Headstone every year.

4.2.9 ANALYSIS

The marine litter from each beach was transported back the WMC categorised, weighed and the data recorded as shown in Figure 44 above using the OSPAR beach litter monitoring method.

Figure 3.44: MPS Marine litter survey characterisation and data recording

These results were then analysed and provided in a series of graphs following recording and analysis within Kobol toolbox generated data collection programs as shown in the following Figures below.

Figure 3.45 shows that on average plastic dominated the marine litter found on Norfolk Island beaches with 70% of all marine litter items made from this material with glass being the major item.

Many of the plastic items had a burnt appearance which tends to indicate a Headstone origin for plastic where uncompacted materials which contain many hard plastic components are burnt and the residues disposed into the ocean.

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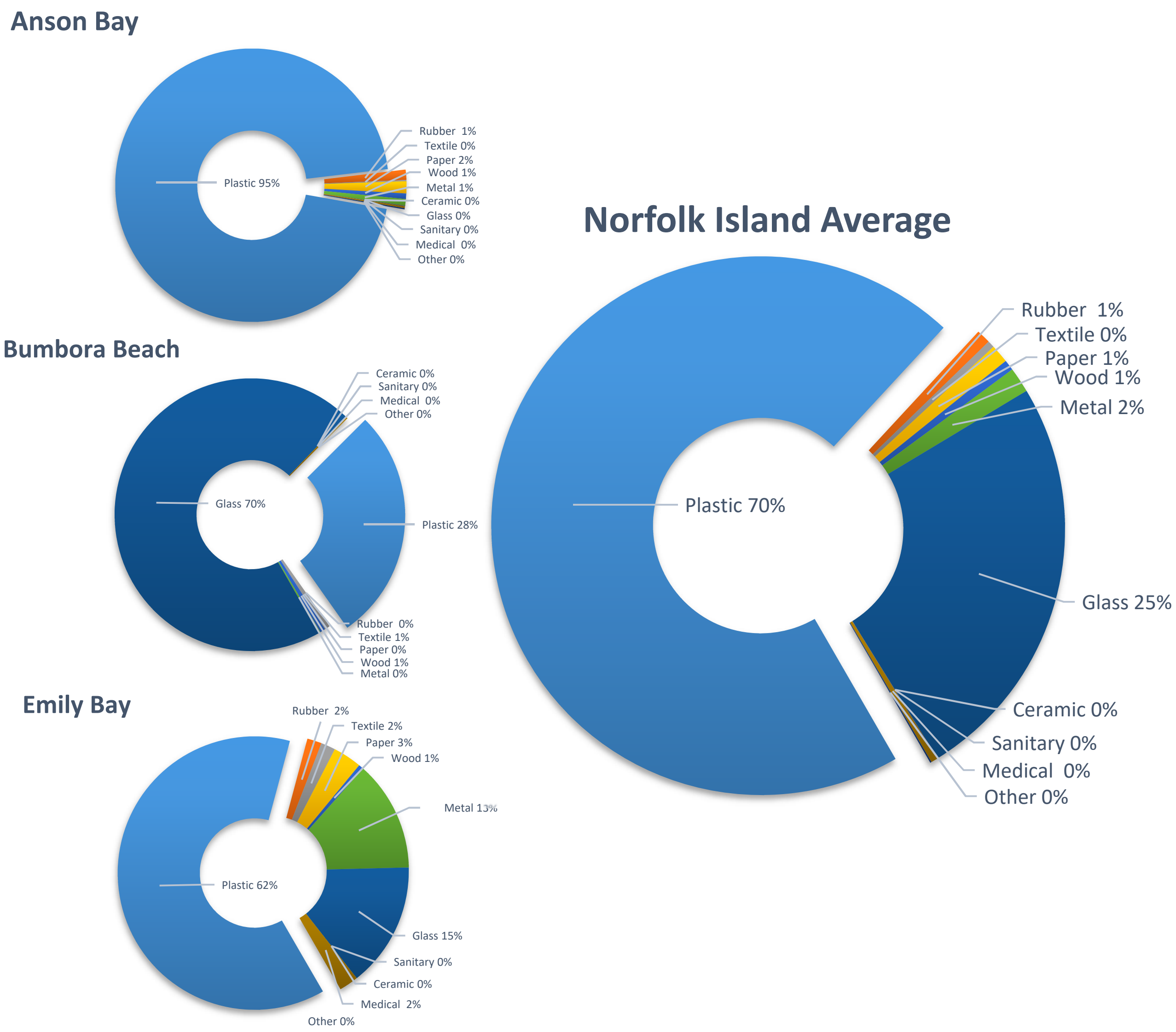

Figure 4.45: Composition of litter abundance recorded on Norfolk Island beach litter survey sites

As illustrated in Table 3.17 below, a total of more than 2,362 pieces of marine litter were found on each of the beaches, with an average of 787.33 pieces, which is greater than the average of 300 to 600 reported on Western European beaches. Plastic and glass were found to be the predominant litter items on Norfolk Island beaches with 1,658 and 585 pieces respectively.

Table 3.17: Norfolk Island Average 100m litter abundance results by item categories

Item Categories	Norfolk Total Abundance of Litter (Items)	Items/100m Ave
Plastic	1658	552.67
Glass	585	195
Metal	36	12
Paper	26	8.67
Rubber	20	6.67

Wood	15	5
Textile	10	3.33
Medical	9	3
Other	2	0.67
Sanitary	1	0.33
Ceramic	0	0
Total	**2362**	**787.33**

Table 3.18 further illustrates the types and potential sources of the marine litter with pieces of hard plastic, broken glass, burnt plastic, plastic bottle labels matching the glass bottles and burnt plastic residues disposed of at Headstone Point. Table 18 shows that 8 out of the top 10 items found on Norfolk Island beaches are made of plastic.

Table 3.18: Norfolk Island top 10 most abundant litter items on beaches

Rank	Top 10 Litter Items (Items)	Abundance (Items)	Percentage of Total
1	Plastic/Plastic pieces 0-2.5cm	815	34.50%
2	Glass/Glass broken	584	24.72%
3	Plastic/Plastic pieces 2.5-50cm	304	12.87%
4	Plastic/Burnt plastic	118	5.00%
5	Plastic/Caps/lids	91	3.85%
6	Plastic/Other plastic	71	3.01%
7	Plastic/Cap rings	69	2.92%
8	Plastic/Cigarette butts	52	2.20%
9	Plastic/Plastic bottle labels	49	2.07%
10	Paper/Other paper items	24	1.02%
	Subtotal	**2177**	**92.17%**

5. LOGISTICAL CONSIDERATIONS

5.1 SEA FREIGHT NORFOLK ISLAND TO AUSTRALIA

For those wastes requiring export from Norfolk Island Sea Freight has historically been the most affordable option as a backloaded freight on ships or barges. Usually this has occurred on ships delivering consumer goods from New Zealand/Australia but in small amounts and often as break bulk. Less frequently this has occurred on barges delivering goods and materials associated with infrastructure projects on Norfolk Island which have been able to remove large quantities in full shipping containers and even bulky items.

Table 3.19: Cost of Sea Freight for Bailed Waste Norfolk Island to Australia per M3

Sea Freight			
Baled Residual Waste Costs (M3)			
	Units (M3)	Units	Total Cost (FCL)
Sea Freight	18.71	$ 347.41	$ 6,500.00
Customs/Quarantine Charges	18.71	$ 26.11	$ 488.44
Container Storage	18.71	$ 0.00	$ 0.00
Land Transport	18.71	$ 42.54	$ 796.00
Disposal Costs	18.71	$ 273.00	$ 5,107.83
Total Cost	**18.71**	**$ 799.08**	**$ 14,950.72**

Table 3.20: Cost of Sea Freight for Bailed Waste Norfolk Island to Australia per Tonne

Sea Freight			
Bailed Residual Waste Costs (Tonne)			
	Units (T)	Units	Total Cost
Sea Freight	8.69	$ 748.36	$ 6,500.00
Customs/Quarantine Charges	8.69	$ 56.23	$ 488.44
Container Storage	8.69	$ 0.00	$ 0.00
Land Transport	8.69	$ 91.60	$ 796.00
Disposal Costs	8.69	$ 273.00	$ 2,371.20
Total Cost	**8.69**	**$ 1,169.19**	**$ 10,155.64**

The costs of sea freight have been analysed based on backloading rates of barges present in Norfolk as part of an infrastructure project completed in 2020. Based on a cost of $6500 per 20-foot container load (FCL) it was found that using baled residual waste as an example the cost for transporting and disposing of 1 tonne of material (approx. 2 bales) would be $1169 or $799 per cubic metre as shown in Table 19 and 20 above.

Freight costs are given on both a weight and volume basis as this may be factor in reducing costs through increasing density of waste materials such as aluminium cans, PET plastics, steel cans and other materials. This is because higher density may mean the same amount of waste is shipped in fewer movements incurring much lower freight charges especially where fixed costs are a factor.

As illustrated in Figure 3.46 below sea freight makes up 64% of total costs for disposing of residual waste to Australia, followed by 23% for disposal costs (deep burial as quarantine waste), 8% for land transport and 5% for customs and quarantine clearance. Significant charges can also occur for container storage but have been assumed to have not occurred in the above figure.

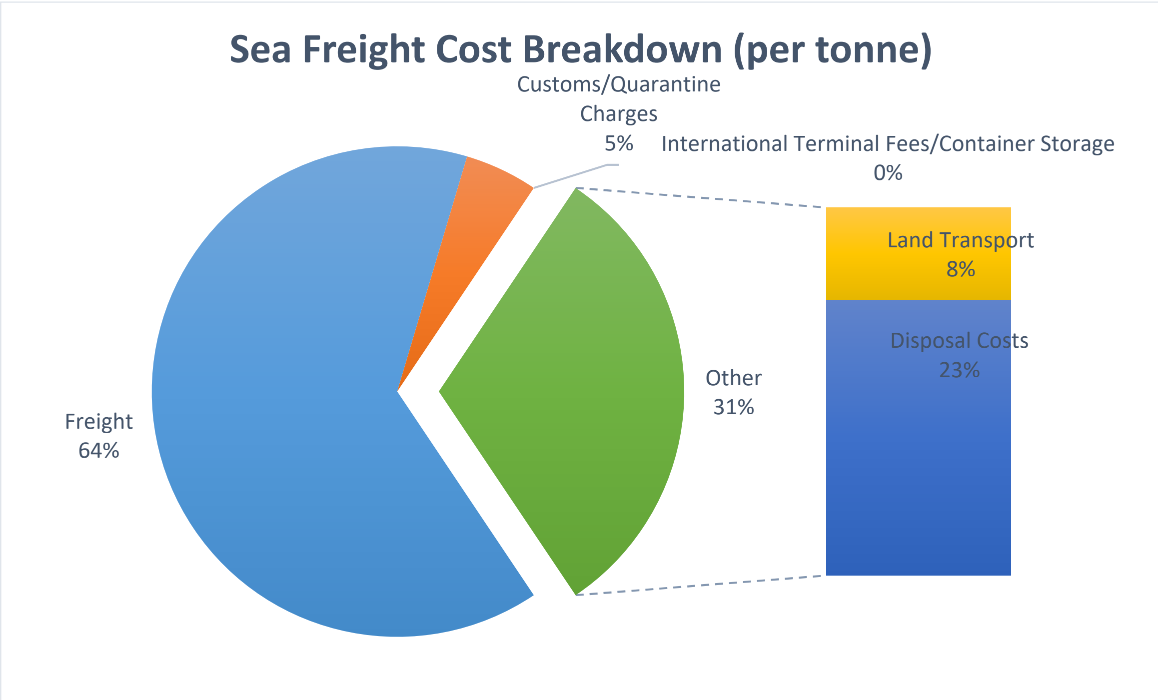

Figure 3.46: Sea Freight Costs for Residual Waste - Based on 2020 Backloading with Boral

Regularity of sea freight for taking backloaded wastes from Norfolk Island to New Zealand or Australia has not always been unreliable. Previous Norfolk to New Zealand waste backloading for affordable rates of approximately AUD $2500 per FCL was possible due to competition, but this has now been lost as Norfolk's changed status has resulting in an orientation to Australian shipping.

Without a regular shipping line both delivery, reliability and cost of both shipping to Norfolk and backloaded waste items has become difficult to predict and without competition backloaded costs when available have increased for $2500 to $6500 per 20 FCL. Though there is the possibility that regular shipping and the ability to regularly backload full shipping containers may be possible with the proposed establishment of improved facilities at the Cascade Pier[19].

[19] https://www.regional.gov.au/territories/norfolk_island/administrator/media/2021/ni-a-mr-202123.aspx

5.2 AIR FREIGHT

Unique to Norfolk Island is the backloading of certain waste back to Australia on air freight services that are delivering a range of perishable and other items to Norfolk Island that helps to counter sometimes unreliable sea freight services. Mostly this seems to have been used for plastic and aluminium recyclables as well as baled residual waste and has been an important component in ensuring the sustainability of that service which is critical for other components of the Norfolk Island economy.

The costs of air freight more recently have been analysed based on backloading rates for a variety of wastes sent from Norfolk Island to mainland Australia as part of a regular service in 2020/2021 based on a 13.92 tonne load of residuals which was 30 cubic metres in volume. Based on this example the cost for transporting and disposing of 1 tonne of material via air freight (approx. 2 bales) was found to be $2288 or $1061 per cubic metre as shown in Table 3.21 and 3.22 below.

Table 3.21: Cost of Air Freight for Bailed Waste Norfolk Island to Australia per M3

Air Freight			
Bailed Residual Waste Costs (M3)			
	Units (M3)	Units	Total Cost
Air Freight	30	$ 676.69	$ 20,300.56
Customs/Quarantine Charges	30	$ 16.28	$ 488.44
International Terminal Fees	30	$ 215.63	$ 6,468.88
Land Transport	30	$ 26.53	$ 796.00
Disposal Costs	30	$ 126.67	$ 3,800.16
Total Cost	**30**	**$ 1,061.80**	**$ 31,854.04**

Table 1. Cost of Air Freight for Baled Waste Norfolk Island to Australia per Tonne

Air Freight			
Bailed Residual Waste Costs (Tonne)			
	Units (Tonnes)	Unit	Total Cost
Air Freight	13.92	$ 1,458.37	$ 20,300.56
Customs/Quarantine Charges	13.92	$ 35.09	$ 488.44
International Terminal Fees	13.92	$ 464.72	$ 6,468.88
Land Transport	13.92	$ 57.18	$ 796.00
Disposal Costs	13.92	$ 273.00	$ 3,800.16

Total Cost	**13.92**	**$ 2,288.36**	**$ 31,854.04**

As for Sea Freight costs are given on both a weight and volume basis as this may be factor in reducing costs through increasing density of waste materials such as aluminium cans, PET plastics, steel cans and other materials. This is because higher density may mean the same amount of waste is shipped in fewer movements incurring much lower freight charges especially where fixed costs are a factor.

As illustrated in Figure 3.47 below air freight makes up 64% of total costs for disposing of residual waste to Australia, followed by 20% for international terminal fees, 12% for disposal costs (deep burial as quarantine waste), 2% for land transport and 2% for customs and quarantine clearance.

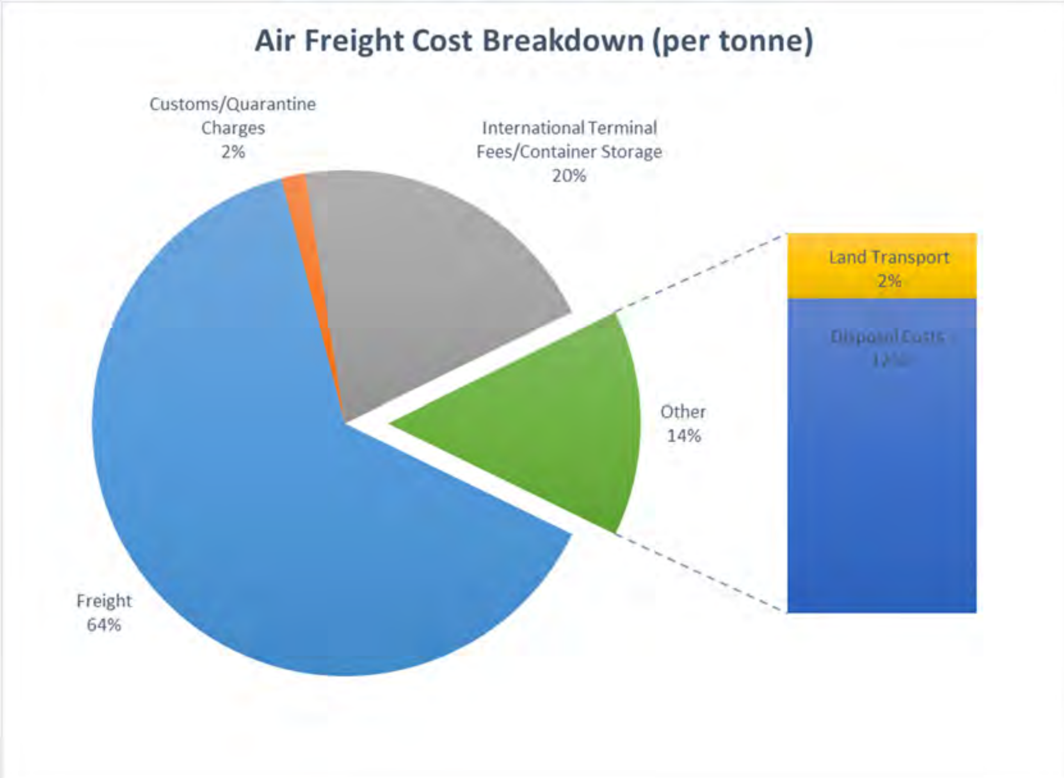

Figure 3.47: Composition of litter abundance recorded on Norfolk Island beach litter survey sites

6. FINANCIAL CONSIDERATIONS

As discussed in previous chapters waste management revenues raised in 2019 from the waste management levy and ticket sales for waste drop off at the WMC amounted to $793,492 which was approximately 2.3% of the Norfolk's Annual Budget for that year.

This is low in comparison with a regional NSW Council such as Port Macquarie Hastings which contributes approximately 10% of its budget to waste management but without the high costs of freight and fees that Norfolk Islands has to provide to dispose of its wastes. As shown in figure 3.48 equivalent costs for disposing of residual waste is only $240 pet tonne for Port Macquarie Hastings but is almost 5 to 10 times higher for Norfolk Island waste depending on whether sea freight or air freight is used.

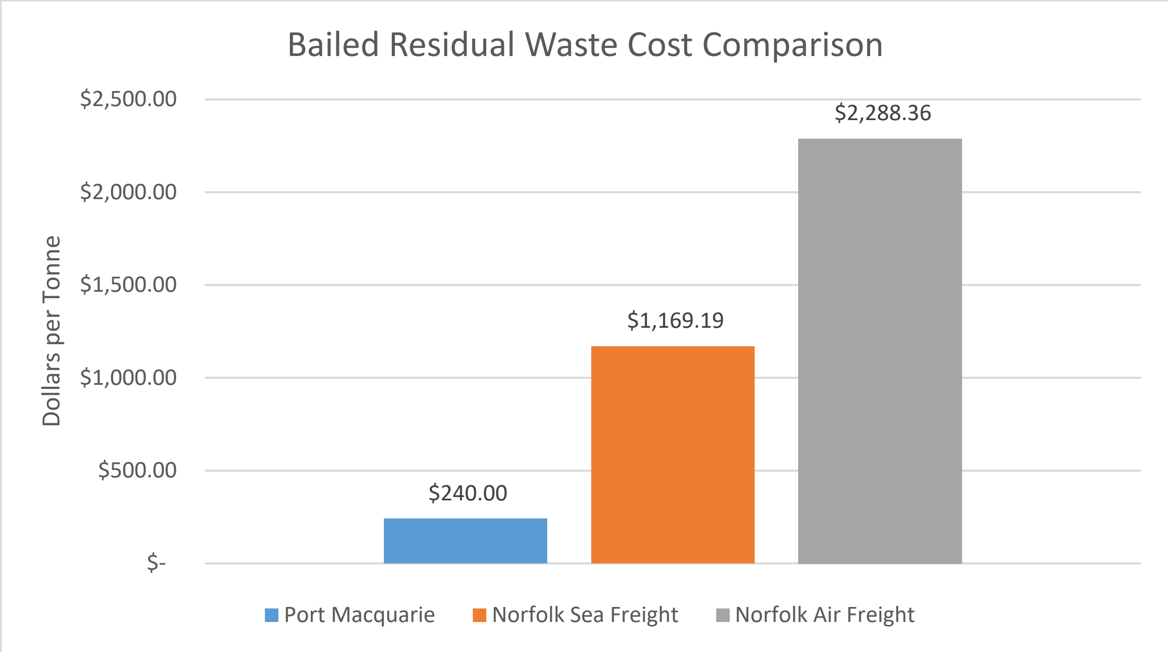

Figure 3.48: Comparison of transport and disposal costs for 'residual' municipal wastes for Port Macquarie and Norfolk Island

NIRC is constrained in its revenue raising measures with only 7.8% raised from rates compared to PMHC raising 48% of its revenue from rates. PMHC and other mainland Australian councils also charge a specific waste management fee through rates where as NIRC has no solid waste management fee in its rates.

Other financial benefits NSW councils receive that NIRC misses out on includes allocations given to them by the NSW EPA from the NSW Waste Levy, the NSW Container Deposit Legislation program and national programmes such as the Australian Packaging Covenant. Current estimated quantities of municipal solid waste exported through this study is 179 tonnes which includes baled residual wastes and minor quantities of recyclables as shown in Table 3.23. The estimated cost for freight and disposal of these quantities and types of wastes is projected as $199,413 for sea freight and $400,639 for air freight.

Table 3.23: Estimates of Current Municipal Waste Exported – Costs and Quantities

Bailed Residual Waste Costs (Tonne)			
	Units (Tonnes)	Sea Freight (SF)	Air Freight (AF)
Major Solid Waste Components			$
Residual Waste*	151.4	$176,987	$346,403
Minor Solid Waste Components			
Steel Cans	11.4	$ 9,229	$22,321
Aluminium Cans	10.4	$ 8,420	$20,363
PET Plastic Bottles	5.8	$ 4,777	$11,552
Total	**179**	**$ 199,413**	**$ 400,639**

**Residual Waste could be reduced by 51% by eliminating FOGO/Nappies reducing cost by $89,732 (SF) or $134,750 (AF)*

These costs would consume a major component of a slim budget, but it should be noted this represent only represents 30% of the total municipal waste stream (excluding green waste, bulky waste, hazardous waste) with cardboard, uncompactable wastes and glass making up the other 70% of the total waste stream. If the other elements of the waste were no longer disposed of at Headstone through burning and or dumping were instead also exported for disposal in mainland Australia the estimated total cost would be $571,297 for sea freight and $1,245,691 for air freight as shown in Table 3.24.

Table 3.24: Cost Scenario for Export of All Municipal Waste Exported – Costs and Quantities

Municipal Waste Costs (Tonne)			
	Units (Tonnes)	Sea Freight	Air Freight
Major Solid Waste Components			$
Residual Waste*	151.4	$ 176,987	$ 346,403
Uncompactable Waste	100.8	$ 117,835	$ 230,630
Cardboard	177.6	$ 143,783	$ 347,741
Glass	136.2	$ 110,266	$ 266,680
Minor Solid Waste Components			
Steel Cans	11.4	$ 9,229	$ 22,321
Aluminium Cans	10.4	$ 8,420	$ 20,363
PET Plastic Bottles	5.8	$ 4,777	$ 11,552
Total	**593.6**	**$ 571,297**	**$ 1,245,691**

**Residual Waste could be reduced by 51% by eliminating FOGO/Nappies reducing cost by $89,732 (SF) or $134,750 (AF)*

This is based on recent costings for sea freight which have been doubled so there is potential this could be reduced if this stabilises and more affordable backloading rates become possible as is the case for air freight. Such costs for export of all collected municipal wastes are unlikely to be supported through even an expanded NIRC revenue base and it is likely to be much more feasible to reduce the residual waste stream through redirecting FOGO and potentially even compostable nappies and possibly even compostable feminine hygiene products to the HotRot composting system.

It would also be more feasible to process and use glass on the island than to export it at a cost of $809 a tonne and cardboard export is equally unfeasible and options for utilising uncontaminated cardboard in the HotRot system, possibly controlled burning of the remainder (similar to forest trash burning) or other options need to be explored.

Unlike cardboard or glass uncompactable waste is unlikely to be easily reduced or reprocessed on Norfolk Island as it is composed of too many different kinds of mixed wastes that make up a large number of commercial and household items. It is currently being burnt and the residue disposed to the ocean which clearly cannot be continued as the residues from this activity are found polluting Norfolk Islands beaches.

NIRC has applied for specialised equipment that can reduce such wastes into a compact form for export. Table 3.25 therefore projects export costs based on those targeted materials and quantities that would plausibly be exported for disposal to mainland Australia with estimated annual costs ranging from approximately $250,000 for sea freight and $500,000 for air freight.

Table 3.25: Probable Near Future Cost Scenario for Export of Targeted Municipal Waste Exported – Costs and Quantities

Bailed Residual Waste Costs (Tonne)			
	Units (Tonnes)	Sea Freight	Air Freight
Major Solid Waste Components			
Residual Waste*	92.35	$ 107,961	$ 211,305
Uncompactable Waste	100.8	$ 117,835	$ 230,630
Minor Solid Waste Components			
Steel Cans	11.4	$ 9,229	$ 22,321
Aluminium Cans	10.4	$ 8,420	$ 20,363
PET Plastic Bottles	5.8	$ 4,777	$ 11,552
Total	**220.8**	**$ 248,223**	**$ 496,173**

**Assumes Residual Waste could be reduced by 39% by eliminating FOGO*

What is clear in relation to financial considerations is that the current revenue collected for waste management activities is inadequate to cope with the increased costs associated with stopping all disposal at Headstone. In order to address this, measures need to be taken both to increase revenue streams by using traditional (rates) and novel (EPR) approaches as well as adopting the least cost measures to manage wastes.

While the variability and costs associated with freight are high better strategic financial planning for funding waste management is needed that identifies and integrates alternate means of generating income with current revenue streams. This would provide both equity, user pays and adequate income to offset current and future activities at the WMC including the annual export of targeted household and other wastes.

On one final note Norfolk Island may not be subject to the GST that has been standardly levied by freight and waste companies on wastes taken from Norfolk Island and disposed of or recycled in mainland Australia. While NIRC or the Administrator should formally confirm this (probably through a tax ruling) the following information was provided from the ATO to Marine Plastic Solutions.

1. ***Where an Australian based entity is contracted directly by the Norfolk Island Regional Council.***

The supply of services would be GST-free under item 2 in the table in subsection 38-190(1) of the GST Act if the Council is not 'in Australia' (does not have any presence in Australia) at the time of supply; and

- *the supply is not a supply of work physically performed on goods situated in Australia and is not a supply directly connected with real property in Australia; or*
- *the Council is not registered or required to be registered for GST in Australia.*

It would not matter if the services in Australia.

2. ***Where you are contracted by an Australian entity to provide the services to the Council***

The supply of your services would be GST-free under item 3 in the table in subsection 38-190(1) of the GST Act if:

- the Council does not have any presence in Australia; and
- the supply is not a supply of work physically performed on goods situated in Australia and is not a supply directly connected with real property in Australia.

Please refer to:

- Goods and Services Tax Ruling GSTR 2004/7 for guidance in determining whether a particular entity is in Australia for the purposes of item 2 and item 3.
- Goods and Services Tax Ruling GSTR 2007/2 for guidance in determining whether the supply is provided to another entity outside Australia; and thus, the effective use or enjoyment of the supply takes place outside Australia.

6.1 WASTE FEES

As of 2017, the WMC charges a fee for disposal of general waste ranging from $2 for up to 120 litres of waste to $20 for 2000 litres or 2 cubic metres of waste. Disposal of recyclables is free for domestic loads (Figure 3.49). The centre employs a prepaid ticket system and does not accept cash payment.

Figure 3.49: Fee ticket collection booth at WMC

The Waste Management Act 2003 includes provisions to raise income to support the waste management operations and fund improvements to waste on the Island. The income maybe derived from a waste levy imposed on all imported goods whether by sea or air, a fee may also be prescribed for certain types and categories of waste and a gate fee or entry fee may also be imposed. The Waste Management Regulations 2004 as amended specifies in clause 3(1) the fees applicable which last amended in 2009 as follows:

- for goods imported by sea a rate of $41per cubic metre or per tonne whichever is the greater; and
- if imported by air the rate is $0.26 per kilogram.
- $100 per container of livestock
- Asbestos disposal fees
- Domestic - <1m^3 – free, 1- 2 m^3 - $150/m^3, and $100/m^3 for each additional
- Commercial - $200m^3

While the levy approach does not bear a relationship to the cost to manage different types of waste it is not without precedent as the NSW EPA has a waste levy on all waste going to landfill which is in addition to the waste rates management charge applied to all N\SW households. Currently the NSW EPA applies a levy of $146 per tonne of waste for the Sydney Metropolitan area and $84.10 per tonne in regional and rural areas.

The levy approach is also being directly applied to packaging companies in mainland Australia, Northern Territory, New South Wales, Queensland, the Australian Capital Territory and Western Australia have Container Deposit Schemes. Tasmania and Victoria have announced their scheme models which are expected to launch in late 2022 and 2023 respectively.

In our opinion the current method of charging a waste levy on all imported product bears no resemblance to the amount of waste generated by any business or household. Indeed, a price penalty is provided on any air freight when the article is the same irrespective of the freight delivery method. The levy on sea freight is $41.00 per cubic metre or tonne whichever is the greater and air freight is 26c per kg which is the equivalent of $260.00 per tonne if air freighted.

Throughout Australia a land rating system applies based on valuations and different states use different methodologies. In NSW the Unimproved Capital Value (UCV) of the land is the basis for charging multiplied by the agreed rate and a Domestic Waste Management Charge (DWMC) is identified on all rate notices and is a charge levied specially for the purposes of cost recovery for waste management activities. This charge cannot be hypothecated to other activities, however, it can be used to build a reserve fund for future capital works.

The amount charged by local councils through NSW varies considerably from $280 to over $500 per property based on the level of service provided, scale and economies achieved. Typically, the charge includes the cost for or access to a waste management system which in urban communities is through a kerbside collection of garbage, recycling and garden organics or in rural areas access to a transfer station to self-deliver these materials. Costs associated with street sweeping, litter, street litter bins, community education, waste management centre and/or landfill operations, facility licensing and compliance reporting to statutory authorities are also included.

Where a kerbside service is provided councils tend to charge more based on bin size, as bigger bins mean greater amounts of waste to be disposed. In addition, most councils throughout NSW and indeed Australia also incorporate a component for future funding to cap and closure landfills, upgrade waste facilities and invest in new technologies which do not occur in a linear manner.

If the NIRC is to consider the introduction of a rating scheme to the residents of Norfolk Island, the introduction of a Domestic Waste Management Charge could augment the current waste levy which is insufficient and is fully transparent to the community and property owner. To establish the amount of income required, an annual operating budget of waste management activities is required which is then divided by each occupied portion. Typically, unoccupied vacant land pays a minimal fee. In addition, most councils charge fees for delivery of certain waste types i.e. problem, hazardous and building wastes where no kerbside collections are provided.

In some situations weight, volume or pallets are applied to calculate costs associated with the transport and disposal costs for waste products. The NSW EPA has released a conversion table based on extensive landfill audits that allows volume to weight conversion to be undertaken with some accuracy based on estimated compaction levels. It is strongly recommended that this be used as the basis of tonnage calculations.

6.2 OPERATING BUDGET

Norfolk Islands reported collecting total waste management revenue of $793,492 from a population of 1748 from a revenue base (2019) of $41.70 million (7.8% from rates), which includes $20.4 million in grants from the Australian Government [20]. Waste management revenues raised for Norfolk Island Regional Council is therefore equivalent to just 2.3% of its total budget compared to Port Macquarie Hastings Council which had waste management costs amounting to 9.6 % of its total budget (48% from rates) in 2019[21] despite enjoying much lower waste management costs.

In 2020/2021 total waste management revenue raised was even less with a total of $689,012.35. Total operational costs for the WMC for 2020/2021 amounted to $1,960,338.85. This has left a deficit of - $1,271,326.50 excluding capital cost and depreciation. It would appear that the operation of the WMC and associated works are solely reliant on the levy and sale of tickets from the waste drop offs at the WMC with no additional funds available.

Further funds are however needed for even further improvement in waste management practices to improve protection of environmental and human health to the level statutorily required given Norfolk Islands location in a Marine Park. Further funds are needed to cover costs for baled residual waste and bulky metal now been diverted from Headstone, aluminium cans, steel cans and PET plastics. In addition to these many hazardous or special waste

[20] Norfolk Island Regional Council Annual Report 2018/2019.
[21] Port Macquarie – Hastings Council Annual Report 2019/2020.

items also need to be exported and disposed of on mainland Australia (oil, used tyres, batteries, asbestos, e-waste and chemicals (household, industrial, agricultural).

The situation since the previous waste review has changed markedly with the collection of waste management revenue having almost doubled compared to the 2013 where the levy generated income of $320,000 and an additional $10,000 income from sales. At that time however operations at the WMC for 2013-14 amounted to only $388,497. Of this an amount of $60,000 was allocated to plant and equipment and $70,000 to the preparation of the Environment Impact Study (EIS) associated a high temperature incinerator. At that time most waste was burnt and or dumped off Headstone including bulky vehicles, residual waste, uncompacted waste, glass and cardboard.

Norfolk Islands reported in 2016 a total island operating budget of $31,341,498 with a dedicated waste budget of $452,257 or 1.44% of the total budget. This has increased in 2019 with Norfolk Islands reporting total revenues of $41.70 million (7.8% from rates), but that included $20.4 million in grants from the Australian Government [22] and total waste management revenue of $793,492, equivalent to 2.3% of the total budget.

To better develop a sustainable operational budget further information is required including the following components which were raised in the 2015 APC review:

- Labour - The amount of time to undertake the existing activities is not known in respect of the amount of labour and time taken for various current and future tasks. Therefore, it is not possible to predict with accuracy how long it will take and how many staff will be required to undertake the new program. It is suggested the program will be staged based on funding and approvals are provided. It is expected that the proposed program will involve more labour and higher skill levels than the current practices. The ANI reduced the labour by 2 staff when the composting operations ceased. A labour force will be required to undertake the activities associated with the new waste management program: subject to the final agreement on preferred approach.
- Freight - No provision has been made for the freighting of materials and equipment to the Island by suppliers in their quotes. The consultants suggest the footprint and weight of each item be provided so that indicative freight cost can be obtained. Also freight and associated costs - local transport, wharfage, other port fees, international freight costs, administration costs, permits fees and approvals for the export of problematic and hazardous wastes need to be incorporated.
- Disposal or processing costs – the disposal and processing costs for the full range of materials is unknown.
- Equipment - adequate provision for personal protective equipment (PPE) - steel cap boots, high- visibility safety vests, gloves and eye protection must be provided and renewed.
- Training - staff training is required on all new practices and commissioning of any new equipment. Specific training will be provided by the various equipment suppliers in the products they provide. Specific training in the storage and handling of chemicals is imperative. Certificate level courses in Asset Maintenance (Waste Management) are available. These can be conducted in the workplace. There are a number of avenues available to obtain funding to assist with the training.
- Maintenance - ongoing maintenance of all equipment is required. Manufacturers were generally not very forthcoming with costs pertaining to maintenance practices so actual costs should be recorded.
- Replacement costs - Inevitably the equipment will reach the end of its lifespan and will require replacement. This should be provided for by way of a sinking fund. It is considered that 15% of the replacement cost should be put aside each year to provide for new equipment. In addition new bins, crates and bunded pallets are likely to be needed each year due to breakages, loss or damage It is expected that 10% of the bin infrastructure equipment will need to be replaced each year.

[22] Norfolk Island Regional Council Annual Report 2018/2019.

The emphasis should be on systems that will work in a Norfolk Island context and that can be supported by actual funds collected, grants and access to other support (such as the Australian Packaging Covenant).

7. PRIVATE SECTOR

Businesses have a critical role to play in achieving the System Change Scenario. The specific actions required by business depend on where they exist across the supply chain, and whether they are in high-income or middle-/low-income economies. Commercial opportunities await those ready to embrace change and position themselves as leaders in a near-zero plastic pollution world, for example:

1. Plastic manufacturers and converters should prepare for a low-virgin-plastic world by entering new value pools more aggressively, radically innovating for more recyclable and recycled plastic, and mitigating the risk of products leaking into the environment by reaching 100 per cent collection and voluntarily paying for collection in geographies where producer responsibility is not mandated.

2. Brand owners, fast-moving consumer goods companies and retailers should lead the transition by committing to reduce at least one-third of plastic demand through elimination, reuse, and new delivery models; embracing product redesign and supply chain innovations; working across supply chains on sustainable sourcing, effective end-of-life recycling, and composting substitutes; and ensuring maximum recycled content and recyclability by creating products that are 100 per cent reusable, recyclable, or compostable.

3. Waste management (collectors, sorters, and recyclers) should scale up and improve collection to reduce plastic leakage and secure feedstock for recycling, facilitate source separation in collection systems using incentives and improved standards, reduce the risk of direct discarding of plastic waste into waterways, scale up and expand recycling systems, and improve efficiencies through technological improvements.

4. Paper and compostable material manufacturers should act fast to capitalize on opportunities to develop alternative formats and materials and improve resource efficiency and paper recycling capacity.

Recent EPR requirements have been strengthened under Australian Government legislation that requires private sector actors all along the value chain to be held increasingly responsible for the end of life (EOL) management of their products. For packaging this can be accessed via the APCO and ANZPAC initiatives while others exist for e-goods, vehicles and other items and are areas that NIRC should also increasingly seek resources.

The packaging Brand Survey has identified the dominant companies whose packaging has to be collected, managed, processed, exported and disposed of at great cost to NIRC whereas most of those same companies provide resources for managing their wastes in mainland Australia through projects such as RedCycle.

As such approaches include all actors along the value chain the private sector who have businesses importing goods into Norfolk Island also have a role to play given that this survey and report has illustrated the prominent commercial waste footprint; particularly for cardboard and residual wastes.

8. COMMUNITY ASPECTS

Across the globe there is a growing understanding that waste is an issue that everyone is responsible for and so everyone including businesses, industry, government, and community members have a role to play in its minimisation and management. The role of civil society in waste management is complex and multifaceted. Community members can act as watchdogs keeping governments, businesses, and institutions accountable, they can be responsible for advocacy and awareness raising, or for coordinating research and citizen science[23]. Community members also have significant influence through their role as consumers which gives them the power to demand and accelerate changes to products and services. This is important as consumer demand for more

[23] The Pew Charitable Trusts, 2020.

sustainable options motivates businesses to go above and beyond their legal and regulatory responsibilities especially in addressing the growing plastic crisis[24]. In short, the community is hardly a passive player in the waste management process and therefore needs to be consulted, educated, and encouraged to participate if we hope to move towards more sustainable practices and systems.

8.1 THE NORFOLK ISLAND COMMUNITY

During 2015 a series of meetings were held with elected representatives, Administration officials, Norfolk Island Administration managers, WMC staff, waste generators, business owners, special interest groups and community representatives[25]. From these meetings it was clear that the community perception of the WMC was mixed from the start. While the WMC and its programs and initiatives were initially embraced by the community, residents eventually became frustrated with their efforts to separate waste streams being undermined by back of house practices at the WMC where certain waste streams were being mixed back together, burnt and then dumped at Headstone[26]. However, since 2015 a number of positive changes have been made at the WMC and as a result waste deposited at the WMC is no longer burnt and dumped into the ocean at Headstone. Instead, residual waste, which is unfit for recycling, is baled and flown to mainland Australia to be landfilled. Additionally, there is now a dedicated waste bay at the WMC for 'clean plastic' which is plastic suited for recycling such as PET bottles.

Another area of ongoing frustration is the accessibility of the WMC. Among residents and businesses there is strong objection to the centre being closed on two consecutive days (Sunday and Monday), on the basis that people are too busy during the rest of the working week, and that it leads to waste pile ups especially at commercial businesses such as restaurants[27].

In 2018 the Norfolk Island Regional Council published their Norfolk Island Environment Strategy 2018-2023. In preparing this document, the Council consulted with over 200 community members engaged through a survey, workshops, and community information pop-ups. According to this document, the community identified waste management as a key environmental priority for Norfolk Island.

There is a clear sense of urgency regarding the immediate improvement of waste management on the island, and the community recognises that a better system in which less waste is produced, and more materials are reused or recycled needs to be established. The community also acknowledges that waste disposal practices such as backyard burning, and ocean dumping are unsustainable and have harmful environmental impacts.

However, disconnects between actual current waste management systems/services and education/information available to the community still exist. For example, new practices such as the 'clean plastic' waste bay for recycling at the WMC, and the transportation of residual waste to mainland Australia for landfilling, have not been fully updated on the Norfolk Island Regional Council website which still states that general household refuse, including paper, cardboard and plastic, is taken to Headstone, burnt and the ash deposited into the sea.

This disconnect may provide an explanation for why some community members choose to burn certain waste types that are now being managed in a more environmentally conscious manner such as bailing and exporting. Contemporary information and education must be provided to the community in order to avoid non-compliance and to ensure that individuals can make informed decisions when it comes to their waste behaviours.

In order to be an effective environmental strategy, the education, participation, and needs of the community must be considered to be integral to waste management. Moving forward, Council must demonstrate strong leadership and be sure to include the community in the design and implementation of waste management systems and services.

8.2 APPROACHES FOR COMMUNITY ENGAGEMENT IN WASTE MANAGEMENT

[24] The Pew Charitable Trusts, 2020.
[25] APC, 2015.
[26] APC, 2015.
[27] APC, 2015; The Norfolk Regional Council, 2018.

8.2.1 CHANGING BEHAVIOUR TOGETHER: NSW EDUCATION STRATEGY

Having recognised the importance of community education and engagement in waste management, the NSW EPA developed the Changing Behaviour Together: NSW Waste Less, Recycle More education strategy 2016–2021 in order to meet the goals of the Waste Less, Recycle More and the Waste Avoidance and Resource Recovery Strategy 2014–21 (WARR Strategy). This education strategy demonstrates the significant influence that community behaviour can have on waste management and explores how to deliver community behaviour change programs and promote the adoption of positive waste behaviours (Figure 3.50).

Figure 3.50: The Role of the Community in the Waste Hierarchy (Source: https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/wastestrategy/changing-behaviour-together-waste-less-education-strategy-170171.pdf)

This Strategy is based on UNESCO's Education for Sustainable Development (ESD) approach which provides a global framework for working towards a sustainable future and places emphasis on education's contribution to the achievement of the 17 Sustainable Development Goals (SDGs). Actions and activities proposed in this Education Strategy include workshops, printed educational materials, increased tangible infrastructure (e.g., bins), community events, formal training (vocational education certificates and diplomas), and use of mass media (e.g., television and radio). All proposed actions and activities within the Strategy link back to at least one of the following six strategic directions:

- develop and use consistent messaging
- integrate education
- build capacity
- promote excellence
- provide resources and tools
- work with and support stakeholders

This Education Strategy could serve as a useful tool for Norfolk Island in creating their own community focussed waste management education strategy which could be used to help meet the goals set out in the current Norfolk Island Environmental Strategy 2018-2023, as well as any future environmental strategies.

8.2.2 COMMUNITY BASED SOCIAL MARKETING

Community Based Social Marketing (CBSM) is a proven method of fostering sustainable behaviour change that is being used globally across a range of thematic areas including agriculture, conservation, energy, transportation, waste, water, health, and safety. CBSM is based in social psychology and was developed through the notion that sustainable behaviour change is most effective when it involves direct community engagement[28]. The CBSM method involves a process of first selecting indivisible end-state behaviours that will ultimately result in the desire outcome. A barriers and benefits study is then carried out which may involve research, observations, focus groups and surveys. Strategies to mitigate barriers and enhance benefits are then created often through the use of the following behaviour change tools:

- Commitment
- Social norms
- Social diffusion
- Prompts
- Communication
- Incentives, and
- Convenience.

The final stages are to pilot the selected strategies and make any necessary adjustments before moving into broad scale implementation and evaluation. CBSM as outlined in Figure 3.51 ensures that projects and activities are guided by theory and evidence rather than by assumptions, and therefore increases the likelihood of desired behaviours and activities being adopted in high rates and for the long-term[29].

The CBSM method would be extremely valuable in the design, piloting and running of any new waste management systems or services for Norfolk Island, especially those where community participation is key.

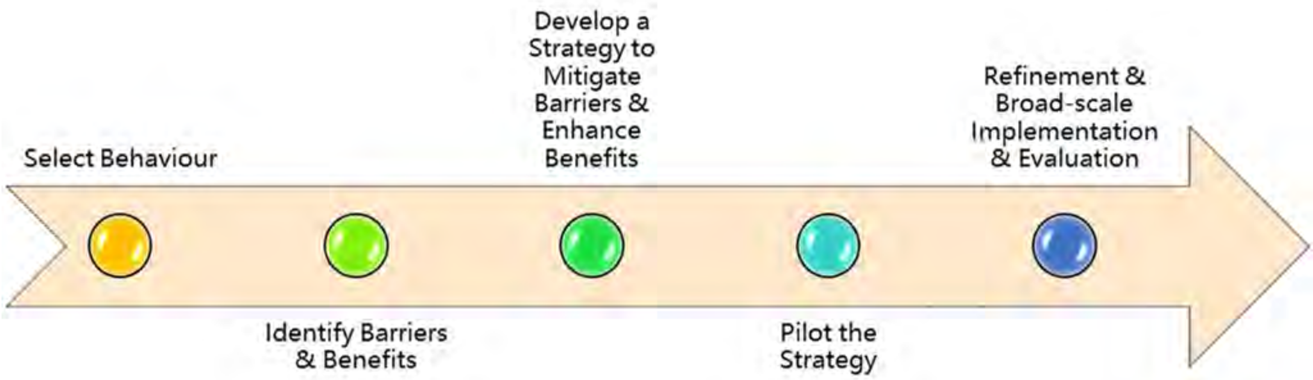

Figure 3.51: Steps for Developing a Strategy through CBSM

[28] McKenzie-Mohr, 2011.
[29] McKenzie-Mohr, 2011.

9. ALTERNATE WASTE SYSTEMS

Norfolk Islands waste management system is unique compared to mainland Australia and even most island communities in having no landfilling of solid waste which in the past has led to any non-combustible waste materials that cannot be exported as a recyclable material or cannot be compacted being dumped into the ocean.

As examined within this report as the practice of ocean dumping has been reduced the volumes of recyclable and residual wastes exported has greatly increased but at great cost. If uncompactable wastes that are currently burnt were to be shredded with new equipment and cardboard was compacted and exported, then the costs for export of waste for disposal to Australia would be likely to triple as residual wastes, cardboard waste and uncompactable waste make up a major percentage of all waste streams.

The cost to export and dispose of residual waste from Norfolk Island to Australia is $2,288 per tonne by air and $1,169 per tonne for sea freight though it is expected sea freight could be reduced to approximately $708 per tonne with regular ship backloading and below $500 for carboard, clean plastics recyclables (with some potential return as well).

By contrast the cost for landfilling the same waste by Port Macquarie-Hastings Council is $240 per tonne. However, the Norfolk Island Environment Strategy 2018-2013 identifies that due to the remote location and small size of the island landfilling (of solid waste) is not a feasible option for waste management.

As an alternative Norfolk Island administrations have considered if other alternative waste systems are a feasible option in a number of previous studies which are highlighted below.

9.1 THERMAL TREATMENT SYSTEMS

Facing limited space, high volumes of waste from trade imbalance and a dependence on imported food thermal treatment systems including municipal waste incineration, waste to energy, pyrolysis and plasma systems have appeared to be a panacea for island waste management.

However, the authors of this study are unaware of any viable system with a proven technical, environmental and financial performance in any of the 15 Pacific Island nations or six Caribbean Island nations they have currently worked in.

Waste to energy is also specifically excluded from being a Circular Economy process and instead identified as a linear process where fossil fuel products are disposed of in the atmosphere, for the combustion gases, and landfill, for the ash which makes up 5% to 20% of the mass of the original waste.

However, it should be noted that the Asia Development Bank is currently funding a USD 151.13 million Waste to Energy plant in the Maldives, which has a current population of 530,953 and approximately 550,000 tourists per year. Given this plant is still in the process of being commissioned the test of island based WTE effectiveness in this Maldives is still unknown.

9.1.1 PACIFIC EXPERIENCE

In considering ‘Waste to Energy’ technologies in the Pacific Islands nations the Secretariate of the Pacific Regional Environmental Program (SPREP) have noted that:

‘There is a growing interest among Pacific Island communities in exploring municipal waste-to-energy options as a means of reducing the need for landfills and dependence on diesel importation for electricity generation. This interest is being driven primarily by international companies promoting proprietary waste-to-energy technology, with little regard to long-term affordability and sustainability.’[30]

And;

‘*Conventional wisdom suggests that the waste-to-energy approach is unsuitable for the majority of Pacific SIDS due to relatively small municipal waste volumes and the dense, wet quality of most waste streams. This is reinforced by*

[30] https://sustainabledevelopment.un.org/content/documents/commitments/1326_7636_commitment_cleaner-pacific-strategy-2025.pdf

the lack of successful case studies of municipal waste-to-energy implementation in other SIDS. Waste-to-energy technologies that combust MSW also transform a fairly innocuous waste stream (general waste) into bottom ash, as well as fly ash and flue gas, which may contain particulate matter, heavy metals, dioxins, furans and sulphur dioxide.'[31]

9.1.2 MSW INCINERATION IN OKINAWA'S SMALL ISLANDS

Experience in Okinawa, which was supplied with municipal solid waste incinerators on 15 rural islands was that that average installation costs were USD 1.3 million (AUD $1.65 million) per tonne of treatment capacity with an average cost of USD 510 (AUD $650) per tonne of waste treated and upper-level costs reaching USD 1050 (AUD $1340).[32]

While transport costs are much lower than airfreight (over AUD $2200) to Australia regular ship backloading may be cheaper with recent rates being AUD $1169 per tonne but historic and potential future rates being AUD $708 for residual waste and approximately $344 for recyclables including carboard and plastics.

Translated to the Norfolk Island context this would require a plant costing approximately AUD $2 million installed to treat 334 tonnes (56% of the municipal solid wastes) of 'combustibles (residual waste, carboard, plastic) at an annual cost of between AUD $255, 844 AUD $469,604 if it was based on Japanese costs.

However, all costs are likely to be considerably higher, at least double, for Norfolk Island supply and operation as Japan has economies of scale for incinerators that do not exist in Australia and Norfolk's remoteness would incur significant costs while fuel (diesel or gas) in Norfolk is also likely to be much more expensive. Additionally, ash would still have to be exported probably as a hazardous waste.

Further equipment would also be required to reduce the size of bulky wastes, such as special shredders already sought by NIRC through the regional grants program, so such waste could be introduced into the WTE plant.

Many of the Okinawan Islands have now ceased to use the incinerator systems and opted for other waste management systems that were much more affordable is costs per tonne of waste managed.

9.1.3 NORFOLK ISLANDS PREVIOUS STUDIES ON WASTE TO ENERGY

In 2009 *The Administration of Norfolk Island* and the *Natural Heritage Trust* funded the 'Norfolk Island Municipal Waste Stream Feasibility Study' which investigate options for waste management on Norfolk Island and the development of specifications for a high temperature incinerator as transportation of waste off Norfolk was costing $2 million per year.

The study concluded that:

'*Norfolk Island's relatively small amounts of solid waste will produce a small amount of intermittent electrical power. This would likely result in a small revenue stream that does not adequately offset the additional complexity and higher construction and operating cost of a WTE facility (as compared to an incineration only facility). Pending a cost-benefit analysis, it seems unlikely that WTE would be economically feasible on Norfolk Island.'*

In 2015 *The Administration of Norfolk Island* funded the 'Norfolk Island Waste Management Strategic Plan' which considered the full range of thermal treatment systems including incineration, pyrolysis and gasification and gasification and concluded:

'Thermal Waste Treatment solutions are expensive - $4M
Dealing with only 15% of the waste stream
Lack of local skills and expertise in operating AWT
Lack of maintenance expertise for AWT
Insufficient waste composition data for planning

[31] https://sustainabledevelopment.un.org/content/documents/commitments/1326_7636_commitment_cleaner-pacific-strategy-2025.pdf

[32] Okinawa Prefectural Government. 2014. Haikibutsu taisaku no gaiyō (Heisei 26-nen 3 gatsu-ban) [Overview of waste management (March 2014 edition) – Section 2: general waste]. http://www.pref.okinawa.jp/site/kankyo/seibi/documents/03iltupanhaikibutu.pdf.

Correct equipment selection and installation essential
Ash will require special disposal due heavy metal contamination Community objections due to fear of emissions profile
Long lead time minimum 24 months
There are no AWT facilities processing mixed waste in Australia at this time'.

9.1.4 CURRENT CONSIDERATIONS

The experience of MPS concurs with the Pacific and Okinawan experience in thermal treatment. There is a high level of risk and uncertainty surrounding thermal treatment system for Norfolk with no scale examples that would clearly work in the Norfolk Island context.

MPS has however conducted an analysis on the calorific value of the residual waste bales utilising the International Solid Waste Associations (ISWA) calorific checker for viability of 'waste to energy' which is as follows:

LCV (kcal/kg = 40 (a+b+c+d)+90e-46w [33].

In short it states you need your waste to have a calorific value of 1500 Kcal/kg to make energy, or at least 1000 Kcal it has to use energy and below this level you normally have to add energy. This formula is then matched to the characteristics of baled residual waste currently exported for landfill disposal in Australia which is shown in Table 26 below.

Table 3.26: Waste Characterisation of Bailed Residual Waste.

Category	Weight	%
Cardboard/Plastic Composite	1.539	3%
Paper	4	8%
Polystyrene	0.248	0%
Plastic Films and Other	5.012	10%
SUPs	2.667	5%
Hygiene	4.576	9%
Textiles	4.934	10%
Plastic Containers	0.769	1%
Food	12.446	24%
Wood and Leaves	2.629	5%
Cardboard	12.562	24%

This results in the Norfolk Island waste characterisation being entered into the equation as shown below.

a. – Paper/Cardboard = 8%

b. – Textiles = 10

[33] https://www.dropbox.com/s/vmbxaxbtgnuqwvk/Calorific%20Value%20-%20HD%20720p.mov?dl=0

c. – Wood/Leaves/carboard = 29

d. – Food waste and hygiene = 33%

e. – Plastic/Rubber = 20%

w - moisture content=60

Calculation

LCV (kcal/kg =40*(8+10+29+33)+90*20-46*60 = 2240 kcal/kg

These results show that at 2240 kcal/kg Norfolk Island residual waste has ample calorific value for waste to energy but that the low volumes and other barriers mean that financially and practically thermal treatments do not currently appear to be a viable option for small communities such as Norfolk without considerable investigation. With the potential to compost organic wastes, cardboard and paper in the HotRot composting system, including piloting compost friendly nappies/feminine hygiene products as well as reducing the volumes of residual waste through new segregation such as plastic films there may be other avenues to reduce total volumes costs of waste that need to be expensively exported.

10. SCALE CIRCULAR ECONOMY APPROACHES

10.1 FROM LINEAR TO CIRCULAR

With the introduction of mass production and the development of cheap consumer goods which tend to sacrifice quality and longevity for a more attractive price point, consumers began to fall into the practice of buying and discarding items rather than investing in their maintenance or repair.

Over time, this take-make-waste extractive industrial model has contributed to a global increase in a variety of waste streams which need to be managed. Of course, the most effect practice would be to simply produce less packaging and other waste in the first place. However, for locations like Norfolk Island this may not yet be feasible. Instead, useful options for sustainable management of waste may be found in the Circular Economy.

The Circular Economy involves a systemic shift from *linear* to *circular* in which growth is redefined by decoupling economic activity from the consumption of finite resources. In this approach, waste is designed out of the system by making changes to all phases of product lifecycle from design and production to consumer use so that the product is continuously captured in a circle of use.

Circular Economy is underpinned by a transition to renewable energies and prioritises the development of economic, natural, and social capital. The three base principals around which the Circular Economy operates are:

- Design out waste and pollution
- Keep products and materials in use
- Regenerate natural systems

This is presented in Figure 3.52 below.

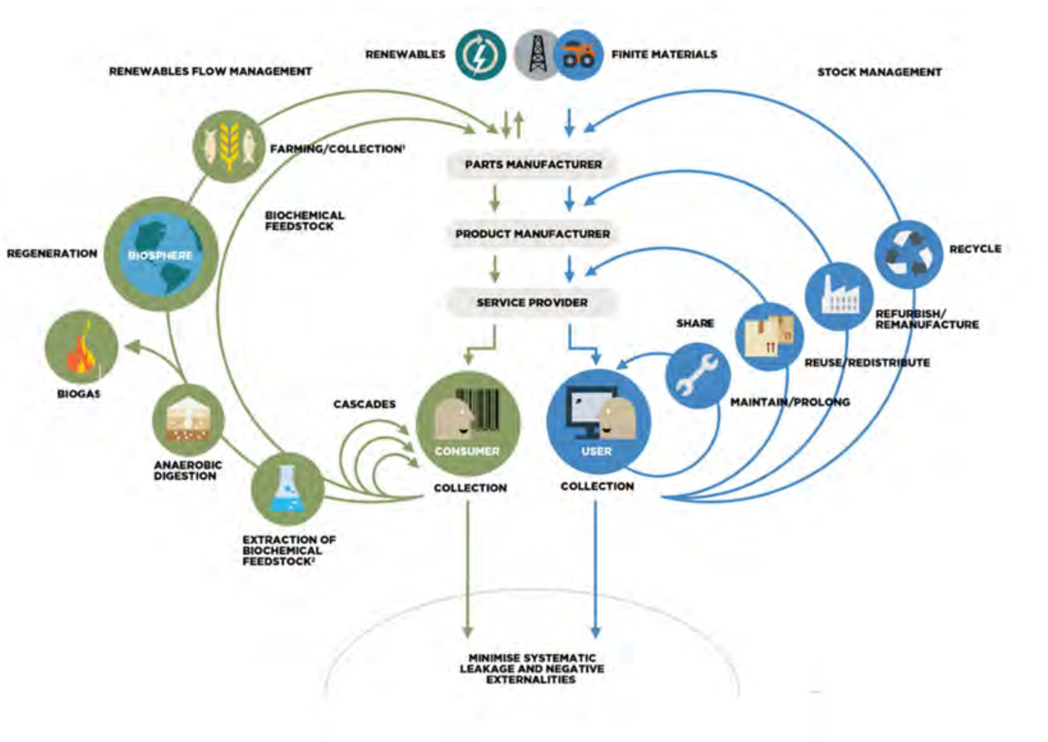

Figure 3.52: Circular Economy - Source: Ellen MacArthur Foundation, circular economy systems diagram (February 2019), www.ellenmacarthurfoundation.org

10.2 CIRCULAR ECONOMY FOR NORFOLK ISLAND

Norfolk Islands remoteness, small scale of economy, logistical constraints and reliance on imported goods make it challenging to participate in the circular economy. Extended producer responsibility schemes under the Australian Packaging Covenant (APCO), through state-based container deposit systems, and arrangements with packaging companies such as Red Cycle have not been applied to Norfolk Island.

The majority of goods that arrive on Norfolk Island come by ship. As a result, goods must be heavily packaged, far beyond the standard packaging requirements of the mainland, so that they meet maritime, health and quarantine standers and requirements. Thus, it is unrealistic to expect the packaging on these goods to be reduced.

However, there are other areas where waste can be minimised through circular economy approaches including redesign over-packaging such as double-wrapping plastic film and excess “headspace;” develop packaging-free products; decrease consumption and production of avoidable bags and films; increase utility per package; extend life of household goods

Reusables owned by consumers (e.g., water bottles, reusable bags) or owned by institutions (e.g., cutlery, crockery, plastic pallets). Refill from dispensers (e.g., bottles, multi-layer/multi-material flexibles, and sachets), subscription services, concentrated capsules, take-back services with reverse logistics and washing, package-as-a-service models (e.g., shared ownership of take- away containers

The Boomerang Bag is a good example of multi-use items produced within Norfolk Island replacing single use plastics while the approaches and products provided in the Prinke store in Burnt Pine has excellent examples of circular economy approaches.

10.2.1 REUSE SHED

The reuse shed, tip shop, revolve or ‘trash and treasure’ are all terms referred to the concept that is ideally suited to the island communities given the scarcity of materials and the delay and cost of bringing new or replacement items (Figure 3.53). Goods no longer needed but that are useable, workable or can be used for parts are made available to other members of the community.

Figure 3.53: Norfolk Island WMC Re-use Section

There is an ad hoc system in use at the WMC currently where unwanted materials are deposited inside the exit drive-through door for the community to scavenge and take at will. Previous studies concluded that the current area is inadequate in size, poorly located as it impedes traffic flow if persons park on that side of the driveway to forage and has no formal shelving or system for materials to be displayed.

These facilities have the ability to divert a considerable amount of material from disposal if adequately supported by the community who both donate and reuse.

11. REVIEW OF APPLICABLE UPSTREAM MANAGEMENT APPROACHES

11.1 BANS

Most recent waste related bans in Australia, the Pacific and the world have targeted single use plastic (SUP). This has typically concentrated in single use plastic bags, plastic straws, cutlery, polystyrene and plastic takeaway food containers and a myriad of other unessential plastic items. These have often focused on the top 10 to 20 marine litter items found on beaches in the targeted location.

An analysis of household waste in Norfolk Island however shows that classic SUPs only make up 2.1% of waste items. The use of cardboard boxes for shipping, the Boomerang bag initiative, the cost on plastic bags at Food land's, the work of the touristic organisations, presence and activity of Prinke and other activities appear to have reduced SUPS to a low level. While the marine litter survey found mostly plastic it was also not composed of plastic SUP items, instead being dominated by fragmented plastic pieces and plastic components from both plastic and glass bottles. Plastic SUP items are not a priority problem in Norfolk Island.

'Plastic' nappies however are however a costly problem in Norfolk Island as they are included in the residual waste stream where they are exported and disposed of to quarantine waste landfill at great expense. The survey results for this report found that nappies and feminine hygiene products made up approximately 12% of the residual waste stream, or almost 20 tonnes (1 full shipping container) and costing up to $40,000 a year to dispose.

The contamination of the residual bale may also add additional costs of $60,000 as it might otherwise be recycled as plastic film. A move from 'plastic' nappies to compostable ones that can be treated in the HotRot system has the potential to save $100,000 in export and disposal costs a year.

This could potentially be approached through a ban, as was proposed in Vanuatu but given Norfolk Islands bast success on reducing SUPs to negligible amounts, the small community size and the small number of recyclables their seems to be potential to achieve the same result through a co-operative approach potentially supported by government and the private sector.

11.2 DEPOSIT LEGISLATION

Container deposit scheme (CDS) – This approach has been proposed under the National Waste Policy 2009 and has already been implemented in the South Australian (SA) some 30 years ago and more recently in the Northern Territory. New South Wales (NSW) has just announced it will introduce a CDS in July 2017 and Queensland in July 2018. The framework of the NSW scheme is yet to be developed however in SA and NT a handling fee is paid on all containers redeemed at a licensed depot and the manufactures pay the return freight. This policy has a significant financial implication for Norfolk Island.

For Norfolk Island this could be a valuable tool levied on imported beverage containers following successful approaches used in Pacific Island countries such as Palau and Kiribati with models that are already suitable for a small island situation such as on Norfolk Island. Monies collected have the potential to manage a quarter of the municipal waste stream based on typical CDL costs of 10 cents per container used in Palau, Vanuatu and most Australian states.

11.3 EXTENDED PRODUCER RESPONSIBILITY

11.3.1 THE ROLE OF GOVERNMENT

Governments play a critical role in the recycling and waste management industries through their ability to create policies with clear and stable targets, definitions, and incentives for more sustainable business models[34]. Through these policy instruments governments are able to increase producer accountability, direct control regulations (including bans), create market-based instruments (e.g., deposit-return schemes, taxation for virgin plastic or hard-to-recycle items), and support initiatives such as subsidised waste recovery, funding for education and training, and funding waste management infrastructure.

The rise in public pressure to end marine plastic pollution has caused many governments and businesses to commit to plastic bans, set ambitious standards for Extended Producer Responsibility (EPR), invest in recycling infrastructure, and impose trade restrictions on plastic waste[35]. While industries and businesses have also made commitments through vehicles such as the New Plastics Economy Global Commitment and the Alliance to End Plastic Waste, they mostly focus on downstream actions such as recycling[36]. Thus, in order to drive upstream action on reduction, reuse, and redesign, government policies and leadership are critical.

11.3.2 AUSTRALIAN PACKAGING COVENANT

The Australian Packaging Covenant, managed and administered by APCO (Australian Packaging Covenant Organisation), is a national regulatory framework under the National Environment Protection (Used Packaging Materials) Measure 2011 (NEPM) that sets out how governments and businesses across Australia share the responsibility for managing the environmental impacts of packaging.

The Covenant is supported by a five-year Strategic Plan (2017-2022) and aims to reduce the environmental impacts of Consumer Packaging by supporting two goals:

1. Optimising resource recovery of Consumer Packaging through the supply chain.
2. Preventing the impacts of fugitive packaging on the environment.

The Covenant requires manufacturers, importers and brand owners to take responsibility for their packaging by making sustainable changes so that waste is minimised during every stage of a product's lifecycle from product and

[34] The Pews Charitable Trusts, 2020.
[35] The Pews Charitable Trusts, 2020.
[36] The Pews Charitable Trusts, 2020.

packaging design to development and manufacturing, and finally to customer use and disposal. The Covenant applies to businesses in the supply chain that have an annual turnover of or greater than 5 million AUD.

These businesses are required to either become a Signatory to the Covenant and contribute to the collective national efforts in managing packaging waste, or to meet compliance obligations under the National Environment Protection Measure (NEPM), which are implemented by the laws and other arrangements of participating states and territories where a business sells or distributes its products. The Covenant is agreed between APCO, representing industry participants in the packaging supply chain, and commonwealth, state and territory governments, and endorsed by all environment ministers.

According to APCO's 2020 report, Packaging Waste Collection and Processing Options in Remote and Regional Areas, Norfolk Island is classified as a *Primarily non-Indigenous with many visitors Island Community.* APCO's report describes this category as remote island communities comprised mainly of non-indigenous residents, that is greater than 5 km from the mainland of Australia.

These remote island communities face a range of plastic and packaging related challenges such as high transportation costs, small waste volumes that cannot be managed economically and lack of access to waste management expertise and infrastructure. However, unlike remote islands which receive few visitors, these islands generally have the financial resources, from revenue associated with tourism, to support recurrent investment in waste related services[37].

12. RECOMMENDATIONS

Points of discussion and recommendations have been provided throughout this document in the different sections and can be followed up depending on NIRC and the other stakeholders' areas of interest and focus. However, key recommendations are repeated below.

12.1 PLANNING

The Strategic Waste Management Plan should be updated following the information presented in this survey and study and include:

- A costed implementation plan (5 years);
- A funding plan (5 years); an
- Asset and operational management plan;
- Training plan;
- Logistics plan; and
- Monitoring & evaluation plan.

12.2 TECHNICAL

12.2.1 CARDBOARD

- Is a major waste stream for Norfolk Island
- The commercial sector as the main generator should assist in management of this waste stream.
- Use in the HotRot system has to be carefully considered given contamination concerns (microplastics, chemicals and dyes) and carbon/nitrogen limitations.
- On island destruction and other options. (BBQ briquettes, co-generation use) should be considered including 'controlled burning' analogous to timber trash destruction.

[37] APCO, 2020.

- Cardboard utilisation as 'renewable' material as part of the biomass load in the energy sector should also be considered either as cogeneration with timber trash and woody wastes such as occurs in Fiji at the sugar and timber mills or as part of biogas generation. Further information on this is provided in the energy section of the report.
- Export should be a last option and is probable not viable based on large quantities present.

12.2.2 RESIDUAL WASTE

- Is a major waste stream for Norfolk Island
- FOGO and hygiene wastes present in 'residual waste should be targeted for removal and diversion to the HotRot composting unit (requires move to compostable nappies)
- Support for island wide use of compostable nappies compatible with the HotRot system should be considered through a cost benefit analysis.
- The savings from eliminating 'plastic nappies' so that residual bales can potentially be recycled in Australia and not be sent to quarantine waste. Landfill should be explored
- Pilot with the private sector bilaterally or via ANZPAC on converting the residual bale into a plastic film bale for use in Red Cycle or similar projects should be considered.

12.2.3 GLASS

- Is a major waste stream for Norfolk Island
- Higher quality automatic glass reprocessing unit is required to replace ineffective unit.
- Public works should consider integrating processed glass into infrastructure projects (as has been done by Lake Macquarie in NSW)
- All glass disposal from headstone should cease as glass and associated wastes are impacting Norfolk Islands beaches and environment.
- CDL to be considered to fund glass beverage container management.

12.2.4 ALUMINIUM

- Is a minor waste stream on Norfolk Island
- A small, dedicated aluminium compactor should be considered and would have a fast return on investment as current compaction is poor
- Aluminium cans should be exported due to poor Australian returns (this is also the case for used lead acid batteries) and Australian recyclers export anyway
- Improved compaction will also greatly reduce freight costs due to smaller volume

12.2.5 STEEL

- Is a minor waste stream for Norfolk Island
- Steel cans can be better compacted using the same dedicated compactor as has been recommend for aluminium cans
- Improved compaction will also greatly reduce freight costs due to smaller volume

12.2.6 CLEAN PLASTIC

- Is a minor waste stream on Norfolk Island
- The receival chute at the WMC has to be changed so that only clean PET plastic bottles are received.
- Possibly a separate chute is needed for other plastics (HDPE and PP in particular).

- Consideration should be given to segregating other plastic for separate baling particularly plastic wrap from commercial sources, packaging and break bulk.

12.2.7 ORGANIC WASTE

- Is a major waste stream on Norfolk Island
- Most FOGO is disposed offsite as fodder for animals, composting, vermiculture and burning.
- Organic sources of nitrogen and phosphorous will need to be captured (food waste, fisheries waste, animal waste (including carcasses) to balance high levels of carbon from green waste, cardboard etc.
- Compostable nappies and potentially even feminine hygiene products could be diverted into the organic waste stream for treatment in the HotRot system.
- Caution needs to be taken with use of any wood that a screening exercise has been conducted to eliminate any potential entry of treated timber.

12.2.8 HAZARDOUS AND SPECIAL WASTES

- Collectively this is a moderate waste stream on Norfolk Island
- Oil imports should have a specific export and/or processing levy similar to that proposed for Pacific Island countries (charged per litre) to cover EOL management.
- Public Works should consider integrating processed tyres into infrastructure projects (i.e. playgrounds, pathways, parks) with processing funded by an export or processing levy.
- Treatment of timber with CCA or other metal treatments should be banned as should import of such treated timbers and replaced with non-metal treatments.
- A treated timber pilot should be conducted, potentially using handheld XRF devices to understand the extend of treated timber present in the waste stream.
- Disposal of asbestos to a confined disposal cell on Norfolk should be considered following an asbestos survey to determine the volumes present.

12.3 LOGISTICAL

- Regular shipping needs to be secured with a preference for full container loads being able to be accepted.
- High level efforts from NIRC, the administrator and the Australian Government are needed to secure sustainable backloading rates.
- Improved segregation, removal of contaminants, diversion to compost, compaction rates (for target metals) are needed to reduce waste streams requiring export.

12.4 FINANCIAL

- Resources for waste management need to reach equivalent percentages of the total budget as is provided by other Australian Councils.
- A waste management fee should be considered within rates equivalent to that allocated in mainland councils and comparable to water.
- EPR sources of funding should be developed including a CDL system and linking to programmes and projects that are active in mainland Australia (i.e. APCO, RedCycle etc.).
- Best cost outcomes for each waste stream needs to be developed to minimise costs, maximise returns and to identify processes and equipment needed.
- Financial plans and scenario modelling is needed for the waste management sector.

- EOL management fees for special wastes should be considered (vehicles, white goods, oil, tyres etc) as have been proposed in other jurisdictions
- NIRC should seek a tax ruling on the charging of GST on waste services provided by companies based in mainland Australia.

12.5 PRIVATE SECTOR

- The private sector should be engaged and expected to assist with waste management in Norfolk Island as part of extender producer responsibility, circular economy and corporate social responsibility.
- The Brand Survey results should be used to leverage assistance from companies whose products dominate the Norfolk Island waste stream though projects such as APCO, ANZPAC and RedCycle.
- The Norfolk Island private sector should be further engaged in seeking solutions on waste streams they dominate as shown in the waste audit results.
- Private sector entities such as Prinke should be emulated to reduce packaging waste through low and no waste systems and linkages made to replicable practices in mainland Australia (and elsewhere).

12.6 COMMUNITY ASPECTS

- Purposeful engagement of community through structured Community-Based Social Marketing (CBSM) should be employed.
- Projects should then integrate systematic approaches used in mainland Australia and abroad to identify best pathways for improved waste management.
- Barriers to effective engagement and communication specific to Norfolk Island need to be identified and addressed specifically.

Summary/Findings

- Waste management costs significantly high due to a reliance on exporting wastes back to Australia.
- Waste management costs for NIRC is equivalent to 2.3% of its total budget with grants, or 4.5% without, total per capita waste management costs is $454 per annum.
- Quantity of exported waste likely to increase both as NIRC reduces the amounts of waste being disposed of at Headstone and with increased consumption if regular shipping is introduced.
- Clear gap in available funding versus costs in pursuing higher levels of waste management to protect the unique environment of Norfolk Island.
- Suitability of thermal treatment systems such as incineration, pyrolysis or gasification not conclusive (high costs, risks, source of air pollution and ash.

Recommendations

- Develop a Circular Economy strategy for better resourcing of programmes, equipment and human resourcing, to ensure waste such as glass and cardboard (which together make up 53% of all commercial and household municipal wastes) are processed and utilised on Norfolk Island.
- Engage in partnership with plastic packaging companies as an option to convert residual waste bales, which currently contain 60% to 70% plastic, from a quarantine waste to plastic bales through concentrating the plastics and addressing contamination.

- Implement a NIRC program subsidising bio-based nappies and feminine hygiene products so food and hygiene products could be diverted to the HotRot system.
- Engage further with the private sector to move toward packaging free and low packaging products, following the example of the Prinke store on Norfolk Island.
- Formulate a Community-Based Social Marketing strategy to develop targeted projects to change normative behaviours with regard waste.
- Develop some guidelines – and implement - a system that focuses on reduction and reuse.

CHAPTER 4: NORFOLK ISLAND'S ENERGY SYSTEM

EXECUTIVE SUMMARY

A literature review and interviews with Norfolk Island Regional Council (NIRC) staff and members of the public has revealed the following current issues associated with electrical energy generation, management and use on Norfolk Island. The Island has high diesel usage for electricity production, high energy costs and high overall GHG emissions. The Island power plant is old, lacking automation, and a lack of data on both the plant production and power grid. The power grid suffers from localised grid voltage issues because of unplanned high penetration of rooftop Solar PV (1.4MW of solar). This causes localised outages and tripping of Rooftop solar PV inverters. Most rooftop Solar PV inverters are nearing end of life and have a limited management ability to assist with grid stabilisation.

There has been a moratorium in place since 2013 on the installation of Solar PV due to the high penetration of rooftop Solar PV. A high feed in tariff for rooftop Solar PV has resulted in an inequity between homes and businesses that have Solar PV and those that do not. Together with a mix of old disk type and bidirectional digital meters, there is no time of use tariffs resulting in non-Solar PV users subsidising Solar PV users use of diesel generated electricity at night. A load bank is used to burn off power generated by rooftop Solar PV that cannot be utilised through the day rather than being stored for later use. The load bank itself has caused outages to the grid in previous years. In addition, one Diesel generator is run continually at minimum 30 per cent capacity for spinning reserve and other ancillary services.

Norfolk Island has abundant wind, solar, and wave resources. Solar and Wind energy are mature forms of energy generation that have low running costs. Data from previous studies has shown that both solar and wind are viable forms of renewable energy to help satisfy energy demand on the island. Wave energy is an emerging technology as an alternative renewable energy source which, in the longer term, could supply a sizeable part of the Island's energy needs.

Solar and Wind are inherently variable in supply. With appropriate firming capacity from energy storage or dispatchable electricity generation, solar and wind energy would displace and potentially eliminate diesel generation on Norfolk Island. This could take the form of a hybrid system entailing wind, solar, battery storage, and diesel generation. With reduced diesel requirements, biodiesel could partially or completely replace diesel for the remaining diesel generation. Biodiesel, if not able to be produced locally, could be imported. Catalytic pyrolysis is a promising process that converts plastic waste into energy. Catalytic pyrolysis product syn-gas can be co-fired with diesel in diesel generation and bio-oil product has similar catalytic properties to diesel and can replace diesel use for several applications.

Biomass is a renewable fuel that can be used as dispatchable electricity generation. Generation from biomass requires adequate fuel sources such as wood waste to be viable. For example, biogas is produced from anaerobic digestion of organic matter and can be used in dispatchable energy generation through gas generators and combined heat and power units. However, feedstock availability for biogas on Norfolk Island is limited as recent changes in waste management on the island have reduced the quantity of feedstocks to provide an effective dispatchable electricity load for the island.

Pumped hydro is a popular form of energy storage, where excess wind and solar energy pump water an upper reservoir to later generate electricity through hydropower when electricity demand exceeds supply. Seawater pumped hydro is a promising technology for energy storage on Norfolk Island.

Battery storage can provide an effective form of energy storage, providing firming capacity for variable renewable energies such as wind and solar and can also be used to stabilize the grid and take that burden away from diesel generation that traditionally provided ancillary services on remote islands.

Demand response is the voluntary reduction or shift of electricity use by customers to help balance electricity demand and supply. Customers receive incentives for their participation which is more cost effective than providing additional generation through say diesel generation.

Energy efficiency can produce significant fuel and monetary savings for Norfolk Island through reduced power demand. Payback periods for energy efficiency are generally much shorter than renewable energy. Therefore, prior to investing in further energy generation it is essential that energy efficiency measures are undertaken first prior to the installation of renewable energy to minimize capital costs.

Prior to embarking in further renewable energy installations several changes should be implemented. The grid needs to be stabilised, this would include several changes: the replacement of old Rooftop solar PV inverters with new smart inverters that can assist with grid stabilisation; the implementation of a microgrid control system, and the implementation of a demand management system.

This should be done in conjunction with the migration of ancillary services from the diesel generators to centralised Battery Storage. Please note these technologies will also assist in grid stabilisation. The power plant should be automated, together with improvements in data logging of both plant and grid generation and consumption. The diesel generation would also be reconfigured to be in standby mode (diesel off mode).

Once in these things are in place, tariff reform would be required to reduce the inequity between the Rooftop Solar PV haves and have nots and to reduce electricity charges across the island. This should be done in conjunction with the removal of the Rooftop Solar PV moratorium.

A number of renewable energy projects could then be undertaken/investigated, including Rooftop Solar PV and Home Battery bulk buys, Solar Farm/Community Owned Solar Farm, Solar Garden, Grid Battery Storage, Wind Farm, Wave Energy, Electric Vehicle strategy, and Biomass/Gasification Plant and Induction Cooking replacing LPG gas.

The report below details the background of energy production and management on Norfolk Island, what previous studies were undertaken on the Island, relevant case studies of other islands and remote communities, the current state on the island, and proposed projects and case studies to ameliorate current issues and improve energy production and management on Norfolk Island.

1. INTRODUCTION

Norfolk Island, like many other remote islands, is dependent on the importation of diesel fuel to generate electricity with cost of electricity on Norfolk Island dependent on the cost of imported diesel fuel. Due to high fuel importation costs, the cost of this electricity is high. Electricity generation costs are therefore highly susceptible to economic factors that influence the oil price and it appears that no attempt has been made to protect the Island against adverse movements in oil prices or exchange rates, e.g. through the purchase of futures contracts or other hedging strategies (Deloitte, 2014). The price of electricity on Norfolk Island doubled in the last decade and is almost four times more expensive than on the mainland (ACIL Tasman, 2012; SGS Economics and Planning, 2015).

The currently 1,748 inhabitants and 28,000 annual visitors of Norfolk are supplied with electricity by diesel engines and rooftop solar PV meeting an average 0.8 MW load (Hydro Tasmania, 2018a; KPMG, 2019). Considering that visitors stay on average just over one week, this translates into a power requirement of below 0.5 kW per capita, which is low in comparison with other islands (Lenzen, 2008). There are a few commercial users of energy such as the supermarket, the hospital and some large hotels, the largest load on island is the new crane at the Cascade Bay wharf (Barton, 2003; Hydro Tasmania, 2018a). Barton (2008) found that the price of electricity on Norfolk Island was greater than any country listed by the International Energy Agency.

A fuel tanker ships petrol, diesel and aviation fuels, and a separate gas tanker brings Liquefied Petroleum Gas (LPG) to Norfolk Island. The tankers anchor in Ball Bay on the southeast coast, where fuel is transferred onshore through a floating hose to the Island's bulk fuel storage facilities (NIRC, 2018a). Fuel is then transferred to smaller tanks by road tanker and in the case of LPG sold in portable 50 kg tanks to be used for cooking, heating and some hot water. (Barton, 2003).

The Norfolk Island grid consists of 6.6 kV/415VAC HV/LV mains, and has a 0.6MW base load, an average load of approximately 0.8MW and a 1.75MW peak load (Barton, 2008). The centrally located powerhouse contains three new 1MW diesel units and 3 legacy 1MW diesel engines (approaching end of life) that are entirely manually controlled. One of the units is run at minimum load 40% for spinning reserve and other ancillary services during a small proportion of the day, and then during peak times of the day, a member of the powerhouse staff turns on a second unit. During night-time hour's generators operate closer to 80%. (Barton, 2003; Barton, 2008; Hydro Tasmania, 2018a; Hydro Tasmania, 2018c; NIRC, 2017b).

1.1 RENEWABLE RESOURCES

Norfolk Island had abundant wind, solar, and wave resources, potentially good ocean current resources with a significant ocean current between Norfolk Island and Nepean Island, some biomass resources, limited hydro resources, low tidal range, and no geothermal resources (Barton, 2003; 2008; Hydro Tasmania, 2003). Barton (2003) noted that although the rainfall on this island is 1314mm per annum, there are no natural water storages, and high soil porosity prevents high stream flows, and inhibits water retention for potential hydroelectric systems.

1.1.1 SOLAR ENERGY

Solar energy could supply up to 60% of daytime electricity needs of Norfolk Island and combined with energy storage (to store energy captured during the day) solar could theoretically provide 100% of electricity needs (Hydro Tasmania, 2003). The mean number of daily sunshine hours for the island varies from 5.1 to 7.8 (as seen in Fig 4.1 and Figure 4.2 (Barton, 2008), and the solar radiation for Norfolk Island is like the east coast of NSW at an estimated 4.97 kWh/day (Hydro Tasmania, 2018a).

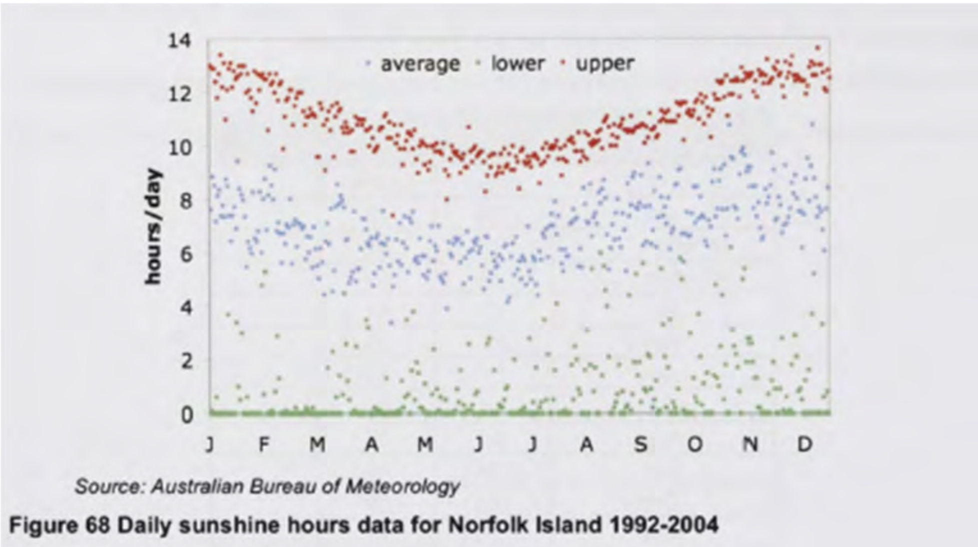

Figure 4.1: *Daily sunshine hours data for Norfolk Island 1992-2004 (Barton, 2008)*

Hydro Tasmania (2018a) noted that there is likely land and multiple locations suitable for a centralised medium scale (1-2 MW) solar farm, however that this land may be prioritised for other uses and not be available. A 2003 study (Hydro Tasmania, 2003) identified two potential Solar Farm sites: The airport periphery and Headstone. A 1MW system was considered that would generate 1,565,500 kWh a year, and represent an 18-20% penetration level (Barton, 2008).

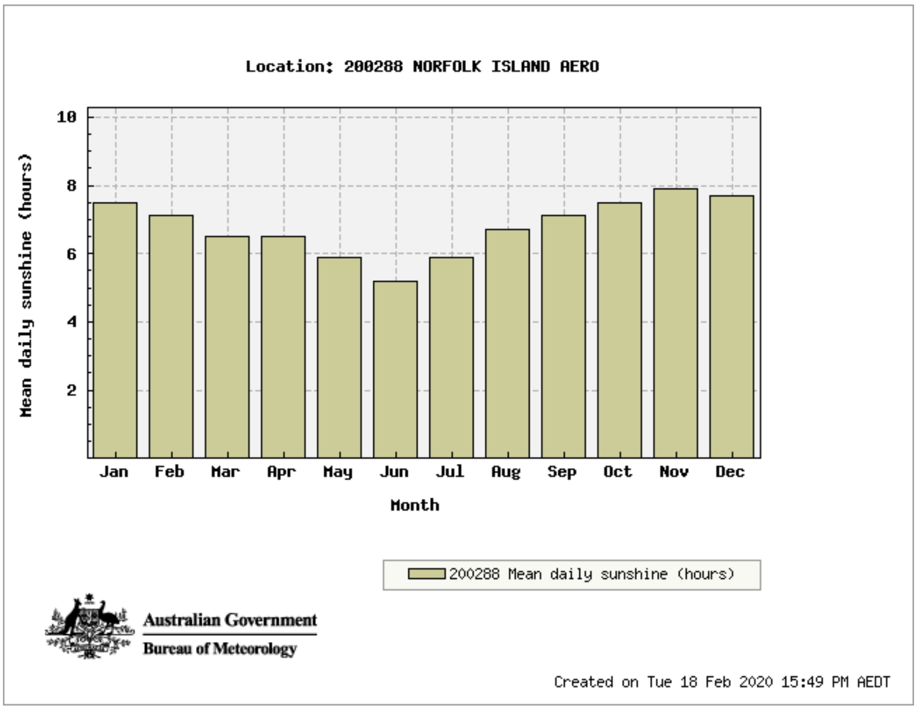

Figure 4.2: *Norfolk Island mean daily sunshine (hours) (1945 - 2016) (Bureau of Meteorology, 2020).*

Ta'u Island

Ta'u Island in American Samoa has a seasonally fluctuating population of between 200 to 600 people. Ta'u has previously depended on diesel shipped from the main island Tutuila to power homes, government buildings and crucially water pumps. The diesel shipments were heavily subsidized by the government and were frequently interrupted by bad weather or rough seas. In 2016, a solar-powered microgrid was implemented shifting the entire Island's energy generation from 100 percent diesel to 100 percent solar. This consists of a solar farm of 5000+ solar panels that generate approximately 1.4MW of electricity and 60 Telsa Powerpack large batteries that can store the energy, allowing the Island to stay powered for up to 3 days without any sunlight (Lin, 2017; Roy, 2016).

1.1.2 WIND ENERGY

Wind energy could meet 33% of electricity needs for the island and would achieve a strong economic benefit and with an energy storage system could supply 95% of the electricity requirement with a moderate economic benefit (Hydro Tasmania, 2003). Hydro Tasmania (2003a) noted that a wind project (not including storage) would reduce power costs and return good revenue using commercial technology with a proven track record, with power produced intermittently from wind turbines during all times of the day.

Norfolk Island has great wind resources with winds between 6 to 7 m/s (measured at 10m height) common across the Island (see Figure 4.3) with wind speeds typically higher during daylight hours (see Figure 4.4), and many sites with speeds between 7 and 8 m/s (Morgan and Andrews 2003 cited by Barton, 2008) which is similar to the average wind speeds on King Island. Early studies showed an average wind speed of 8.3m/s at Steels Point (Marsden 1996, cited by Barton, 2008). As shown in Figure 4.5, the wind direction is predominately from the South East to East. The wind is consistent throughout the year. As shown in Figure 4.6, this ranges from 4.8 m/s in May to a high of 5.4 m/s in February for the average 3pm wind speed.

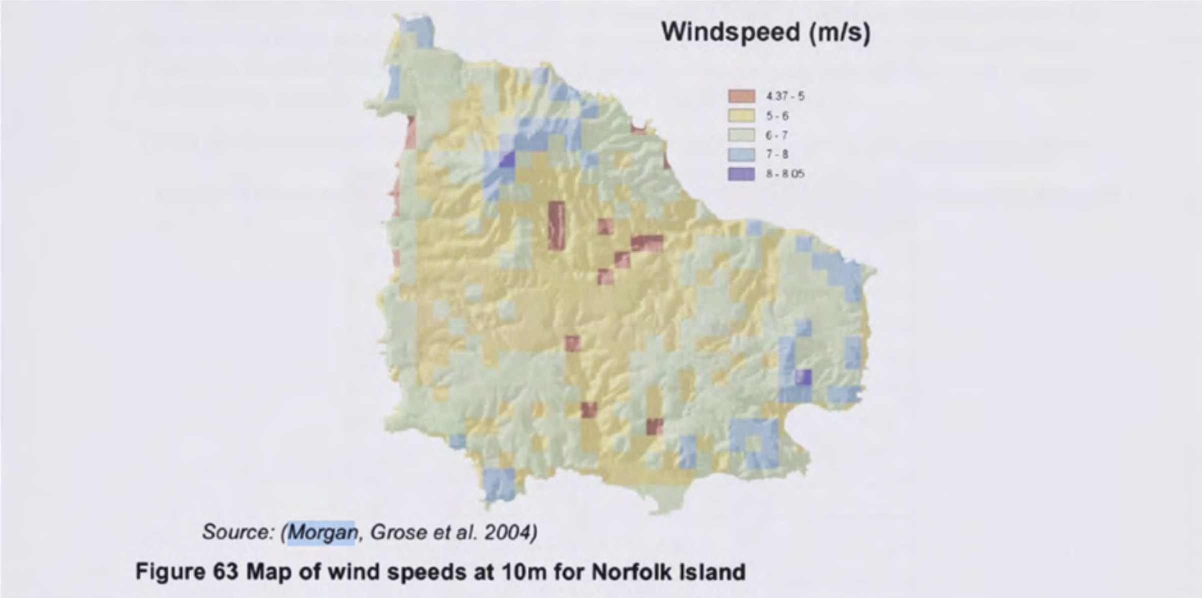

Figure 4.3: *Norfolk Island Wind speeds at 10m height (Barton, 2008).*

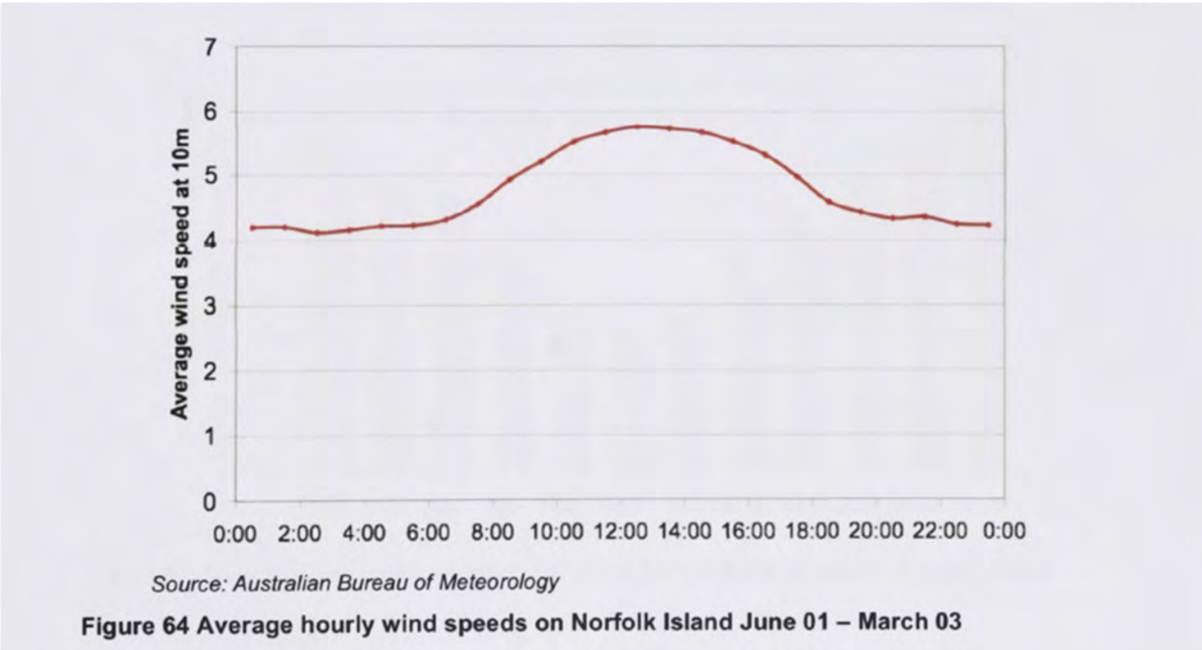

Figure 4.4: *Norfolk Island average wind speed from a record of hourly wind speeds (m/s) from June 2001 to March 2003 (Barton, 2008).*

Rose of Wind direction versus Wind speed in km/h (06 Apr 1939 to 11 Aug 2019)
Custom times selected, refer to attached note for details

NORFOLK ISLAND AERO
Site No: 200288 • Opened Jan 1890 • Still Open • Latitude: -29.0389° • Longitude: 167.9408° • Elevation 111.7m

An asterisk (*) indicates that calm is less than 0.5%.
Other important info about this analysis is available in the accompanying notes.

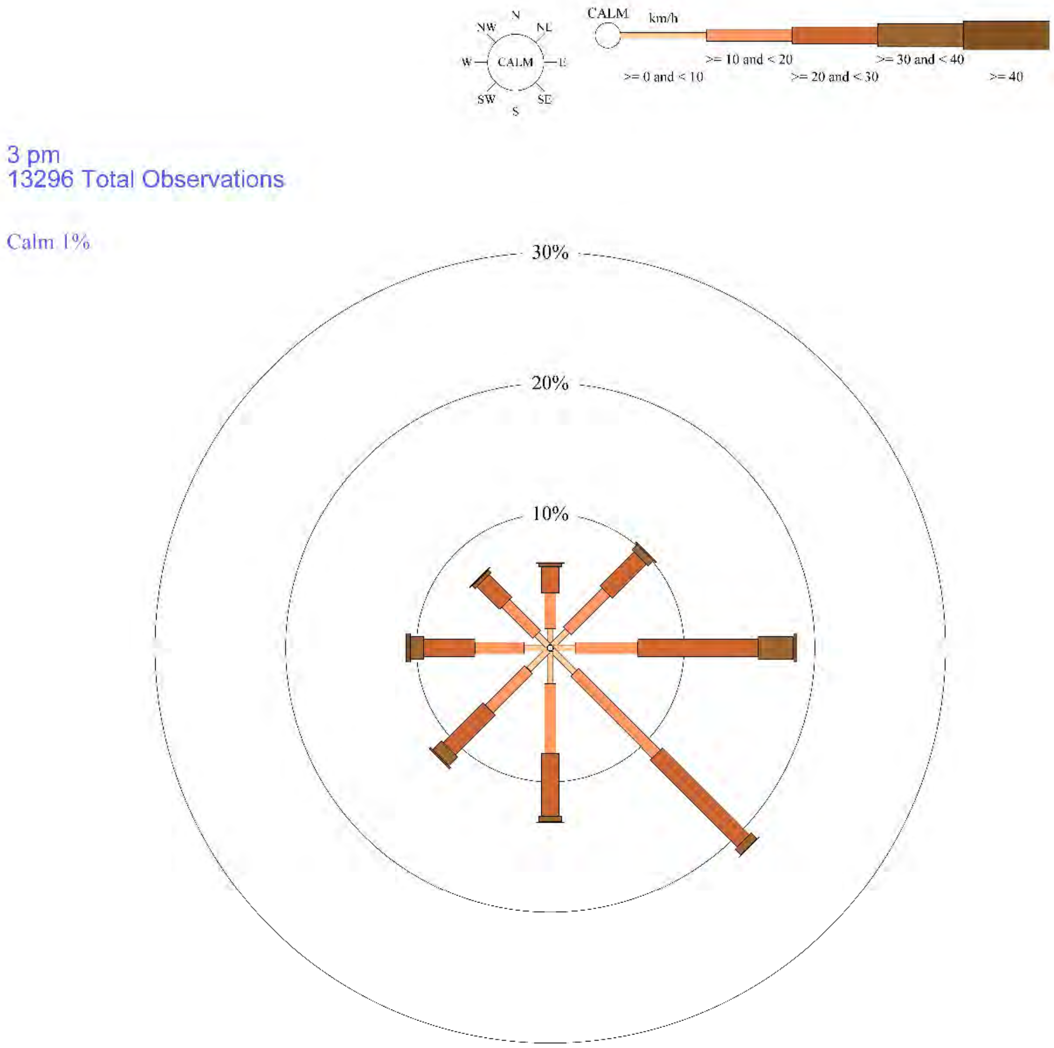

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Figure 4.5: Rose of Wind direction versus Wind speed in km/h at 3pm (06 Apr 1939 to 11 Aug 2019) (Bureau of Meteorology, 2019).

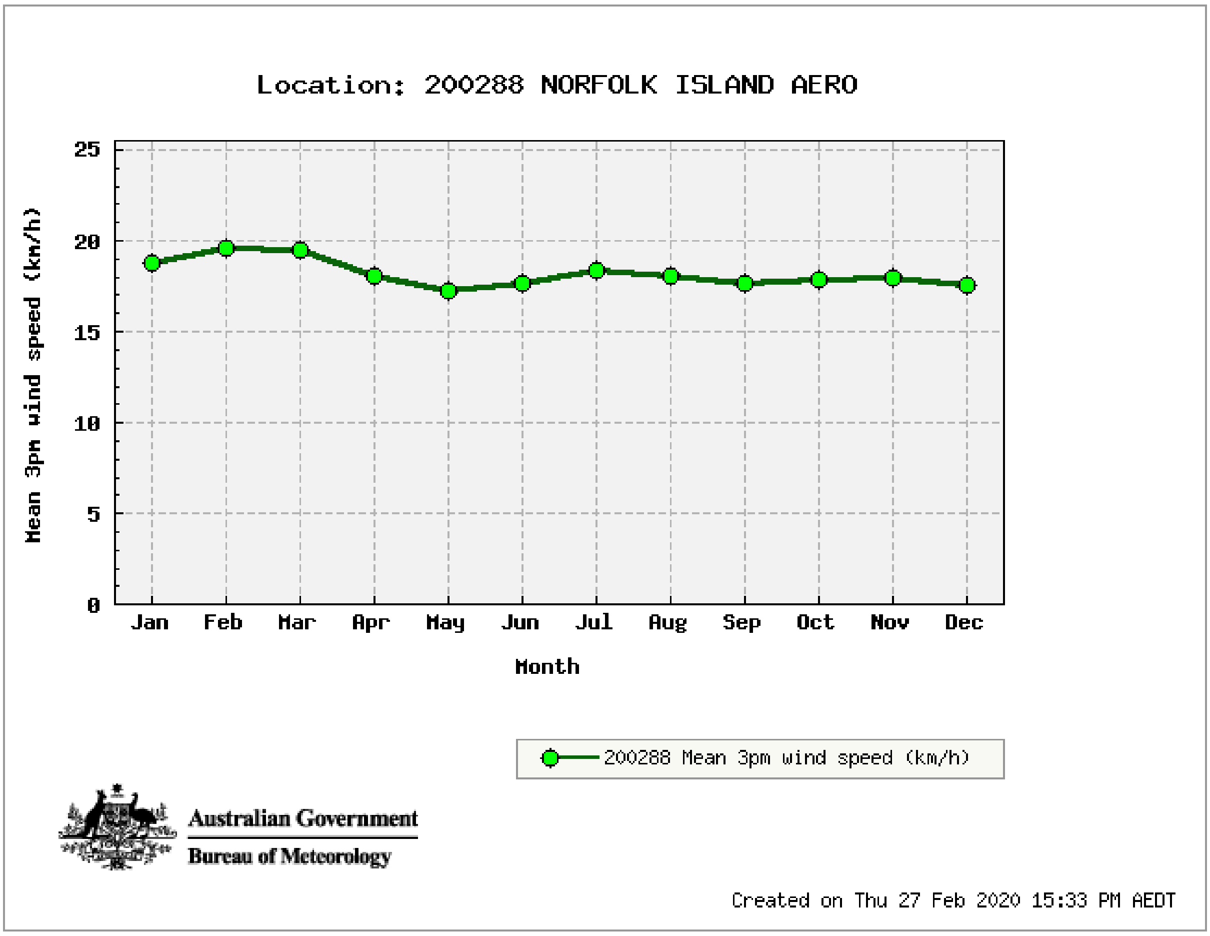


Figure 4.6: *Norfolk Island mean 3pm wind speed (km/h) (1939 - 2010) (Bureau of Meteorology, 2020).*

Barton (2008) noted that Wind turbines are a commercially proven and reliable technology, with a track record of generation in remote areas, and with the power of the wind being proportional to the cube of its speed slightly windier sites would provide large increases in energy production. However, turbulence from the Island cliff edges would result in lower energy yields and higher wear on equipment and therefore a site a few hundred metres inland would be best suited to wind energy (Morgan and Andrews 2003 cited by Barton 2008).

A 2003 study by Hydro Tasmania (Hydro Tasmania, 2003) identified the sites of Headstone and Steels Point as potential wind projects for Norfolk Island (see Figure 4.7 for details). Steels Point had excellent wind resource but was close to houses (see Figure 4.8). Headstone proved a better site, as its quasi-industrial nature minimized the impact of the turbines, provided a balance between wind resource availability, proximity to residential and industrial areas and protection of heritage areas (Barton, 2008). The estimated wind speed at 10m height at Headstone was 6.5 m/s. As noted in Figure 4.9, the modelled average wind speed at 44m at Headstone is approximately 8.2 m/s. It should be noted that areas with good exposure to prevailing winds and average wind speeds of around 4 m/s and greater at a height of 30 m are generally considered to have a suitable wind resource for small wind turbine projects (WINDExchange, n.d.).

The study determined that the 1.2 MW wind farm of 2-3 turbines located at Headstone would make use of the prevailing south-easterly winds would and operate with a capacity factor of 35%, provide 27% of the Island's annual electricity requirement and require a capital investment of AUD 2.2 million (Barton, 2008; Hydro Tasmania, 2003). The study noted that the wind project located at Headstone warranted further investigation.

Figure 4.7: *Potential Wind Turbine Sites & Maximum 800m Noise Buffer Zones (Hydro Tasmania, 2003).*

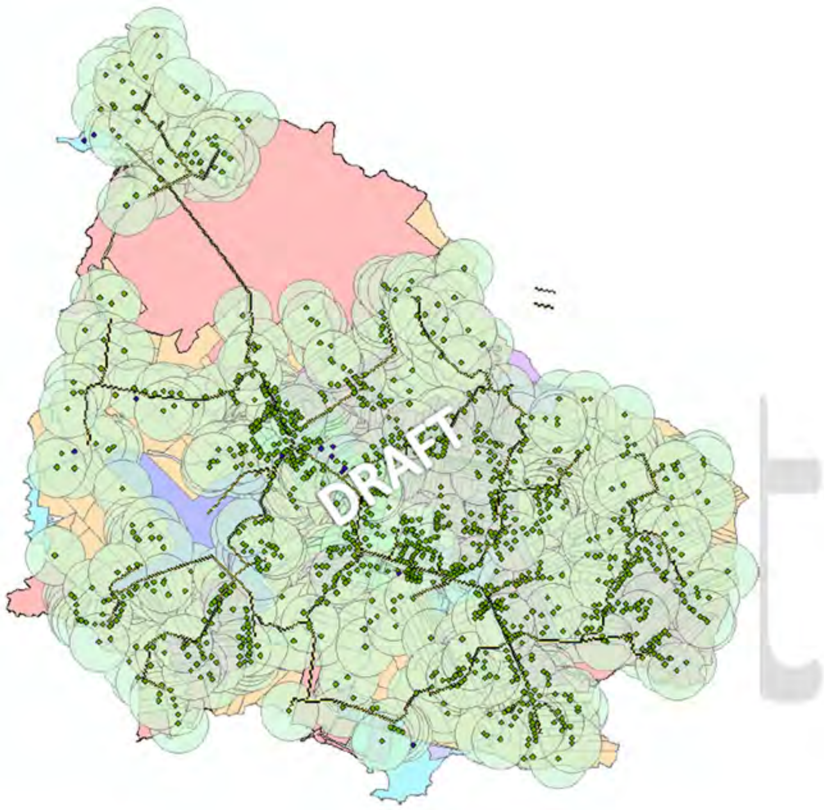
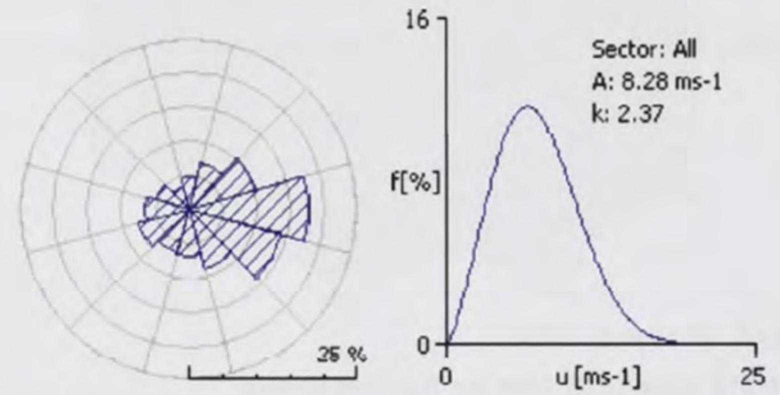


Figure 4.8: *Draft picture of supplied data, dwellings with a 300 m buffer applied, cadastral parcels and distribution lines (Hydro Tasmania, 2018a).*



Source: (Morgan, Grose et al. 2004)

Figure 66 Wind Resource (modelled) at 44m at Headstone on Norfolk Island

Figure 4.9: *Estimated wind rose and wind speed distribution at 44m for Headstone (+/-10% error in wind speeds) (Barton, 2008).*

San Cristóbal Island (Galapagos Islands)

Following an oil tanker spill near San Cristóbal Island in the Galapagos Islands that threatened one of the Earth's most fragile and important ecological treasures, a global renewable energy programme on the Galapagos Islands was implemented to reduce greenhouse gas emissions and the risk of another oil spill at this UNESCO World Heritage Site. As part of this programme the San Cristóbal Wind Project involved the construction of three 800 kW wind turbines to replace the use of diesel fuel for power generation (Ghani, et al, 2019; Global Sustainable Electricity Partnership, 2016a; 2016b).

The Galapagos petrel (Pterodroma phaeopygia) is a critically endangered endemic bird that nests in the highlands of San Cristóbal Island. Following a two-year study of flight patterns, flight elevation and nesting behaviour of the petrel, the three turbines were located on a hill away from the bird's normal flight direction. The first 3 km of HV transmission line from the wind farm were placed underground as a protection for birds in the area. The studies also showed that the petrels mostly flew below 20 m, below the tips of the turbine blades. Since the commissioning of the wind farm, monitoring results have confirmed that turbines had not killed or injured any of the critically endangered Galapagos seabirds (Global Sustainable Electricity Partnership, 2016a).

However, it should be noted that in areas where bird migrations are significant, the risk of collisions can be greatly reduced if wind farm operators switch off their installations during the most intense periods of migration (SWISS-birdradar.com, n.d.). Furthermore, avian-specific radar can be deployed that allows remote monitoring of birds in the landscape and can initiate the shutdown of turbines to avoid collisions. Both Musselroe Wind Farm and Cattle Hill Wind Farm in Tasmania are trialing these technologies in 2020 (Manzengarb, 2019; Vorrath, 2019).

As part of the San Cristóbal Wind Project, the existing diesel generators were automated and together with the wind turbines are controlled by a SCADA system that optimises the use of the wind resource and minimised the use of diesel. For technical requirements, at least one diesel unit remains operating at a minimum of 25% capacity. Local powerhouse staff were trained to operate the new hybrid system and carry out all maintenance. The wind farm had an availability of 92% for its first 8 years of operation. Electricity generated is sold through a power purchase agreement for 0.1282 USD / kWh (Global Sustainable Electricity Partnership, 2016a).

Wind production on the Island is seasonally variable with wind energy production providing most of the generation during the high wind season but only providing a modest production during the low wind season. Some curtailment is required during high wind periods as there is no battery storage system on the Island. This is compounded by the fact that wind generation and power demand are negatively correlated, resulting in very high seasonal variations of diesel power generation. Overall, the wind farm contributes to 30% of the Island's electricity demand (Global Sustainable Electricity Partnership, 2016a).

As a comparison, average wind speed and therefore wind production on Norfolk Island is fairly constant throughout the year with a variation of approximately 13% across the year (Bureau of Meteorology, 2020).

The San Cristóbal Island wind farm site has good wind conditions with space for an additional turbine. However, solar radiation is relatively stable throughout the year. Therefore, it may be more beneficial to add solar PV capacity in preference to wind. Analysis has found that a renewable penetration rate of 70% could be achieved (at reasonable cost) through the optimisation of a mix of additional Wind, Solar PV and Battery Storage (Global Sustainable Electricity Partnership, 2016a; 2016b).

1.1.3 WAVE ENERGY

The potential of a vast wave energy resource hits the Norfolk Island from the south throughout most of the year (Barton, 2003). A 2003 study (Morgan and Andrews 2003, cited by Barton, 2008) found the wave energy resource at several different potential sites around the Island was substantial (see Figure 4.10). Wave power at Norfolk Island was found to be between 14 and 20 kW per metre of wave front, with a significant seasonal variation in wave power with the predominant wave direction in Summer from the north, and in the other months of the year from the directions of south and south-south-west (See Figure 4.11) (Hydro Tasmania, 2003).

Source: (Morgan and Andrews 2003)
Figure 79 Wave power at different sites on Norfolk Island

Figure 4.10: *Wave power at different sites on Norfolk Island (Barton, 2008).*

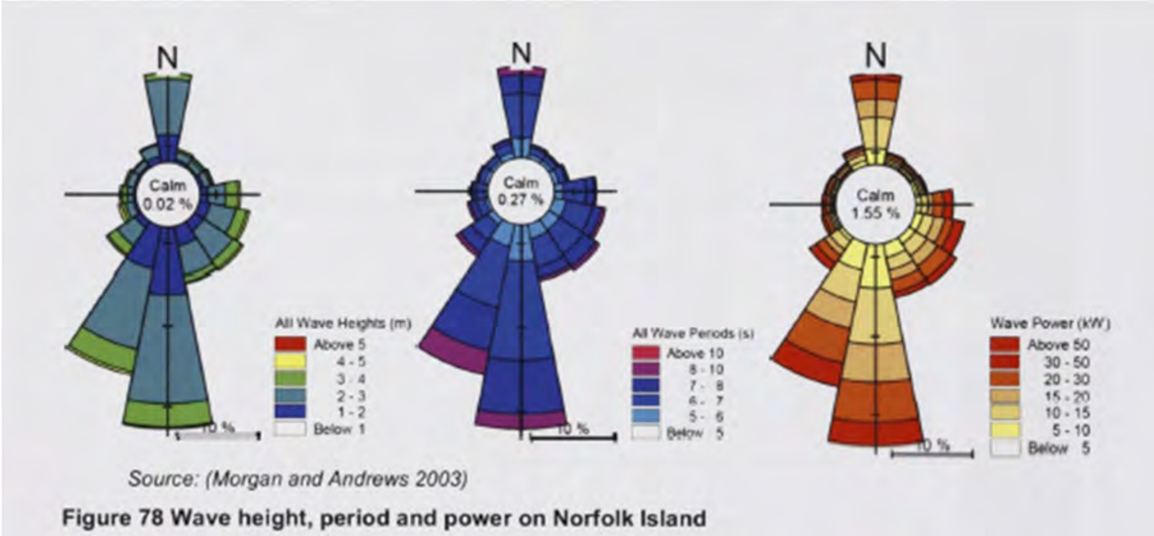


Figure 4.11: *Wave height, period and power on Norfolk Island (Barton, 2008).*

ARENA (2019b) recently announced $4 million funding towards a wave power demonstration project for King Island. Sitting partially submerged on the seabed, the 200KW wave energy converter will use "oscillating water column" technology to push air into a chamber fitted with an electricity-generating turbine. The system functions like an artificial blowhole, using changes in air pressure to spin the turbine as waves force their way through an opening on one side of the device.

Wave energy is an emerging technology as an alternative renewable energy source with over 200 wave energy devices in various stages of testing and demonstration, however there is limited published data on its viability as an alternate energy source (CSIRO, 2019). Wave energy has the potential to be integrated into microgrids, particularly on island locations with limited space, to reduce the need for significant battery storage due to the relative predictability and consistency of wave energy (ARENA, 2019b). In the longer term, wave energy could supply a substantial proportion of the Island's energy needs as the cost reduces and operational experience grows (Hydro Tasmania, 2003).

Gran Canaria Island (Canary Islands)

A common problem with mid-latitude small and remote islands is the low annual rainfall and the associated freshwater scarcity, which leads to the installation of desalination plants powered by diesel/oil. This problem is becoming more prevalent now on Norfolk Island. In the Canary Islands, 55% of water demand is met by desalination plants consuming nearly 12% of electricity demand (Fernández Prieto, Rodríguez Rodríguez, & Schallenberg Rodríguez, 2019).

Analysis of wave power for Gran Canaria Island was found to be predominately from the North to Northwest and showed a clear seasonal pattern from 27 kW/m in winter to 12 kW/m in summer (Fernández Prieto, et al, 2019). This is similar to wave power calculations noted above for Norfolk Island (Barton, 2008; Hydro Tasmania, 2003). Wave power was also found to decrease closer to shore but is still sufficient for the purpose of wave power generation.

Fernández Prieto, et al (2019) conducted a study to select the best location for the installation of wave energy converters in the north of Gran Canaria island to power a desalination plant. In addition to selecting a site with sufficient wave power potential, socio-economic activities, such as harbour zones, maritime routes, sailing, and tourist uses of potential sites needed to be considered. The study also found that due to steep cliffs and difficult access, connection to the island grid was considered technically problematic and a direct connection to a desalination plant located very close to the sea was preferable. Furthermore, an environmental assessment of the area determined there were no vulnerable areas, such as reserves or marine/land habitats, which could have restricted installation of the wave converters.

2. ENERGY STORAGE AND DISPATCHABLE ELECTRICITY GENERATION

Solar and Wind are inherently variable in supply. Fluctuations in renewable supply can easily be absorbed by larger grids but can create instability in small grids such as on Norfolk Island (Smit and Bondesen, 2010). Technologies and Dispatchable forms of electricity generation can work in concert with variable supply such as Solar and Wind to satisfy energy demands and maintain stability within the electricity grid. Dispatchable electricity generation includes Hybrid systems such as utilizing on-demand diesel generation and bioenergy. Bioenergy is a form of renewable energy that uses biomass (organic renewable materials) to produce heat, electricity, biogas, and biofuels (such as ethanol and biodiesel) (ARENA, 2020b). Various energy storage technologies can also provide dispatchable generation including: Pumped Hydro and Battery Storage. Demand management provides a mechanism to reduce electricity demand rather than increase supply to satisfy requirements.

2.1 HYBRID SYSTEMS

A hybrid renewable energy system is one that couples more than one type of energy generation source, including renewable resources and fossil fuels (Neves, 2016; Ruggiero, Onkila, & Kuittinen 2014). In utilizing local resources, it provides an opportunity to increase sustainability and security of supply and improve energy efficiency and decrease the importation of fossil fuels. As such, it is becoming popular with isolated and small communities (such as remote islands), although concerns arise with regard to reliability in the case of large renewable energy penetration (Neves, 2016).

2.1.1 FLINDERS ISLAND

Electricity on Flinders Island was traditionally generated entirely from diesel fuel supplied by the 3 MW power station, serving 6.7 GWh of annual customer demand, peaking at 1.3 MW (Hydro Tasmania, n.d.-a). The Flinders Island Hybrid Energy Hub features a single 900 kW wind turbine and 200 kW solar array. The enabling systems include a 750 kW/300 kWh battery, 850 kVA flywheel, and 1.5 MW dynamic resistor. This system is capable of displacing 60% of the annual diesel fuel used to generate electricity on Flinders Island and is capable of "diesel off" operation, allowing 100% renewable penetration (ARENA, 2017-b).

The modular units were fabricated and tested off-site, reducing the risk, cost and duration of construction. Such units could provide a lower cost and scalable solution that will allow easy and rapid transport and installation for renewable energy projects to remote sites (ARENA, 2019).

2.1.2 TILOS ISLAND (GREECE)

The TILOS program, with EUR 11 million of funding, will develop and operate an intelligent, innovative hybrid system using solar and wind energy, which, through a battery storage system, that will cover (to a micro-grid level) the electricity needs of the 500 odd residents of the village of Livadia on the Greek island of Tilos (not confusing at all) (Energy Industry Review Staff, 2018).

With the implementation of the TILOS program, the island of Tilos will be the first non-interconnected autonomous 'green' energy island in the Mediterranean with the first smart island micro-grid system based on renewable energy and batteries.

The project will maximise the Island's energy production in a sustainable way, ensuring self-sufficiency, lower prices, greater stability, and a smaller ecological footprint than the previous oil-based electricity generation. Surplus energy will be used to charge electric vehicles for local transport (Energy Industry Review Staff, 2018).

2.1.3 GIGLIO AND GIANNUTRI ISLANDS (ITALY)

The islands of Giannutri and Giglio lie in the Tyrrhenian Sea off the coast of Tuscany, Italy. The islands have a variable electricity load through the year with a peak during the summer period due to tourism activities. Both islands have traditionally relied on diesel generation for their electricity supply needs. As part of a "smart islands" project, TERNA (the Italian Transmission System Operator) aims to replace the diesel generators with renewable energy sources. For both islands, PV and Lithium-ion battery energy storage system (BESS) sizing was determined using the actual load profiles of the islands and the actual power output of a nearby solar PV farm. Similarly, both islands projects will be implemented in a phased approach. On the smaller of the two islands, Giannutri, Phase I is complete with the implementation of a small PV plant and a BESS. Phase II will involve a larger PV plant and BESS and a hydrogen energy storage system (Palone, et al, 2017).

Giglio Island is similar in size and population to Norfolk Island (21.1 km2 and a resident population of approximately 1500) and is part of the Arcipelago Toscano National Park. The summer tourist influx raises electricity consumption to 3.4MW peak demand which includes a 500kW desalination plant (Gatta, et al, 2019). Two thirds of Island's water needs are satisfied with the reverse osmosis desalination plant (Global Islands Network, n.d.).

The diesel generators have an inherently high fuel cost and low efficiency, resulting in high energy costs. The 1st stage of the Giglio Smart Island project involves the installation of a 500kW solar farm along with 200kW of smaller distributed PV installations, together with a 1000 kW / 500kWh Lithium-ion battery storage system (BESS). The second stage will be additional distributed PV plants and the BESS will be increased to 2.5 MW / 1.25 MWh.

Due to the limited size of the island, PV production is expected to experience steep variations because of cloud coverage. The main purpose of the BESS will be to cope with sudden fluctuations in PV production. The BESS will also charge up when PV output exceeds total demand.

The BESS will also supply load during start up time of the diesel generators. Furthermore, when a single diesel generator is running, its trip will not lead to load shedding, as the BESS handles the load. At night, the battery will supply part of the load and will be discharged down to 20%. The diesel generators will supply residual load (that not supplied by PV or BESS). To avoid PV curtailment, one novel approach proposed will be to load shift the desalination plant to take advantage of high PV production periods.

Following stage II, the network will operate without the need for diesel generators to run constantly. When no diesel generators are running, a synchronous condenser will provide inertia and short-circuit power. A flywheel will be included to effectively increase the condenser inertia. To increase the efficiency of the existing diesel power plant a 125 kW Organic Rankin Cycle generator will be installed to utilise the waste heat from the existing diesel generators exhaust gasses (>450 degrees C) (Gatta et al, 2019).

2.2 BIOENERGY, BIOMASS, AND BIOGAS

The use of a biogas plant to supplement the electricity supply on Norfolk Island was dismissed in the 2017 EOI (NIRC, 2017b) under the assumption that the biogas plant would need to operate during the day instead of when additional power was required. Furthermore, the EOI suggested that community concerns raised regarding emissions from a proposed high temperature incinerator and the inability to "isolate potentially contentious activities" from residents on the island would preclude the installation of a biodigester on the island.

It should be noted that a biodigester can store produced biogas and produce dispatchable electricity on demand when the grid requires. Further investigation on potential emissions and placement of biodigester on Norfolk Island to mitigate potential planning concerns would be indicated.However, a number of circumstances has reduced the quantity and range of feedstocks needed for an anaerobic digestor of sufficient scale to provide an effective dispatchable electricity load for the island.

These include:

- The Point Howe pig farm has been drastically scaled back and as such the amount of pig effluent produced.
- The recent decision to accept the business case for the development of a Membrane Aerated Biofilm Reactor as a replacement/upgrade to the Wastewater Treatment Plant establishes that sewage effluent would not be available as a feedstock (NIRC, 2019f; 2019g).
- The implementation of the HotRot Composting Facility will utilise both green waste (garden waste) and source separated organics (NIRC, 2020a) which would also be unavailable for use as feedstock.

Therefore, due to insufficient feedstock, the use of a co-digestion plant to provide sufficient dispatchable electricity load does not appear feasible for Norfolk Island."

3. ENERGY STORAGE

3.1 PUMPED HYDRO

Pumped hydro is the oldest and the largest of commercially available energy storage technologies. Pumped hydro systems allow increased penetration of electricity from variable sources such as wind and solar by storing energy and being able to responsively contribute to shortages in generating capacity (Bueno and Carta 2006).

El Hierro, the westernmost of Spain's Canary Islands, is using a wind/pumped hydro hybrid system to move towards a 100 per cent renewable energy supply. El Hierro is a small volcanic island, with a population of about 11,000. The island was declared a UNESCO Biosphere Reserve in 2000 due to its rare flora and fauna. Prior to the implementation of a renewable energy system, the island relied upon imported diesel. To remove El Hierro's reliance on diesel, a wind farm of five 2.3 MW turbines now generates most of the electricity on the Island. This is backed up by a pumped-storage hydropower system comprising an upper reservoir of 500,000 m^3 at an elevation of 715 m situated in a volcanic caldera, and a lower man-made reservoir of 226,000 m^3 at an elevation of 54.5 m. The diesel units remain in an operational condition to act as a backup (at@hydropower.org, 2015).

The 'Cultana' pumped hydro facility near Port Augusta, South Australia is currently under development which will provide a 225 MW of pumped hydro energy storage using seawater (ARENA, 2019a). Seawater pumped hydro systems appear to be a promising technology, with sites on Norfolk Island that could accommodate a small dam to store up to twelve hours of capacity (Barton, 2008).

3.2 BATTERY STORAGE

Battery energy storage systems (BESS) can be used to stabilize the grid and take that burden away from diesel generation that traditionally provide ancillary services on remote islands. Urban (Avanindra, Urban, Macaw, Williams, & Richards, 2019) stated that fluctuations in voltage, load, and frequency put stress on the grid and create resilience issues and reduce the efficiency of diesel generation. Urban maintained that battery systems (using Lithium Ion Technology) can handle this very well and can react very quickly and accurately reducing the total impact of a fluctuation. With grid noise/fluctuations being absorbed by the battery system, dispatchable generation (such as diesel) can be set to optimal levels increasing their efficiency (Avanindra, Urban, Macaw, Williams, & Richards, 2019).

Modelling conducted by the ANU Battery Storage and Grid Integration Program (Shaw & Ransan-Cooper, 2020) found that community-based battery installations were economically feasible. Their cost-benefit model looked at the installation of a 500kWh/250kW battery in Jacka, ACT, servicing about 200 residential homes, and found that battery revenue slightly exceeds costs and that customer savings were approximately double the battery costs (see Figure 4.13).

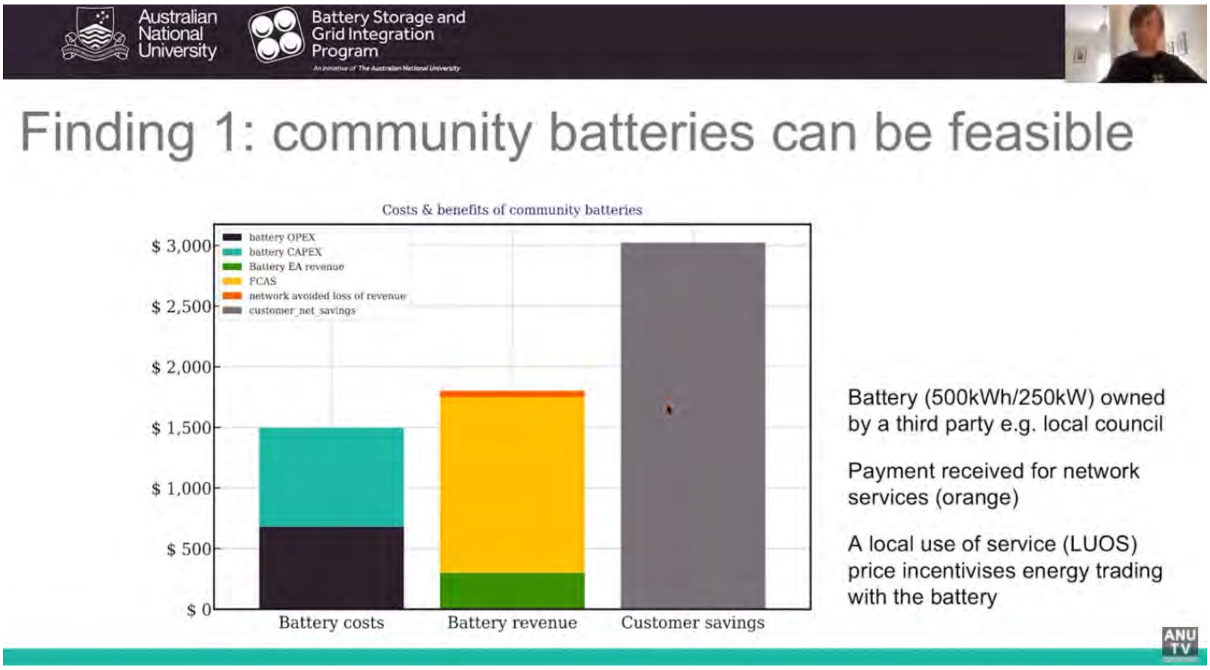


Figure 4.12: Community Batteries can be feasible (Shaw & Ransan-Cooper, 2020)

Shaw stated that where energy exports from Rooftop Solar PV could cause headaches for the electricity network, batteries did a good job of reducing these exports with household batteries reducing exports by approximately 25% and community batteries reducing exports by a factor of about 50%. This would allow for a greater amount of solar energy to be generated by households without impacting the grid (Shaw & Ransan-Cooper, 2020).

Ransan-Cooper stated that there was a "huge range of benefits" from a community battery, including "stabilising the grid, avoiding grid upgrades", and building trust in the electricity grid (Churgwin, 2020). Ransan-Cooper noted that one of the most important aspects of the use of community battery is that it helps overcome one of the thorniest renewable energy issues – equity (Churgwin, 2020). Households excluded from Rooftop Solar PV, in being able to take electricity from a community battery, would benefit from the use of renewable energy from Rooftop Solar PV.

SGS Economics and Planning (2015), in looking at the opportunity to establish eco-friendly industries on Norfolk Island with commensurate improved environmental outcomes and increased employment, suggested a trial of home battery systems for households to help reduce the load feeding back into the grid from home Solar PV systems during periods of peak supply.

More recently, to maximize the use of solar PV on Norfolk Island, and potentially decrease electricity costs, Norfolk Island Regional Council have looked at utilizing energy storage (Parkinson, 2017). In 2019 they sought to supply and install "a new Battery Energy Storage System at the Norfolk Island Powerhouse" (Australian Tenders, 2019).

3.2.1 GRACIOSA ISLAND (PORTUGAL)

Island grids present a unique set of challenges, particularly a heavy dependence on liquid fossil fuel imports, coupled with a growing concern for climate change and the need for reliable energy to provide critical power needs (Wärtsilä, 2020).

On Portugal's Graciosa Island, a commissioned hybrid renewable power system combining wind, solar and battery storage has enabled the use of renewables to increase from 17% to 65%, decreasing diesel fuel consumption and maximising renewable energy for the 4,000 island inhabitants (Renewables Now, 2020; Wärtsilä, 2020).

The battery storage will help overcome the intermittency of the renewable sources, manage the frequency and quality of the supplied power, and provide backup energy to meet spikes in demand (Wärtsilä, 2020).

The hybrid renewable energy plant includes a 4.5MW wind farm of 5 turbines, a 1MW solar farm, and 7.5MW / 2.6MWh battery power consisting of 3 Lechlandé Lithium Titinate BESS units (Avanindra, Urban, Macaw, Williams, & Richards, 2019).

The BESS units provide grid management capability, act as a spinning reserve, provide black start capability, and will allow for a 100% renewable energy supply "under appropriate meterological conditions" (Avanindra, Urban, Macaw, Williams, & Richards, 2019).

This system has improved the quality of power to the island by: significantly improving the voltage and frequency profiles; notably improving continuity of supply on the island (load shedding events from when diesel engines have tripped have been avoided); and providing reliable and robust system response following short circuit events (Avanindra, Urban, Macaw, Williams, & Richards, 2019).

The entire Island's energy management is monitored, integrated and optimised by Wärtsilä's GEMS, advanced energy management software system to maximize renewable energy use and reduce costly diesel power generation (Wärtsilä, 2020). This includes day ahead forecasting for wind and sun to optimise use of generation assets (Avanindra, Urban, Macaw, Williams, & Richards, 2019).

Similar day ahead forecasting / dispatch is planned for the St Kitts large scale solar, energy storage and microgrid project in the Caribbean, which will allow the scheduling of dispatchable generation. This will provide predictable dispatch throughout the year with the exception of the hurricane season (Avanindra, Urban, Macaw, Williams, & Richards, 2019).

3.2.2 BONAIRE ISLAND

A similar BESS system was implemented on the Dutch Caribbean island of Bonaire in 2019 with the BESS integrated with a hybrid wind and dual-fuel diesel engine grid (Burger, 2019). Overall grid reliability and resilience has increased significantly following commissioning with no outages. The 6MW/6MWh BESS provides spinning reserve and grid frequency stabilization allowing diesel engines to be used on standby and avoid the curtailment of wind power almost doubling the wind power utilised on the grid. Additional solar power is now planned for the grid, as part of the Island's plan to transition to 100% renewable energy (Burger, 2019).

4. DEMAND RESPONSE

Isolated and remote energy systems of the future must accommodate more diverse resources and control behaviours if a transition to fossil fuel-free energy supply is to be achieved (Wu, Larsen, Heussen, Binder & Douglass, 2017). Electricity production from wind and solar is governed by the availability of the energy source (i.e. when the sun is shining and wind is blowing) that may or may not be correlated with local consumption (Montuori, Alcázar-Ortega, Álvarez-Bel and Domijan, 2014). This can be mitigated through technologies such as energy storage, demand–side flexibility, for example, from pumping, and desalination, dispatchable generation, and demand response (Wu, et al, 2017).

The simple idea behind demand response is that rather than pay to increase how much capacity is available on the grid we pay to reduce the amount of electricity is used (ARENA, 2017-a). ARENA (n.d.) describes demand response is the voluntary reduction or shift of electricity use by customers, which can keep the electricity grid stable by balancing demand and supply, which is particularly useful where there is increasing amounts of variable renewable energy in the grid (see Figure 4.14). Customers, for their participation in demand response, receive an incentive or pay less for the energy they consume (Montuori, Alcázar-Ortega, Álvarez-Bel and Domijan, 2014).

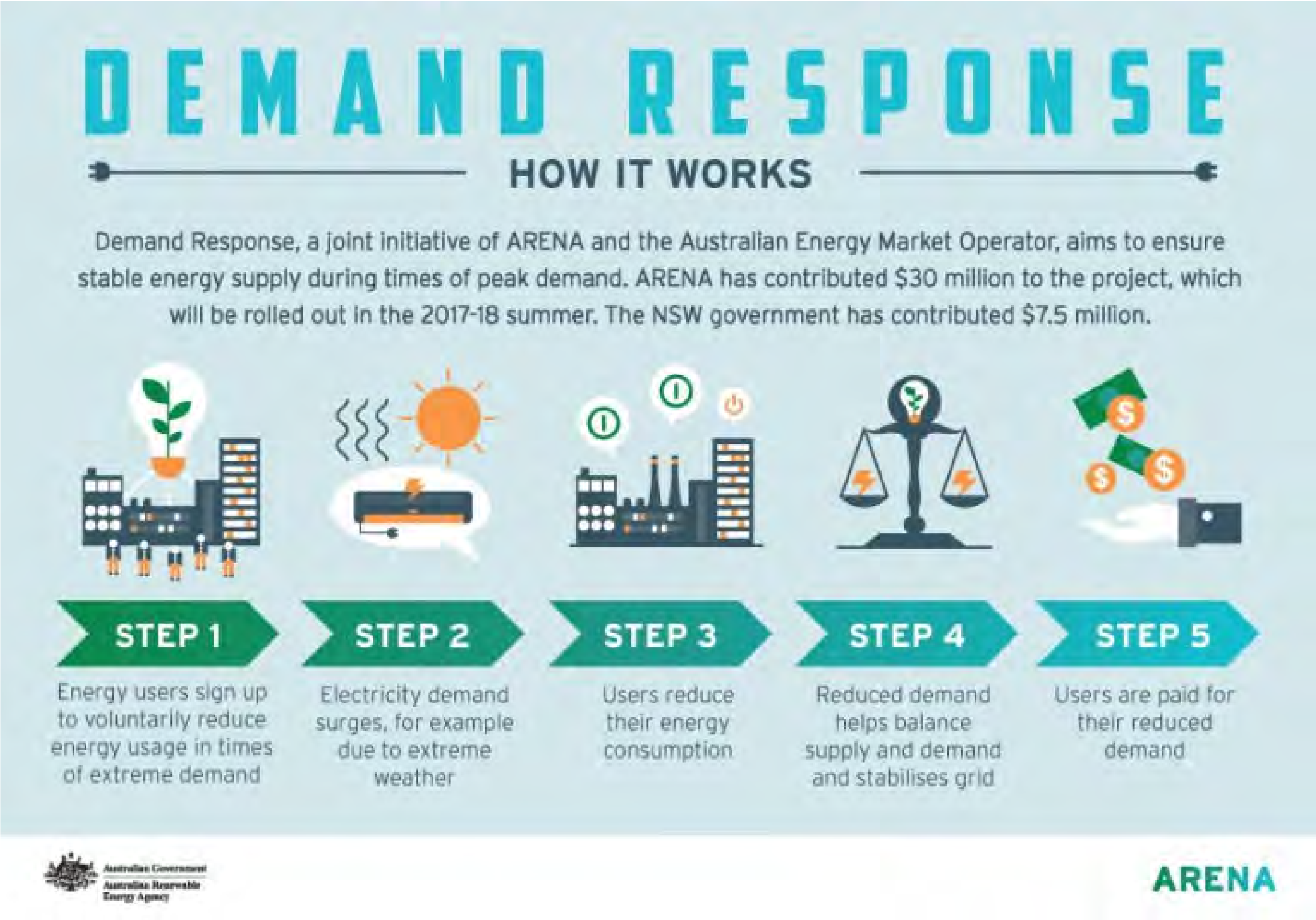


Figure 4.13: *Demand Response: How it works (ARENA, 2017-a)*

Demand response actions that can be utilised within overall power grid control include: reductions in the load when demand is high, disconnection of unnecessary load, and management of devices to improve energy efficiency (Montuori, Alcázar-Ortega, Álvarez-Bel and Domijan, 2014).

Demand response provides a quick and cost-effective way to reduce demand of electricity during peak periods and provides an alternative to increasing the amount of electricity being generated (ARENA, n.d.).

Montuori, et al (2014) found that in isolated microgrids, such as remote islands, the cost of addressing the variability of renewable resources with other conventional resources such as diesel generation is more expensive than requiring the participation of customers to reduce the total load in the microgrid. Furthermore, the participation in and use of demand response to solve unbalances in a nonconnected microgrid is economically the most profitable option for the microgrid as a whole, as it reduces the total operation cost, the energy loses in the grid and the carbon footprint (Montuori, Alcázar-Ortega, Álvarez-Bel and Domijan, 2014).

Montuori, et al (2014) conducted a simulation of current demand response programmes using Homer Energy and confirmed the economic profitability of using demand response resources. They found in all of cases, the price paid to customers participating in the different demand response programs was lower than the cost of producing additional power to supply the total load. In particular, payments to customers reducing their consumption was found to be 44% cheaper than if diesel generators produced the same amount of energy.

Demand management technologies are often integrated with Smart Grid technologies such as Virtual Power Plants (see below). A grid control platform integrates with customer demand response enabled devices such as air conditioners, water heaters and electric vehicles often through edge control devices. In times of peak load, the edge control devices work with the control platform to reduce load by either turning off or reducing the amount of power drawn by customer demand response enabled devices (such as air conditioners). The SwitchDin industrial Droplet™ controller is local example of an edge control device with this capability (SwitchDin, n.d.).

The Norfolk Island Electricity Working Group investigated the problem of excess daytime PV generation (NIA, 2013) and highlighted that having a technical solution in place, which includes the ability to shut down PV generation at times of over generation, as well as the ability to price electricity (buying and selling) based on its value at the time, should be a high priority (NIA, 2014a). They also noted that a large portion of the technical solution put forward is likely to focus on Demand Side Management including leveraging off time of use metering and stated that if it was not in place before a solution, it would inevitably follow such a solution (NIA, 2014a).

Hydro Tasmania (2018c) recommended that all inverters (solar and battery) be capable of Demand side management by the utility. They noted that the smart use of Demand Response Modes (DRM) functionality could greatly strengthen the grid by adjusting generation and being used as distributed power conditioning.

5. ENERGY EFFICIENCY

Renewable energy can be seen as a panacea for the high cost of energy on remote islands resulting from the use of expensive and polluting imported diesel fuel. However, in considering how to reduce both energy costs and emissions, it is essential that energy efficiency measures are undertaken first prior to the installation of renewable energy to minimize capital costs (Roberts, 2019).

"The most ecological economical kilowatt is the one that isn't consumed" José Vicente Barcia - Ecooo (Benítez, 2014).

Increasing the efficiency of energy consumption and energy conservation can produce significant fuel and monetary savings for Norfolk Island through reduced demand, with a wide range of technically mature energy efficiency improvements available to both households and businesses (Barton, 2008). Potential energy efficient measures that could be undertaken include replacement or rationalising of lights, lamps, fridges, air conditioners, hot water systems, heaters, and fans, with a payback period of these measures likely to be between 1-4 years depending on what work was undertaken (Roberts, 2019). Barton (2008) noted that solar hot water systems were a financially beneficial option on Norfolk Island and suggested that existing houses could be retrofitted with energy efficient appliances and lighting, insulation, and measures to increase ventilation and decrease drafts. The 2012 Census stated that 54% of Norfolk Island households had solar hot water systems.

A NSW government report on energy efficient lighting technology (OEH, 2014) stated that energy use associated with lighting systems can be reduced by up to 82% if energy efficient lighting practices are adopted. An early study of potential savings of increased energy efficiency measures on Norfolk Island found replacement of Commonwealth Buildings lighting would save approximately 56% of electricity costs and Airport Terminal Lighting 85% at that time (Barton, 2008).

Payback periods for energy efficiency can be quite dramatic. For example, in NSW:

- Replacing a spotlight with a like-for-like LED can reduce energy use by 54-78%, with a payback period less than a year,
- Replacing a halogen downlight with like-for-like LED, would result in a 75% reduction in usage, and just over one year's payback, and
- Replacing fluorescent tubes would result in a 67% reduction in usage, with a payback period of about 18 months (Roberts, 2019; OEH 2014).

With the relatively high cost of electricity on Norfolk Island, payback periods may be even shorter.

It is important to consider at a minimum like-for-like replacements when upgrading lighting so not to decrease the quality of lighting. That said, energy efficient lighting uses less energy without compromising on brightness and quality and as well as saving money through reduced electricity usage, it will require far less maintenance as the operating life is longer; and may improve the quality of lighting, that can in turn enhance the working environment improving productivity and safety (OEH, 2016). Furthermore, energy efficient lighting often has a significantly lower heat load than traditional lighting, which means that less energy is required to cool a space (OEH, 2014).

Upgrades and replacements are only half the story for energy efficiency measures. Behavioural changes to reduced energy use can result in significant reductions in energy use and resulting savings and are relatively inexpensive to implement. An audit of a small independent Newcastle High School found that their electricity costs could be reduced by 50% through a combination of Rooftop Solar PV (25%) and Energy Efficiency measures (25%). Half of the energy efficiency savings were from lighting upgrades and half from a behavioural change campaign to shut doors and turn off lights when not in use (Roberts, 2019).

In looking at the perceptions of adopting energy efficient measures on Norfolk Island, Barton (2008) stated that many residents felt there was no imperative for the local government to encourage increases in energy-efficiency, as this would only reduce their own revenue. However, most study participants were in favour of measures to increase energy efficiency.

A 2012 survey of the Norfolk Island population (Webb, 2018) found 91% of households reportedly switched off lights when not in use, suggesting that the local Norfolk Island population are already to some extent environmentally conscious and may exhibit a culture of energy savings. The Norfolk Island Regional Council are planning to conduct an education campaign in 2020-2021 on electricity and incentives available for energy efficiency (NIRC, 2020c).

5.1 ENERGY EFFICIENCY ON OTHER ISLANDS

The Archipelago of San Andres consists of three main islands, San Andrés, Providencia, and Santa Catalina, and more than 20 keys and islets. Located in the Caribbean Sea, it is located 720 km from Colombia's Caribbean coast. To address high electricity costs from imported diesel and to reduce greenhouse gas emissions, a 5-year program is being implemented to provide loans in the form of a revolving fund to finance the adoption of energy efficiency measures and renewable energy solutions. These include:

- Technological reconversion: by replacing refrigeration, ventilation and lighting equipment with high efficiency equipment, aimed at residential, commercial, industrial (medium and small hotels) and government; and
- The installation of individual Solar PV systems to reduce the consumption of energy generated with fossil fuels in the industrial and government sectors (Marti and Cárdenas, 2019).

The Program is also replacing 90,000 inefficient light bulbs with LED bulbs at no charge in low income households and provides training in includes training in energy saving and efficient use.

The use of LED technologies has reduced electricity consumption by 28% in eight years on the island of Krk (Croatia) (Rogulj, 2020).

To moderate the demand for electricity and to promote the efficient use of energy on the Galapagos Islands, the Ecuadorian government launched an initiative to replace conventional light bulbs by energy saving ones and another to replace 3000 old-fashioned and low-efficiency refrigerators with modern high efficiency units (Global Sustainable Electricity Partnership, 2016a; Morales, Besanger, Erazo & Medina, 2017).

6. BENEFITS OF RENEWABLES

Norfolk Island is supported financially by tourism, and is marketed as a clean, green, pristine, picturesque destination, thus a clean, environmentally friendly, sustainable system of electricity production would almost certainly attract tourists (Barton, 2003). Troman (2013) noted that renewable energy implemented in off-grid island communities such as Norfolk Island produced many social, economic, and environmental benefits such as:

- Reduced exposure to fluctuating and rising diesel prices,
- Fuel cost savings,
- Avoided diesel spills both on land and in water,
- Improve the trade balance,
- Reduced noise and clean air,
- Produced Local employment and capacity building including:
    - Local employment in construction and operation, and
    - Utility staff learn skills necessary for long-term management, operation and maintenance of the renewable energy systems,
- Avoided (in the case of Norfolk Island) 38,468 tonnes CO2-e GHG emissions per year (See Appendix 4 for calculations), and
- The resulting inexpensive electricity would boost economic growth.

7. HIGH ELECTRICITY COSTS

Electricity costs on Norfolk Island are high in comparison to other Australian Islands with prices approximately double to similar sized islands (Hydro Tasmania, 2018a). Unlike Lord Howe, Christmas, Cocos and King Islands, there is no fuel subsidy or state based subsidy such as Community Service Obligations and the cost of electricity production and reticulation must be met entirely by the Norfolk Island Regional Council's budgeted funds or passed on to Norfolk Island consumers which has left little funds for infrastructure replacement and no scope for reduced prices (NIRC 2017b).

The council is looking to pursue tariff subsidies in line with other island communities with the Commonwealth Government (NIRC, 2019c).

In 2010, Smit and Bondesen (2010) discussed that due to high electricity prices, Norfolk Island had been identified as an area where renewable energy is competitive on a cost basis (Barton, 2008) and that the island also has an abundance of renewable resources including wind and solar energy, that had been assessed as cost-competitive and feasible (Barton, 2008; Hydro Tasmania, 2003; Lenzen, 2008). A lower electricity price resulting from the replacement of diesel generation with renewable energy would have a ripple effect on the Island economy, lowering the CPI, bolstering the agriculture sector and improving the competitiveness of tourism (Smit and Bondesen, 2010).

The Norfolk Island Government in its submission to Joint Standing Committee on National Capital and External Territories on "Economic Development on Norfolk Island" (NIG, 2014) stated:

"Norfolk Island has the potential capability to move to an environment where there is significant reduction in the use of fossil fuel for electricity generation and the majority of energy is sourced from solar; and the excess stored in batteries or by such alternative technology as deemed best for our situation. Norfolk Island can then move towards being be one of the first places to utilise 100% renewable energy for electricity generation. Such innovation would be a positive marketing tool akin to New Zealand's clean green image and tie in to eco-tourism promotion."

8. HIGH PENETRATION OF ROOFTOP SOLAR PV AND THE RESULTING MORATORIUM

Under the Norfolk Island Electricity Act 1985 (still in force today), no person may generate grid connected electricity without the permission of the Administration (NIA, 1985). Permission was not originally given due to fears of islanding, the perception that distributed generation will cause a reduction in power quality, and fears of instability in the grid (Barton, 2003).

Barton (2008) noted that renewable energy was not being used in any significant scale on Norfolk Island and attempted to examine why (outside of the prohibition of distributed generation) this was the case. Barton found that although there was a good general awareness of energy options there was poor knowledge and understanding of specific energy options among members of the community who had little knowledge of the impacts new energy systems would have on their lives, and were sensitive to perceived risks involved in switching to alternative energy options.

In 2008, the Norfolk Island Government introduced measures to encourage private solar energy generation, so that households and businesses had the ability to generate electricity surplus to their needs that had "the potential to lower Norfolk Island's reliance on diesel generated electricity and reduce emissions" (NIA, 2008). Taking advantage of an Australian Commonwealth subsidy and the refund of duty or GST by the Norfolk Island Government, a considerable number of households and businesses installed Rooftop Solar PV which began to reduce the operating costs of the Norfolk Island power house through a reduction in diesel use or at least kept costs down as the cost of diesel rose (NIA, 2009). By 2017, the total powerhouse load had decreased by approximately 35% over 7 years due in part to a demand decrease from a decrease in population and the advent of Rooftop Solar PV (NIRC, 2017b).

The uptake of Rooftop Solar PV accelerated dramatically, increasingly contributing power to the grid (NIA, 2014a). From an administrative/revenue perspective, the introduction of Rooftop Solar PV occurred in an ad hoc manner, far outstripping that which was envisaged by the legislators of the day (NIA, 2014a). Smit and Bondesen (2010) noted that the renewable energy penetration potential on Norfolk Island, with the load management control systems in place at the time, was around 40%. However, by November 2012 over 55% of households and businesses had solar installed a total of 1.4MW of consumer owned distributed PV representing 25% of the total electricity requirements for the Island and over 60% of the average daytime load (ABS, 2017b; Hydro Tasmania, 2018a; NIA, 2014a).

A study by Lenzen, et al. (2014) found that during peak periods of solar insolation the Norfolk Island grid experienced a mid-day 1.35 MW peak load fed in by Rooftop Solar PV, with a resulting significant reduction in diesel fuel use at the power plant. However, this created a mid-day excess solar generation of up to 0.4 MW, where electricity supply on the Island exceeded demand which contributed to instability of the Electricity system and grid (See Figure 4.15) (Lenzen et al., 2014; NIA, 2014a). Consequently, a moratorium was placed on new installations of Rooftop Solar PV in November 2012 to control this system instability with intention that a solution to the issue by financial year end (Hydro Tasmania, 2018a; NIA, 2014a; NILA, 2013).

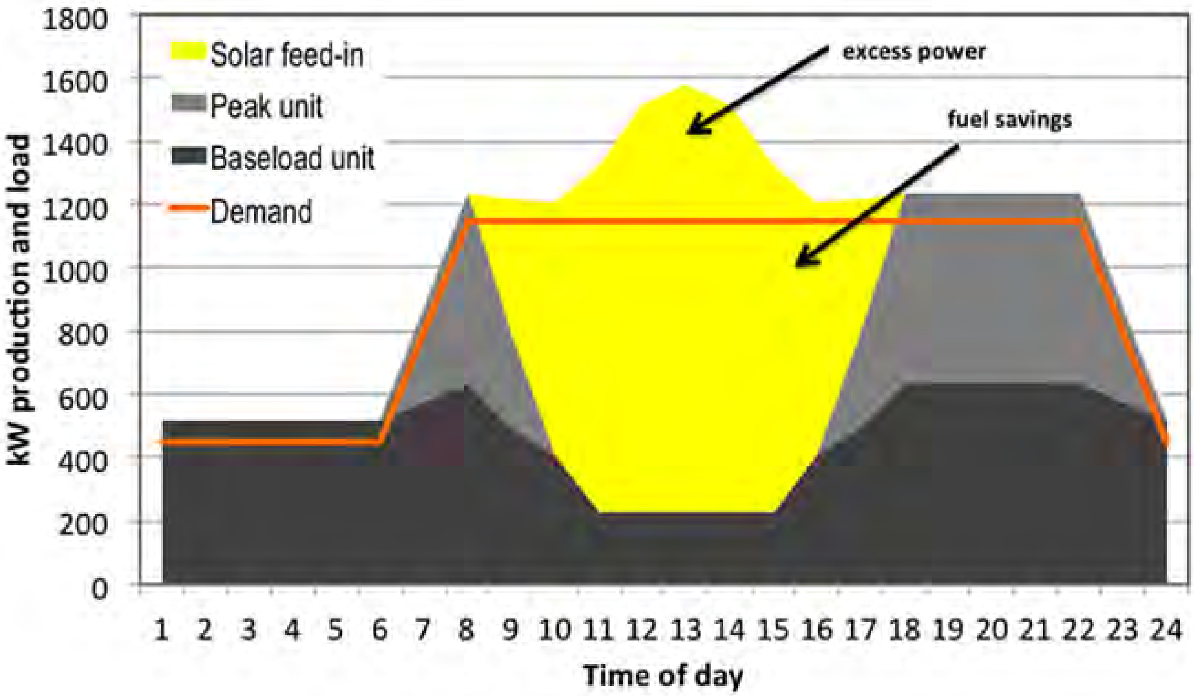


Figure 4.14: *Electricity production and load profile on Norfolk Island (Lenzen et al., 2014)*

9. METERING AND TARIFF REFORM

Due to the Solar moratorium there exists an ongoing inequity between homes and businesses that have Rooftop Solar PV and those that do not. The current electricity tariff for Norfolk Island is a flat tariff of $0.74/kWh (NIRC, 2020c). However, the current solar feed in tariff is metered at a rate of $0.62 kWh (Hydro Tasmania, 2018a). Therefore, non-solar consumers subsidise the cost of solar consumer's night-time consumption (NIA, 2014a).

Currently there is no infrastructure to store excess energy, and a 400 Kw load bank is used for shedding excess generated power during peak periods of solar insolation (Hydro Tasmania, 2018a; NIA, 2014a), and the island must instead rely on expensive diesel generation in the evening (NIRC, 2018b). During the day, Rooftop Solar PV consumers can generate more electricity than they are using during daylight hours. This often produces a surplus of solar energy that cannot be wholly used by residents on the Island resulting in the need for Norfolk Island Electricity (NIE) to shed the excess electricity using a load bank (NIA, 2014a). These Rooftop Solar PV consumers are provided with credits for this electricity to use in the evening, even when excess energy cannot be used by the rest of the island (NIRC, 2018b).

The feed-in tariff/credits for Rooftop Solar PV has resulted in an increase in the average cost of generating electricity (ACIL Tasman, 2012). The Island's power system has been running at a financial loss for several years and the feed-in credits cannot be sustained at current levels if the power system is to remain financially sustainable (NIRC, 2018b).

9.1 METERING

Older style disk type meters are the norm on Norfolk Island, with the existing metering reading process not differentiating between time of use nor import or export (Hydro Tasmania, 2018a), with only 14% of Rooftop Solar PV metered connections having the ability to measure time of day demand/supply (NIA, 2014a). This restricts the ability to enact tariff changes, such as being able to differentiate and charge different amounts for solar exports compared to energy consumed from the grid to better reflect the cost of energy, or to implement time of use tariffs to reflect the lower cost of energy during the middle of the day (due to solar generation) (Hydro Tasmania, 2018a).

Reform of the tariff structure is required and any recommendations on tariff reforms and price need to be done in concert with improvements in metering and time of day charging (NIA, 2014a).

The Norfolk Island Regional Council argued that an electricity system must be paid for by all residents to ensure equitable access to electricity and financial sustainability and equitable access to power is a Council priority and that some changes to regulation and technology will be required to achieve this (NIRC, 2018b).

9.2 POWERHOUSE AGE AND CONDITION

ACIL Tasman (2012) reported that there had been sustained underinvestment in the electricity generation, distribution, and transmission network, and new investment and major maintenance works were urgently needed. ACIL Tasman noted that the introduction of the load from Rooftop Solar PV had exacerbated the strain on the electricity generation and distribution infrastructure, and investment was required to better understand the nature of the problems caused by Rooftop Solar PV.

The powerhouse has a useful remaining life of 10 years (NIRC, 2019b). Apart from the recently installed Diesel Generators purchased in 2018, most plant and equipment in the Powerhouse is over 20 years old, is nearing end of life, and generally in average to poor condition (Hydro Tasmania, 2018a). With ageing assets in poor condition, a key concern is that revenue is wholly remitted to the Revenue Fund with no allowance made for infrastructure upgrades (Deloitte, 2014). Hydro Tasmania (2018a) noted that reliability, among other things, is linked to the asset condition and maintenance procedures and as assets continue to age, the underlying risk of increased plant outages increases, which may have a future impact on reliability.

Barton (2003) noted that there have been attempts at modernising the system by installing control and automation systems. However, these have met with opposition, and the small additions that have been made have been removed after technical difficulties arose from them. Barton (2008) noted that Diesel Generators were brought on and offline manually to increase or decrease generation capacity. Staff were called out to perform changes.

9.3 ANCILLARY SERVICES

As the diesel generators currently provide ancillary services such as spinning reserve for the Island, one generator must always be on. The current generators purchased in 2018 need to run at a minimum load of 30% (300KW) even when Rooftop Solar PVs could theoretically supply total demand during peak periods of solar insolation. (NIA, 2014a; Parkinson, 2017). Hydro Tasmania (2018c) suggested purchasing low loading diesel generators that can operate down to minimum load of 5% to progressively replace existing diesel generation. However, since the latest generators were bought in 2018 this does not seem to be a practical way of reducing diesel use.

See Sections 3.2 Battery Storage and 12.2 E-mobility-Electric Vehicles for solutions for Ancillary Services.

10. PAST STUDIES

Many studies have been made on energy options over the last 20 years for Norfolk Island, including biomass, biogas, wind, solar, diesel hybrid, ocean current, wave, mini hydro, pumped storage, energy efficiency/demand management (Barton, 2008; Hydro Tasmania, 2003; ITP Renewables, n.d.; NIA, 2009b; NIRC, 2017b). However, NIRC (2017b) noted that the primary challenge in re-considering these options is that all the previous feasibility studies were made in the context of the pre-Rooftop Solar PV environment and that Norfolk is no longer a "green-field' site and with 1.4MW of consumer owned distributed PV, has a different set of challenges.

10.1 SOLVING THE ROOFTOP SOLAR PV OVERSUPPLY PROBLEM

A Norfolk Island Electricity Working Group (EWG) was formed in 2013 and tasked with investigating the problem of excess daytime PV generation and to ensure that there is a pricing structure in place so that Rooftop Solar PV users contribute to the overheads of electricity generation and distribution (NIA, 2013). The Commonwealth agreed to work with the Norfolk Island Administration on solutions for the PV oversupply problem and to provide expertise in the policy development and the assessment process for technical solutions (NIA, 2014a).

Following a community consultation process, the Norfolk Island Government issued an Expression of Interest to find solutions to the surplus electricity generated and consider how reduce this loss, how to store or utilise this waste energy, the equipment needs in the power house and improved metering and charging mechanisms (NIA, 2014b; NILA, 2015). A limited tender was then to be issued in which the successful parties were required to submit more detailed solutions, pricing models, funding options and metering (NIA, 2015). However, we are unsure whether this tender went ahead, as the Norfolk Island Legislative Assembly was abolished shortly afterward by the Australian Government.

In 2016 the Norfolk Island Regional Council sought Expressions of Interest for the appointment of members to the Council's Sustainable Energy Advisory Committee to identify and advise Council on the strategic direction for sustainable energy on Norfolk Island and in particular assess the oversupply of Rooftop Solar PV electricity (NIRC 2016c; 2016d).

In early 2017 a tender was developed to investigate, and address the current technical issues facing electrical generation on Norfolk Island and consequently the Sustainable Energy Advisory Committee was dismantled NIRC (2017a). A detailed Expression of Interest (NIRC, 2017b) was then released looking to develop and supply a solution for the Island's current problems of energy oversupply during peak periods of solar insolation and concurrent inability to store this oversupply for later use. It also sought to address instability and a reliance on manual processes. Hydro Tasmania was the successful tenderer (NIRC, 2018c).

Hydro Tasmania was tasked to investigate and recommend energy policy and technical design for power generation on Norfolk Island and to examine the current technologies being used on Norfolk Island and explore ways to improve how these technologies are being used. The project would also investigate how new renewable energy technologies could be employed to improve the current system (NIRC, 2018b; 2018c).

Hydro Tasmania was tasked with investigating:

- Solar connection regulations (including the current feed-in tariff),
- Battery storage,
- Equitable access to solar power installation,
- Automation of the power station, and
- Network stability and reliability (NIRC, 2018c)

10.2 HYDRO TASMANIA STUDY FINDINGS AND RECOMMENDATIONS

10.2.1 SUMMARY OF FINDINGS

Hydro Tasmania (2018a) found that the existing power station is currently manually operated and (apart from 3 new diesel engines) uses equipment that is nearing end of life. The system was found reliable likely to be sufficient in the context of a remote power system. They noted that significant equipment replacement and/or upgrade works would be required to automate the system.

The current system of metering was found to be very limited, and did not differentiate between time-of-use, import or export, and would restrict the ability to make tariff changes such as time of use tariffs to reflect the lower cost of energy during the middle of the day (Hydro Tasmania, 2018a).

The study found that the current penetration of uncontrolled Rooftop Solar PV had reached a limit without any significant changes in technical management of installations being adopted. Furthermore, they stated that "*Before additional solar generation is installed further work is required in order to determine how and where additional distributed solar power could be added to meet load, without impacting on system security and reliability*." This would include work on the economic, tariffs and policy changes in addition to electrical equipment and energy storage (Hydro Tasmania, 2018a).

Hydro Tasmania (2018a) noted that although the amount of solar being diverted to load banks to keep the grid stable is relatively small, the load banks are fully loaded at peak solar generation time and any additional solar could destabilise the grid without significant equipment modification, connection and policy changes.

Operating costs were found to be reasonable and like many other systems, with the exception of the Solar Feed-in-tariff which is significantly higher than the cost of generation. However, with the economic cost of generation with the current system estimated to be $0.83 /kWh, the cost of supply exceeds the tariffs charged (currently $0.74/kWh (NIRC, 2020c)). This results in a negative financial position estimated at approximately $1 m annually (Hydro Tasmania, 2018a).

The study noted that there remain barriers to community support for change that may impact energy reform on the island. Better community education, transparency, and efforts to develop mutual understanding, between council and community are required to engage in constructive dialogue about the future of energy (Hydro Tasmania, 2018a).

10.2.2 SUMMARY OF RECOMMENDATIONS

Several options and recommendations were given by Hydro Tasmania (2018b):

- 1MW Wind Farm, Centralised battery storage 1.5MW / 6MWh, no new solar, diesel generators on standby mode (with grid formed by the battery).
- 2MW Solar farm, no wind, battery storage 1.5MW / 7 MWh, diesel generators on standby mode (with grid formed by the battery).
- 1MW Solar farm, no wind, battery storage 1.6MW / 5.5 MWh, diesel generators always on (30% minimum load) as currently configured.

Hydro Tasmania (2018b) recommended that the wind farm be excluded from the short-term implementation project and be considered as part of a longer-term solution with the proviso that wind farm site access be secured at this time. The 1MW solar farm option did not achieve the council objective of a 50% reduction in diesel usage (or approximately 60% annual renewable energy contribution) and does not automate the power station but could be used in a staged approach to achieve objectives. The 2MW Solar farm was the preferred option as the logistics of construction would be easier than the wind farm but was more expensive requiring larger battery storage and lacked generation diversification.

The study noted that none of the options presented appeared to result in the solar moratorium being lifted. Moratorium could only be lifted with extensive alterations to existing installations, such as inverter replacements and significant policy and tariff changes (Hydro Tasmania, 2018b).

From the presented options the Norfolk Island Regional Council selected the 1 MW centralised solar farm with a battery for energy shifting and no wind component as the preferred option for the new renewable project. Slightly amended, this would entail a: 1MW solar farm, no wind, battery storage 2MW / 5.5 MWh, a new central control system, with one diesel generator always on (at 30% minimum load) (Hydro Tasmania, 2018c).

The new control system would automate additional diesel scheduling, keeping diesel use to a minimum. It would also control scheduling of the load banks, solar farm generation and battery storage to assist in maintaining stability and reliability of the grid (Hydro Tasmania, 2018c).

The battery storage system can smooth the solar output during periods of intermittency. The use of energy storage means that the diesel generators are not required to carry additional spinning reserve to cover the entire solar output. During a cloud event the energy storage system provides power for a sufficient period to allow an additional diesel engine to be started which can compensate for the reduced solar output (Arena, 2019d).

Hydro Tasmania (2018c) remarked that this project was not expected to be economically feasible but represented the cheapest capital cost option of the scenarios examined. This outcome is primarily because the diesel savings do not offset the capital and operational costs of the proposed project, as under this option at least one diesel will always remain on (Hydro Tasmania, 2018c). The new system is expected to raise the percentage Renewable Energy contribution for Norfolk Island from the current 22% to 45%. This is below the 60% council objective for the project.

Hydro Tasmania (2018c) recommended energy policy changes be implemented in parallel to the Renewable Energy project to ensure ongoing grid reliability and financial viability of the Electricity System on Norfolk Island. These would be implemented appropriately phased in over time, with sufficient notification periods to allow consumers to plan for changes, avoiding abrupt changes. These included:

- A long-term meter replacement strategy be adopted, with bi-directional smart meters with time of use functionality, allowing for future changes such as flexible tariff arrangements that allow the billing of consumption and export separately.
- Existing metering data be downloaded and stored from metering within the powerhouse and community, as this would allow future decisions regarding the grid to be based on measured data.
- A detailed connection policy or technical standard be developed in line with Australian standards.
- Existing inverters are replaced, as and when they fail, and that all new inverters will require additional functionality and utility configurable settings to keep the grid operating reliably.
- A home/business battery storage connection policy be developed to assist in maintaining the quality and reliability of grid supply.

To maintain financial viability, Hydro Tasmania (2018c) recommended that continued tariff reform be undertaken to better reflect the costs in providing reliable electricity on the island. This would include that over time the solar feed in tariff should be transitioned to a lower, more cost reflective amount, and solar credits be phased out by paying out the current contingent liability as a once-off amount.

The study did not recommend technologies associated with a smart grid such as smart control of distributed energy resources such as Rooftop solar PV and home batteries, to assist with grid reliability and resilience (Hydro Tasmania, 2018c). The study did however recommend a long-term strategic plan be developed to ensure that future network investment decisions incorporate controllable distributed energy resources. Such technologies could be implemented as part of energy policy changes and tariff reform. Localised voltage regulation issues on the island could be assisted by this technology. Furthermore, smart control of distributed energy resources in combination with ancillary services and load balancing provided by the centralised batteries (BESS) would allow for additional renewable energy on the grid, further displacing diesel usage, and potentially ending the moratorium on new generation.

The selected option continues to use the diesel generators for ancillary services which could be served by the centralized batteries (BESS) with the grid formed by the batteries. This appears to be a lost opportunity to further modernize and automate the powerhouse and provide the option of all diesel generators to be on-demand (diesel-off system) further reducing the use of diesel, increasing the renewable energy contribution of the island, and the financial viability of the project.

A diesel-off system incorporates a large solar array or arrays (such as a solar farm) and a grid-forming battery energy storage system (BESS). The BESS replaces the services provided by a diesel generator, including frequency and voltage control and provision of fault current. This allows for diesel engines to be shut down once the solar array and BESS can fully meet load, so long as the BESS has sufficient storage to allow for a diesel engine to be called online if solar output drops. The control system needs full integrated control over solar, BESS and diesel engines, to coordinate scenarios of diesel only, solar/diesel hybrid, and diesel off operation (ARENA, 2019c).

11. SMART GRID/MICROGRID

"Significant advances in solar and wind generation technologies, coupled with the latest storage and microgrid technologies, highlight a new era of energy independence for countries or islands seeking to upgrade their power ecosystems."

(Avanindra, Urban, Macaw, Williams, & Richards, 2019)

A microgrid is a small electrical distribution system that connects multiple customers to potentially multiple distribution sources of generation and storage that are operated in coordination to reliably supply electricity (Montuori, Alcázar-Ortega, Álvarez-Bel and Domijan, 2014).

Remote islands are often served by isolated microgrids, where diesel generators are usually oversized due to the significant difference between average and peak load, resulting in generators often running at partial load with resulting low efficiency rates; furthermore, voltage and frequency need to be controlled utilizing microgrid controllers. In addition, the integration of renewable energy systems can present particular technical issues related to equipment and penetration levels (Clairand, Arriaga, Cañizares and Álvarez-Bel, 2019).

A smart grid utilizes information and communication technologies, sensors and smart meters to monitor and act on information from generators (such as renewable energy systems), storage and energy users to ensure the balance between electrical generation and use is achieved at lowest cost and to operate the grid safely and reliably without having to rely on significant infrastructure investments (Ernst, 2016).

Smart grids help improve reliability and system efficiency, allow the integration of variable renewable energy and distributed energy resources, and enable demand response capabilities through technologies such as smart metering (Neves, 2016).

For isolated systems, such as remote islands, smart grid capabilities facilitate:

- The increased use of local renewable resources for energy generation, instead of imported fossil fuels,
- Use of demand and peak control strategies for more efficient use of resources (such as storage and flexible demand),
- Decreased demand and resource variability and uncertainty through forecasting, and
- Optimize generation dispatch to optimize costs and reduce GHG emissions (Neves, 2016).

11.1 ORKNEY ISLANDS

The Orkney Islands produce 130% of their electricity needs through renewable energy. However, curtailment of wind turbines is common due to limitations in exporting via the undersea grid cables (Watts, 2019). Furthermore, the islands then import expensive energy (including fossil fuel generated electricity) when local generation is low (Spowart, 2020).

The ReFLEX Orkney (Responsive Flexibility) project is a 3-year project that aims to create a 'smart energy island' through the development of a 'virtual energy system' to monitor generation, grid constraint and energy demand. It will use smart grid control technologies to balance demand and supply by storing energy during peak local renewable production so it can be released during times of high demand, maximizing the use of cheaper locally generated renewable energy (EMEC, 2019; Orkney Islands Council, 2019; Spowart, 2020). The virtual energy system will digitally link local electricity, transport, and heat networks and generation on the islands with flexible energy demand, balancing the intermittency of the renewable resources (EMEC, 2019).

Together with the virtual energy system and smart grid software platform, the project aims to decarbonize Orkney's energy system and increase the use of local renewable energy through a rollout of domestic and commercial batteries, electric vehicles, Vehicle to Grid chargers, an electric bus, an e-bike integrated transport system, a hydrogen generation plant and the introduction of a competitive local renewable energy tariff (EMEC, 2019; Hamilton, Davies, Lidderdale, & Ainsworth, 2019).

The project will assist Orkney to maximize its significant renewable energy resources, help ensure cheaper energy for its residents, and decrease the county's carbon footprint through decreased reliance on imported carbon-intensive grid electricity from the UK mainland (EMEC, 2019). Following successful demonstration in Orkney, ReFLEX is planned to be replicated across other islands around the world (Hamilton, Davies, Lidderdale, & Ainsworth, 2019).

11.2 LOCKHART RIVER

Lockhart River is a remote community of about 700 people on the Cape York Peninsula that is served by an isolated microgrid primarily powered by diesel generators. To reduce the community's reliance on expensive and polluting diesel fuel the local electricity provider Ergon Energy needed to augment the grid with diverse distributed resources of solar PV and battery storage at four council sites (SwitchDin, n.d.-b).

A SwitchDin industrial Droplet™ controller was installed at each site to manage these distributed resources to help achieve grid stability and guarantee supply. SwitchDin's technology integrates with most PV inverter & battery storage products, creating a uniform interface for smart control of Virtual Power Plant-participating systems. The Droplets™ were integrated with Ergon's Power Station Controller (PSC) which monitors diesel generator output, grid conditions, and solar irradiance. The Droplets™ virtualise the distributed resources so that the Ergon PSC "sees" a single virtual controllable resource at each site. The result included the ability of Ergon to control the diverse resources resulting in a greater reliability of the grid, and a reduction in diesel fuel consumption with commensurate direct savings to the community together with reduced GHG emissions (SwitchDin, n.d.-b).

Distributed grid control technologies often rely on mobile communication technologies to manage edge of grid controllers. Fourth generation broadband cellular network technology (4G) is required for the SwitchDin industrial Droplet™ controller. The implementation of 4G mobile technology on Norfolk Island has commenced (NIRC, 2020b) and is expected to be completed by November 2020 (NIRC, 2020c). The rollout of 4G would be a necessary pre-condition for the implementation of this smart grid technology.

12. OTHER FORMS OF FOSSIL FUEL USE AND REPLACEMENT STRATEGIES

Lenzen, et al. (2014) determined that diesel fuel utilised for electricity generation accounts for approximately 39% of fossil fuel imports (excluding aviation fuel). However, petrol and the remaining imported diesel (that are used primarily for road and marine transport (Barton, 2008)) account for approximately 46% of fuel imports, with LPG accounting for the remaining 15% of imports. LPG is mostly used for cooking, space heating, and some water heating (Barton, 2008).

The proportion of fuels utilised, and total amount varies between seasons, and thus the amount of carbon emissions released (See Figure 4.16).

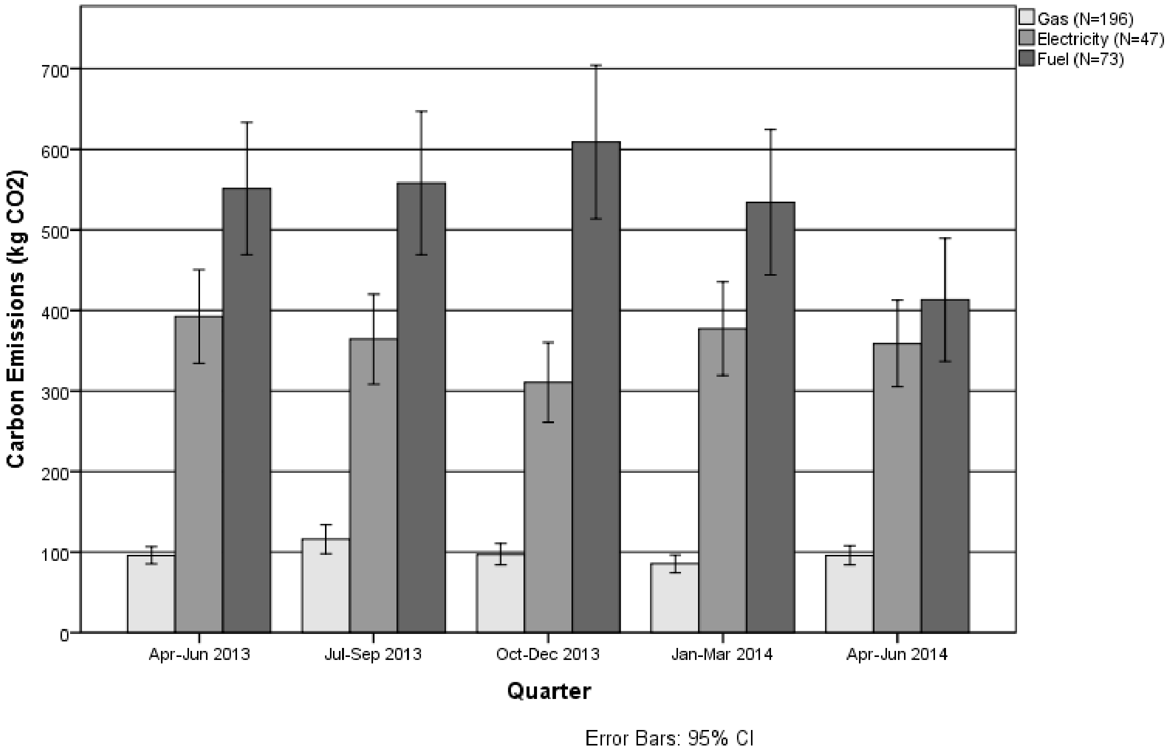


Figure 4.15: *Mean quarterly household carbon emissions relating to gas, electricity, and fuel consumption (Webb, 2018)*

The price of diesel, regular unleaded petrol, and LPG on Norfolk Island (taken from the International Energy Agency) was noted by Barton (2008) to be among the highest in the world.

These other forms of fossil fuel use have similar issues to diesel generation on islands (fuel cost, logistics, sustainability, and GHG production). Therefore, it would be prudent to look at replacement strategies for these fuels and their associated technologies.

12.1 REPLACEMENT OF LPG WITH ELECTRICITY OF HEATING AND COOKING

Induction heating is a very attractive technology due to its high-power density that allows fast heating. The main domestic application of induction heating is induction stoves/cooktops, which significantly improves safety, cleanness, and efficiency compared to flame or resistance stoves (Clairand, et al., 2019). Aligning with the Ecuadorian government's "zero fossil fuels" goal for the Galapagos Islands, on San Cristóbal Island a total of 2,500 LPG Stoves are being replaced with induction stoves through monthly instalments paid through electricity bills (Global Sustainable Electricity Partnership, 2016).

12.2 E-MOBILITY - ELECTRIC VEHICLES

In 2009 the Norfolk Island Government decided to introduce a rebate of 50% of the Customs Duty or Goods and Services Tax on fully imported all-electric motor vehicles. The duty reduction was the Government's contribution toward making such technology available to all in Norfolk Island at an affordable price and to encourage green energy usage and to reduce the Island's carbon footprint (NIG, 2009). However, there appears to have been little uptake at the time of electric vehicles on Norfolk Island.

Island Innovation (2019) declared that islands and e-mobility (or transport electrification) are a natural fit. They noted that:

- Islands are geographically compact, minimizing charging infrastructure for Electric Vehicles (EVs) and driving distance issues,

- Islands often have expensive and risky fossil fuel supply chains, making electrification of vehicles more attractive,
- Islands frequently have ample solar and wind resources, reducing the cost of electricity for EV charging, and
- Islands are particularly vulnerable to the effects of climate change.

Island Innovation (2019) remarked that these factors should ensure both social and political support for renewables-based electrification of vehicles on islands and noted that many islands are actively pursuing e-mobility development efforts.

A study of Electric Vehicle expansion in the Caribbean islands by Viscidi, Graham, Madrigal, Masson, Prado & Monticelli (2020) noted that the Caribbean islands are heavily dependent on oil imports making fuel expensive and exposing them to oil price and foreign exchange risk. The transport sector accounts for a large share of energy consumption on these islands. However, Viscidi, et al. (2020) remarked that renewable energy resources were abundant which could be exploited to maximise the environmental benefits of EVs and that Caribbean islands are small, naturally mitigating range anxiety of drivers and requiring less extensive Electric Vehicle charging networks. Viscidi, et al. (2020) stated that these factors make the Caribbean region ideal for electrification of transport.

In a review of studies exploring the effects of electric vehicle integration on isolated island grids, Gay, Rogers & Shirley (2018) noted that although islands often had good renewable resources, their small populations and limited energy demand limited the diffusion of renewable energy technologies. EVs provide the opportunity to utilize these resources by storing generated renewable energy for later use and in turn displacing the use of imported fossil fuel.

Gay, et al. (2018) noted that for many small island developing states, they depend heavily on imported fuel, and that the prospect of reducing dependency on fossil fuel imports and improving energy security could act as a key incentive towards transportation sector reform on those islands. Gay, et al. (2018) remarked that these countries often pay premium prices for their fuel and in many cases the islands' transportation sectors represent a 50% share of fuel imports.

Like other islands, the transport sector represents over 60% of fuel imports for Norfolk Island, with road and marine transport accounting for approximately 1/3 of fuel imports for Norfolk Island (Lenzen, 2008; Lenzen, et al., 2014). On a household basis, between 50-60% of household emissions on Norfolk Island are from vehicle use (See Figure 16) (Webb, 2018). Furthermore, the price of diesel and petrol on Norfolk Island is among the highest in the world (IEA, 2019; Johnson, 2020; Barton, 2008).

Norfolk Island is geographically compact with an overall area of just over 37 square kilometres (Geoscience Australia, n.d.), minimizing the need for EV charging infrastructure and mitigating range anxiety issues. Norfolk Island also has abundant renewable energy resources including wind, wave and solar (Hydro Tasmania, 2018a), but has excess solar generation from Rooftop Solar PV that cannot be utilized and contributes to grid instability (Lenzen et al., 2014; NIA, 2014a).

Norfolk Island has also shown to be particularly vulnerable to the effects of climate change, with the effects likely to be increased intensities and frequency of extreme weather events such as high rainfall events, cyclones and droughts, increases in sea surface temperatures, and sea level rise (Director of National Parks, 2011; Watkins Consulting 1999 cited by Webb 2018). This is likely to cause problems such as flooding, soil erosion, shoreline and dune erosion, adverse effects on marine organisms in reefs, and damage to island assets such as jetties, and roads (Webb, 2018). This could disrupt supply chains for Norfolk Island including for imported fuels.

Small islands, such as Norfolk Island, are a prime market for EVs with limited road networks, high fuel costs and the need for direct grid storage solutions (Gay, et al., 2018).

12.3 EV EFFICIENCY IN REDUCING COSTS AND GHG EMISSIONS

A net reduction in greenhouse gas emissions is attainable through the adoption of electric vehicles, even if they are charged by fossil fuel generation, the reasoning being that power plants will operate more efficiently than individual petrol or diesel vehicles (internal combustion vehicles (ICVs)) (Gay, et al., 2018).

Pina, Baptista, Silva, & Ferrão (2014) determined that as the number of EVs increased on an island (supplanting ICVs) there would be a continuous decrease of CO2 emissions, indicating replacing ICVs with EVs would be beneficial in terms of reducing CO2 emissions alone.

However, the real benefits of electric vehicles depend on the way that electricity is generated. By charging EVs when renewable energy is plentiful and exceeding demand, it would lower both the costs and the emissions of the transportation sector by enabling a more efficient use of the generation technologies and by exploiting cleaner ones such as wind and solar when available (and also avoiding curtailments) (Fattori, Anglani & Muliere, 2014).

12.4 EVS – HIGH CAPITAL COSTS VS LOW RUNNING COSTS

EVs are currently more expensive to buy than equivalent ICVs. Edghill noted the higher capital costs of EVs compared with ICVs in Barbados (Borison, Edghill, Taylor, Mariani & O'dwyer, 2019, 10:00). Similar results were noted for EVs on the Galapagos Islands (Clairand, et al., 2019). However, battery prices have fallen by 87% in real terms in the last 9 years and are forecast to drop by a further 35% in the next 4 years (BloombergNEF, 2019). Consequently, price parity between EVs and ICVs in Australia is expected by 2024 mostly due to these falling battery costs (Collie, 2019; Electric Vehicle Council, 2019).

While purchase costs of EVs are currently high compared with ICVs, running costs are low. Edghill stated, that in Barbados, an electric vehicle's fuel costs were 30% and annual maintenance costs 25% of a petrol vehicle (Borison, et al., 2019).

12.5 CHALLENGES – THE IMPACT OF CHARGING ON THE GRID

With the introduction of EVs, the consumption of energy shifts from the transportation sector to the electricity production sector (Pina, Baptista, Silva, & Ferrão, 2014). This can bring about some challenges to the electricity grid and opportunities to utilize renewable energy sources on Islands. The unplanned charging of EVs on small islands can cause certain challenges.

An electric vehicle can increase the home or business's electricity demand by 25% or more whilst charging. Therefore, the simultaneous charging of several electric vehicles may have an impact on grid performance and stability. This is particularly so for relatively small, isolated grids such as small isolated islands (Gay, et al., 2018).

12.6 UNCONTROLLED/UNCOORDINATED CHARGING

Gay, et al. (2018) stated that the uncoordinated charging of a large number of EVs could compromise the reliability, security, efficiency and economy of an Island's electricity grid. Gay, et al. (2018) noted that without any coordination of when EVs charge, as the number of electric vehicles increased, the additional loads posed by charging could lead to a change in an Island's daily load profile and an increase the demand peak. This could affect the ability of the electric utility to manage generation, supply and distribution and put a strain on existing generating capacity. Furthermore, peak demand hours have, in general, higher marginal GHG emissions due to the use of fossil fuels (such as diesel generators) to satisfy demand, whereas low demand periods can utilise excess electricity from renewable energy to recharge EVs (Pina, et al., 2014).

Pina, et al. (2014) investigated the impact of EVs on the small isolated grid of Flores Island (Azores). They found that even though there was a high share of renewable energy on the island, this did not guarantee a significant use of renewable energy for recharging EVs, with additional electricity needing to be produced mainly from diesel generators. The reduction in emissions depended on the time of day that the EVs were charged and the amount of excess renewable energy available at the time.

12.7 PRE-DETERMINED OFF-PEAK CHARGING

Grid operators have several options to ensure that vehicle charging minimises any impact on the grid. Known collectively as charge management, these options involve the operators implementing scheduling mechanisms such as coordinated charging, smart charging, and vehicle-to-grid, and applying pricing mechanisms such as demand charges, time-of-use rates, and dynamic pricing (Gay, et al., 2018). Pricing mechanisms provide incentives for Electric Vehicle users to change their Electric Vehicle charging behaviour. These can be tied to scheduling mechanisms such as smart charging to implement such behaviour.

Demand (or capacity) charges are applied based on a maximum rate of power consumption during a period rather than an average. Time-of-use rates are lower power prices during periods of expected low grid demand or when there is likely to be excess renewable energy generated, and higher prices during periods of expected high demand so as to dissuade peak power usage and prevent overload (Gay, et al., 2018; Viscidi, et al., 2020).

With dynamic pricing, it is possible to react to changes in operating conditions at the time, such as changes in supply from variable renewable energy resources, with pricing incentives. Dynamic pricing for Electric Vehicle charging is a form of demand response, which refers to a procedure that motivates end users to change their electricity consumption, in response to financial incentives (Limmer, 2019).

Coordinated charging is a simple form of demand scheduling that can be implemented using Electric Vehicle chargers with programmable timers, that can be set to charge the vehicle at pre-determined off-peak times (Gay, et al., 2018).

12.8 SMART CHARGING

Smart charging allows for the active control of Electric Vehicle charging by a utility/grid controller, charging the battery of the vehicles when convenient, either through a smart charger or the vehicle itself if enabled to be remotely controlled (Fattori, et al., 2014; Hilson, 2019; Lambert, 2020).

This could reduce potential electricity peaks due to Electric Vehicle charging and decrease the need for additional electrical capacity (Fattori, et al., 2014). Lambert (2020) stated that this could have a significant impact on the grid by reducing peak demand and charging when demand is lower but noted vehicle-to-grid services would have an even greater impact, as unlike smart charging, Vehicle-to-grid offers the possibility of reducing electricity demand peaks that are not due to EVs (Fattori, et al., 2014).

12.9 VEHICLE-TO-GRID SERVICES

Vehicle-to-grid technology enables an electric vehicle to send power back into the grid with a bidirectional charger and vice versa, allowing the electric vehicle's on-board battery to help maintain the quality of the electricity supply (Gay, et al., 2018; Lambert, 2020). The bidirectional chargers enable electricity to be stored in an Electric Vehicle for later reintroduction into the grid, which is particularly useful with the integration of renewable energy such as wind or solar, where excess energy from intermittent renewable energy sources can then be stored for later use (Gay, et al., 2018; Viscidi, et al., 2020). When renewable energy sources provide excess supply (such as mid-day in summer for Rooftop Solar PV) the EVs can be charged (charging vehicles when electricity generation exceeded demand on the island), then when power supply is low, they reinject power into the grid. Referred to as load balancing, this strategy uses EVs as a source of electrical power storage that supplements the grid and reduces the need for dispatchable power such as diesel generators to cover peak demand (Viscidi, et al., 2020).

The ability to soak up excess renewable energy supply through EV charging (which is a feature of both Smart Charging and Vehicle-to-grid) facilitates the introduction of more Variable Renewable Energy (such as wind or solar) into the grid (Viscidi, et al., 2020). This is supported by research into energy systems with a high penetration wind and solar, which found that engaging in smart charging can aid a grid operator's task of matching supply to demand (Fattori et al., 2014; Gay, et al, 2018).

12.10 EV ROLE IN GRID STABILISATION

Gay, et al. (2018) remarked that EVs can also act as controlled storage, providing ancillary grid services such as spinning reserve, voltage and frequency regulation and therefore increase the efficiency of the grid while at the same time offsetting expensive fossil fuel use and reducing the GHG emissions in the transportation sector.

12.11 DISASTER RESILIENCE & EVS

Viscidi, et al. (2020) noted that in addition to mitigating GHG emissions, EVs can bolster resilience to natural disasters exacerbated by climate change. By serving as energy storage, Electric Vehicle batteries provide support to the grid through Vehicle-to-grid technology. When the grid is damaged by disaster, EVs can provide a mobile source of energy that can be reinjected to the grid. They can also diversify transportation options, which is useful since electricity supply is often restored before transport fuel supply (Viscidi, et al., 2020).

12.12 PROS AND CONS OF VEHICLE-TO-GRID SERVICES

Vehicle-to-grid services are not without their disadvantages. Some studies suggest that for certain applications of Vehicle-to-grid services can accelerate battery degradation (Viscidi, et al., 2020). Gay et al. (2018) noted that services that require large amounts of energy such as spinning reserve and peak shaving could lead to significant depth-of-discharge of the batteries, thereby reducing battery life. However, Edghill (Borison, et al., 2019, 14:00) stated that battery degradation is not so much of a problem as island distances are often short compared to battery range even when degraded.

12.13 BATTERY END OF LIFE USAGE

When electric vehicle batteries age and are no longer suitable for driving, with minor refurbishment, the batteries can then be reused for other applications (Gay et al., 2018). The applications include battery storage for renewable energy installations, spinning reserve and localised voltage/frequency regulation, load shifting, home battery installations, office battery installations, streetlights, and golf carts (Gay, et al., 2018; Borison, et al., 2019, 16:50).

12.14 NEED FOR A NORFOLK ISLAND SPECIFIC STUDY

Data collection and analysis of the potential impacts, challenges and opportunities presented by the integration of EVs into the grid will depend on the characteristics of the given system, and to some extent, be island specific and is required well before high levels of Electric Vehicle adoption is reached (Viscidi, et al., 2020).

For example, Gay, et al. (2018) identified the following research needs for the expansion of EV use in Barbados:

- research on time-of-use tariffs, and how they impact home charging profiles,
- research into billing strategies to encourage use public charging infrastructure, and
- simulation of demand-side smart control technology on moderating charging during the evening peak.

This research should inform a planning strategy for fleet conversion on the island.

12.15 ELECTRIC VEHICLE CHARGING STRATEGY

To ensure success of Electric Vehicle use in Norfolk Island a comprehensive planning strategy is required. This would include public awareness campaign, electrification of the council vehicle fleet, customer incentives, planned public charging facilities, training, partnerships, and parallel expansion of EVs and Renewable Energy. Viscidi, et al. (2020) found public awareness was a top barrier to Electric Vehicle expansion in the Caribbean islands. A lack of familiarity with EV technology led to the propagation of misconceptions regarding their range and performance, and a lack of knowledge about the benefits of EVs, such as how long-term fuel and maintenance savings can compensate for the higher upfront cost. Viscidi, et al. (2020) stated that the levels of public awareness should be assessed and increased, and top consumer concerns should be identified and addressed, and suggested that local government and auto dealers should partner to dispel myths about EVs through marketing campaigns, public events, and other channels.

12.15.1 ELECTRIFY GOVERNMENT FLEET

To demonstrate the viability of electric vehicle technology to the public, the council vehicle fleet should be electrified. This will also allow the council to capitalize on cost and emissions savings and address broader decarbonization goals (Viscidi, et al., 2020).

12.15.2 PUBLIC CHARGING FACILITIES

Sufficient public charging infrastructure is an essential pre-requisite to Electric Vehicle use. Viscidi, et al. (2020) found public charging infrastructure was insufficient to support large numbers of EVs despite the small size of many of the Caribbean islands. They noted that, though it may lose money in the short term, a robust charging ecosystem must precede large-scale Electric Vehicle usage, as consumers need to feel confident that they can access a public charger near them and will not buy an Electric Vehicle merely trusting that charging infrastructure will materialize.

12.15.3 TRAINING

While maintenance requirements for EVs are much lower than for ICVs, they represent a new technology that requires a different set of skills from maintenance personnel (Viscidi, et al., 2020). Viscidi, et al. (2020) noted that an ample supply of trained maintenance personnel was a precondition for the export of large numbers of EVs to Caribbean markets by automakers, and that a lack of trained sales and maintenance personnel was an impediment for consumers interested in driving an Electric Vehicle.

12.15.4 PARTNERSHIPS

Electric vehicles are a multisectoral technology, therefore partnerships are essential to their success. In Barbados, the Electric Vehicle importer Megapower established partnerships with the electricity utility, landlords where charging stations were to be installed, companies to implement pilot projects, and with local educational and vocational institutions to train technicians to carry out EV maintenance (Borison, et al., 2019, 01:26; Viscidi, et al., 2020). Joint marketing was undertaken through the partnerships to ensure success (Borison, et al., 2019, 01:26).

12.15.5 PARALLEL EXPANSION OF EVS AND RENEWABLE ENERGY

The high use of diesel for power generation reduces the GHG emission reduction benefits of EVs unless electricity demand growth stemming from electrification of transport is met by concurrent increases in renewable energy capacity (Viscidi, et al., 2020). Viscidi, et al. (2020) remarked that "pairing Electric Vehicle deployment with a parallel expansion of renewable energy could stem oil price vulnerability, reduce both transport and electricity costs, and drastically cut greenhouse gas emissions."

12.16 ELECTRIC VEHICLES ON OTHER ISLANDS

Several programs are underway and research studies undertaken into Electric Vehicle expansion on remote islands. Ioakimidis & Genikomsakis (2018) modeled the potential for Plug-in Hybrid Electric Vehicles (PHEVs) on the island of São Miguel in the Azores, an autonomous state of Portugal. They examined smart charging strategies for different scenarios of electric vehicle market penetration and found that a 32% share of electric vehicles in the Island's vehicles fleet could be realized, yielding major benefits countering the environmental impact of their heavily fossil-fuel dependent energy system through allowing more intermittent renewables onto the grid. Importantly, this could be accomplished with no technical barriers to integration.

An analysis of the vehicle-to-grid impact in low capacity electrical systems, in Tenerife (Canary Islands), found that by charging in low demand periods, this improved the overall performance of the grid by flattening the electric energy demand curve (Colmenar-Santos, Linares-Mena, Borge-Diez, & Quinto-Alemany, 2017).

Clairand, et al. (2019) noted that the Ecuadorean government is introducing incentives to change from ICVs to EVs, to address greenhouse gas and fuel transportation issues and to preserve the eco-system of the Galapagos islands.

Renault aims to power Portuguese island of Porto Santo entirely by renewable energy. This will be achieved by:

- provision of EVs and charging stations,
- implement vehicle-to-grid technology to discharge power back to the grid, and

- place 'second-life' battery packs (former car batteries that can no longer function in EVs) on the island to store energy generated by the Island's wind and solar farms (Casey, 2018).

Bornholm Island (Denmark) is situated just south of Sweden and has the goal to become 100% based on renewable energy. As the island is connected to the Swedish power system through a single cable connection, it is expected to be able to operate stand-alone if necessary. In island mode, the Bornholm power system can represent a future renewable-based energy system and as such several smart grid projects and new systems have been tested in the system. The EDISON project developed Electric Vehicle system integration solutions on the island, which not only reduced GHG emissions from the transport sector but was utilised as a distributed energy resource to provide system services to the electricity grid (Wu, et al., 2017).

13. NORFOLK ISLAND COMMUNITY STRATEGIC PLAN 2016-2026: ENERGY

The Norfolk Island Community Strategic Plan – *Our Plan for the Future* 2016-2026 identified renewable energy infrastructure as a key issue to be addressed (NIRC, 2016a). The strategic direction "*An environmentally sustainable community*" through the objective "*Use and manage our Resources wisely*" identified developing a clean energy future as a key path.

The council's role detailed in the plan included to "*Investigate the viability of solar generation and battery storage options and other renewable energy generation sources*" and to "*Investigate Public Private Partnership options for the provision of essential services*". The Norfolk Island community's role included to "*Maximise alternative energy harvesting by households and businesses*". Indicators of success included a "*Raised awareness of, and a commitment to, the uptake of alternative energy options*" and "*Identification of Public Private Partnerships*".

Consistent with the strategic objectives detailed in the Community Strategic Plan 2016 – 2026, the Norfolk Island Delivery Program 2016 – 2020 (NIRC, 2016b) detailed committed actions by the council over a 4-year term. The targets in the Delivery Program moving towards the vision: "***Norfolk Island – the Best Small Island in the World***" included ceasing all waste disposal into the sea, minimising waste and ensuring solar battery storage, or an alternative option, is installed to capture excess electricity generated by photovoltaics. The target of lifting the moratorium on the installation of new photovoltaic systems was also included. The targets were subsequently amended to include "*Achieve 100% renewable energy generation on Norfolk Island by 2024*" as detailed in the Draft Operational Plan 2020-2021 (NIRC, 2020c).

Actions to achieve these targets were detailed in the Operational Plan 2019-2020 (NIRC, 2019c) included:

- Hydro Tasmania's detailed engineering plan to reconfigure island power generation is fully costed by an Energy Economist, and a recommendation on implementation prepared for Council,
- Discussions with the Commonwealth as to subsidy for tariffs in line with other island communities,
- Installation of a new diesel generator and battery capacity to reduce the Powerhouse's diesel fuel requirements,
- Complete Grant Funding Application on Energy Solution options,
- Reform the Electricity Supply Act 1985(NI),
- Public education on electricity incentives (specifically on electricity and energy efficiency).

These were subsequently updated in the Draft Operational Plan 2020-2021 (NIRC, 2020c) to include:

- Determine optimal implementation pathway to achieve the objective of 100% renewable energy at lowest capital cost, within specified timeframes, keeping ongoing operational costs as low as possible.

14. CURRENT COMMITMENTS - SOLAR ANALYSIS

Following the presentation of Hydro Tasmania's Study Findings and Recommendations (Hydro Tasmania, 2018a; 2018b; 2018c), in 2019 NIRC sought quotes from an Energy Economist to "*to determine and document the financial impacts of engineering solutions designed to increase the renewable energy contribution to the Norfolk Island electricity supply*." The analysis would include:

- Solar PV yield of the proposed centralised solar PV system,
- Optimal size of storage system's capacity, energy configuration, potential operating modes
- Operational profile of diesel plant within the new hybrid system,
- Quantification of expected diesel fuel cost savings,
- Analysis of tariff structure, and
- The impact of third-party funding possibilities (NIRC, 2019d)

Frontier Economics was engaged to "undertake an assessment of the financial implications of implementing the Hydro Tasmania Plan" (NIRC, 2019e).

On 16 September 2019, an evaluation panel shortlisted the applicants who submitted tenders to provide and install a replacement generator and batteries, of appropriate size, to address the current issue of solar oversupply and to reduce diesel usage (NIRC, 2019e). A subsequent request for tender has been issued for a design and construct contractor to supply and install a new Battery Energy Storage System at the Norfolk Island Powerhouse (NIRC, 2020d).

15. LOCAL COMMUNITY ACCEPTANCE OF CHANGES IN ENERGY PRODUCTION AND MANAGEMENT

Barton's in-depth study of technical, economic and social analyses of issues relating to energy development on Lord Howe Island and Norfolk Island (Barton, 2008), found there was a long history of political tension between the communities, their governing bodies and external institutions that resulted in disempowerment of large sections of the communities and poor levels of communication between these institutions. The long history of investigation of alternatives with little change had frustrated many.

Due to these factors, Barton found there were low levels of engagement and participation in community level decision-making on energy options. Further to this, traditional cultural values of the communities relating to independence, self-sufficiency, and resilience conflicted with modern pressures to form allegiances with external institutions. These cultural values manifested themselves in the discourse on energy options as general resistance to outside involvement in the affairs of the Islands, an emphasis on the value of local knowledge and a willingness to accept non-optimal financial decisions. The high levels of social connectivity and small populations of the communities also affected decision-making on energy options.

Barton noted that personal relationships had a strong influence on the process and there was evidence of consensus decision-making that excluded those with conflicting opinions. The close coupling of institutions with individuals made the impacts of decision immediately visible within the communities, and there was a hesitation by many to disturb the status quo.

16. COMMUNITY ENERGY

Community Energy is an approach to renewable energy development that involves the community in initiating, developing, operating, owning, and/or benefiting from a renewable energy project (Hicks, Ison, Gilding and Mey, 2014). Across the world communities are coming together to respond to fundamental challenges such as climate change, regional economic development and energy access and affordability. They are doing this through creating community owned and community run renewable energy projects (Roberts, 2019). The social model behind this is that everyone should be able to participate in renewable energy (Roberts, 2017). Not only is Community Owned Renewable Energy an important element of the transition to renewable energy, it can also contribute to economic opportunities, democratisation, community-building, empowerment, and community mobilisation (Hicks, 2019). Figure 4.17 details the benefits of community owned renewable energy projects.

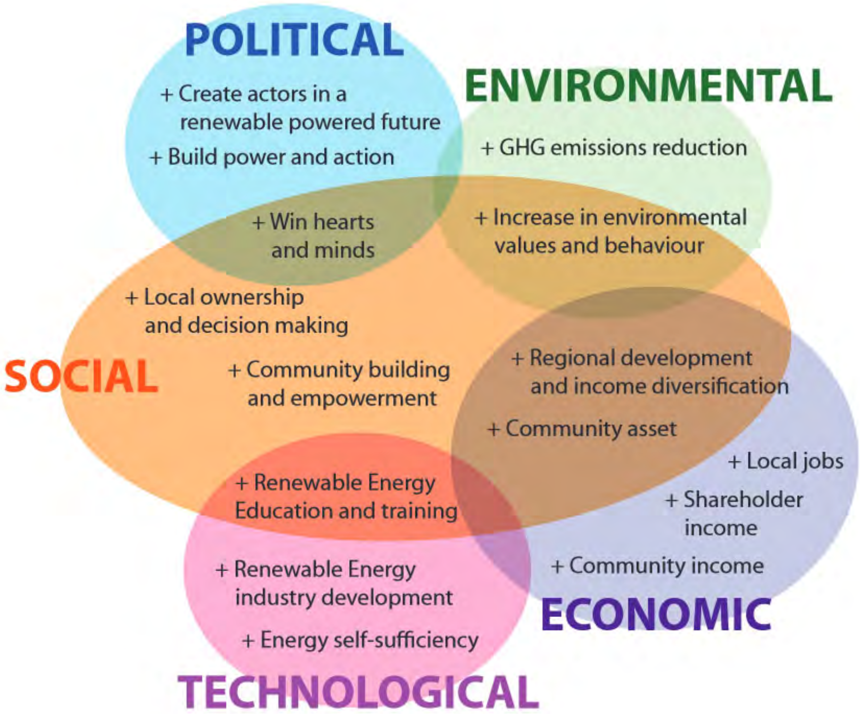


Figure 4.17: The Benefits and Motivations of Community Renewable Energy Projects (Hicks et al, 2014)

Barton (2008) noted that models of both co-operative ownership and individually owned micro-generation have proven to be successful in European contexts, and because they encourage local participation and deliver benefits to local communities, these could be appropriate models of energy development for the Norfolk Island community.

Brown and Vergragt (2008) argued that technological innovation is about technology as much is about people, their perceptions, and their interactions with each other and with the material world, and that sustainability will not be reached by technology alone, but by learning by individuals, groups, professional societies and other institutions.

16.1 COMMUNITY ACCEPTANCE

Community ownership of renewable energy projects such as community owned solar and wind farms can mitigate local opposition through greater community acceptance (Ruggiero, Onkila, & Kuittinen 2014). CSIRO noted that community-scale wind farms can engender greater local acceptance of wind farms through providing local input in development and management as well as financial gain (Hall, Ashworth & Shaw, 2012).

Public involvement in wind energy projects in Denmark, for example, show how co-ownership increased public acceptance of the project. This is paramount in Denmark, where almost 20% of electricity is generated by wind (Central Coast Community Energy Association Incorporated, n.d.). Community acceptance of wind farms has been shown to increase when there are clear benefits flowing back to the local community.

Community renewable energy projects generally have extensive and ongoing community consultation processes and greater opportunities for input, both through formal proceedings and informally via project organisers also being community members than commercial renewable energy developments resulting in greater community acceptance of these projects (Hicks & Ison, 2011).

16.2 COMMUNITY ENERGY ON OTHER ISLANDS

16.2.1 SAMSØ ISLAND

Community energy projects underlie the success of renewable energy in Denmark. Samsø, a Danish island of about 4000 people, won the national competition to become Denmark's "Renewable Energy Island". Over its 10-year life, the Renewable Energy Island Samsø community energy project managed to transform Samsø's energy system from largely fossil-fuel to one based on renewable energy. The project implemented district heating using biomass and solar thermal, energy efficiency in buildings, onshore and offshore wind turbines and individual renewable energy installations such as heat pumps and solar PV. Most of the investments are owned by local cooperatives, farmers or businesses.

The project's success was in part due to government support, including a national energy policy with clear guidelines, technology support, and establishment of local information centres to promote renewable energy use and energy efficiency.

The long Danish tradition of local cooperatives owning and running local production infrastructure is also important in this regard, as it has helped foster a 'natural' environment for community engagement and acceptance of renewable energy (Sperling, 2017).

Local conditions that helped included Samsø's long experience with agricultural cooperatives, a strong innovative drive and entrepreneurial ethos, previous experience with renewable energy, and an active community and community spirit that included inclusiveness and respect for alternative opinions.

The project's master plan translated national goals and guidelines into concrete local action and a common vision on Samsø. Local community interests and the plan were successfully combined through numerous meetings in the Island villages. Communities were given the ability to adapt plans to their local context, focusing on local development. The project was a "true" community energy project with broad local participation. (Roberts & Roberts, 2017; Roberts, 2017)

Once Samsø island had achieved its first objective to become 100% self-sufficient with renewable energies for electricity in 2007, a second phase was launched, "Samsø 2.0", to focus on other sectors such as transportation, and to achieve the Island's long-term goal, to become fossil-fuel free by 2030. Since 2014, the ferry between the island and mainland Denmark runs on biogas which is produced in a multi-functional biogas plant on the island. This plant is the heart of the Island's organic waste management (Renewables Networking Platform, n.d.).

16.2.2 THE ISLE OF EIGG

Eigg is a Scottish island of 30 km^2 with some 100 residents. In 2008, Eigg became the world's first community to launch an off-grid electric system powered by wind, hydro and solar with battery backup. This replaced expensive diesel generators that only ran for a few hours a day. The electrification scheme made 24-hour power available to residents for the first time, integrated into a stable, high-voltage underground grid.

In summer, thanks to the long hours of daylight that benefit Eigg's far-north location, the Solar panels come into their own providing power during a period with there is not much wind or rain. Eigg runs on average 90-95% renewable energy. The use two 70 kW backup generators are necessary for those times when the weather does not cooperate (usually in spring). In winter, excess power is used to heat community facilities on the Island.

When renewables are generating a relatively low amount of energy, a traffic light system set up at the pier provides a form of demand management. A red light requests the residents to limit their usage, a green light, normal usage.

The £1.66m project largely was financed by the European Union's European Regional Development Fund, as well as by national bodies and contributions from the islanders. Where possible, the community owned energy grid Eigg Electric cut down on costs by doing certain jobs themselves, such as laying concrete for the solar panels (BBC, 2017)

The benefits to the Island were cheaper, more reliable energy, with reduced carbon emissions. Follow on benefits included increased the environmental consciousness and pro-environmental behaviour of the community with a rise in awareness of environmental issues and an increase in energy efficiency and local food production on the island (Hicks and Ison, 2011).

16.3 SOLAR GARDENS

Rooftop Solar PV reduces electricity costs and carbon emissions. However, not all are able to have Rooftop Solar PV due to various reasons (renting, no suitable roof space, upfront cost prohibitive, etc). Solar Gardens provides a way for those unable to benefit from having Solar PV on their roofs to benefit from Solar PV. A solar garden is a centralised solar array that offers consumers the opportunity to purchase or lease solar panels with the electricity generated credited to their energy bill (see Figure 4.18 for details). Virtual Net Metering (also known as Local Electricity Trading) provides the mechanism to allow exported electricity generation at one site to be assigned to another site. The term 'virtual' is used to describe this sort of metering arrangement as the exported electricity generation is not physically transferred to the consumer, but rather transferred for billing reconciliation purposes (Langham, Cooper, and Ison, 2013; Inglis, Mitchell, and Passey, 2015). This provides a way of accessing renewable energy for those who are unable to place solar on their homes. The solar panels are located off-site but the household receives a similar outcome as having solar on their own roof (UTS, 2018).

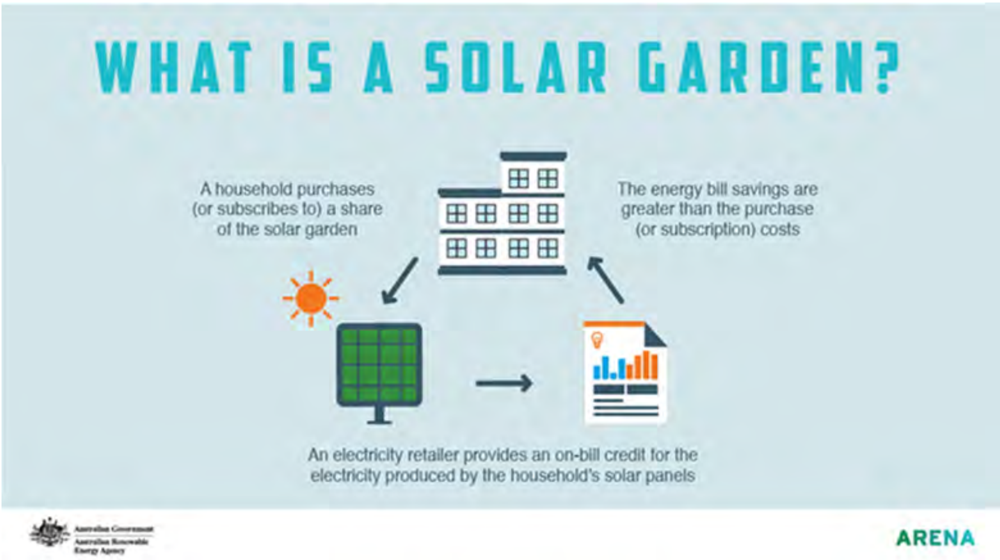


Figure 4.16: *What is a Solar Garden (ARENA, 2020a)*

The people that are locked out of the benefits of rooftop solar often include those on low-incomes where a significant proportion of their daily costs are from the power they consume, and solar gardens may provide a way for these people to access the benefits of solar to reduce their energy costs (Roberts and Roberts, 2018).

UTS and Community Power Agency conducted a study into enabling locked out and low income energy users to participate in solar through Solar Gardens (UTS, 2018). The study found that solar gardens were both feasible and desirable for consumers, provided returns are comparable to rooftop solar provided support equivalent to what is provided to Rooftop Solar PV owners were available (Rutovitz, McIntosh, Ison, Noble, Hicks, and Mey, 2018). As part of the study Norton Rose Fulbright (NRF) explored the legal issues associated with social access solar gardens models and found that there are no legal or regulatory barriers. NRF found a co-operative legal form to be the most appropriate vehicle for a Solar Garden as it facilitates community participation, has low regulation and establishment costs and is easily scalable (Norton Rose Fulbright, 2018). NRF noted that this would best be complemented by a management entity to provide services and expertise to the community vehicle.

In 2019, Enova Community Energy installed Australia's first solar garden and pioneered the systems and processes that will distribute benefits to "Solar Gardeners" (electricity consumers participating in the Solar Garden). The financial benefits generated by a 35kW solar array situated on the rooftop of North Coast Community Housing in Lismore, NSW, are being distributed in the form of energy bill credits to 19 social housing tenants, four community organisations and North Coast Community Housing (Energy Source & Distribution, 2019). The aim is to reduce costs through sharing renewable energy that is locally generated, stored and distributed. Participants in this pilot have had individual smart metering devices installed to measure power inputs and outputs. This data will help work out a new pricing structure based on sharing locally generated power (Williams & Crook, 2020).

Following legislative changes, Greek households, businesses, farmers, and local governments can create their own community solar gardens, up to 1 MWp, and offset their electricity bills through virtual net metering (Greenpeace Greece and REScoop.eu, 2018) and a number of Solar Gardens have been established on the Greek mainland. Hedno, a Greek electricity system operator, has recently established Virtual Net Metering scheme for PV systems on Greek non-interconnected islands such as Crete (Politopoulou, 2018).

Haystacks Solar Garden is a 1MW Solar Farm that will occupy about four hectares of land in Grong Grong, in the NSW Riverina, and will generate enough electricity to supply the daytime energy needs of up to 300 homes (Meier, 2020).

Designed to offer solar power to people without a suitable rooftop of their own, the solar garden will be owned by solar cooperative members formed from people in the local Riverina community (Pingala, n.d.-a). Cooperative members purchase a plot in the Solar Garden, and the electricity generated is sold to an electricity retailer who then provides a credit on the members' electricity bills (Haystacks Solar Garden, n.d.). The amount credited to each "solar gardener" is determined by the size of their "plot" and the arrangements made with the participating retailer (Vorrath, 2020).

The concept is a particularly good fit with renters, in that the electricity credits generated by a 'virtual plot' of solar panels moves with its owner, if they move to a new house, as long they remain with the retailer (Vorrath, 2020).

The project is expected to be completed in 2021 and will provide local opportunities to design, build and maintain the solar farm, and income for host site (Haystacks Solar Garden, n.d.; Meier, 2019).

17. MOVING TOWARDS 100% RENEWABLE ENERGY

In June 2020, the NIRC released its Draft Operational Plan 2020-2021 (NIRC, 2020c). This contained an updated target for the Norfolk Island Delivery Program 2016-2020 (NIRC, 2016b) to "*Achieve 100% renewable energy generation on Norfolk Island by 2024*". This target was in support of the strategic direction "*An environmentally sustainable community*" and strategic objective to "*Use and manage our resources wisely*" and associated plan "*Develop a clean energy future*" detailed in the Community Strategic Plan 2016 – 2026 (NIRC, 2016a).

The council operational plan targets associated with this new target were:

- Develop a 100% Renewable energy Vision and Exploration Statement for Council approval by September 2020,
- Establish a Norfolk Island 100% Renewable Energy Transition Advisory Committee to maximise expert input and help to steer program implementation over next 5 years by November 2020,
- Develop a Request for Proposals by February 2021 to undertake a business case to assess best options for achievement of 100% renewable energy, and
- Undertake preliminary assessments realistic funding, financing, and procurement and delivery options by February 2021 (NIRC, 2020c).

17.1 BENEFITS OF MOVING TO 100% RENEWABLE ENERGY

Transitioning Norfolk Island to 100% Renewable Energy will result in a number of benefits:

- The cost of electricity will be lower as the cost of renewable energy plus storage is below the cost of diesel generation (Mburu, 2020; IEEFA, 2020). This would have a ripple effect on the Island economy, boosting economic growth (Smit and Bondesen, 2010; Troman, 2013).
- GHG Emissions would be significantly be lower, avoiding (in the case of Norfolk Island) 38,468 tonnes CO2-e GHG emissions per year (See Appendix A for calculations). This helps towards Australia's contribution to the Paris Agreement. The Paris Agreement sets out a global framework to avoid dangerous climate change by limiting global warming to well below 2°C and pursuing efforts to limit it to 1.5°C (European Commission, n.d.).

The dependency on volatile priced imported fuel oil is reduced or eliminated, resulting in:

- Reduced exposure to fluctuating and rising diesel prices,
- Fuel cost savings,
- The environmental risk is reduced from diesel spills both on land and in water,
- Reduced noise and clean air, and
- Greater energy independence for Norfolk Island (Troman, 2013).

The profile of the island as an *environmentally sustainable community* is enhanced. This aligns with The Norfolk Island Tourism Strategic Plan stated that "*Norfolk Island should seek to establish itself as a beacon for sustainable practice in our region*" (Norfolk Island Tourism, 2013). A clean, environmentally friendly, sustainable system of electricity production would tie in to eco-tourism marketing of the island as a clean, green, pristine, picturesque destination (Barton, 2003; NIG, 2014), providing considerable scope to increase earnings from tourism by targeting different age groups and market segments (SGS Economics and Planning, 2015).

The transition would also produce local employment and capacity building including:

- Local employment in construction and operation, and
- Utility staff would learn skills necessary for long-term management, operation and maintenance of the renewable energy systems (Troman, 2013)

17.2 HOW TO GET THERE/TRANSITION APPROACH

Hydro Tasmania (2018c) recommends a staged deployment to transition Norfolk Island to 100% Renewable Energy. To detail the pathway to greater renewable energy, they recommend the creation of a Strategic Implementation Plan. This would map out how the end goal could be realised through a series of implementation stages and would be a valuable risk mitigation tool. With each stage, more renewable energy is added, and technological enablers added as appropriate. These enabling technologies, such as power system integration and control systems, that Hydro Tasmania (2018c) note are key to building high renewable penetration power systems.

In additional to enabling technologies, maximum renewable energy penetration grids require a mixture of renewable sources (Hydro Tasmania, 2018c). The current planned project lacks generation diversification. With the first stage planned to be Solar PV farm and centralised battery storage, subsequent stages would need to pursue other forms of renewable energy that are available on the island such as Wind and Wave Energy. If possible, a mix of variable renewable energy (such as wind and solar) and dispatchable renewable energy such as bioenergy or forms of energy storage such as pumped hydro or batteries, would provide this generation diversification.

The complementarity of renewable resources is another important factor, such as does the prevailing wind blow at night or during the middle of the day when solar irradiance is at its peak?

Seasonal complementarity between renewable sources is a further aspect for high renewable energy penetration grids and needs to be considered. For example, Galapagos Islands has higher wind speeds in winter months and lower speeds in summer impacting on renewable generation during the tourist season. However, solar irradiation is higher in summer months which could supplement the low generation from wind with the implementation of Solar PV (Global Sustainable Electricity Partnership, 2016a).

Switching from diesel to biofuels is another step towards 100% renewable energy. Hydro Tasmania (2018c) remarked that directly substituting diesel with biodiesel is appealing because it uses existing infrastructure and required very little capital cost and can be purchased internationally like diesel.

A dedicated thermal biomass gasifier gasification plant could form an alternative or complementary approach to achieving 100% renewable energy.

For the transition as a whole and in each planning each stage, analysis of technical feasibility, economic evaluation and lifecycle costs, system reliability and environmental impact are required. A suitable tool for this is HOMER Pro (HOMER Energy, n.d.).

HOMER Pro Microgrid Analysis Tool software (Hybrid Optimization of Multiple Energy Resources) (HOMER Energy, n.d.) is a widely used and reliable tool for microgrid planning purposes. It provides least cost solutions and allows you to mix conventional power such as diesel generation with renewable resources such as wind, solar PV, biomass generators, gasification plants, fuel cells, along with storage such as batteries, pumped storage and load management including demand management and energy efficiency (HOMER Energy, 2016, 2:00; Montuori, Alcázar-Ortega, Álvarez-Bel, & Domijan, 2014). HOMER Pro's approach to modelling combines simulation, optimisation, and sensitivity analysis to determine the technical feasibility and lifecycle costs of a microgrid for each hour of the year for power generation planning including Net Present Cost, LCOE, and CO2 emissions (Clairand, Arriaga, Cañizares and Álvarez-Bel, 2019; HOMER Energy, 2016, 2:00). It is suitable for use with Island Grids with an existing 24x7 grid typically powered by diesel like Norfolk Island (HOMER Energy, 2016, 3:00)

HOMER Pro has been used in a number of studies of island microgrids including Galapagos Islands (Clairand, et al., 2019), Pulau Ubin (Fan, Rimali, Tang, & Nayar, 2012), and Hainan Island (Bin, Jie, Liji, Jiemin, & Xiaomei, 2012).

17.3 FINANCING THE TRANSITION

Borrowing by local government authorities differs across Australia. The state borrowing authority is a major source of finance for councils in most states, but generally councils can borrow from other sources including commercial banks and the Clean Energy Finance Corporation (CEFC, 2016).

The Clean Energy Finance Corporation (CEFC) offers tailored finance for Australian councils to invest in clean energy and energy efficiency, to reduce costs and lower carbon emissions through their Local Government Finance Program (CEFC, 2016).

The key features of the CEFC Local Government Finance Program are:

- Three-year availability period, allowing councils to secure committed finance for a three-year program of works.
- It provides funding certainty for councils to implement clean energy projects and reduce operational costs without the upfront capital requirement.
- Flexible drawdown, either upfront drawdown of 100 per cent of the funds or quarterly drawdown over the availability period
- Long loan tenor: Long-term CEFC debt of up to 10 years provides council with scope to spread the capital costs of an upgrade project over a longer period of time, in line with the asset life of the investments.
- Fixed interest rates for repayment certainty.

- Flexible repayment arrangements tailored to the council's needs; As many clean energy projects have payback periods of less than 10 years and the long loan term allows councils to match or extend the financing to the forecast payback period (CEFC, 2016).
- Flexible repayment profiling, where repayments can be matched to the project economics or the council's cashflows, creating a debt product that is aligned to the project. In this way the savings from clean energy investments can offset the loan repayments, minimising the effect on council budgets. It is expected that the financing of the capital costs would be covered by the reduced electricity costs for the length of the loan (Roberts**,** Stace, Roberts, Conway, Van Nettern & Woodard, 2016; CEFC, 2016).

Green bonds fund projects that have positive environmental and/or climate benefits such as renewable energy and energy efficiency projects. Green bonds are compliant with the Climate Bond Initiative Standard. Under this international standard, bonds must be independently certified to verify the proceeds will be used in projects that meet certain criteria, developed by scientists and industry experts (Roberts & Roberts, 2016).

Queensland Treasury Corp., Treasury Corp Victoria, and TCorp (NSW) have issued local government green bonds to finance a range of transport, water, buildings, and energy projects (Climate Bonds Initiative, 2018). Local government Green Bonds provide an alternative debt instrument to fund local government infrastructure projects such as renewable energy and energy efficiency projects.

Funding could possibly come from grant funding from ARENA. The key purpose of ARENA is to improve the competitiveness of renewable energy technologies, and to increase the Australian supply of renewable energy by advancing renewable energy technologies towards commercial readiness, improving business models, and reducing overall industry costs (Roberts**,** Stace, Roberts, Conway, Van Nettern & Woodard, 2016).

Rather than the council raising the funds for a renewable energy project through grants or loans, it may be preferable for a renewable energy installation to be owned by the community of Norfolk Island and sell the power to Norfolk Island Electricity (owned by NIRC) through a dedicated power purchase, lease or loan agreement. This would increase community acceptance and buy-in of these proposed changes to the Island's Electrical System and release funds for less visible but equally important parts of the renewable project.

17.4 TRANSITIONING TO 100% RENEWABLE ENERGY ON OTHER ISLANDS

17.4.1 ISLE OF MAN

The Isle of Man government recently declared a climate emergency and committed the island to a target of net zero carbon emissions by 2050, which is in accordance with the European Union's Paris climate agreement (Vannin, 2019).

The government's "action plan" includes a commitment to produce 75% of the Island's electricity from renewable sources by 2035, including projects to construct on and offshore wind turbines, and investigating options for tidal and solar power energy generation (Vannin, 2020).

Vannin (2020) remarked that local support for wind turbines was high, with a 2019 consultation finding that about 80% of respondents would back wind turbines, with 76% in favour even if they were "visible from their home".

Measures to offset current emissions during the first year of the plan include repairing peatland, planting a woodland, and the creation of more marine nature reserves to promote carbon capture. A ban on all peat cutting will also be introduced (Vannin, 2020).

Plans to stop the sale of petrol and diesel cars on the Isle of Man by 2040 have already been announced, along with the banning of oil and gas boilers in new houses by 2025 (Vannin, 2019).

17.4.2 KRK ISLAND (CROATIA)

The people of Krk aim to make their island the first CO2 neutral and energy self-sufficient island in the Mediterranean and is the only Croatian island to be included in the prestigious list of European energy-transition islands. In 2012, they adopted the "Island with 0 percent CO2 emissions" strategy and have conducted studies on wind farm development and solar power plant integration. They are now planning construction of a 5 MW solar farm, 25.2 MWP of wind power and 250 KWP of biogas plant expected to make the island completely energy independent (Rogulj, 2020).

17.4.3 GALAPAGOS ISLANDS

The Ecuadorean Government has identified the Galapagos Islands as a national priority for conservation and environmental management, developing the Galapagos Zero Fossil Fuels program, which consist of measures and actions to avoid habitat degradation and ecological impact (Clairand, Arriaga, Cañizares and Álvarez-Bel, 2019).

The Ecuadorean government invested and installed solar farms, wind turbines, and a battery storage systems and is proposing additional solutions such as the change from propane stoves to induction stoves, and from Internal Combustion Vehicles (ICVs) to Electric Vehicles (EVs) (Clairand, Arriaga, Cañizares and Álvarez-Bel, 2019).

In addition to the island of Krk, which is the only Croatian island to be included in the prestigious list of European energy-transition islands, the Dutch island of Ameland, the Irish Aran Islands, the Portuguese Azores, the Isle of Gigha, the Swedish Gotland, the Spanish Menorca, the Italian Pantelleria, the Greek Tilos and the Danish Samso are also on the list of good practices (Rogulj, 2020).

17.4.4 SAMSØ ISLAND

Samsø is well recognised nationally and internationally as a best practice example of how a community can transform its fossil fuel-based energy system into a renewable energy-based one.

In 1997, Samsø, with its roughly 4,000 inhabitants, won a national competition to become Denmark's "Renewable Energy Island" with the goal to implement a self-sufficient energy supply based on renewable energy in combination with reductions in energy demand. Starting from a renewable energy share of only 13% in 1997, by 2005 Samsø had achieved this goal of 100% local renewable energy for electricity (Sperling, 2017). A second phase was then launched, "Samsø 2.0", to focus on other sectors such as transportation, and to achieve the Island's long-term goal, to become fossil-fuel free by 2030 (Renewables Networking Platform, n.d.).

17.5 ENERGY TRANSITIONS AND FUTURE COMMUNITY ENERGY ON ISLANDS

As part of the Clean Energy for EU Islands Initiative of the European Commission (Clean Energy for EU Islands, 2019), Six European islands/island groups recently published their clean energy transition agendas, including a strong citizen focus on community ownership in decarbonizing their energy systems. The Aran Islands (Ireland), the Cres-Losinj archipelago (Croatia), Culatra (Portugal), La Palma (Spain), Salina (Italy), and Sifnos (Greece) have each developed decarbonisation pathways tailored to their individual needs and assets:

- The Cres-Lošinj archipelago aims to completely decarbonise its energy system by 2040 in part through community-owned solar farms;
- Culatra will work towards 100% renewable energy self-consumption, which will be owned by the local community;
- The Aran Islands will install community-owned wind power, retrofit homes, and deploy heat pumps or other renewable energy sources for domestic hot water and space heating;
- Salina aims to increase public awareness on energy and environment. Salina will decarbonise its power generation plants, switch to 100% electric/hybrid mobility on the Island, increase efficiency in its buildings and decarbonise its maritime transport;
- La Palma aims for full decarbonisation and self-sufficiency in the energy sector. The island transition team puts a strong focus on building a resilient island energy system, actively involving the more than 100 local associations who committed to supporting the Island's transition; and
- Sifnos aims to become 100% renewable and self-sufficient. Any installations will be co-owned by the local community and private investors (Clean Energy for EU Islands, 2019).

18. FUTURE STATE

18.1 ENERGY CASE STUDY 1 – PROGRAM TO STABILIZE THE ELECTRICITY GRID

Norfolk Island Regional Council (NIRC) are planning to upgrade the Island's electrical system based on recommendations of a comprehensive study by Hydro Tasmania (2018a; 2018b; 2018c). From the presented options the NIRC selected a 1 MW centralised solar farm with a battery for energy shifting and no wind component as the preferred option for the new renewable project. Slightly amended from the recommended option, this would entail a: 1MW solar farm, no wind, battery storage 2MW / 5.5 MWh, a new central control system, with one diesel generator always on (at 30% minimum load). The new control system would automate additional diesel scheduling, keeping diesel use to a minimum. It would also control scheduling of the load banks, solar farm generation and battery storage to assist in maintaining stability and reliability of the grid.

Hydro Tasmania (2018c) remarked that this project was not expected to be economically feasible but represented the cheapest capital cost option of the recommended solutions, primarily because there are insufficient diesel savings to offset the capital and operational costs of the proposed project (as one diesel generator continues to be always on). Furthermore, the new system is expected to raise the percentage Renewable Energy contribution for Norfolk Island from the current 22% to 45% which is below the 60% council objective for the project. Moreover, the selected option continues to use the diesel generators for ancillary services which could be served by the centralized batteries (BESS) with the grid formed by the batteries.

It is recommended to investigate and implement a "diesel-off" system, that incorporated the solar farm and a grid-forming battery energy storage system (BESS). The BESS replaces the services provided by a diesel generator, including frequency and voltage control and provision of fault current. The control system would fully integrate control over solar, BESS and diesel engines, to coordinate scenarios of diesel only, solar/diesel hybrid, and diesel off operation (ARENA, 2019c). This would further reduce the use of diesel, increasing the renewable energy contribution of the island, and the financial viability of the project.

Similar projects and studies have been conducted or are underway on other islands, including Bonaire Island (Burger, 2019), and Graciosa Island (Wärtsilä, 2020).

The Hydro Tasmania study noted that none of the options presented appeared to result in the solar moratorium being lifted. Moratorium could only be lifted with extensive alterations to existing installations, such as inverter replacements and significant policy and tariff changes (Hydro Tasmania, 2018b).

Hydro Tasmania (2018c) recommended energy policy changes be implemented in parallel to the Renewable Energy project to ensure ongoing grid reliability and financial viability of the Electricity System on Norfolk Island. These would be implemented appropriately phased in over time, with sufficient notification periods to allow consumers to plan for changes, avoiding abrupt changes. The study recommended a long-term strategic plan be developed to ensure that future network investment decisions incorporate controllable distributed energy resources.

It is recommended that technologies associated with a smart grid with smart control of distributed energy resources (i.e. Rooftop solar PV and home batteries) be implemented as part of energy policy changes and tariff reform. This would assist with grid reliability and resilience (Hydro Tasmania, 2018c). Furthermore, smart control of distributed energy resources in combination with ancillary services and load balancing provided by the centralised batteries (BESS) would allow for additional renewable energy on the grid (such as additional Rooftop Solar PV), further displacing diesel usage, and ending the moratorium on new generation.

Similar projects and studies have been conducted or are underway on other islands, including Orkney Islands (EMEC, 2019), and the remote Australian community of Lockhart River (SwitchDin, n.d.-b).

18.2 ENERGY CASE STUDY 2 – PROGRAM TO EXPAND ROOFTOP SOLAR PV AND BATTERY

Following the successful completion of the grid stabilisation project, the implementation of energy policy changes and tariff reform, and the removal of the moratorium on new generation, a program should be initiated to expand the use Rooftop Solar PV to both households and businesses. This would further help address the inequity between homes and businesses that have Solar PV and those that do not. It would also reduce cost of electricity and the reliance on diesel generation on the island.

Centralised grid forming BESS provides the ability smooth the solar output during periods of intermittency and ancillary services for the grid such as frequency and voltage control and provision of fault current. However, the degree to which a centralised BESS can implement load shifting or peak shaving associated with the effective management of variable renewable energy such as solar PV and wind is limited to the size of the centralised BESS and the capital cost associated with its implementation, and risks curtailment of these resources. A more effective way to utilise excess wind and solar energy would be to supplement the centralised BESS through distributed battery storage of home and business battery storage. This would reduce the need for diesel generation when the supply of renewable energy was low.

Both Rooftop Solar PV and battery storage for homes and businesses could be effectively promoted on Norfolk Island through a Rooftop Solar PV and battery storage bulk buy scheme. Community bulk-buys increase the affordability and take-up of solar and batteries through discounted bulk offerings of high-quality Tier 1 solar PV and battery systems. Through partnering with a well-established and proven solar power installer and through bulk ordering significant discounts of between 20-30% of recommended retail prices are possible. Installations are usually conducted in blocks with say 40 installations in 4 weeks for each block. Rooftop Solar PV packages can be upgraded to include battery storage and are made available to home, farms, and businesses. Several successful bulk buy schemes have been conducted across NSW. For example, the Farming the Sun Solar Bulk Buy scheme in New England and Northern Rivers NSW has exceeded 2.4MW of home and business Rooftop solar PV installations with an average system size of 4.8kW (Farming the Sun, 2018).

18.3 ENERGY CASE STUDY 3 – COMMUNITY OWNED SOLAR FARM

Community Energy is an approach to renewable energy development that involves the community in initiating, developing, operating, owning, and/or benefiting from a renewable energy project (Hicks, Ison, Gilding and Mey, 2014). The social model behind this is that everyone should be able to participate in renewable energy (Roberts, 2017). Community ownership of renewable energy projects such as community owned solar and wind farms can mitigate local opposition through greater community acceptance (Ruggiero, Onkila, & Kuittinen, 2014).

Norfolk Island Regional Council (NIRC) are planning to upgrade their electrical system based on recommendations of a comprehensive study by Hydro Tasmania. As noted above, from the presented options the NIRC selected a 1 MW centralised solar farm together with a battery for energy shifting the preferred option for the new renewable project.

Rather than the council raising the funds for the solar farm through grants or loans, it may be preferable for the Solar Farm to be owned by the community of Norfolk Island and sell the power to Norfolk Island Electricity (owned by NIRC) through a dedicated power purchase, lease or loan agreement. This would increase community acceptance and buy-in of these proposed changes to the island's Electrical System and release funds for less visible but equally important parts of the renewable project.

The solar farm would be owned by cooperative members from local people on Norfolk Island by investing in shares in the cooperative. The cooperative would seek to pay dividends to its members each year. At the end of the agreed term (typically 3 years), the solar farm would be nominally sold to Norfolk Island Electricity. Shareholders would remain members of the cooperative with their returned capital reinvested in new renewable energy projects. If there are no new projects, then the funds would be returned, and the shares bought out by the Co-operative (Pingala, n.d.-b).

Similar projects and studies have been conducted or are underway on other islands, including Samsø Island (Denmark) (Roberts, 2017), and the Isle of Eigg (Scotland) (Hicks & Ison, 2011).

18.4 ENERGY CASE STUDY 4 – TRANSITIONING TO 100% RENEWABLE ENERGY

The 2016-2026 Norfolk Island Community Strategic Plan – *Our Plan for the Future* Our is a critical strategic and aspirational plan for the Norfolk Island community and for the Norfolk Island Regional Council. It sets out a long-term vision for the Norfolk Island community along with meaningful and measurable objectives and strategies. The plan presented a vision for Norfolk Island, "*Norfolk Island – the Best Small Island in the World"*. To help achieve this vision, the key strategic direction "An environmentally sustainable community - Our choices benefit our natural environment and our community" with the objectives "*Use and manage our Resources wisely*" and "Preserve a healthy environment" were identified. One of the key paths in addressing this strategic direction and objectives was "Develop a clean energy future". The Norfolk Island Delivery Program 2016 – 2020 (NIRC, 2016b) identified targets for this path as "Solar battery storage, or an alternative option, is installed to capture excess electricity generated by photovoltaics. The moratorium on the installation of new photovoltaic systems is lifted." These targets were subsequently amended in the Draft Operational Plan 2020-2021 (NIRC, 2020c) to be "*Achieve 100% renewable energy generation on Norfolk Island by 2024*".

Many benefits will accrue to transitioning Norfolk Island to 100% Renewable Energy. These include:

- The cost of electricity will be lower,
- GHG Emissions will be significantly be lower, avoiding (in the case of Norfolk Island) 38,468 tonnes CO2-e GHG emissions per year (See Appendix A for calculations),
- The dependency on volatile priced imported fuel oil would be reduced,
- The profile of the island as an *environmentally sustainable community* will be enhanced, and
- The transition will produce local employment and capacity building (Troman, 2013).

Hydro Tasmania (2018c) recommends a staged deployment to transition Norfolk Island to 100% Renewable Energy and the creation of a Strategic Implementation Plan to map out how this would be achieved.

With each stage, as more renewable energy is added, technological enablers such as power system integration and control systems are added. Generation diversification is also important. With the first stage planned to be Solar PV farm and centralised battery storage, subsequent stages would need to pursue other forms of renewable energy that are available on the island such as Wind and Wave Energy. A mix of variable renewable energy and dispatchable or forms of energy storage would also prove useful in providing this diversification. Fuel switching from diesel to biofuels or a dedicated thermal biomass gasifier gasification plant could form an alternative or complementary approach to achieving 100% renewable energy.

For the transition as a whole and in each planning each stage, analysis of technical feasibility, economic evaluation and lifecycle costs, system reliability and environmental impact are required. A suitable tool for this is HOMER Pro (HOMER Energy, n.d.).

HOMER Pro Microgrid Analysis Tool software (HOMER Energy, n.d.) is a widely used and reliable tool for microgrid planning purposes that provides least cost solutions and allows you to mix conventional power such as diesel generation with renewable resources along with storage (HOMER Energy, 2016, 2:00; Montuori, Alcázar-Ortega, Álvarez-Bel, & Domijan, 2014). Its approach to modelling combines simulation, optimisation, and sensitivity analysis to determine the technical feasibility and lifecycle costs of a microgrid and is suitable for analysis and planning for island grids like Norfolk Island (HOMER Energy, 2016).

Financing for a renewable energy transition can come from several sources including:

- Traditional loan arrangements with a state borrowing authority,

- The Clean Energy Finance Corporation (CEFC) offers tailored finance for Australian councils to invest in clean energy and energy efficiency, to reduce costs and lower carbon emissions through their Local Government Finance Program (CEFC, 2016). This is effectively cost neutral, as the financing of the capital costs could be covered by the reduced electricity costs for the length of the loan (Roberts**,** Stace, Roberts, Conway, Van Nettern & Woodard, 2016; CEFC, 2016).
- Local government Green Bonds provide an alternative debt instrument to fund local government infrastructure projects such as renewable energy and energy efficiency projects.
- Grant funding from ARENA is available to increase the Australian supply of renewable energy by advancing renewable energy technologies towards commercial readiness, improving business models, and reducing overall industry costs (Roberts, Stace, Roberts, Conway, Van Nettern & Woodard, 2016).
- Community Owned Renewable Energy projects are community investment models that allow community members to own renewable energy installations such as wind and solar farms through a legal structure such as a cooperative. The cooperative has a loan, lease or power purchase agreement with the council that is repaid through use of the generated electricity.

18.5 LINKAGES TO OTHER THEMES: TRANSPORT CASE STUDY – ELECTRIC VEHICLE STRATEGY

Local transportation on Norfolk Island is almost entirely dependent on imported petrol and diesel fuel, accounting for 1/3 of island fuel imports. This makes fuel expensive and exposes the island to oil price changes. Consequently, the price of diesel and petrol on Norfolk Island is among the highest in the world.

Norfolk Island has also shown to be particularly vulnerable to the effects of climate change such as increased intensities and frequency of extreme weather events and sea level rise that could disrupt imported fuel supply chains, however, with a dependence on imported fossil fuel, vehicle use currently accounts for 50-60% of household emissions on Norfolk Island.

Electric Vehicles (EVs) are a natural fit for small remote islands such as Norfolk Island. Like other small islands, Norfolk Island is geographically compact, minimising charging infrastructure and driving distance issues. It has good solar and wind resources, reducing the cost of electricity of charging of EVs and has expensive and somewhat risky fossil fuel supply chains. However, previous efforts to introduce electric vehicles to Norfolk Island have not been successful.

Uncontrolled charging of EVs can lead to additional electricity needing to be produced mainly from diesel generators. The additional loads posed by charging could lead to a change in the Island's daily load profile and an increase the demand peak. Charge management strategies are required to minimise the impact on the grid. These would include smart charging and vehicle-to-grid technology together with pricing incentives for users to change their Electric Vehicle charging behaviour. Smart charging and vehicle-to-grid technology can soak up excess renewable energy supply allowing more variable renewable energy onto the grid and decreasing fuel costs and emissions. Through vehicle-to-grid technology, EV batteries (like battery storage) can also act as controlled storage, providing ancillary grid services such as spinning reserve, voltage and frequency regulation, and therefore increase the efficiency of the grid.

To ensure success of Electric Vehicle use in Norfolk Island a comprehensive planning strategy is required. The integration of EVs into the grid is somewhat island specific and depends on vehicle usage patterns, potential energy supply and the characteristics of the grid. Data collection and analysis would inform the planning strategy. A study into vehicle-to-grid technology use on Norfolk Island to assist in grid stabilisation may also prove useful.

The planning strategy would include a public awareness campaign, electrification of the council vehicle fleet, customer incentives, smart charging, planned public charging facilities, training for maintenance and sales personnel, partnership development, pilot program, battery end of life usage, and planning for parallel expansion of EVs and Renewable Energy development.

Similar projects and studies have been conducted or are underway on other islands, including Bornholm Island (Denmark) (Wu, et al., 2017), Porto Santo Island (Madeira archipelago) (Casey, 2018), Tenerife (Canary Islands) (Colmenar-Santos, et al., 2017), São Miguel (Azores) (Ioakimidis & Genikomsakis, 2018), and Barbados (Borison, et al., 2019, 01:26; Viscidi, et al., 2020).

Summary/Findings

- Norfolk Island has abundant solar, wind and wave energy resources.
- Norfolk Island has high diesel usage for electricity production, high-energy costs and generates high overall greenhouse gas emissions.
- The Island power plant is old, lacking automation, and a lack of data on both the plant production and power grid.
- The power grid suffers from localised grid voltage issues because of unplanned high penetration of rooftop Solar PV (1.4MW of solar). This causes localised outages and tripping of Rooftop solar PV inverters.
- Most rooftop Solar PV inverters are nearing end of life and have a limited management ability to assist with grid stabilisation.
- A high feed-in tariff for rooftop Solar PV has resulted in an inequity between homes and businesses that have Solar PV and those that do not.
- An initial centralised battery storage system has been commissioned smoothing of the Island 1.4MW distributed solar systems and to absorb energy that would otherwise be diverted to the Power Station Load Bank.

Recommendations

- Prior to undertaking further renewable energy installations several changes should be considered to stabilize the electricity grid, including the replacement of old rooftop solar PV inverters with new smart inverters that can assist with grid stabilisation, the implementation of a micro-grid control system, and the implementation of a demand management system. This should be done in conjunction with the migration of ancillary services from the diesel generators to the centralised Battery Storage. The power plant should be automated, together with improvements in data logging of both plant and grid generation and consumption. The diesel generation would also be reconfigured to be in standby mode (diesel off mode).
- Consider tariff reform to reduce the inequity between the Rooftop Solar PV haves and have-nots and to reduce electricity charges across the island in conjunction with the removal of the Rooftop Solar PV moratorium.
- Consider the deployment of additional battery storage to provide firming capacity for variable renewable energies such as wind and solar, to stabilize the grid and take that burden away from diesel generation that traditionally provided ancillary services on remote islands.
- Consider a hybrid system entailing wind, solar, battery storage, and diesel generation, and increasing capacity of energy storage or dispatchable electricity generation, so that solar and wind energy would displace and potentially eliminate diesel generation.
- Consider several renewable energy pilot projects, such as Rooftop Solar PV and Home Battery bulk buys, Solar Farm/Community Owned Solar Farm, Solar Garden, further Grid/Community Battery Storage, Wind Farm, Wave Energy, Electric Vehicle strategy, and Induction Cooking replacing LPG gas.

CHAPTER 5: NORFOLK ISLAND'S FOOD SYSTEM

In a well-functioning community food system, the food production, processing, distribution, consumption and post-consumer waste disposal are all integrated to enhance the environmental, economic, social and nutritional health of a particular place and its inhabitants.[38]

5.1 BACKGROUND

Norfolk Island has an interesting and varied food landscape. When it comes to producing food, the Island is fortunate to possess a mild climate moderated by the ocean, with average temperatures of 13–19 degrees Celsius in winter and 18–25 degrees Celsius in summer, rich volcanic soils, and generally favourable rainfall levels. It has a long history of self-sufficiency in terms of food, and still produces a wide range of fruit, vegetables and animal products such as meat and eggs. Historically, due to the limited nature of shipping, the local population has relied on growing their own food and eating seasonally. Norfolk Island has an area of around 3855 ha, of which ~460ha were cultivated in the 1830's, down to only 10ha presently (Petheram et al, 2020). Hence the food landscape has now a greater diversity of local and imported food. Nevertheless the community has a high degree of awareness and passion for its culinary traditions and for the Island's diverse and seasonal produce.

This study sought to investigate the characteristics of Norfolk Island's food system, its organisation, capacity and constraints, to better assess the opportunities and challenges to build a sustainable and resilient food system for Norfolk Island. The context for this study was to inform the implementation of the Norfolk Island Community Strategic Plan 2016-2026 and make recommendations for the realisation of a 'Food Secure Community'.

Information was collected from the food system actors on Norfolk Island (consumers, producers and retailers) on the key issues in the current production, processing, importation and distribution of food. The information collected also served as a basis to examine both options and barriers to food localisation, i.e., for the Island to produce and transform more food locally to increase self-sufficiency and ensure long-term food security.

5.2 METHODOLOGY

A combination of two main methods of information gathering were utilised for this report: a review of existing literature and a public consultation, which included online surveys and semi-structured interviews.

The public consultation sought to elicit community knowledge and perspectives from key actors within the community, participants in the food system. Specifically, it aimed to:

- Understand what underpins consumers' preferences for local or imported food
- Assess the potential for increasing local food production and processing to provide a broader range of locally produced and processed food and farm products as a way to strengthen the Norfolk Island food economy
- Identify points where investment of resources or other actions could eliminate barriers currently impeding the development of local agri-food businesses
- Assess the community interest in education/awareness-raising around sustainable food and regenerative agriculture, soil health and its relation to nutrient dense food, health and wellbeing outcomes

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[38] *https://growingfoodconnections.org/about/community-food-systems-planning/*

Online Surveys
Two online surveys were created, one was targeted at consumers (those buying food for themselves or their household), and the other targeted at commercial operators (those buying food for a food-related business such as a restaurant, cafe, takeaway or for catering). Surveys were promoted via full-page newspaper advertisements, radio announcements and through various Norfolk Island Facebook community pages. Online surveys took the form of a series of multiple choice and checkbox answer questions.

Food purchasing behaviour can be a sensitive subject in a small community, and so to encourage participation and honest feedback survey, responses remained anonymous.

Semi-structured interviews
Semi-structured face-to-face interviews with a variety of local food system actors were undertaken. These included:

- seven well-established producers (three market gardeners, one cow milk producer);
- one goat milk producer;
- one mushroom producer;
- one egg producer;
- four community members with an interest in starting or growing their food producing/processing businesses (one cheese producer, one avocado producer, one mushroom producer, one duck meat producer);
- two retailers;
- two restaurant owners, and;
- a representative of the Norfolk Island Central School.

In the interests of anonymity, the identity of the interviewees remain private.

5.3 AN OVERVIEW OF NORFOLK ISLAND'S FOOD SYSTEM: VULNERABILITIES, CONSTRAINTS AND OPPORTUNITIES

An examination of Norfolk Island's food system – i.e., the current state of food production, food system actors, infrastructure, importation, and distribution, shows opportunities to strengthen the local food system, better support community-based initiatives to diversify local food production, as well as the constraints of the system, which were raised and discussed during the interviews.

5.3.1 FOOD PRODUCERS
Norfolk Island is home to a number of commercial food producers, including several larger market gardeners, graziers of cattle and sheep, pig owners, egg producers, beekeepers, a cow dairy, a goat dairy, and a number of smaller part-time and fledgling producers producing everything from duck meat and nuts to seasonal fruit, tea, coffee and herbs. Norfolk Island also has a number of commercial fishermen who supply all the restaurants, cafes, takeaways, residents and tourists. The following are the major commercial food producers on Norfolk Island:

- 4 major market gardens
- 1 mushroom producer
- 1 coffee producer
- 2 honey producers
- 1 pork producer
- 1 duck meat producer
- 2 egg producers
- 1 cow milk producer (who ceased to operate in April 2021)
- 1 goat milk (and other dairy products) producer
- Numerous commercial fishermen

Beef and dairy

A substantial herd of beef cattle graze both commons and private land, and which are owned by dozens of residents (Figure 5.1). From this herd, cows are periodically slaughtered for private and commercial purposes.

For much of Norfolk Island's history, the Island produced all or most of the dairy products it required including milk, cream, butter, and cheeses. When pasteurisation was mandated producers faced a substantial increase in costs due to the need for purchasing and freighting-in the necessary pasteurising equipment, along with the associated energy costs required to heat and rapidly cool the milk as a part of this process (noting that both electricity and gas costs are several times higher on Norfolk Island than Australia). The increase in the frequency and severity of droughts was also identified by interviewees as contributing to the demise of the local dairy industry. Imported long life (UHT) milk and other mass-produced dairy products replaced the local alternative and the dairy industry all but ceased to exist.

Figure 5.1: Beef cattle grazing near Kingston, Norfolk Island.

A small-scale milk producer re-entered the market in the late 2010s and produced a modest amount of milk, approximately 50 litres per day. In April 2021, the milk producer ceased to operate.

Due to it being done largely by hand, the local milk had a final price tag of around twice the imported long-life alternative. As a result, the buyers mostly consist of tourists, who are evidently prepared to pay more for local milk, some restaurants and cafes and a minority of local residents prepared to pay more for the local, fresh alternative. A substantial quantity of milk locally produced was purchased by a few local cheese and yogurt makers who sell their products locally. The majority of residents responding to the online surveys have indicated that they would prefer to buy locally produced milk but are constrained primarily by price and availability. The local milk is not always available for purchase, whereas the imported alternative usually is and can be stockpiled by consumers and food-businesses due to its long life.

The local milk producer indicated that they could increase production and reduce prices, and presumably others may be prepared to enter the market, if certain challenges could be overcome:

- Drought and seasonal rainfall variability are clearly a challenge, as animals must still be fed during periods when the grass will not grow, and there is already strong competition from beef cattle and other ruminants for feed. In large countries like Australia, feed (hay) can be imported from other parts of the country. This is not an option on Norfolk Island. The ability to irrigate pastures / fodder crops would mitigate this, but there is subject to water availability. The local milk producer indicated that he could carry around twice the number of dairy cows on his land if he had irrigation.
- An ability to mechanically harvest fodder crops such as banna grass or maize would be an advantage, as these crops could be grown in the wetter months, harvested and fed to the cattle in the dryer months in a cost-effective manner. Currently they need to be harvested by hand with a scythe. Hay-making equipment suitable for small acreages, such as a device called a "forage harvester" would assist with this, but such

smaller scale equipment is difficult to source in Australia (more commonly found where acreages a smaller such as in Italy) and the producer has not been able to locate one.

- The challenges associated with improving herd genetics is also a major constraint impeding the expansion of this industry, and obstructing entrance of new players. The herd currently consists of mostly beef cattle, which produce much smaller quantities of milk with low levels of cream compared to specialised dairy breeds. This also effects the viability of the business and precludes the farmer from producing cream and butter.

Figure 5.2: Calves on Norfolk Island.

Fruit and vegetables

Four major market gardens provide local restaurants, cafes and various retail outlets, with vegetables. An important supply of vegetables at the household level and for some local restaurants also originates from home gardens.

There appears to be no major fruit producers on the Island, but rather numerous individuals, including the market gardeners and 'part-time backyard growers', who sporadically supply shops and roadside stands with excess fruit from their properties.

Figure 5.3: Fruit trees on private properties.

The local farmers market is held on Saturday mornings where local produce, essentially fruit and vegetables, is made available, and, additionally there are number of weekly drops done by the commercial food growers to the local restaurants, cafes and various retail outlets including the local supermarkets and roadside stalls. Roadside stalls with honesty boxes are a feature of Norfolk Island where locals also sell their excess home-grown produce. The local community also have a rich history of sharing and exchanging their excess produce with friends and neighbours.

Figure 5.4: Local farmers market at Burnt Pine.

Value adding on Island

There are several value-add food producers who utilise locally grown food to create food items with a longer shelf like jams, pickles, and baked goods. It is generally done on a small-scale, and distributed at roadside stalls or through various retailers. There is limited capacity currently for commercial distribution (lack of finance, infrastructure), and some residents/ food growers are seeking ways to address these shortcomings in order for more local food produce to be made available.

The local restaurants, cafes, takeaways, and catering businesses generally plan their menus around what is available on the Island and showcase the Island's bounty in their culinary creations. Several restaurants have vegetable gardens, fruit trees and laying hens of their own, and make their own preserved food, which contribute to their kitchens needs.

5.3.2 FARMING METHODS

Farming methods on Norfolk Island do not engage in some of the most destructive attributes of broad-scale monoculture cropping and confined livestock production prevalent elsewhere. For example, market gardeners utilise smaller parcels of land, rely less on machinery, and tend to sew a variety of different crops in one plot. This diversity of planting leads to less pest pressure and less reliance on pesticides. Due to their smaller scale hand weeding is achievable, thus they are less reliant on herbicides than larger operations elsewhere.

Figure 5.5: Local market garden.

Common farming methods include:

- Market gardeners on Norfolk Island generally use a low level of mechanisation. Tractors with attached rotary-tillers are typically used to control weeds and till the soil prior to planting. Another attachment may be used to create furrows in the soil. The remaining activities are typically done by hand: fertilising, seeding, weeding, watering, and harvesting. Some producers use irrigation systems when water is available.
- Market gardeners sometimes utilise “green manure” cover cropping to build soil fertility.
- Market gardeners rely on imported fertilisers (NPK, dynamic lifter) to boost soil fertility. In some cases, this is supplemented with locally sourced chicken and cow manure.
- Routine spraying of crops with herbicides is not common. Imported herbicides are generally used to control invasive grasses and woody weeds, however.
- Producers occasionally use imported pesticides or fungicides to control insect or fungal damage to certain susceptible crops.
- Fruit tree crops are entirely harvested by hand on Norfolk Island.
- Certain susceptible fruit trees (such as stone fruit, mango) may be sprayed for insects or fungus, but overall spraying of fruit trees is not a common practice on Norfolk Island.
- Cows, sheep and goats are all free-ranging on Norfolk Island and their pastoral diet is only sometimes supplemented with imported grain-based feed. In the case of dairy goats, their imported feed requirements are greater, due to the complex and demanding nutritional requirements for goat milk production.
- Egg and duck meat producers rely on imported grain-based feed for the majority of their animals’ nutritional requirements.

Figure 5.6: Local produce in market gardens

Hydroponic systems

Hydroponic food systems are typically small-scale operations set up to produce vegetables using less water, avoiding soil disturbance and producing greater yields per square metre than other traditional farming practices (i.e., irrigated broad acre crops and mechanised harvesting). There are estimated to be over 20 hydroponics setups on Norfolk Island.

Figure 5.7: Hydroponics system

In hydroponic systems, water can be controlled and applied only when needed, evaporation is significantly reduced, and the system can be climate controlled in the right setting and type of crop grown (i.e., use of "poly-tunnels"). The use of "poly-tunnels" also decreases/limits the likelihood of pests and disease. In the absence of soil, growing any fresh produce in hydroponic systems requires a soluble nutrient source. The main nutrients needed for best growing results/yields include nitrogen (N), phosphorus (P), and potassium (K). N, P, and K in a soluble form (amongst other micronutrients and trace elements), are applied to the hydroponic system, via the reticulated storage unit; and are typically imported from commercial sources. However, the ultimate aim of a sustainable hydroponic system is to utilise existing nutrient sources available, and only supplement with imported products when needed. Local nutrient production examples are likely to include, but are not limited to:

- Composting of household green waste – use mulch to propagate seedlings before moving to hydroponic system
- Composting of household food waste – use to mix with "green waste compost" to improve nutrient levels
- Composting of chicken litter, then let ferment in water to create a "compost tea" – dilute with rainwater in the hydroponic system
- Worm farming – use the "juice" and dilute with rainwater in the hydroponic system

5.3.3 RELIANCE ON IMPORTED GOODS AND FREIGHT ISSUES AFFECTING FOOD SECURITY

Whilst most food-related businesses on the Island (restaurants, cafes, caterers) utilise a large proportion of local, seasonal produce for their menus, businesses and consumers generally still rely on freight for various dry goods and those not easily (presently) produced on Norfolk Island - such as flour, sugar, and oil as well as fresh produce. Some aspects of the food production have also become reliant on the importation of inputs such as fertilisers, herbicides, pesticides, and stock feed. Producers rely on imported seed (including potato seed stock), fertiliser and some herbicides, pesticides and fungicides for their enterprises, as well as various other farming equipment, spare parts, diesel, and so forth whose procurement is also affected by supply shortages, freight backlogs and increased freight costs.

Norfolk Island residents have always had to deal with freight delays and shortages, which sometimes leads to disruptions to food production activities. The more significant freight issues which have been occurring over the past year have had major impacts on local food producers. For example, a major egg producer had to sell-off all their laying hens as there was no stock feed on the island with which to feed them. This has occurred twice in the past year. At various times, a total absence of fertiliser, certain herbicides, pesticides and stock feed on the Island has equally affected other producers. Food-related businesses have also been affected as they are unable to source essential ingredients. Cafes have been unable to sell coffee to tourists at times due to an absence of milk, for example. Some cafes and restaurants have had to close their businesses or operate on a reduced opening schedule.

Norfolk Island's freight situation has become more problematic for residents and business owners in recent years, with closure of one of the two ships which previously serviced the Island. This has resulted in a reduction in surface freight of approximately two thirds, causing serious supply issues for local businesses. More air freighters have been scheduled in an attempt to make up a small fraction of the shortfall, however with this has come at increased costs compared to sea freight, and it remains uneconomical to air-freight heavier items like flour, sugar, rice, stock feed, and most building supplies.

Figure 5.8: Shortages of supplies in the local supermarket

Whilst freight issues are an impediment to strengthening the local food system (e.g., reliance on imported stock feed, etc.), the unreliability of freight is also a factor that should trigger the strengthening of the local food system for self-sufficiency. The ongoing freight issues with respect to certain food and farm-related items may constitute an additional motivation to explore opportunities to produce and process more on the Island and become less reliant on imported alternatives.

For example, Norfolk Island is dependent on imported flours for its baking and cooking needs. The Island is also dependant on imported grain-based feed for livestock (chickens, ducks, and pigs). Large quantities are freighted to the Island regularly, and when there are shortages, businesses and consumers are affected. Three of the producers interviewed suggested local grain and flour alternatives be investigated. They provided suggestions for several crops that could be grown very easily on Norfolk Island from which flour and other products such as livestock feed could be derived. Maize and hemp seed were examples given of crops easily grown in the Island's climate and soils, which are relatively drought tolerant and minimally affected by pests. Maize and hemp seeds can both be used as high-quality animal feed and can be processed into flours for baking and cooking. Banana is another plant which grows very well on Norfolk Island, and which also has the potential to be processed into flour for baking and cooking.

5.3.4 CLIMATE, WATER SCARCITY AND DROUGHTS

Norfolk Island receives on average 1312mm of rainfall per year, much of it arriving during the autumn - winter period. Its climate is changing, and average annual rainfall has been in decline since the 1970s (Petheram et al, 2020). There is strong agreement among 21 global climate models that mean annual rainfall over Norfolk Island will decrease in the future and that potential evaporation will increase (Petheram et al, 2020).

Due to the absence of surface water storages such as large dams or reservoirs, and with most creeks across the Island now drying up during the summer months, Norfolk Island relies on rainwater collected in water storage tanks, and groundwater pumped from bores to irrigate crops and water livestock. Ground water levels have been steadily declining across Norfolk Island since 1990, with many bores now completely dried up, while many of the remainder are in decline and/or operating at substantially reduced flow rates (Petheram et al, 2020). During the summer months in recent years, many of Norfolk Island's largest producers have reported that they have had to reduce or eliminate production due to a lack of water. This is due to the exhausting of their water supplies - creeks drying up, bores drying up, and/or rainwater storage tanks being depleted.

Four of the producers interviewed stressed the importance of water and would like to see additional sources of water developed. There is significant potential to capture and store a lot more of the 1312mm/year of annual rainfall Norfolk Island receives (Petheram et al, 2020). Interviewees suggested that some funding could be provided to offset the very high cost of purchasing water storage tanks on Norfolk Island (as much as three times the price of an equivalent tank in Australia due to additional freight costs). Construction of dams/reservoirs, tanks farms, and managed aquifer recharge (such as swales and recharge weirs) are amongst measures identified by the CSIRO (Petheram et al, 2020) which could be taken to mitigate climate change and drought and improve overall productivity. If improved sources of water for irrigation purposes could be provided, then all producers interviewed indicated this would generally be able to increase production of vegetables, fruit, meat and dairy products considerably, and help to stabilise production volumes through dry periods as well.

Water shortages and fresh food scarcity all act as barriers to investment when looking to plan for increasing population, as well as being limitations for sustaining the tourism industry. It is important for sustainable solutions to be considered for water security, to support investment in food production and remediate the lack of fresh produce. Imported products create a false sense of food security, as the Island remains reliant on freight and shipping, and all products imported on Norfolk Island are quite expensive compared to the Australian mainland. In 2021, Norfolk Island was in emergency mode due to water shortages and lack of fresh produce.

5.3.5 BIOSECURITY

There is a high level of awareness and appreciation of the importance of biosecurity on Norfolk Island amongst the community. Cargo vessels and regular passenger aircraft are the main human-assisted pathways for introduction of pests, diseases and pathogens of quarantine concern to Norfolk Island (Norfolk Island Regional Council Environment Strategy 2018-2023). Importation of fresh produce is another major pathway for the introduction of pests, diseases and pathogens to the Island.

Until recently, fresh food imports have been restricted to potatoes, onions, garlic, ginger, meat, eggs, and dairy products. Restricted importation of fresh food has protected Norfolk Island from many pests and diseases that are prevalent in Australia and New Zealand. For example, Norfolk Island does not have any kind of Fruit Fly - a devastating pest afflicting a wide range of fruit and vegetables and prevalent throughout much of Australia.

In 2018, changes in Biosecurity have resulted in the ability to obtain a permit for the importation of a much wider variety of fresh fruit, vegetables and cut flowers for the first time. While a segment of the community (some visitors included) wanted increased fresh imports, many recognise the risk that the importation of fresh produce along with associated pests, diseases and pathogens, may have to local food production, endemic plants and fragile species such as the honeybee (Norfolk Island Regional Council Environment Strategy 2018-2023).

The Australian Government Department of Infrastructure, Transport, Regional Development and Communications (DITRDC) and the Department of Agriculture, Water and the Environment (DAWE) are jointly responsible for biosecurity on Norfolk Island.

Under the *Biosecurity Act 2015*, DAWE is responsible for regulating the import of goods into Norfolk Island. DAWE has a legislated responsibility to protect Norfolk Island's animal and plant health status, and some commodities are prohibited from importation. In order to grant import permits, the Department must be satisfied Australia's Appropriate Level of Protection (ALOP) can be applied. ALOP is defined as 'a high level of sanitary and phytosanitary protection aimed at reducing biosecurity risks to a very low level, but not to zero'. Under the Act and the Biosecurity (Prohibited and Conditionally Non-prohibited Goods – Norfolk Island) Determination 2016 (Goods Determination), certain goods cannot be imported or brought into Norfolk Island, including from the Australian mainland, unless they are accompanied by an import permit or comply with relevant alternative conditions set out in the Goods Determination.

While DAWE is responsible for regulating the importation of goods into Norfolk Island, it is the Department of Infrastructure, Transport, Regional Development and Communications (DITRDC) which is responsible for the provision of state type functions for Norfolk Island including biosecurity functions that may typically be delivered by a state or territory government body.

DITRDC administers a number of programs to support biosecurity on Norfolk Island. These include surveys to collect baseline data, and monitoring of, biosecurity risks:

- DITRDC funded the 2012-14 Norfolk Island Quarantine survey, to generate baseline data for decisions regarding quarantine arrangements for plant pests and animal diseases.[39]
- DITRDC has recently funded new and expanded round of biosecurity surveys.[40]
- DITRDC is in the final stages of contracting three components of these surveys, covering bees, plants and the marine environment, and a fourth component, on animals, will be commissioned later in 2021.
- The surveys are being run in partnership with DAWE and Parks Australia, which has provided joint funding to the marine study. All surveys will involve close engagement and collaboration with the Norfolk Island community.
- These surveys will fill gaps in the 2012-14 survey and expand the scope to include the Marine environment.

These surveys are expected to help determine the "pest and disease health status" on the Island and will help inform import conditions based on biosecurity risks.

In addition, DITRDC has provided some funding for other relevant programs on Norfolk Island:

- Funds to Parks Australia for the Tarler Bird Control Program for the past three years. This arrangement will continue for the next three years.
- The Argentine Ant Eradication Program has recently received an additional $735,000 to continue, with more than 26 percent of the infested area already successfully treated.[41]
- DITRDC works in collaboration with the Norfolk Island Regional Council (NIRC) to deliver an Environment Program to manage wood weeds in Public Reserves.

Financial Assistance Grants are provided to NIRC to supplement other funding sources for the delivery of local government services to Norfolk Island. Under the Service Delivery Agreement (SDA), Council is engaged and funded to:

- Deliver Pest and Noxious Weed Services on state and federal invasive species as agreed by the department, including Argentine Ants.
- Manage pest and disease incursions on NI that are not emergency plant or animal pests or diseases, as agreed by DITRDC.
- Prepare a program of work to manage new pest and disease incursions, as agreed by DITRDC.
- Comply with the First Point of Entry requirements (infrastructure, equipment and ongoing operation and maintenance) under the *Biosecurity Act 2015*. This includes biosecurity waste management services.
- Make available information about the Service Delivery Agreement between the Commonwealth and NIRC is available on the Council's website.

Given NIRC's status under administration and its financial situation, a closer examination of how these services are implemented may be warranted to ensure sufficient capacity to effectively deliver their obligations against the SDA.

The importation of ruminants

The importation of live ruminants to Norfolk Island requires an import permit from the Department. A number of serious ruminant diseases including Bovine Johne's disease (BJD), virulent footrot, and Q fever are present on the

[39] https://www.regional.gov.au/territories/publications/files/Department_of_Agriculture_Pest_and_Diseases_survey_2015.pdf
[40] https://www.regional.gov.au/territories/norfolk_island/administrator/media/2021/ni-a-mr-202131.aspx
[41] https://minister.infrastructure.gov.au/marino/media-release/budget-2021-delivering-norfolk-island

Australian mainland but not on Norfolk Island. According to the Department, there are currently no economically feasible conditions that can be applied to sufficiently manage the risk of introduction of these diseases to allow the importation of live ruminants into the island. The Department's position remains that importing ruminant reproductive material, rather than live animals, is the best risk management approach to lower the risk of the introduction of serious ruminant diseases.

Although these changes were purportedly enacted to protect the disease-free status of Norfolk Island's livestock, owners of beef cattle, dairy cattle, sheep, and goats also face the dilemma of being unable to cost-effectively infuse their herds with new genetics which are periodically required on such a small island to keep their herds productive and healthy. Interviewees stressed that it remains more expensive, more complex, and comes with a high risk of failure for local graziers when compared with the importation of live animals. With an already challenging business environment, this adds another level of burden to already struggling local producers and is contributing to a further decline in their long-term viability.

In 2021, the Australian Government, acknowledging the additional costs associated with the use of reproductive material, has provided a total of $210,000 under the Community Development Grants Programme to enable the supply of the critical infrastructure required to support the artificial insemination and embryo transfer of Norfolk Island livestock. A funding agreement with the Norfolk Island Cattle Association to deliver the project was recently signed. The funding will provide the infrastructure to boost the genetic diversity and sustainability of local ruminant livestock, including a liquid nitrogen plant, generator, portable cattle crush and portable yard fencing.[42]

Moreover, if aspiring graziers are barred from importing new animals to the Island, and if existing graziers are unable or unwilling to sell animals or accommodate AI on their behalf, this prevents new entrants from starting new animal product enterprises entirely. Some community members expressed an interest in starting a meat goat business for example, however there is no pathway available to import the animals required to initiate a herd.

If the importation of ruminants was allowed, as it was prior to 2016, it would give existing and aspiring graziers the opportunity to effectively and affordably maintain and grow their herds, introduce trait improvements required to maintain and increase and diversify meat and dairy production, start new enterprises, meet consumer demand, retain and build the island's food security. If AI is to remain the only option, then some sort of subsidy could be offered to help offset some of the high costs and risk of failure associated with maintaining and improving herd genetics in this manner.

Importation of rootstock

There is presently no ban on the importation of rootstock into Norfolk Island. All live nursery stock, including bare rooted plants, are permitted from mainland Australia which require an import permit and to meet relevant import permit conditions. The conditions are not currently listed on the website but are in the process of being included in the department's BICON system for stakeholders to access.

The Argentine Ant Eradication program

The NIRC delivers the Argentine Ant Eradication program, a program which received funding to remove Argentine Ants from Norfolk Island before they spread and wreak further havoc on Norfolk Island's ecosystems and agriculture sector (The Conversation, 2019). Besides affecting biodiversity (including birdlife, bees, other beneficial insects and plants), Argentine Ants have a huge impact on the agricultural industry through the destruction of beehives, irrigation systems, and their **"**farming" of sap-sucking insects. Argentine ants protect and care for these insects, and in return they receive an energy source called 'honeydew' that is excreted from the sap-sucking insects. This farming leads to devastating losses for a wide variety of fruit trees and crops (Landcare Research, 2021). They also cause disruption of the poultry industry through stress on chickens and the killing of hatchlings (Landcare Research, 2021). The DITRDC have recently announced they are committing an additional $735,000 in 2021-22 for the ongoing NI Argentine Ant Eradication program, with more than 26 percent of the infested area already successfully treated. There is also $552,000 to kick off a project to address water supply and quality issues on Norfolk Island.[43]

[42] https://minister.infrastructure.gov.au/marino/media-release/norfolk-islands-artificial-reproduction-livestock-project-commences

[43] https://minister.infrastructure.gov.au/marino/media-release/budget-2021-delivering-norfolk-island

5.3.6 OUTCOMES OF THE PUBLIC CONSULTATION (ONLINE SURVEYS)

The public consultation sought to elicit community knowledge and perspectives from key actors within the community, participants in the food system. Specifically, it aimed to understand what underpins consumers' preferences for local or imported food and assess the community interest in education/awareness-raising around sustainable food and regenerative agriculture, soil health and its relation to nutrient dense food, health and wellbeing outcomes.

206 responses were received to the survey targeted at consumers (those buying food for themselves and/or their household), and 14 responses were received to that targeted at commercial operators (those buying food for a business such as a restaurant, cafe, takeaway, or catering).

Shopping preferences were collected for range of produce sold on Norfolk Island, for which there are generally both local and imported alternatives. This includes vegetables, beef, eggs and milk.

The results of the online surveys can be found in Appendix A and B. A brief summary is given below.

5.3.6.1 CONSUMERS

Most respondents place a high degree of importance on their produce being locally produced, and in most cases will try to buy the local alternative when they can.

The reasons for this are various, the most commonly cited reasons being -

- Supporting the local economy
- Taste / flavour / freshness
- Perceived health benefits
- Lower-food miles

In the case of milk however, whilst most consumers indicated a preference for a local alternative, just over three quarters of respondents indicated they purchased mostly imported. The most commonly cited reasons for this included -

- It's more readily available
- It's easy to store due to it being long-life and shelf-stable
- It's less expensive

These responses are expected as there is currently a limited and irregular supply of local milk, and the retail price is substantially higher than the imported long-life (UHT) alternative. Due to irregular shipping and frequent shortages of certain imported goods on the Island, many people have become accustomed to stocking an extended supply of such items at home to buffer against shortages, which likely explains why ease of storage was selected as one of the reasons for buying imported by just over a third of respondents.

For eggs, more than two thirds of respondents indicated they purchased mostly local eggs instead of the imported alternative, despite the imported alternative being as much as half the price.

Approximately one third of respondents predominantly source their vegetables not from shops, but from their own gardens or those of someone else (i.e., share/exchange/barter for vegetables).

Community interest in food education

A little over half of respondents indicated that they would be interested in learning more about sustainable food (i.e., food produced with consideration of its health benefits, environmental and social impacts) and regenerative agriculture. Similarly, a little over half of respondents indicated they would be interested in learning more about soil health and its relation to nutrient dense food, health and wellbeing outcomes.

Community interest in food literacy and locally sourced canteen food for students

Almost three quarters of respondents indicated they would be interested in expanding the food literacy program for students at the local school and more than half indicated that they would like to see the provision of canteen food which is made from local organic ingredients for students.

5.3.6.2 COMMERCIAL OPERATORS

Of the 14 food-related businesses that responded, just over three quarters consisted of restaurants or cafes, and the remainder were catering businesses.

Similar to the consumers, most commercial operators who responded place a high degree of importance on their produce being locally produced, and in most cases will try to buy the local alternative when they can.

More than three quarters of respondents indicated they purchase mostly fresh and locally grown vegetables, as opposed to imported (frozen/canned) alternatives. As per the consumers this was mainly due to a desire to support the local economy, for taste / freshness, perceived health benefits, lower food-miles and because it is more readily available. For those purchasing imported alternatives the most commonly cited reason was because it is more readily available.

For beef, the majority of commercial operators purchase imported beef, despite their preference for local. The reasons given for doing so include reasons of tenderness / taste / flavour and it being more readily available.

A larger proportion of commercial operators purchased imported eggs, primarily due to the reduced cost and to a lesser extent availability.

Milk appeared to face similar challenges for commercial operators as with consumers – many would prefer to buy local, but the imported alternative is more readily available and less expensive.

5.4. PATHWAYS TO A FOOD SECURE COMMUNITY

Norfolk Island has seen a progressive shift from a strong reliance on local food supplies to food sourced from an increasingly globalised food industry network. This shift has brought substantial benefits in the form of competitive pricing and access to a wider variety of food types. Yet some aspects of Norfolk Island's food system have become heavily reliant on external supplies, that is for a range of consumable goods (fresh and processed food), as well as farm inputs such as fertilisers, pesticides, and stock feed. This reliance on importation creates vulnerability of both residents and businesses affected by freight delays and shortages of some inputs.

There is also a strong interest in local food, as well as an increasing number of initiatives amongst community members that take part in producing food. All interviewees reported a strong demand from both tourists and residents for better access to local food products, and many stated that they perceive significant untapped market potential. The producers interviewed expressed interest for expanding production, diversifying and improving their offerings, and taking advantage of new technologies and tools for land regeneration and sustainable farming. Similarly, aspiring food producers cited numerous opportunities for contributing to the expansion of Norfolk Island's food sector, by producing and/or adding value to food. On the other hand, Norfolk Island's agri-food businesses face unique impediments, including higher energy costs, higher input costs, expensive freight and irregular freight schedules, uneasy access to finance, and frequent droughts and water unavailability.

This context demands attention and the development of a considered approach to simultaneously ensure long-term food security for Norfolk Islanders and leverage the economic, social and environmental potential of an underdeveloped economic sector, the agri-food sector.

The Norfolk Island Community Strategic Plan 2016-2026 determines to '*protect and enhance {Norfolk Island} unique culture, heritage, traditions and environment for the Norfolk Island People'.* It outlines the objectives to create a 'food secure community', as well as to safeguard environmental sustainability, reduce waste, and promote cultural diversity, social engagement, health and wellbeing, tourism and economic diversification.

Norfolk Island has a unique opportunity to strengthen its local food system to ensure food security for its residents, while placing food at the core of a place-based sustainable development strategy that would benefit the Island's economy, its tourism sector and the health and wellbeing of its residents.

In line with the objectives of the Norfolk Island Community Strategic Plan 2016-2026, a strategic approach needs to drive an island-wide transition towards increased availability, accessibility and affordability of nutritious and local foods to support healthy-eating practices, sustainable economic development and environmental sustainability.

5.4.1 THE DETERMINANTS OF FOOD SECURITY

Food security has four interrelated elements: availability, access, utilisation and stability. It is defined by the United Nations' Food and Agriculture Organization (FAO) as when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.[44]

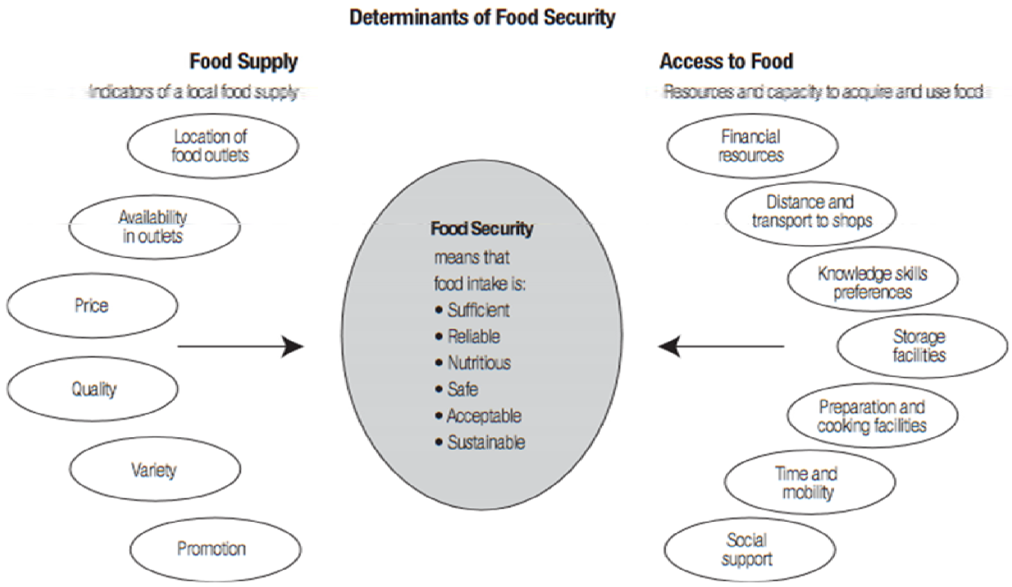

Figure 5.8: Determinants of Food Security[45]

5.4.2 THE NEED FOR A STRATEGIC APPROACH TO FOOD SECURITY

The implementation of the Norfolk Island Community Strategic Plan 2016-2026 warrants a strategic approach to building a more resilient and sustainable food system in Norfolk Island. That is a comprehensive and holistic approach to address food security and other related development objectives in a synchronized manner.

Effectively addressing the determinants of food security requires taking a multi-sector approach by operationalizing the linkages between agriculture, food security, nutrition, the environment, culture and heritage and the local economy.

While the primary function of agriculture is the provision of food security, it is now broadly accepted that agriculture has a range of associated environmental, economic and social functions, also referred to as the multi-functionality of agriculture. The concept refers to all the various goods and services generated by agricultural land use, which connect food production with ensuring the regeneration of environmental resources and the sustainability of agricultural ecosystems, as illustrated in Figure 5.9.[46]

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[44] https://aifsc.aciar.gov.au/food-security-and-why-it-matters.html

[45] Source: Rychetnik L, Webb K, Story L, Katz T. (2003) Food security options paper: A planning framework and menu of options for policy and practice interventions. Sydney: NSW Centre for Public Health Nutrition. Available from: http://www.health.nsw.gov.au/pubs/2003/pdf/food_security.pdf

[46] United Nations' Food and Agriculture Organization (FAO), Towards multifunctional agriculture for social, environmental and economic sustainability, 2012, https://www.globalagriculture.org/fileadmin/files/weltagrarbericht/IAASTDBerichte/IssuesBriefMultifunctionality.pdf

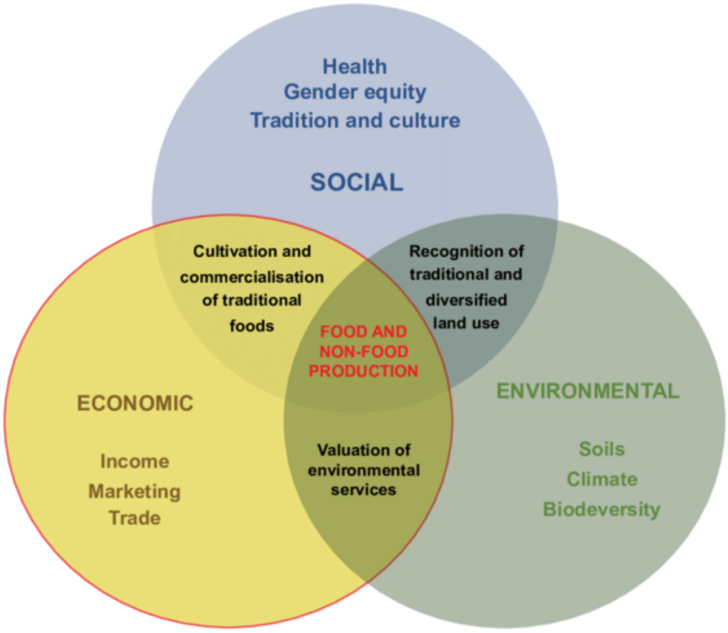

Figure 5.9: Multifunctional Agriculture - the interconnectedness of agriculture's different functions[47]

Globally, industrial agriculture has presented some major challenges for the sustainability of our planetary ecosystems, with, notably, a significant contribution to air pollution and CO_2 emissions, soil degradation, the depletion of water resources, biodiversity loss and the destruction of ecologically fragile ecosystems.[48] The shift in diets that has occurred with the industrialisation of agriculture has also born significant impacts on public health (WHO, 2021). The world faces an evolving malnutrition crisis, with countries moving from the challenges of undernutrition and micronutrient deficiency to a crisis that encompasses also overweight and obesity (Htenas, 2017).

Mounting evidence of these environmental, social and public health impacts has prompted calls for transforming the global industrial food system. The transition to more sustainable food systems is now considered a fundamental lever of action to achieve the United Nations 2030 Sustainable Development Agenda and concurrently realise the range of development objectives defined in the Sustainable Development Goals (SDGs), including food security, environmental sustainability, social inclusiveness, economic development, nutrition and health (Caron, 2018).[49] Models, tools and techniques have been developed worldwide to support the transition towards more sustainable, socially inclusive and healthy food systems that allow to restore environmental integrity, the renewal of natural resources and ensure the provision of adequate, nutritious food for all.[50]

5.4.3 A STRATEGIC FRAMEWORK TO STRENGTHEN NORFOLK ISLAND'S FOOD SYSTEM

Currently food security issues are addressed incrementally, in a siloed-approach. Responsibility for food policy is highly dispersed, food-related matters are scattered across various departments and agencies. There is no centralised authority that has oversight of the Island's food system, nor a policy framework, to guarantee food security for Norfolk Island.

A strategic approach to food security will need to integrate various domain areas - such as land stewardship, agrobiodiversity, local economic development, culture& heritage, tourism, nutrition and community wellbeing -

[47] RRB, Leakey. (2017). Socially Modified Organisms in Multifunctional Agriculture-Addressing the Needs of Smallholder Farmers in Africa. Scientific Pages of Crop Science. 2017. 20-29. 10.36959/718/598.
[48] https://www.unep.org/news-and-stories/story/rethinking-food-systems; https://www.unep.org/news-and-stories/press-release/our-global-food-system-primary-driver-biodiversity-loss
[49] https://www.un.org/en/food-systems-summit, https://sc-fss2021.org/materials/publications-and-reports-of-relevance-for-food-systems-summit/; https://www.glopan.org/foresight2/
[50] http://www.fao.org/3/ca2694en/CA2694EN.pdf; https://www.un.org/esa/ffd/wp-content/uploads/sites/2/2015/10/IntegratedLandscapeManagementforPolicymakers_Brief_Final_Oct24_2013_smallfile.pdf

and actors participating in the system. It would necessitate a fit-for-purpose governance framework, inclusive and participatory mechanisms, community ownership of a vision and a policy agenda. Interventions do not happen if there is no shared vision for what is needed and why.

The following outlines some priority actions, and pathways to strengthen Norfolk Island's food system and provide the foundations for a more resilient and sustainable food system, placing food production at the heart of a comprehensive sustainable development strategy that will benefit the local economy, the community and the environment.

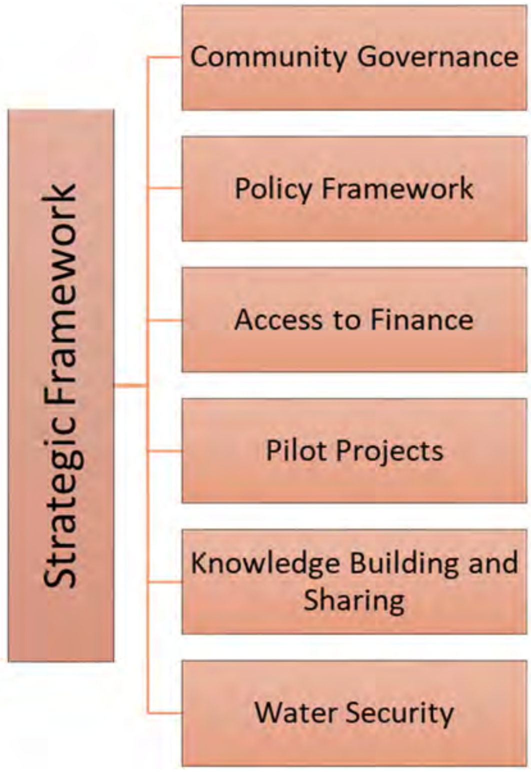

Figure 5.10: A strategic framework for food security, sustainability and resilience

STRATEGIC PILLAR 1: COMMUNITY GOVERNANCE / COMMUNITY FOOD SYSTEM

The potential for creating an innovative multi-sector approach to food security and sustainable development will be contingent upon the mobilisation and participation from the community. A fundamental determinant of transformative capacity in any system lies in the degree and effectiveness of collective organisation between various actors. Inclusiveness and effective engagement are key to system change (Olsson, 2010).

There is wide documentation worldwide on how local communities have played a central role in the development of local food systems to overcome their food vulnerabilities and limited market access (Feenstra, 1997). As early as the 1960s, local food movements emerged in reaction to the impacts of industrial food to bring the focus back around the values, relationships, and methods surrounding the production, distribution, and consumption of food (Autcoin, 2015). Over the last decade, many regions, cities, municipalities have recognised the importance of the role local governments can play in addressing food security and nutrition issues in tandem with supporting sustainable agriculture and the local economy (FAO, 2021). The benefits of locally designed and run food systems are broad ranging in terms of social cohesion, community resilience and enhanced health outcomes. Their effectiveness and successes often lie in the existence of an inclusive multi-stakeholder approach where members of the community and food system actors come together to drive the development of a community food system that reflect local needs, values and aspirations. For instance, Food Policy Councils in North America provide a range of examples of how to proceed with the establishment of multi-stakeholder governance structures, how to bring together a diverse pool of skills, expertise, knowledge, interests and develop a shared vision of an ideal community food system (and its actualization/ implementation).[51]

A community food system is a highly complex, dynamic, and adaptive system that includes the people, land, infrastructure, and interdependent processes of food from farm to table to waste management.[52]

There is no one-size fits all approach, each community being different with regard to the issues they face, their values and aspirations, hence the importance of a ground-up, inclusive approach, where the Norfolk Island community takes full command of the process and defines its vision for a food secure future.

Figure 5.11: Components of a Community Food System

ENTRY POINTS FOR POSSIBLE ACTION

- *Mobilise key stakeholders within the community to drive a strategic approach to food security and sustainable development.*
- *Set- up a multi-stakeholder working group to initiate, coordinate actions.*

STRATEGIC PILLAR 2: A FOOD POLICY FRAMEWORK

Once the dysfunctionalities within the food system have been acknowledged and, needs and opportunities identified by the system participants, the development of a policy framework will enable to formalise the direction, support and resources required for the establishment of a new system. While the process needs to be community-driven, Government's involvement may be appropriate in supporting the development of a policy framework that will provide support for the implementation of the community's vision and guide decisions to achieve rational outcomes.

A policy framework needs to focus on operationalizing the linkages between agriculture, food security, nutrition, the environment, culture and heritage and the local economy – and provide for incentives and support to that effect.

It may integrate various aspects, such as:

- The key pillars upon which the food policy is constructed, e.g.:
    - food localisation
    - economic viability
    - environmental sustainability
    - community health, wellbeing and prosperity
    - resilience
- Incentives for food production an land stewardship;

[51] https://goodfoodlosangeles.files.wordpress.com/2011/01/fpc_final_dist-5-indd.pdf
[52] https://www.extension.uidaho.edu/publishing/html/BUL995-Guide-to-Developing-Food-Coalitions-and-Policy-Councils.aspx

- Access to finance for food producers, land users, eco entrepreneurs;
- Support for 'integrated landscape management' as a way to improve the resilience of Norfolk Island's ecological and economic systems through the sustainable, productive and integrated management of the land;
- Implement a soil health and land management program (incl., soil organic carbon, agrobiodiversity and crop diversification)
- Break down the barriers between sectors, scale and food system actors;
- Facilitate knowledge building and knowledge sharing;
- Implement a Farm to School Program (food literacy and gardening programs at Norfolk Island Central School);
- Support agri-ecotourism and the sharing of 'sustainable food' knowledge with the global community;
- Consider a food export strategy, encouraging niche markets for food export from Norfolk Island.

ENTRY POINT FOR POSSIBLE ACTION

- *Consider the development of a food policy / strategy to improve coordination and synchronized action between key stakeholders, and drive institutional support and investment in infrastructure and resources needed for sustaining a community food system.*

STRATEGIC PILLAR 3: ACCESS TO FINANCE

The transformation of the food system needs an enabling environment, including incentives and support to encourage sustainable regenerative food production practices, land stewardship and eco-entrepreneurship. Incentives might include low-interest loans, grant programs and revised regulatory structures where appropriate, support to innovative business models, subsidies for farming practices that concurrently regenerate the health of the landscape and increase local food availability.

Interviews with food producers and community members reveal that lack of access to finance or support is a major impediment in the development of new initiatives. Norfolk Island's agri-food businesses face impediments unique to Norfolk Island – that include higher energy costs, higher input costs, expensive freight and irregular freight schedules. In addition, residents and businesses of Norfolk Island are ineligible for some key support schemes or grants that are available in other jurisdictions as most of the funding mechanisms are state-based, or administered by states, and Norfolk Island is under the jurisdiction of the Commonwealth of Australia as external territory (Australian National Audit Office 2019).

For instance, Norfolk Island is not part of a 'Natural Resource Management' region,[53] making a range of relevant opportunities, including those within the National Landcare Program, unavailable. Presently, there are 56 regional Natural Resource Management (NRM) organisations which act as delivery agents under the regional stream of the National Landcare Program. The Australian Government recognises the important role regional Natural Resource Management (NRM) organisations play in delivering natural resource management activities across Australia, including by receiving a funding allocation to deliver five year long projects to help ensure natural resources remain sustainable, productive and resilient (Natural Resource Management 2018). If Norfolk Island were included as part of an existing NRM region, or defined as one, that would facilitate access to funding to address environmental sustainability issues such as soil degradation, loss of vegetation, pest and weeds management and water availability/ quality.

Norfolk Island Regional Council (NIRC) also has very limited access to grant funding. In their 2019 report, the Australian National Audit Office (2019) stated:

"Local government bodies also generally have access to additional funding for activities through grants provided by states and territories. For instance, grant programs that councils in NSW can access include the Youth Opportunities

[53] https://nrmregionsaustralia.com.au/what-is-nrm/

program and the Environment Trust program. There was no formal channel established by the Department (responsible for state-type service delivery) for the NIRC to apply for this type of additional funding. The Department should consider establishing a process for the NIRC to be able to apply for grant funding for activities that are generally funded by states and territories." At this stage, it appears that the changes recommended above have not yet been actioned.

Neither the 2019 KPMG report '*Monitoring the Norfolk Island Economy*' nor the Commonwealth Grant Commission 2019 Norfolk Island Inquiry Final Report address the lack of access to grants for residents and businesses of Norfolk Island and the impact on the agricultural sector or the overall economy.

Adequate incentives and support for Norfolk Island residents, businesses and local government is necessary to encourage entrepreneurship, facilitate business expansion, support producers during extreme whether periods, and best practice ecological land management and regenerative farming. Ultimately, this could lead to a greater (and more consistent) supply of produce and increased diversity of food offerings.

ENTRY POINTS FOR POSSIBLE ACTION

- *Undertake a comprehensive gap analysis of grants and similar opportunities that Norfolk Island is unable to access.*
- *Address jurisdictional restrictions and other eligibility criteria which make residents and businesses of Norfolk Island ineligible for relevant schemes, grants, subsidies, support and finance (such as low interest agri-food business loans, the National Landcare Program, the National Water Grid/The Australian Government's plan for a water secure future[54]) available in other Australian jurisdictions.*

STRATEGIC PILLAR 4: AGRI-ENVIRONMENTAL INNOVATION (PILOT PROJECTS)

Interviews with local food system actors indicated that several niche areas could be further investigated to expand and strengthen the local food sector on Norfolk Island. Some pilot projects may be developed to further investigate the feasibility of some the proposed options to increase food production and availability, integrating best practice in agri-environmental innovation:

[54] https://www.nationalwatergrid.gov.au

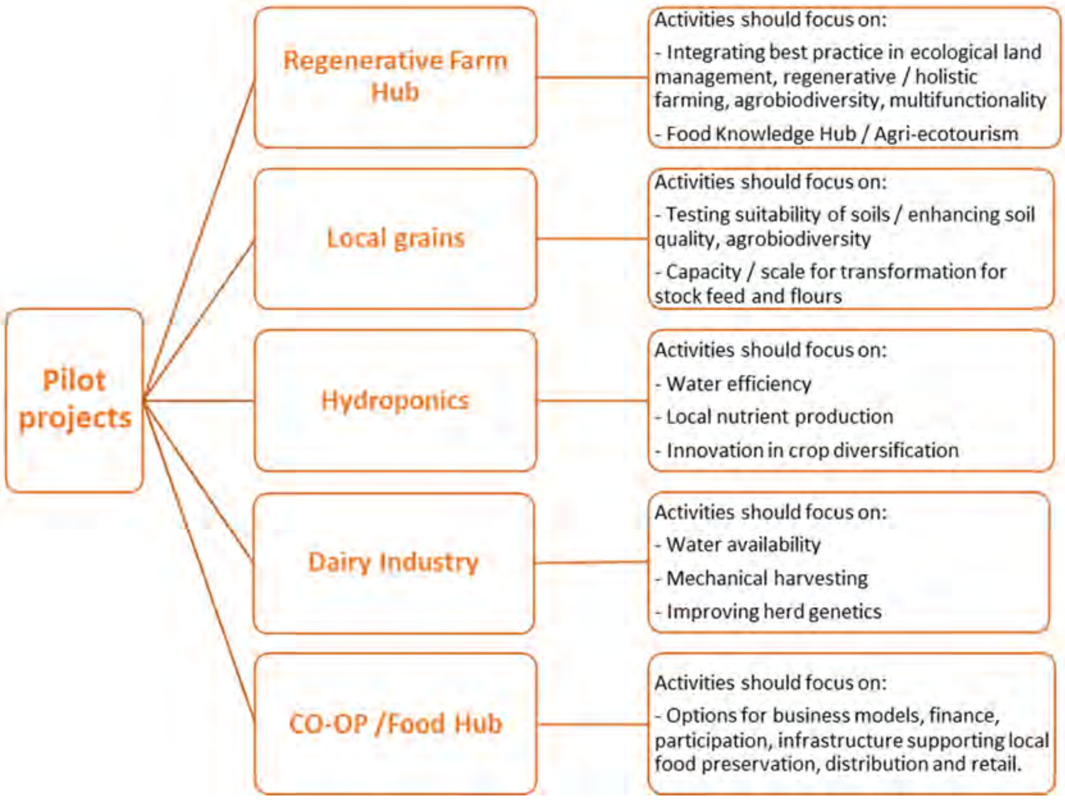

Figure 5.12: Proposed Pilot Projects to advance agri-environmental innovation on Norfolk Island

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STRATEGIC PILLAR 5: KNOWLEDGE BUILDING AND KNOWLEDGE SHARING

The importance of nutrition and healthy food systems for human development is now widely acknowledged, and education about food – food literacy - has become a major lever for action in the transition to sustainable food systems.

The term "food literacy" has been broadly applied, and has varying definitions (Truman, 2017). For the purpose of this discussion, food literacy refers to the idea of proficiency in food related knowledge, attitudes and behaviours, that includes an understanding of food system dynamics, actors and institutions, and the links between food, nutrition, health and the environment, with the goal to create healthier connections between consumers, food and food producers.

The day-to-day choices made by food consumers affect not only their personal health and planetary health, but also the viability of local food producers. Awareness and knowledge can assist consumers with making more conscious decisions around where to spend their money. Buying "local" keeps more money in the community and helps support local businesses (Swenson, 2009). On Norfolk Island, frozen or canned alternatives can be purchased for many of the fruit and vegetables also produced locally. Frozen/canned vegetables may be mass-produced in countries where labour and input costs are substantially lower than on Norfolk Island, benefiting from large-scale, mechanised farming practices, low input costs, various subsidies all driving down the cost of production. Conversely, on Norfolk Island most stages in the farming process are done by hand - spreading fertiliser, sowing seeds, controlling weeds and harvesting. Broad-acre monocultures are generally dependant on the use of chemical fertilisers, herbicides, and pesticides, which potentially lead to nutrient deficiency, residual chemical contamination and poorer health outcomes when compared to local, diversified, small-scale market gardeners growing vegetables, and small producers free ranging livestock (Crews, Carton & Olsson, 2018).

Interviewees on Norfolk Island indicated they felt that if the benefits (nutritionally, economically, environmentally) of eating locally and seasonally were more widely known, then consumers would be more inclined to select the local alternative when/if available. Additionally, public interest in where their food comes from and how it is grown can drive producers to ramp-up regenerative agricultural practices, reduce or eliminate the use of toxic chemicals and sprays, increase agrobiodiversity, reduce waste etc., which would lead to better environmental, economic, and health outcomes for the community.

The importance of building and disseminating knowledge and information to empower people to make informed decisions about their food preferences and enable people to engage in and shape their local food system cannot be overstated. Based on the interviews with the Norfolk Island community and international best practice, some possible pathways are proposed here:

A 'Food Knowledge Hub'

Interviews suggested that some kind of concerted program of public awareness-raising around the aforementioned benefits of buying local, seasonal produce be created to impart knowledge on the community. The majority of online consumer survey respondents seem to support this suggestion as they indicated that they are interested in learning more about sustainable food (i.e. produced with consideration of its health, environmental and social impact) and regenerative agriculture, soil health and its relation to nutrient dense food, health and wellbeing outcomes.

As shown in the literature, learning spaces for food literacy can take different forms but generally constitute valuable educational opportunities and platforms for positive social interactions, community building and engagement as well as for strengthening the connections between farmers and consumers, and consumers with their environment and the food they consume and their own health and wellbeing (Dickinson, 2013).

On Norfolk Island, the creation of a community learning space, 'Food Knowledge Hub' potentially in tandem with the 'Regenerative Farm Hub' Pilot Project would provide an open space for the community to participate, learn, develop and share knowledge on regenerative farming, land stewardship, agri-biodiversity and nutrition, cooking/ preserving food.

A Farm to School Program

The majority of respondents also indicated that they would be interested in seeing a food literacy program for students and the provision of canteen food which is made from local organic ingredients at the Norfolk Island Central School.

School-based programs centred on food literacy and healthy eating have been promoted around the world, considered as important instruments for advancing children's health and wellbeing, their understanding of planetary health and their own impacts as consumers of food.[55]

On Norfolk Island, such program may be designed to foster healthier and more diversified meals that use local fresh products and reinforce the linkages between local agricultural production, school feeding, education and the personal development of children.

Studies show that providing knowledge and training about nutrition and healthy eating habits, as well as garden-based learning, not only increase food literacy and change food attitudes and behaviours of children and their families, but also provide multiple benefits in terms of learning abilities, social development opportunities and awareness of the environment.[56]

Agriculture-based tourism: Agri-ecotourism

Norfolk Island's tourism sector can strongly benefit from a food localisation strategy. Agri-ecotourism is embraced in various parts of the world to support traditional land management practices, enhance the preservation of cultural

[55] EU URBACT BioCanteens Transfer Network https://urbact.eu/biocanteens. Mouans-Sartoux, a municipality in the south of France, has created a program for preserving agricultural lands and supporting local organic food production to provide school canteens with 100% organic meals and 80% is locally grown, the drastic reduction of food waste fully compensating the higher cost of switching to organic products. Accompanied by nutrition-sensitive and food literacy programs in the local schools, this has led to significant changes in the whole community's food behaviours and attitudes. The MEAD (Center for Sustainable Food Education) and the EU URBACT BioCanteens Transfer Network have been established to enable shared-learnings across Europe based on Mouans-Sartoux's experience in the distribution of sustainable school meals as a key lever towards the development of an integrated local agri-food approach, to enhance both citizens' health and the environment. https://mead-mouans-sartoux.fr/en/la-mead/

[56] https://www.gardentotable.org.nz/Research/Shore%20Whariki%20Garden%20to%20Table%20Prog%20Eval%20-%202013%20June.pdf>

knowledge and promote sustainable farming practices, integrating conservation, food security, local economic development and cultural heritage.[57]

Agri-ecotourism usually involves promoting local products and services thus supporting the multi-functionality of agriculture, and may also include visitors participating in sustainable farming and learning about local produce, local ecosystems, culture and values. Branded as 'socially responsible' and 'eco-friendly', agri-ecotourism is growing in popularity as increasingly people seek new experiences in outdoors environments that relate to health and wellbeing and developing sustainable solutions to our world's global sustainability challenges.

In small islands of the South Pacific and the Caribbean notably, agri-ecotourism is widely adopted and central to policy agendas for building the linkages between tourism and agriculture to enhance rural livelihoods while promoting food and nutrition security and resilience of the local agriculture sector.

ENTRY POINTS FOR POSSIBLE ACTION

- *Allocate resources for the creation of a community learning space 'Food Knowledge Hub' to facilitate knowledge creating and sharing, trialling regenerative farming practices, build capacity in sustainable food production, and raise community awareness around food, agrobiodiversity, nutrition and health, and food production/preserving.*
- *Examine the potential for developing a Farm to School program at the Norfolk Island Central School (including providing local organic food meals at the canteen, garden-based learning and practicing).*
- *Investigate how to promote agri-ecotourism development, appropriate capacity building programs on agri-ecotourism for local community and food producers.*

STRATEGIC PILLAR 6: WATER AVAILABILITY

Norfolk Island's water security is under threat due to the historical reduction in rainfall and increasing temperatures (refer Chapter 2). The reduction in water availability can have significant environmental, social, and economic implications, and notably a direct impact upon food security from the perspectives of water deficiency for crop irrigation and stock watering.

A strategic approach to food security, sustainability and resilience necessarily implies ensuring water availability. Norfolk Island Regional Council (NIRC) has made progress towards the upgrade of the Norfolk Island Sewerage Treatment Plant by commissioning the Balmoral Report (in 2019), which may be a solution to ensure water is available in the future, for the purpose of providing irrigation and stock watering, while reducing the demand on groundwater in the event of insufficient rainfall. Other options may likely be considered too.

ENTRY POINT FOR POSSIBLE ACTION

- *Investigate ways to mitigate the effects of climate change, droughts, and seasonal water shortages on food producers, such as alternative sources of water for irrigation.*

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[57] http://www.fao.org/3/y5558e/y5558e02.htm

Summary/Findings

- Progressive shift from a strong reliance on local food supplies to food sourced from an increasingly globalised food industry network.
- Norfolk Island's food system is heavily reliant on external supplies, for a range of consumable goods (fresh and processed food), as well as farm inputs such as fertilisers, herbicides, pesticides, and stock feed.
- Reliance on importation means vulnerability of both residents and businesses affected by freight delays and shortages of some inputs.
- Strong demand within the Norfolk Island community for better access to local food produce.
- Consensus within the community that there is a significant untapped market potential to grow more food, diversify crop and food produce, and process food on Island.
- Norfolk Island's agri-food businesses face numerous impediments, such as high energy costs, water scarcity and limited access to finance and grant support.

Recommendations

- Develop a strategic whole-system approach to food security and sustainable development to drive an island-wide transition towards increased availability, accessibility and affordability of local foods to support healthy-eating practices, sustainable economic development and enhanced landscape functions.
- Mobilise key stakeholders within the community to drive a strategic approach to food security (e.g. setting- up a multi-stakeholder working group to initiate, coordinate action).
- Consider the development of a *Norfolk Island Food Policy / Strategy* to improve coordination and synchronized action between key stakeholders and drive institutional support and investment in the infrastructure and resources needed for sustaining a community food system.
- Continue to search for a solution to the Norfolk Island's freight issues in view of the effects this is having on the island's food producers, food-related businesses and retailers.
- Address jurisdictional restrictions and other eligibility criteria limitations which make residents and businesses of Norfolk Island ineligible for various schemes, grants, subsidies and finance available in other Australian jurisdictions.
- Investigate setting up a '*Regenerative Farm Hub*' applying best practices in regenerative farming and integrated landscape management that focus on resource efficiency, land and ecosystems regeneration, soil organic carbon, agrobiodiversity and crop diversification.
- Investigate the setting up of hydroponic systems and the use of nutrient sources present locally (in place of imported ones).
- Investigate options (business models, finance, and participation) for the development of infrastructure supporting local food preservation, distribution and retail (e.g., a Co-OP, a community-owned facility).
- Investigate options to encourage and facilitate the cultivation of local grains (for animal feed and flours) that can enhance soil quality, biodiversity and agrobiodiversity on Norfolk Island.

- Investigate ways to support the establishment of a dairy industry, including improving herd genetics, and mitigating lack of water and feed to increase productivity.
- Allocate resources to create a community learning space '*Food Knowledge Hub*' as an open space to develop and share knowledge on regenerative farming, land stewardship, agrobiodiversity and nutrition, cooking/ preserving food.
- Examine the potential for developing a '*Farm to School Program'* at the Norfolk Island Central School.
- Investigate how to promote agri-ecotourism, capacity building programs on agri-ecotourism for local community and food producers.
- Investigate ways to mitigate the effects of climate change, droughts, and seasonal water shortages on food producers, such as alternative sources of water for irrigation.

CHAPTER 6: THOUGHTS AND REMARKS FOR BUILDING A RESILIENT AND SUSTAINABLE FUTURE FOR NORFOLK ISLAND

6.1 CONTEXT

2020 was a difficult year for Norfolk Island. A combination of several events - water shortages and droughts, COVID-19 restrictions and their impacts on the tourism sector upon which the Island economy is heavily reliant, freights issues that has affected food security, and several larger rain events that caused multiple closures to Emily Bay due to polluted runoff.

The governance of Norfolk Island has been shifting post 2016, and the new status of Norfolk Island has necessitated institutional and regulatory adjustments, including to the tax regime, which have caused some level of discomfort for a small island community that was used to self-ruling. The multiple initiatives to consult with the community on various issues have not necessarily led to enhanced community trust; in contrast, it may have been overwhelming and under-appreciated. From January 2021, Norfolk Island Regional Council has been placed under administration.[58]

In our study, we also observed some "implementation gaps", i.e., gaps between the vast amount of knowledge/data available from past reports and its integration into subsequent Norfolk Island policy and strategy documents. For example, monitoring of groundwater bores and surface flow levels was recommended in the early 1990's (Abell & Falkland, 1991), but not acted upon, resulting in a lack of knowledge on groundwater recharge rates, runoff volumes and other water balance elements; or the recommendations made in relation to land and soil conservation, including the development of policies and long-term plans to manage soil care, land degradation and rehabilitation (Mosley, 2001).

Various scientific reports (groundwater, climate, and soil), journal articles (economics, social issues), and technical reports (waste, energy), have been published since 1950. And more research projects and strategy documents have been commissioned for Norfolk Island in recent years encompassing a wide range of issues - environmental, social, economic and technical. However, there is no centralised database for researchers, policy-makers and Norfolk Island residents to go to in order to access this vast array of knowledge in perpetuity. It would be relevant to not only centralise all this knowledge so it can be accessed and used by all stakeholders, researchers and interested citizens, but also to connect the people of Norfolk Island to a global pool of knowledge and research / case studies in order to foster shared-learnings on resilience and small islands' sustainable development.

6.2 COMMUNITY EMPOWERMENT TO ACHIEVE RESILIENCE AND SUSTAINABILITY

Most of the challenges that Norfolk Island is facing – land and soil degradation, biodiversity loss, water scarcity, wastewater management, food shortages – are presently addressed in siloes, managed by various separate entities at the federal, state and regional levels. Exemplars of cross-sectoral innovations from Europe, North America and Asia show the importance, and benefits, of integrated approaches to address social, economic and environmental sustainability issues.[59]

The future of Norfolk Island needs to be considered from a strategic stand point, embracing a whole-system perspective to change, to drive an island-wide transition towards sustainable development. Many of the challenges Norfolk Island faces can be approached in an integrated way, such as discussed in Chapter 5. Placing food production and sustainability at the core of a place-based development strategy would benefit the Island's economy, its tourism sector, the health and wellbeing of its residents and environmental health, with the conversation of soils, ecosystems and agrobiodiversity.

[58] http://www.norfolkisland.gov.nf/council/councillors

[59] https://sc-fss2021.org/materials/publications-and-reports-of-relevance-for-food-systems-summit/. The UN Food Systems Summit held in 2021 is an exemplar of increasingly recognised whole-system approaches to change and transitions to sustainability.

Community empowerment and leadership have to be central to the approach. Effective public participation, associating the community to future research design, innovation and policy formulation, can be an important factor in enhancing community trust and ownership of the future.

6.3 FROM VULNERABILITY TO AN EXEMPLAR OF RESILIENCE AND SUSTAINABILITY

We suggest an approach through which the Norfolk Island community is given the tools and structures to effectively participate in, and be at centre of, a new governance approach to envisioning and building its own future. Leveraging existing practices and effective techniques for community engagement from different parts of the world, the approach seeks to foster meaningful public participation in research, innovation and decision-making processes, to empower the community to define its own development trajectory, moving from its current vulnerabilities to become resilient and sustainable (Figure 6.1).

Figure 6.1: Working towards resilience and sustainability

6.4 NORFOLK ISLAND SUSTAINABILITY LAB

The concept, scope and aims of a Norfolk Island Sustainability Lab will have to be discussed with, and determined by, the Norfolk Island community. In our vision, the lab would act as a research and innovation hub on Norfolk Island, assisting dissemination of research outputs, acting as a knowledge repository of past reports/strategies, and enabling the community to play a central role in future research, innovation and policy/ strategy formulation. In our view, the broader objectives of the lab would be to:

- Constitute a platform for the community to be engaged in co-designing and co-implementing projects of value to the Island and for it to play a more significant role in the development of visions and strategies for the future of the Island;
- Provide the tools, materials and a network of global experts to support education and training in a broad range of areas – biodiversity conservation, food literacy, green entrepreneurship, of relevance and necessity for long term sustainability and resilience of the Island;
- Facilitate the development of new projects taking a systemic, participatory approach, and connecting needs, expertise and funding;
- Develop innovative methods, tools and approaches to better understand land use dynamics and develop strategies to sustainably manage Norfolk Island’s resources – and serve the global shift towards environmental sustainability and sustainable development;

- Prepare the Norfolk Island community to be resilient to changes in climate, population and availability of resources to sustain a quality life for residents and visitors and to enhance social, economic and ecological outcomes.

6.4.1 OBJECTIVES OF THE SUSTAINABILITY LAB

- ***Community leadership / Community-led initiatives***

The establishment of a sustainability lab would be of significant value to Norfolk Island residents, as it would constitute an interactive platform for all to participate at any level they desire. It would provide the opportunity for the members of the community to engage in co-designing and co-implementing projects of value to Norfolk Island. When issues arise, the lab would enable to connect people to the relevant information, data, resources or expertise. Some examples:

Starting up an organic farm or other farming system?
Need advice on a water issue?
Have a waste recycling idea?
Want to contribute to citizen-science on NI?
Have a business idea but not knowing how to develop it?
Want your voice heard regarding a major infrastructure/planning issue?
Want to participate in an important project to improve resilience of Norfolk Island?
Have a soil/water problem affecting your business?
Need a voice on any resource you feel is important to Norfolk Island?

- ***Learning, education and training***

The Sustainability Lab would provide the tools, materials and a network of global experts to support education and training in a broad range of areas – biodiversity conservation, food literacy, green entrepreneurship, and other relevant areas, for the local community as well as for visitors. Through various projects, the community could be involved in on-the-ground activities such as the protection of the ecological environment, food production, scientific-testing, and biodiversity conservation.

- ***Ground-up policy formulation***

By connecting community members to decision-makers, the Sustainability Lab would provide a platform for the community to play a more significant role in decision- making and the development of visions and strategies for the future of the Island. The Sustainability Lab may provide the resources, tools and methods that can lead to increased public participation and empowerment of the community in transition to a sustainable and resilient future.

- ***Cross-sectoral innovation: connecting needs, expertise and funding***

The Sustainability Lab could also facilitate the development of new projects taking a systemic, participatory approach; and connecting needs, expertise and funding. Projects vary in scale, costs, and benefits. What will be emphasised are on-the-ground works with the community, participatory processes and the co-design and co-implementation of projects. The Norfolk Island community should be central to the development of future research, experiments and projects, and with the help of a global pool of experts to clarifying issues, formulating research projects, and undertaking studies on Norfolk Island.

Community concerns, and pressing issues to ensure the long term sustainability and resilience of this island community, should be a focus of future research projects, such as[5]:

- Improve monitoring of residential/rural water use
- Develop a "whole-of-Island" water management plan based on continuous simulation at the allotment scale
- Improve allotment-scale waste management (liquid and solid waste)
- Assist the development of circular economies across Norfolk Island

- Improve allotment-scale energy and waste systems
- Optimise allotment-scale food production (import/export, crop types, approaches and co-operatives)
- Increase awareness of culture and connection to Norfolk Island through citizen science (iNaturalist, LandCare, CoastCare, etc.)
- Use of drone technology for monitoring changes in land use and vegetation cover over time

6.4.2 GOVERNANCE & CONNECTIVITY

Figure 6.2 conceptualises the governance and connectivity of the Sustainability Lab.

Figure 6.2: Governance and connectivity objectives of the Sustainability Lab

- A **"Sustainability Board**", composed of representatives of government, community and researchers. The Board meets regularly to provide directions to the Lab, receive information and instructs the development of new knowledge and data as required for the development of policy, strategies for the sustainable development of Norfolk Island.
- A **Learning Centre** as a knowledge bank/research repository that provides all the tools, data, and knowledge for community and researcher access, in a broad range of areas such as to promote sustainable agriculture, environmental education, youth leadership and community building.
- Linked to a **Global Network** of researchers, practitioners and communities from around the world, the Sustainability Lab provides the Norfolk Island community with access to a broad range of resources globally to solve problems and develop new experiments / initiatives for the sustainable development of Norfolk Island. Research outcomes are disseminated through the Lab, peer reviewed journals and other platforms, and become resources for other communities and stakeholders from around the world.
- The **Norfolk Island Community** is central to the establishment and functioning of the Lab and orientation of its activities, not only through its representation in the "Sustainability Board", but also through regular consultations and the opportunity for training and learning in a range of areas that are related to sustainability and resilience.
- A **Sustainability Lead Officer** liaises between the broader community, the Board and the global network associated with the Sustainability Lab and coordinates the activities of the Lab.

Figure 6.3 shows potential funding pathways for the Sustainability Lab.

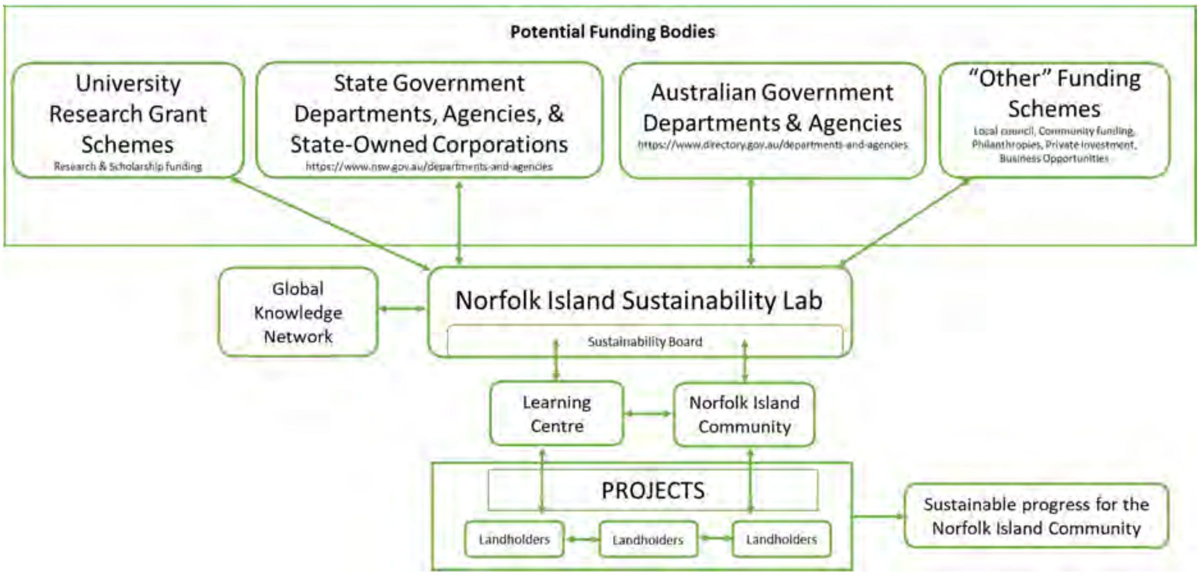

Figure 6.3: Existing connections between Australian Government departments & agencies, State Government department & agencies and the proposed Sustainability Lab

6.4.3 OPERATIONALISATION

The initial development of the Norfolk Island Sustainability Lab will rely on the willingness and dedication of the Norfolk Island Community, and if initiated, the Lab would become a gateway for promoting activities/research contributing to the future resilience and sustainability of Norfolk Island.

Every author in this report is willing to connect the Global Network with the objective to harness global knowledge, through existing platforms such as our respective University networks and research partners, associated staff profile web-links, LinkedIn, ResearchGate, and others.

CONCLUSION

This research project undertook a comprehensive investigation of Norfolk Island's natural systems and the systems in place for waste management, energy and food security – as a basis for assessing Norfolk Island's carrying capacity and guiding decision-making for ensuring the Island's long-term sustainability and resilience.

Some trends were presented on the basis of climate and coastal data, and analyses of land use capability, soils and ecosystems on Norfolk Island. The climate trend summary shows warming of the seas surrounding Norfolk Island, increasing mean annual temperatures, decreasing mean annual rainfall, and increasing mean annual evaporation. These trends indicate a shift in climate patterns that are likely to decrease available water and the Island's biodiversity over the next 100 years.

Priority should be given to protecting sensitive areas, improving coastal resilience and enhancing land management and soil conservation. The soils on Norfolk Island are inherently dispersive, with their stability solely reliant on land use and vegetation cover and the slope of the land where vegetation exists.

The broad analyses of Vegetation and Catchment condition for Norfolk Island provided a baseline of existing condition. Modelling shows that three disturbance classes (Classes 1, 2, and 3) cover 2192 ha of land area on Norfolk Island, or approximately 64% of land area (excluding major roads and shorelines). The worst condition class (Class 1) includes degraded open grass areas with evidence of sheet and gully erosion. Impacts from trampling, grazing, farming and vegetation management have a strong correlation with this class.

The hydrological assessment and preliminary water balance for Norfolk Island focused on the current context and issues, such as water shortages, discharge of wastewater to the Marine Park, and declining groundwater levels. The wastewater treatment plant upgrade (100% reuse + connection of properties) is recommended as a priority to concurrently reduce reliance on groundwater and increase water availability for use by the community, and boost local food production, as well as to reduce septic tank discharge to surface and groundwater.

One important observation was the 'implementation gaps', that is the gaps observed between the vast amount of knowledge/data available from past studies and reports and their integration into subsequent policy and strategy documents. This needs to be addressed to ensure relevant recommendations are taken into account at the policy level. Hence the last chapter of the Report recommended the setting-up of a 'Sustainability Lab' to act as a research and innovation hub as well as a knowledge repository for Norfolk Island, to assist dissemination of research outputs and their integration into decisions that will affect the future of the Island. It would also enable the community to play a central role in future research, innovation and policy/ strategy formulation.

An enabling environment is needed to foster better coordination between all stakeholders -government, the Norfolk Island community and the scientific community - and promote a multi-stakeholder/ multi-sector approach to enhance strategic and operational capacities and synchronise actions towards a comprehensive policy approach to sustainability and resilience on Norfolk Island.

Most of the issues that Norfolk Island is facing present opportunities for integrated solutions. Yet these often interconnected issues – land and soil degradation, biodiversity loss energy, waste, water availability, wastewater, and food security – are presently addressed in siloes, managed by various separate entities at the federal, state and regional levels.

The future of Norfolk Island needs to be considered from a strategic standpoint, embracing a whole-system perspective to change, to drive an island-wide transition towards sustainable development. Many of the challenges Norfolk Island faces can be approached in an integrated way, such as discussed in Chapter 5. For instance, placing food production and sustainability at the core of a place-based development strategy would equally benefit the Island's economy, its tourism sector, the health and wellbeing of its residents, while enhancing soil conversation, land and biodiversity.

The implementation of the Norfolk Island Community Strategic Plan - *Our Plan for the Future* 2016-2026 warrants such a comprehensive and holistic approach to address food security and other related development objectives in a synchronized manner.

Community empowerment and leadership have to be central to defining a sustainable future for Norfolk Island. Effective public participation, associating the community to future research design, innovation and policy formulation, can be an important factor in enhancing community trust and ownership of the future.

REFERENCES

Introduction

ABS (2016). *"Norfolk Island (State Suburb)". 2016 Census QuickStats. http://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/SSC90004, Retrieved 14/02/2019.*

ACIL Tasman (2012) Final Report Norfolk Island Economic Development Report Reform of the Norfolk Island Economy, Report for Department of Regional Australia, Regional Development and Local Government, March 2012. https://www.regional.gov.au/territories/publications/files/Norfolk_Island_EDR_2012.pdf (accessed 8/11/2019)

Administration of Norfolk Island. (2011a). *Norfolk Island Census of Population and Housing: Census Description, Analysis and Basic Tables (PDF). 9 August 2011. Archived from the original (PDF) on 24 March 2012. Retrieved 15/02/2019.*

Administration of Norfolk Island. (2011b). *Population and planning on Norfolk Island. Report No.2: Population and sustainability issues.* The Administration of Norfolk Island.

Ahmadi, A., Mosammam, H.M., Mirzaei, M. (2017). Land Suitability Evaluation to Determine the Appropriate Areas of Development: A Case Study of Hormuz Island. *Open Journal of Ecology* 7: 518-534.

Anderson, A. and White, P. (2001) *Prehistoric settlement on Norfolk Island and its Oceanic context*. In: The Prehistoric Archaeology of Norfolk Island, Southwest Pacific, ed. Atholl Anderson and Peter White, pp. 135–141. Records of the Australian Museum, Supplement 27. Sydney: Australian Museum.

Bird, E. (2010). Norfolk Island. In Eric C.F. Bird (ed.), *Encyclopedia of the World's Coastal Landforms*, 1247-1254. Springer Science + Business Media B.V.

BOM (2020). Bureau of Meteorology, Climate statistics for Australian locations. Norfolk Island Aero. http://www.bom.gov.au/climate/averages/tables/cw_200288.shtml, accessed 24/03/2020

Elliff, C.I. and Silva, I.R. (2016) Coral reefs as the first line of defence: Shoreline protection in face of climate change, *Marine Environmental Research*, 127, p148-154.

Gibbs, M., Brad Duncan, B., Varman, R. (2017) The free and unfree settlements of Norfolk Island: an overview of archaeological research, *Australian Archaeology*, 83, No. 3, 82–99. https://doi.org/10.1080/03122417.2017.1404732

Hoare, M. (1988) *Norfolk Island: An Outline of Its History 1774-1987*, 4th Edn, University of Queensland Press St Lucia, Queensland.

KPMG (2019) Monitoring the Norfolk Island Economy, Report for Department of Infrastructure, Transport, Cities and Regional Development https://www.regional.gov.au/territories/norfolk_island/norfolk-island-economy/files/Monitoring_the_Norfolk_Island_Economy.pdf (accessed 10/11/2019)

NIA (2011) Norfolk Island Census of Population and Housing 9 August 2011. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/public/documents/ANIReports/Census/Census_2011.pdf (accessed 14/11/2019)

NIG (2014) Submission to Joint Standing Committee on National Capital and External Territories - Economic Development On Norfolk Island, Submission 21. https://www.aph.gov.au/DocumentStore.ashx?id=d79154e9-ef00-4130-a2ff-c64e7233628c&subId=251813 (accessed 10/11/2019)

Nimmo, J. (1976). Report of the Royal Commission into matters relating to Norfolk Island. Canberra, Australia: Australian Government Publishing Service.

NIRC (Norfolk Island Regional Council) (2016) *Norfolk Island Community Strategic Plan 2016 – 2026 Our Plan for the Future.* http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/Plans/Community%20Strategic%20Plan%202016-2026.pdf (accessed 29/10/2019)

Norfolk Island Tourism (2013) *Norfolk Island Tourism Strategic Plan 2013-2023*. http://www.norfolkisland.gov.nf/sites/default/files/public/documents/Norfolk%20Island%20Tourism%20Strategic%20Plan%202013-2023.pdf (accessed 29/10/2019)

Norfolk Island Regional Council. (2018). *Norfolk Island Environment Strategy 2018-2023*. http://www.norfolkisland.gov.nf/file/51996/download?token=0icIPedq

Petheram C, Taylor A, Hughes J, Philip S, Tavener N, Greenwood D, Taylor N, Wilson PR, Raiber M, Turnadge C, Yang A, Seo L, Davies P, Vanderzalm J, Davis A, Crane P, Gallant J, Ahmed W, Rogers L, Ticehurst C, Marvanek S, Christoph G, Bui E, Grice T, Crosbie R, Metcalfe S, Fitzpatrick R, Schepen A, Levick S, Nobbs C, Cahill K, Vaze J (2020) *Norfolk Island Water Resource Assessment*. A report to the Australian Government from the CSIRO Norfolk Island Water Resource Assessment team. CSIRO, Australia.

SGS Economics and Planning (2015) *Norfolk Island Economic Development Strategy, Report for Department of Infrastructure and Regional Development.* https://www.regional.gov.au/territories/publications/files/SGS_Norfolk_Island_Economic_Development_Strategy_Action_Plan.pdf (accessed 23/10/2019)

Wettenhall, R. (2016). Decolonizing through integration: Australia's offshore island territories. *Island Studies Journal*, (2), 715. Retrieved from http://search.ebscohost.com.ezproxy.newcastle.edu.au/login.aspx?direct=true&db=edsdoj&AN=edsdoj.00ca6dea3c50465cabce117d0527f34c&site=eds-live

Chapter 1

Abell, R. S. (1976). A groundwater investigation on Norfolk Island. Bureau of Mineral Resources, Geology and Geophysics. Department of Minerals and Energy – Record 1976/62. Australian Government.

Abell, R. S., Falkland, A. C. (1991). The hydrogeology of Norfolk Island, South Pacific Ocean. Bureau of Mineral Resources, Geology and Geophysics Bulletin, 234.

AIMS (2017) Backgrounder: Impact of land runoff. http://www.aims.gov.au/impact-of-runoff

Animal Health Surveillance Quarterly. (2015). 2013–14 Animal Health Survey of Norfolk Island. Newsletter of Australia's National Animal Health Information System, Vol. 20, Issue 3.

ANZECC (2000) *Australian and New Zealand Guidelines for Fresh and Marine Water Quality - Volume 1*, Australia and New Zealand Environment and Conservation Council (ANZECC) and the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), ISBN 09578245 0 5.

APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', Water Environment Federation, 23rd Edition.

Bird E. (2010) Norfolk Island. In: Bird E.C.F. (eds) Encyclopedia of the World's Coastal Landforms. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-8639-7_227.

Cass, A. and Sumner, M. E. (1982). Soil pore structural stability and irrigation water quality. (2). Sodium stability data. *Journal of the Soil Science Society of America.* **46**: 507-512.

Clive Lucas, Stapleton and Partners Pty Ltd (1988) *Kingston and Arthur's Vale historic area (KAVHA) Norfolk Island: Conservation Management Plan*,

https://www.worldcat.org/title/kingston-and-arthurs-vale-historic-area-kavha-norfolk-island-conservation-management-plan/oclc/220402813

Community Title Act (2015). Act No. 1 of 2015. The Administration of Norfolk Island 2015. http://www.norfolkisland.gov.nf/sites/default/files/public/documents/CommunityTitleInformation/Community%20Title%20Act%202015%20%28NI%29.pdf.

Department of the Environment and Heritage. (2004). *What the Environment Protection and Biodiversity Conservation Act 1999 means for Norfolk Island*, Department of the Environment and Heritage, Canberra.

Diamond, J. (2005). Collapse: How societies choose to fail or succeed. (Penguin: New York).

D'Angelo C and J. Wiedenmann (2014) Impacts of nutrient enrichment on coral reefs: new perspectives and implications for coastal management and reef survival. Current opinion in *Environmental Sustainability*, vol 7, April 2014, pp 82-93. doi.org/10.1016/j.cosust.2013.11.029

Director of National Parks (2013) *Temperate East Commonwealth Marine Reserves Network Management Plan 2014–24*, Director of National Parks, Canberra. ISBN: 978-1-921733-72-7

Elliff, C.I. and Silva, I.R. (2016) Coral reefs as the first line of defence: Shoreline protection in face of climate change, *Marine Environmental Research*, 127, p148-154.

Ferrario, F., Beck, M.W., Storlazzi, C.D., Micheli, F., Shepard, C.C., Airoldi, L. (2014) The effectiveness of coral reefs for coastal hazard risk reduction and adaptation. Nature Communication, 5, (3794)

Foster, K., Snedden, B., Harrington, S., Graham, D., Cavallo, R., Mckay, D. (2009). Norfolk Island Natural Resource Management Plan. The Administration of Norfolk Island & Parsons Brinckerhoff Australia Pty Limited, p152.

Gray, J. M., Chapman, G. A., Murphy, B. W. (2015). Land management within capability: a new scheme to guide sustainable land management in New South Wales, Australia. Soil Research 53, 683–694.

Hazelton, P., Murphy, B. (2011) *Interpreting Soil Test Results: What do all the numbers mean?,* CSIRO Publishing, ISBN 978 0 64309 225 9.

Jones, J. G., McDougall, I. (1973). Geological History of Norfolk and Phillip Islands, Southwest Pacific Ocean. Journal of Geological Society of Australia 20(3).

Mariono, N. (2020). Norfolk Island's artificial reproduction for livestock project commences. Media Release 14 July 2020. https://minister.infrastructure.gov.au/marino/media-release/norfolk-islands-artificial-reproduction-livestock-project-commences.

McKenna J. (2005) Boulder Beaches. In: Schwartz M.L. (eds) Encyclopedia of Coastal Science. Encyclopedia of Earth Science Series. Springer, Dordrecht

Mills, K. (2009). *The Flora of Norfolk Island*. 9. The Vegetation of Nepean Island (including Errata and Addenda for Papers 1 to 8). The Author, Jamberoo, NSW.

Mills, K. (2018) *Norfolk Island Vegetation Mapping Project: Towards conserving and enhancing the island's unique plants*, Background Report https://745eb06a-55f0-4950-b91f6850deeb366f.filesusr.com/ugd/4d5ec3_c7be9c48c9a440e383f68328963e64aa.pdf

Mosley, J.G. (2001) *Island on the brink: a conservation strategy for Norfolk Island*, prepared for the Norfolk Island Conservation Society. https://catalogue.nla.gov.au/Record/3301773

Naomi Christian Consulting (2020) *Norfolk Island Vegetation Mapping Project 2020*, Island-wide vegetation maps of Norfolk Island, https://www.naomichristianconsulting.com/norfolkvegetationmap

Norfolk Island Regional Council (2018) *Norfolk Island Environment Strategy 2018 - 2023* http://www.norfolkisland.gov.nf/sites/default/files/docs/Norfolk%20Island%20Environment%20Strategy%202018%E2%80%932023.pdf

Olsen, S. R. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (No. 939). US Department of Agriculture.

Oak, H.L. (1984) The boulder beach: a fundamentally distinct sedimentary assemblage. *Annals Association American Geographers*, **74**(1):71–82.

Parsons Brinckerhoff (2009) *Norfolk Island Natural Resource Plan*, a report the Administration of Norfolk Island.

http://dx.doi.org/10.1038/ncomms4794.www.nature.com/naturecommunications

Pendoley, K. (2015) Pendoley Environmental Pty Ltd: Water Quality in Emily Bay. Letter to the Administrator of Norfolk Island

Petheram C, Taylor A, Hughes J, Philip S, Tavener N, Greenwood D, Taylor N, Wilson PR, Raiber M, Turnadge C, Yang A, Seo L, Davies P, Vanderzalm J, Davis A, Crane P, Gallant J, Ahmed W, Rogers L, Ticehurst C, Marvanek S, Christoph G, Bui E, Grice T, Crosbie R, Metcalfe S, Fitzpatrick R, Schepen A, Levick S, Nobbs C, Cahill K, Vaze J (2020) Norfolk Island Water Resource Assessment. A report to the Australian Government from the CSIRO Norfolk Island Water Resource Assessment team. CSIRO, Australia.

Quirk, J. P. (2001). The significance of the threshold and turbidity concentrations in relation to sodicity and microstructure. *Australian Journal of Soil Research.* **39**: 1185-1217.

Quirk, J. P. and Davidson, J. L. (1959). Effect of electrolyte level of irrigation water on the establishment of pasture on Riverina clay. *Journal of Soil Science* **21**: 191-192.

Quirk, J. P. and Schofield, R. K. (1955). The effect of electrolyte concentration on soil permeability. *Journal of Soil Science* **6**: 163-178.

Rayment, G.E. and Lyons, D.J. (2011). Soil chemical methods: Australasia (Vol. 3). CSIRO publishing.

Reeve, R. C. (1958). The transmission of water by soils as influenced by chemical and physical properties. *Transactions of fifth Congress of Agricultural Engineering.*: 21-33.

Rengasamy, P., Greene, R. S. B., Ford, G. W. and Mehanni, A. H. (1984). Identification of dispersive behaviour and the management of red-brown earths. *Australian Journal of Soil Research.* **22**: 413-431.

Rhoades, J. D. (1982). Reclamation and management of salt-affected soils after drainage. *Proceedings of First Annual West Provincial Conference on Rationalization of Water and Soil Research and Management.*, Lethbridge, Alberta.

Shaw, E. M. (1994). *Hydrology in Practice.*, Chapman & Hall.

Shaw, R., Brebber, C. R., Ahern, C. R. and Weinand, M. (1994). Sodicity and sodic soil behaviour in Queensland. *Australian Journal of Soil Research.* **32**: 143-172.

Stephens, C.G. & Hutton, J.T. (1954) *A Soil and Land Use Study of the Australian Territory of Norfolk Island, South Pacific Ocean*, Division of Soils, CSIRO.

Sumner, M. E. (1993). Sodic Soils: New Perspectives. *Australian Journal of Soil Research.* **31**: 683-750.

Taylor, S. (1996). *Dryland Salinity, Introductory Extension Notes.* Sydney, Department of Land and Water Conservation.

Wilson, P.J. (2017) *Water Quality in the KAVHA Catchment*, Norfolk Island Regional Council.

Vega Thurber, R. L., Burkepile, D. E., Fuchs, C., Shantz, A. A., McMinds, R. and Zaneveld, J. R. (2014) Chronic nutrient enrichment increases prevalence and severity of coral disease and bleaching. *Glob Change Biol*, 20: 544–554. doi:10.1111/gcb.12450

Chapter 2

Abell, R.S. and A.C. Falkland (1991). The hydrogeology of Norfolk Island, South Pacific Ocean. Department of Primary Industries and Energy. Bureau of Mineral Resources, Geology and Geophysics. Bulletin 234.

ABS (2018). Australian Bureau of Statistics, 2016 Census QuickStats. https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/SSC90004?opendocument, accessed 17/02/2020.

AECOM (2017) *Emily Bay and Upper Cascade Creek Catchments: Norfolk Island Water Quality Study*, AECOM Report for Norfolk Island Regional Council.

Allen, R.G., Pereira, L.S., Raes, D. and M. Smith (1998), FAO Irrigation and Drainage Paper No. 56. Crop Evapotranspiration (Guidelines for computing crop water requirements).

BGA & PWA (2019) *Upgrade of Norfolk Island's Sewerage Treatment Plant, Capital Works Construction Project Initial Business Case*, prepared by Balmoral Group Australia and Public Works Advisory.

BOM (2019). Bureau of Meteorology, Climate Data Online. http://www.bom.gov.au/climate/data/, accessed 18/12/2019.

BOM (2020). Bureau of Meteorology, Climate statistics for Australian locations. Norfolk Island Airport. http://www.bom.gov.au/climate/averages/tables/cw_200288.shtml, accessed 24/03/2020

CIA (2011). The World Factbook. https://www.cia.gov/library/publications/resources/the-world-factbook/geos/nf.html, accessed 17/01/2020

DPI, 2014, *Water requirements for sheep and cattle*, Primefact 326 third edition, Agriculture NSW Water Unit, BOM (2019) http://www.bom.gov.au/nsw/norfolk/climate.shtml (accessed 24/9/2019) Department of Primary Industries.

eWater (2016) https://ewater.org.au/?s=music (accessed 8/8/2021)

Falkland, T., 1996, Norfolk Island Water Management Report, ACTEW Corporation, 25p.

GHD (2016). The Administration of Norfolk Island. *Calculation of Stocking Rates on Public Lands*. 21/25213. Green Building Council of Australia (2014). Potable Water Calculator Guide.

https://www.gbca.org.au/uploads/233/35817/Potable%20Water%20Calculator%20Guide%20v1.pdf

GHD (2016) *Drinking Water & Recreational Waters Monitoring Program*, GHD Report for Norfolk Island Regional Council.

Healy, R.W., 2010. Estimating groundwater recharge. Cambridge University Press. DOI:https://doi.org/10.1017/CBO9780511780745.

NIRC (2019a). Registered Tourist Accommodation Properties – July 2019. http://www.norfolkisland.gov.nf/sites/default/files/public/documents/Registered%20Tourist%20Accommodation%20Properties%20July%202019.pdf.

NIRC (2019b). Historical tourism data. http://www.norfolkisland.gov.nf/historical-information/tourism-data.

Ordens CM, Werner AD, Post VEA, Hutson JL, Simmons CT, Irvine BM (2012) Groundwater recharge to a sedimentary aquifer in the topographically closed Uley South Basin, South Australia. Hydrogeology Journal 20 (1), 61-72

NOAA (2019) https://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst-v5 (accessed 24/9/2019)

Norfolk Island Regional Council (2018) *Norfolk Island Environmental Strategy 2018 – 2023*, Resolution Number 2018/188.

Petheram C, Taylor A, Hughes J, Philip S, Tavener N, Greenwood D, Taylor N, Wilson PR, Raiber M, Turnadge C, Yang A, Seo L, Davies P, Vanderzalm J, Davis A, Crane P, Gallant J, Ahmed W, Rogers L, Ticehurst C, Marvanek S, Christoph G, Bui E, Grice T, Crosbie R, Metcalfe S, Fitzpatrick R, Schepen A, Levick S, Nobbs C, Cahill K, Vaze J (2020) Norfolk Island Water Resource Assessment. A report to the Australian Government from the CSIRO Norfolk Island Water Resource Assessment team. CSIRO, Australia.

SKM (2010) *Surface and/or groundwater interception activities: Initial estimates*, Sinclair Knight Merz, CSIRO Bureau of Rural Sciences, Waterlines Report Series No 30, June 2010.

The Administration of Norfolk Island (2014) *Norfolk Island: Water Quality & Sewerage Infrastructure Management Strategy* Wallace J., Macfarlane, C., McJannet, D., Ellis, T., Grigg, A. and A. van Dijk (2013). Evaluation of forest interception estimation in the continental scale Australian Water Resources Assessment (AWRA-L) model. *Journal of Hydrology* 499: 210-223.

UCWS (2019) https://urbanwatercyclesolutions.com/ (accessed 25/9/2019)

URS (2013) *Final Report: Norfolk Island water Quality Study, Emily Bay & Upper Cascade Creek Catchments*, prepared for the Administration of Norfolk Island.

WaterNSW (2020) https://www.waternsw.com.au/waterinsights/real-time-data (accessed 27/2/2020)

Wilson, P.J. (2017) *Water Quality in the KAVHA Catchment*, Norfolk Island Regional Council.

Chapter 3

APC, 2015, The Administration of Norfolk Island Waste Management Strategic Plan.

APCO, 2020, Packaging Waste Collection and Processing Options in Remote and Regional Areas.

Director of National Parks, 2013, Temperate East Commonwealth Marine Reserves Network Management Plan 2014– 24, Director of National Parks, Canberra.

EPA, 2016, The NSW EPA education strategy, Changing Behaviour Together NSW Waste Less, Recycle More education strategy 2016–21.

McKenzie-Mohr, D., 2011, Fostering Sustainable Behaviour: An Introduction to Community-Based Social Marketing, Gabriola Island, B.C: New Society Publishers.

Norfolk Island Regional Council, 2018, Norfolk Island Environment Strategy 2018–2023.

Norfolk Island Regional Council, 2020, Composting Facility at Norfolk Island Waste Management Centre Environmental Impact Statement.

The Administration of Norfolk Island, 2009, Norfolk Island Municipal Waste Stream Feasibility Study Final Report.

The PEW Charitable Trusts, 2020, Breaking the Plastic Wave: A Comprehensive of Pathways Towards Stopping Ocean Plastic Pollution.

Chapter 4

ABS (Australian Bureau of Statistics) (2017a) 2016 Census QuickStats Norfolk Island, https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/SSC90004?opendocument (accessed 1/11/2019)

ABS (2017b) Norfolk Island 2016 Census of Population and Housing General Community Profile, https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/communityprofile/SSC90004?opendocument (accessed 1/11/2019)

ABS (2017c) 2016 Census Data Seminar – Norfolk Island, Retrieved from: https://www.abs.gov.au/websitedbs/d3310114.nsf/home/Census+Data+Seminars/$File/Norfolk+Island+Presentation+Slides.pdf (accessed 14/11/2019)

ACIL Tasman (2012) Final Report Norfolk Island Economic Development Report Reform of the Norfolk Island Economy, Report for Department of Regional Australia, Regional Development and Local Government, March 2012. https://www.regional.gov.au/territories/publications/files/Norfolk_Island_EDR_2012.pdf (accessed 8/11/2019)

Ahlstrom, D. (2018, January 25). Research project aims to turn excess wind energy into hydrogen. Retrieved from https://www.irishtimes.com/business/innovation/research-project-aims-to-turn-excess-wind-energy-into-hydrogen-1.3366905

Al Jazeera English (2014, September 8). *Samoa turns to weeds to produce biogas* [Video file]. Retrieved from https://www.youtube.com/watch?v=70kWpKPaM8A

Anderson, A. and White, P. (2001) *Prehistoric settlement on Norfolk Island and its Oceanic context*. In: The Prehistoric Archaeology of Norfolk Island, Southwest Pacific, ed. Atholl Anderson and Peter White, pp. 135–141. Records of the Australian Museum, Supplement 27. Sydney: Australian Museum. https://media.australianmuseum.net.au/media/Uploads/Journals/17923/1348_complete.pdf (accessed 1/11/2019)

ARENA (n.d.) Demand response. Retrieved from https://arena.gov.au/renewable-energy/demand-response/

ARENA (2017a, October 11). What is demand response? Retrieved from https://arena.gov.au/blog/what-is-demand-response/

ARENA. (2017b, December 19). Flicking the switch: (Hybrid) energy comes to Flinders Island [Blog post]. Retrieved from https://arena.gov.au/blog/flinders-island/

ARENA (2019a) Cultana PHES Project – Phase 2. Retrieved from: https://arena.gov.au/projects/cultana-pumped-hydro-energy-storage-project-phase-2/

ARENA. (2019b, October 4). Full steam ahead for King Island wave power trial [Blog post]. Retrieved from https://arena.gov.au/blog/king-island-wave-power/

ARENA. (2019c, October 23). Flinders Island Hybrid Energy Hub. Retrieved from https://arena.gov.au/projects/flinders-island-hybrid-energy-hub/

ARENA. (2019d). Solar/diesel mini-grid handbook. Retrieved from https://arena.gov.au/assets/2019/10/solar-diesel-mini-grid-handbook-powerwater.pdf

ARENA. (2020a, January 17) Social Access Solar Gardens. Retrieved from https://arena.gov.au/projects/social-access-solar-gardens/

ARENA. (2020b, May 27) Bioenergy and energy from waste. Retrieved from https://arena.gov.au/renewable-energy/bioenergy/

Arguedas Ortiz, D. (2019, March 28). How hydrogen is transforming these tiny Scottish islands. Retrieved from https://www.bbc.com/future/article/20190327-the-tiny-islands-leading-the-way-in-hydrogen-power

at@hydropower.org. (2015, October 30). Case study: El Hierro – renewable energy for remote island systems [Blog post]. Retrieved from https://www.hydropower.org/blog/case-study-el-hierro-%E2%80%93-renewable-energy-for-remote-island-systems

Australian Tenders (2019, September 10) Supply and Installation of a Generator and Batteries - Norfolk Island. Retrieved from: https://www.australiantenders.com.au/tenders/393470/supply-and-installation-of-a-generator-and-batteries-norfolk-island/

Avanindra, D., Urban, B., Macaw, S., Williams, C.J., & Richards, D.O. (2019, October 13). *Energy Independence for Island Nations: Building Sustainable and Microgrids* [Virtual Island Summit] [Video file]. Retrieved from https://www.youtube.com/watch?v=gNnupsMWd18

Barton, D. (2003) *Social and technical barriers and options for renewable energy on remote developed islands. Case study: Norfolk Island*, ANZSES 2003 Destination Renewables conference, Melbourne Australia http://www.globalislands.net/userfiles/norfolk2.pdf (accessed 23/10/2019)

Barton, D. (2006) Technology transfer or Sociotechnical change? Exploring energy options for Norfolk Island: Qualitative interviews exploring energy options for Norfolk Island, In Australian and New Zealand Solar Energy Society. Conference Canberra, A.C.T.) (2006). Clean energy? Can do! : proceedings of Solar 2006, 44th Annual Conference, Canberra, Australia, 13 to 15 September 2006. ANZSES, Canberra ACT, Retrieved from: http://www.globalislands.net/userfiles/norfolk3.pdf (accessed 12/11/2019)

Barton, D. (2008) *Social and technical aspects of community level decision-making on energy options in two remote island communities* (Doctoral dissertation), Retrieved from: https://openresearch-repository.anu.edu.au/handle/1885/151035 (accessed 11/11/2019)

BBC (2017, March 30). The small Scottish isle leading the world in electricity. Retrieved from https://www.bbc.com/future/article/20170329-the-extraordinary-electricity-of-the-scottish-island-of-eigg

Benítez, I. (2014, May 6). Community Electricity Lights Up Spain. Retrieved from http://www.ipsnews.net/2014/05/community-electricity-lights-spain/

BIGH2IT (n.d.) Project Elements: Community Wind Turbine. Retrieved from https://www.bighit.eu/community-wind-turbine

Bioenergy Insight (2019, October 8). Faroese salmon firm wins award for archipelago's first biogas project. Retrieved from https://www.bioenergy-news.com/news/faroese-salmon-company-wins-award-for-biogas-project/

Bin, Y., Jie, T., Liji, Jiemin, H. & Xiaomei, L. (2012) Feasibility Study of Renewable Energy Powered Island-Hainan. (2012). *2012 International Conference on Computer Distributed Control and Intelligent Environmental Monitoring, Computer Distributed Control and Intelligent Environmental Monitoring (CDCIEM), 2012 International Conference On*, (pp 330-333). https://doi-org.ezproxy.newcastle.edu.au/10.1109/CDCIEM.2012.85

BloombergNEF. (2019, December 3). Battery Pack Prices Fall As Market Ramps Up With Market Average At $156/kWh In 2019. Retrieved from https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/

Borison, A., Edghill, J., Taylor, J., Mariani, S., & O'dwyer, L. (2019, October 13). *How can islands move e-mobility into the fast lane? [Virtual Island Summit]* [Video File]. Retrieved from https://www.youtube.com/watch?v=n3-ULk7MO54&feature=emb_logo

Brown, H. S., & Vergragt, P. J. (2008). Bounded socio-technical experiments as agents of systemic change: The case of a zero-energy residential building. Technological Forecasting & Social Change, 75(1), 107–130. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.techfore.2006.05.014

Bueno, C., & Carta, J. A. (2006). Wind powered pumped hydro storage systems, a means of increasing the penetration of renewable energy in the Canary Islands. Renewable and Sustainable Energy Reviews, 10(4), 312–340. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.rser.2004.09.005

Bureau of Meteorology. (2019, August 11). Rose of Wind direction versus Wind speed in km/h (06 Apr 1939 to 11 Aug 2019). Retrieved from http://www.bom.gov.au/clim_data/cdio/tables/pdf/windrose/IDCJCM0021.200288.3pm.pdf

Bureau of Meteorology (2020, February 13) Climate statistics for Australian locations. Monthly climate Statistics. Norfolk Island Aero. Retrieved from http://www.bom.gov.au/climate/averages/tables/cw_200288_All.shtml (accessed 18/02/2020)

Burger, A. (2019, August 13). Caribbean Island Rolls Out Battery Energy Storage System, Looks to Add Solar on Path to 100 Percent Renewable Energy. Retrieved from https://solarmagazine.com/caribbean-island-bonaire-battery-energy-storage-system-solar-100-renewable-energy/

Carlu, E. Truong, T. Kundevski, M. (2019, May). Biogas opportunities for Australia. ENEA Consulting – March 2019. Retrieved from: https://www.energynetworks.com.au/resources/reports/biogas-opportunities-for-australia-enea-consulting/

Casey, J. P. (2018, February 22). Renault aims to power Portuguese island entirely by renewable energy. Retrieved from https://www.power-technology.com/news/renault-aims-power-portuguese-island-entirely-renewable-energy/

CEFC (Clean Energy Finance Corporation). (2016, June). Clean energy opportunities for local government: A market report by the Clean Energy Finance Corporation June 2016. Retrieved from https://www.cefc.com.au/media/203026/cefcmarketreport.pdf

Central Coast Community Energy Association Incorporated (n.d.) Community. Retrieved from https://cccommunityenergy.org/community/

Centre for International Economics (2006) Economic Impact Assessment of extending Commonwealth legislation to Norfolk Island. Report for Department of Transport and Regional Services. https://www.infrastructure.gov.au/department/ips/files/log/FOI_11_17.pdf (accessed 8/11/2019)

Chen, T., Liu, R., & Scott, N. R. (2016). Characterization of energy carriers obtained from the pyrolysis of white ash, switchgrass and corn stover — Biochar, syngas and bio-oil. Fuel Processing Technology, 142, 124–134. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.fuproc.2015.09.034

Churgwin, R. (2020, June 1) Community batteries benefit the grid more says latest research [Blog post]. Retrieved from https://www.solarquotes.com.au/blog/community-batteries-benefits/

Ciolkosz, D. (2016, June 9). What’s So Different about Biodiesel Fuel? Retrieved from https://extension.psu.edu/whats-so-different-about-biodiesel-fuel

Clairand, J.M., Arriaga, M., Cañizares C.A., and Álvarez-Bel, C. (2019). Power Generation Planning of Galapagos' Microgrid Considering Electric Vehicles and Induction Stoves. *IEEE Transactions on Sustainable Energy*, 10 (4), 1916-1926. https://doi-org.ezproxy.newcastle.edu.au/10.1109/TSTE.2018.2876059

Climate Bonds Initiative. (2018, August). Australia and New Zealand Green finance country briefing August 2018. Retrieved from https://www.climatebonds.net/files/files/CBI%20_%20Australia%20%26%20NZ%20_%20country%20briefing%20_final%281%29.pdf

Cloin, J. (2007). Coconut oil as a fuel in the Pacific Islands. Natural Resources Forum, 31(2), 119–127. https://doi-org.ezproxy.newcastle.edu.au/10.1111/j.1477-8947.2007.00145.x

Clean Energy for EU Islands. (2019, November 20). Six EU islands publish clean energy transition agendas, putting citizens first. Retrieved from https://euislands.eu/eu-islands-publish-clean-energy-transition-plans

Collie, S. (2019, August 9) Price parity between electric and internal combustion cars is close - Volkswagen. Retrieved from https://www.caradvice.com.au/782597/price-parity-electric-vehicle/

Colmenar-Santos, A., Linares-Mena, A.-R., Borge-Diez, D., & Quinto-Alemany, C.-D. (2017). Impact assessment of electric vehicles on islands grids: A case study for Tenerife (Spain). *Energy, 120*, 385–396. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.energy.2016.11.097

CSIRO (2019, April 24) Case Study: Wave Energy in Australia. Retrieved from: https://www.csiro.au/en/Research/OandA/Areas/Marine-technologies/Ocean-energy/Wave-energy

Deloitte (2014) Norfolk Island government business analysis: Phase two analysis: Part 2 –Detailed analysis and appendices. Retrieved from: https://www.regional.gov.au/territories/publications/files/Government_Business_Enterprises_Deloitte_Main_Report_Nov2014.pdf

Department of Environment and Energy (2017) National Greenhouse and Energy Reporting Scheme Measurement: Technical Guidelines for the estimation of emissions by facilities in Australia. Applies to the estimation of emissions in the 2017-18 reporting year - October 2017. Retrieved from: https://www.environment.gov.au/system/files/resources/0e76f367-dfad-451d-8f41-859acfad327a/files/ngers-technical-guidelines-2017-18.pdf

Director of National Parks. (2011). Norfolk Island National Park & Botanic Garden Climate Change Strategy 2011-2016. Retrieved from https://www.environment.gov.au/resource/climate-change-strategy-2011-2016-norfolk-island-national-park-and-botanic-garden

Electric Vehicle Council (2019, August) State of Electric vehicles: August 2019. Retrieved from https://electricvehiclecouncil.com.au/wp-content/uploads/2019/09/State-of-EVs-in-Australia-2019.pdf

EMEC (2019, April 3) Press release: Energy system of the future to be demonstrated in Orkney. Retrieved from http://www.emec.org.uk/press-release-energy-system-of-the-future-to-be-demonstrated-in-orkney/

Energy Industry Review Staff (2018, August 20). First energy efficient island in Greece - Tilos. Retrieved from https://energyindustryreview.com/renewables/first-energy-efficient-island-in-greece/

Energy Matters (2019) Solar Power in Norfolk Island, NSW, 2899, https://www.energymatters.com.au/solar-location/norfolk-island-2899/ (accessed 23/10/2019)

Energy Source & Distribution. (2019, December 13). Enova Community Energy delivers Australia's first solar garden. Retrieved from https://www.esdnews.com.au/enova-community-energy-delivers-australias-first-solar-garden/

Ernst, D. (2016) Smart Grids Versus Microgrids. Retrieved from https://orbi.uliege.be/bitstream/2268/204182/1/smart-versus-micro.pdf

European Commission. (n.d.). Paris agreement. Retrieved from https://ec.europa.eu/clima/policies/international/negotiations/paris_en

Fan, Y., Rimali, V., Tang, M. & Nayar C. (2012) Design and Implementation of stand-alone smart grid employing renewable energy resources on Pulau Ubin Island of Singapore. (2012). *2012 Asia-Pacific Symposium on Electromagnetic Compatibility, Electromagnetic Compatibility (APEMC), 2012 Asia-Pacific Symposium On*, (pp. 441-444). https://doi-org.ezproxy.newcastle.edu.au/10.1109/APEMC.2012.6237907

Farming the Sun (2018, August 6). Block#9 of New England North West solar power bulk-buy NOW OPEN! Retrieved from https://farmingthesun.net/news/archive/

Fattori, F., Anglani, N., & Muliere, G. (2014). Combining photovoltaic energy with electric vehicles, smart charging and vehicle-to-grid. *Solar Energy, 110*, 438–451. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.solener.2014.09.034

Fernández Prieto, L., Rodríguez Rodríguez, G., & Schallenberg Rodríguez, J. (2019). Wave energy to power a desalination plant in the north of Gran Canaria Island: Wave resource, socioeconomic and environmental assessment. *Journal of Environmental Management*, 231, 546–551. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.jenvman.2018.10.071

Gatta, F.M., Geri, A., Lauria, S., Maccioni, M., Palone, F., Portoghese, P., Buono, L. & Necci, A. (2019). Replacing Diesel Generators With Hybrid Renewable Power Plants: Giglio Smart Island Project. *IEEE Transactions on Industry Applications, Industry Applications, IEEE Transactions on, IEEE Trans. on Ind. Applicat*, (2), 1083. https://doi-org.ezproxy.newcastle.edu.au/10.1109/TIA.2018.2878155

Gay, D., Rogers, T., & Shirley, R. (2018). Small island developing states and their suitability for electric vehicles and vehicle-to-grid services. *Utilities Policy, 55*, 69–78. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.jup.2018.09.006

Geoscience Australia (n.d.) Norfolk Island. Retrieved from https://www.ga.gov.au/scientific-topics/national-location-information/dimensions/remote-offshore-territories/norfolk-island

Ghani, R., Kangash, A., Virk, M. S., Maryandyshev, P., & Mustafa, M. (2019). Wind energy at remote islands in arctic region—A case study of Solovetsky islands. *Journal of Renewable & Sustainable Energy*, 11(5), N.PAG. https://doi-org.ezproxy.newcastle.edu.au/10.1063/1.5110756

Global Islands Network (n.d.) Green Islands Case Studies, Mediterranean Studies, Italy: Tuscan Archipelago. Retrieved from http://www.globalislands.net/greenislands/index.php?region=6&c=24

Global Sustainable Electricity Partnership. (2016a). *Galapagos San Cristóbal Island Wind Project 2003-2016*. Retrieved from https://www.globalelectricity.org/content/uploads/Galapagos-Report-2016-English.pdf

Global Sustainable Electricity Partnership. (2016b, May 29). Wind turbines on Galapagos replace millions of liters of diesel since 2007, meet 30 percent of energy needs. Retrieved from https://phys.org/news/2016-05-turbines-galapagos-millions-liters-diesel.html

Greenpeace Greece and REScoop.eu. (2018, March 8). Energy communities in Greece: new legislation: Recent developments and steps [Blog Post]. Retrieved from https://www.rescoop.eu/blog/energy-communities-in-greece-new-legislation

Hall N., Ashworth P. & Shaw H. (2012) Exploring community acceptance of rural wind farms in Australia: a snapshot. Canberra: CSIRO; 2012. https://doi.org/10.4225/08/584ee83bb6373

Hamilton, M., Davies, G., Lidderdale, A., & Ainsworth, R. (2019, October 13). *Orkney's Energy Revolution: Leading The Way To A Low Carbon Future [Virtual Island Summit]* [Video file]. Retrieved from https://www.youtube.com/watch?v=mGAZdVNGMUY

Haystacks Solar Garden (n.d.) Haystacks Solar Garden. You can have solar. Sunny roof not required. Retrieved from http://haystacks.solargarden.org.au/

Hicks, J. & Ison, N. (2011) Community-owned renewable energy (CRE): Opportunities for rural Australia, Rural Society, 20:3, 244-255, DOI: 10.5172/rsj.20.3.244

Hicks, J. and Ison, N. (2012) 'Community Energy' In Shepherd, A. Allen, P. and Harper, P. (Eds.), The Home Energy Handbook: a guide to saving and generating energy in your home and community. Centre for Appropriate Technology, Wales.

Hicks, J., Ison, N., Gilding, J. and Mey, F. (2014) Community-owned renewable energy: a how to guide. Community Power Agency, Sydney. Retrieved from https://www.environment.nsw.gov.au/resources/communities/cpa-community-energy-how-to.pdf

Hicks, J.F. (2018). *Community Power: Understanding the outcomes and impacts from community-owned wind energy projects in small regional communities* (Doctoral dissertation). Retrieved from http://unsworks.unsw.edu.au/fapi/datastream/unsworks:50964/SOURCE2?view=true

Hilson, D. (2019, March). Managing the impacts of renewably powered electric vehicles on electricity distribution networks. Retrieved from https://arena.gov.au/assets/2019/03/managing-the-impacts-of-renewably-powered-electric-vehicles-on-distribution-networks.pdf

Hoare, M. (1988) Norfolk Island: An Outline of Its History 1774-1987, 4th Edn, University of Queensland Press St Lucia, Queensland.

Holland, J. (2019, October 10). Bakkafrost's new biogas plant utilizes fish farming waste, scoops award. Retrieved from https://www.seafoodsource.com/news/processing-equipment/bakkafrost-s-new-biogas-plant-utilizes-fish-farming-waste-scoops-award

HOMER Energy. (2016, June 6). Getting the Most out of your HOMER Pro Trial [Video file]. Retrieved from https://www.youtube.com/watch?v=8uJLnNKsogg

HOMER Energy (n.d.). HOMER Pro [Computer software]. Retrieved from https://www.homerenergy.com/products/pro/index.html

Hydro Tasmania (2003). *Norfolk Island Renewable Energy Pre-Feasibility Study*. Report for Australian Greenhouse Office No 114419, Hydro Electric Corporation, Hobart, Tas, Australia. http://www.globalislands.net/userfiles/norfolk1.pdf (accessed 23/10/2019)

Hydro Tasmania (2018a) Present Condition Summary and Input Verification Norfolk Island (Version 2), Report for Norfolk Island Regional Council

Hydro Tasmania (2018b) Initial Concept Options Norfolk Island (Version 1), Report for Norfolk Island Regional Council

Hydro Tasmania (2018c) Norfolk Island Implementation Plan (Version 1), Report for Norfolk Island Regional Council

Hydro Tasmania (n.d.-a) Flinders Island case study. Retrieved from https://www.hydro.com.au/docs/default-source/clean-energy/hybrid-energy-solutions/flinders_island.pdf on 14/12/2019.

Hydro Tasmania (n.d.-b) Biodiesel. Retrieved from https://www.hydro.com.au/clean-energy/hybrid-energy-solutions/integration-solutions/biodiesel

IEA (International Energy Agency) (2019). Fuel price distribution across countries, 2019, IEA, Paris. Retrieved from https://www.iea.org/data-and-statistics/charts/fuel-price-distribution-across-countries-2019

IEEFA (Institute for Energy Economics and Financial Analysis). (2020, January 10). Research shows solar-plus-storage is an increasingly viable option for India’s power sector. Retrieved from https://ieefa.org/research-shows-solar-plus-storage-is-an-increasingly-viable-option-for-indias-power-sector/

Inglis, K., Mitchell, E. and Passey, R. (2015). Recommendations for Implementing Virtual Net Metering into Community-Owned Renewable Energy Projects in Australia.

Intelligent Energy Europe (2020, May 29). Reinforcing investments in Biogas technologies for small scale RES applications in islands. Retrieved from https://ec.europa.eu/energy/intelligent/projects/en/projects/biores

Ioakimidis, C. S. & Genikomsakis, K. N. (2018). Introduction of plug-in hybrid electric vehicles in an isolated island system. *Advances in Building Energy Research, 12*(1), 66–83. https://doi-org.ezproxy.newcastle.edu.au/10.1080/17512549.2017.1314833

Island Innovation. (2019, October 13). How Can Islands Move E-Mobility Into The Fast Lane? [Virtual Island Summit]. Retrieved from https://www.islandinnovation.co/resources/how-can-islands-move-e-mobility-into-the-fast-lane/

ITP Renewables (n.d.) Renewable Energy Integration Study, Retrieved from: http://itpau.com.au/renewable-energy-integration-study/

Johnson, C. (2020). Norfolk Island Prices 2020. Retrieved from http://hikersbay.com/prices/norfolkisland?lang=en

JSCNCET (Joint Standing Committee on the National Capital and External Territories) (2014). *Same country, different world: The future of Norfolk Island*. Canberra: Commonwealth Parliament.

Kua, N. (2012) Biodiesel Production in Karkar Island of PNG - Learning from a Success Story. Retrieved from https://www.sprep.org/attachments/PIGGAREP/Biodiesel_Production_in_Karkar_Island.pdf

KPMG (2019) Monitoring the Norfolk Island Economy, Report for Department of Infrastructure, Transport, Cities and Regional Development https://www.regional.gov.au/territories/norfolk_island/norfolk-island-economy/files/Monitoring_the_Norfolk_Island_Economy.pdf (accessed 10/11/2019)

Lambert, F. (2020, May 19) Tesla quietly adds bidirectional charging capability for game-changing new features. Retrieved from https://electrek.co/2020/05/19/tesla-bidirectional-charging-ready-game-changing-features/

Langham, E. Cooper, C. and Ison, N. (2013). Virtual net metering in Australia: Opportunities and barriers. Report prepared for Total Environment Centre. Retrieved from https://opus.lib.uts.edu.au/handle/10453/31943

Lenzen, M. (2008) Sustainable island businesses: a case study of Norfolk Island. *Journal of Cleaner Production* 16, 2018-2035. https://isa.org.usyd.edu.au/publications/NorfolkTBL.pdf (accessed 23/10/2019)

Lenzen, M., Krishnapillai, M., Talagi, D., Quintal, J., Quintal, D., Grant, R., Abraham, S., Ehmes, C., & Murray, J. (2014). Cultural and socio-economic determinants of energy consumption on small remote islands. *Natural Resources Forum*, 38(1), 27–46. https://doi-org.ezproxy.newcastle.edu.au/10.1111/1477-8947.12030

Limmer, S. (2019). Dynamic Pricing for Electric Vehicle Charging—A Literature Review. *Energies, 12*(18), 3574. https://doi-org.ezproxy.newcastle.edu.au/10.3390/en12183574

Lin, D. (2017, February 21). How a pacific island changed from diesel to 100% solar power. Retrieved from https://www.nationalgeographic.com.au/engineering/how-a-pacific-island-changed-from-diesel-to-100-percent-solar-power.aspx

Malik, A. (2015). *Sustainable futures for Australia – the case of biofuels*. (Doctoral dissertation) Available from Sydney Digital Theses (University of Sydney Access only). http://hdl.handle.net/2123/14337

Malik, A. & Quintal, D. (2016). Sustainable businesses on Norfolk Island. In book: World Guide to Sustainable Enterprise, Publisher: Green-leaf publishing, Editors: Wayne Visser.

Marti, M. A. P. and Cárdenas, J. C. (2019, September 26) Energy Efficiency on an Island: The Archipelago of San Andrés, Providencia and Santa Catalina [Blog post]. Retrieved from https://blogs.iadb.org/energia/en/energy-efficiency-on-an-island-the-archipelago-of-san-andres-providencia-and-santa-catalina/

Mazengarb, M. (2019, December 19). Musselroe Wind Farm to deploy bird protecting radar in Australian first trial. Retrieved from https://reneweconomy.com.au/musselroe-wind-farm-to-deploy-bird-protecting-radar-in-australian-first-trial-89517/

Mburu, A. (2020, April 4). Solar + battery energy storage VS diesel in East Africa. Retrieved from https://www.renewableenergyworld.com/2020/04/10/solar-battery-energy-storage-vs-diesel-in-east-africa/

McKie, R. (2019, January 20). How Orkney leads the way for sustainable energy. Retrieved from https://www.theguardian.com/environment/2019/jan/20/orkney-northern-powerhouse-electricity-wind-waves-surplus-power-hydrogen-fuel-cell

Meier, G. (2019, November 14) Haystacks Solar Garden. National Renewables in Agriculture Conference. Wagga Wagga, NSW. Retrieved from https://assets.cleanenergycouncil.org.au/documents/events/Renewable-Agg-Conf/Gemma-Meier-Haystacks-Solar-Garden.pdf

Meier, G. (2020, June 22). Solar gardens offer opportunities for regions. Retrieved from https://www.canberratimes.com.au/story/6798512/solar-gardens-offer-opportunities-for-regions/

Miandad, R., Barakat, M. A., Aburiazaiza, A. S., Rehan, M., & Nizami, A. S. (2016). Catalytic pyrolysis of plastic waste: A review. Process Safety & Environmental Protection: Transactions of the Institution of Chemical Engineers Part B, 102(Part B), 822–838. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.psep.2016.06.022

Miandad R., Rehan M., Barakat M. A., Aburiazaiza A. S., Khan H., Ismail I. M. I., ... Nizami A. (2019). Catalytic Pyrolysis of Plastic Waste: Moving Toward Pyrolysis Based Biorefineries. *Frontiers in Energy Research, 7*. doi:10.3389/fenrg.2019.00027. Retrieved from https://www.frontiersin.org/article/10.3389/fenrg.2019.00027

Montuori, L., Alcázar-Ortega, M., Álvarez-Bel, C., & Domijan, A. (2014). Integration of renewable energy in microgrids coordinated with demand response resources: Economic evaluation of a biomass gasification plant by Homer Simulator. *Applied Energy, 132*, 15–22. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.apenergy.2014.06.075

Morales, D.X. & Besanger, Y., Erazo, J.P. & Medina, R.D. (2017). Intelligent energy management in the Galapagos islands towards a smart grid. *Medina Technical Sciences Academy of Romania, Journal of Engineering Sciences and Innovation (JESI), Journal* - Volume 2, Issue 1/2017, Pages 63-82. Retrieved from http://jesi.astr.ro/wp-content/uploads/2018/07/17.pdf

Neves, D.P. (2016) *Optimatization of hybrid renewable energy systems on isolated microgrids : A smart grid approach* (Doctoral dissertation), Retrieved from: http://hdl.handle.net/10451/22744 (accessed 12/11/2019)

NIA (Norfolk Island Administration) (1985). Electricity Supply Act. Act no 3 of 1986.

NIA (2008) The Government of Norfolk Island Media Release: Norfolk to encourage private solar energy generation. http://www.norfolkisland.gov.nf/sites/default/files/public/documents/NIAMediaReleases/2008/20081121%20-%20Norfolk%20to%20encourage%20private%20solar%20energy%20generation.pdf (accessed 8/11/2019)

NIA (2009a) The Government of Norfolk Island Media Release: Positive outcomes from private solar power generation. http://www.norfolkisland.gov.nf/sites/default/files/public/documents/NIAMediaReleases/2009/20090911%20-%20Positive%20outcomes%20from%20private%20solar%20power%20generation.pdf (accessed 8/11/2019)

NIA (2009b) Infrastructure Stimulus Package Submission to the Commonwealth - Submission to Building Australia Fund - Norfolk Island Renewable Energy Project https://www.infrastructureaustralia.gov.au/public_submissions/published/files/Norfolk_Island_Renewable_Energy.pdf (accessed 15/12/2014 via TROVE)

NIA (2011) Norfolk Island Census of Population and Housing 9 August 2011. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/public/documents/ANIReports/Census/Census_2011.pdf (accessed 14/11/2019)

NIA (2013) The Government of Norfolk Island Media Release: Electricity Working Group – 18 October 2003. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/public/documents/NIAMediaReleases/2013/2013_10_18_Electricity%20Working%20Group.pdf

NIA (2014a) Report from Business Systems Analyst and Summary of workings of Electricity Working Group June 2013 – February 2014 http://www.norfolkisland.gov.nf/sites/default/files/public/documents/ANIReports/EWG/EWG%20Summary%20of%20Workings%20of%20the%20Electricity%20Working%20Group.pdf (accessed 8/11/2019)

NIA (2014b) The Government of Norfolk Island Media Release: Electricity – Community Consultation and Expression of Interest - 27 August 2014. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/public/documents/NIAMediaReleases/2014/2014_08_27_Electricity%20community%20consultation%20and%20expression%20of%20interest.pdf

NIA (2015) The Government of Norfolk Island Media Release: Solution for Solar Photovoltaic Oversupply Progress – 13 February 2015. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/public/documents/NIAMediaReleases/2015/2015_02_13-%20Solar%20solution.pdf

NIG (Norfolk Island Government) (2009) Media Release: Tariff reductions for all-electric vehicles. Retrieved from http://www.norfolkisland.gov.nf/sites/default/files/public/documents/NIAMediaReleases/2009/20091127%20-%20Tariff%20reductions%20for%20all-electric%20vehicles.pdf

NIG (2014) Submission to Joint Standing Committee on National Capital and External Territories - Economic Development On Norfolk Island, Submission 21. https://www.aph.gov.au/DocumentStore.ashx?id=d79154e9-ef00-4130-a2ff-c64e7233628c&subId=251813 (accessed 10/11/2019)

NILA (2013) Norfolk Island Legislative Assembly 14th NILA Hansard – 16 October 2013. http://www.norfolkisland.gov.nf/sites/default/files/public/documents/Hansards/14th/2013_10_16.pdf (accessed 8/11/2019)

NILA (2015) Norfolk Island Legislative Assembly 14th NILA Hansard – 11 February 2015. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/public/documents/Hansards/14th/2013_10_16.pdf

Nimmo, J. (1976). Report of the Royal Commission into matters relating to Norfolk Island. Canberra, Australia: Australian Government Publishing Service.

NIRC (Norfolk Island Regional Council) (2016a) Norfolk Island Community Strategic Plan 2016 – 2026 Our Plan for the Future. http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/Plans/Community%20Strategic%20Plan%202016-2026.pdf (accessed 29/10/2019)

NIRC (2016b) Norfolk Island Delivery Program 2016 – 2020. http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/Plans/Delivery%20Program%202016-2020.pdf (accessed 29/10/2019)

NIRC (2016c) Terms of Reference – Sustainable Energy Advisory Committee. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC_Council_Meetings/Agendas/2016/2016_10_19%20Ordinary%20Meeting%20of%20Council%20-%2019%20October%202016/2016-7%20Attachment%204%20Terms%20of%20Reference%20Sustainable%20Energy.pdf

NIRC (2016d) Sustainable Energy Advisory Committee Expressions of Interest No 55/16. Retrieved from: http://www.norfolkisland.gov.nf/file/39411/download?token=HoV3i8YW

NIRC (2017a) Minutes Ordinary Council Meeting 15 February 2017: Norfolk Island Electrical Investigation. Retrieved from: http://www.norfolkisland.gov.nf/file/38471/download?token=fdMZrJTx

NIRC (2017b) Electricity Production and Distribution - Opportunity to develop Energy Policy and Technical Design solutions for power generation on Norfolk Island and related issues. EOI 8/17. http://www.norfolkisland.gov.nf/sites/default/files/EOI%2008_17%20Electricity%20Production%20and%20Distribution%20Information.pdf (accessed 11/11/2019)

NIRC (2018a) Norfolk Island Environment Strategy 2018–2023. http://www.norfolkisland.gov.nf/sites/default/files/docs/Norfolk%20Island%20Environment%20Strategy%202018%E2%80%932023.pdf (accessed 23/10/2019)

NIRC (2018b) Designing a new power system on Norfolk Island, Retrieved from: http://www.norfolkonlinenews.com/_literature_241734/DESIGNING_A_NEW_POWER_SYSTEM_ON_NORFOLK_ISLAND (accessed 13/11/2019)

NIRC (2018c) Media Release: Hydro Tasmania. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/MediaReleases/2018_05_04%20MR%20-%20Hydro%20Tasmania.pdf

NIRC (2019a) Electricity. Retrieved from http://www.norfolkisland.gov.nf/services/electricity (accessed 23/10/2019)

NIRC (2019b) Infrastructure Asset Management Plan 2020-2029, http://www.norfolkisland.gov.nf/sites/default/files/docs/NIA/Operational%20Plans/Infrastructure%20AMP%202020-2029.pdf (accessed 29/10/2019)

NIRC (2019c) Operational Plan 2019-2020. http://www.norfolkisland.gov.nf/sites/default/files/Operational%20Plan%202019-2020_0.pdf (accessed 29/10/2019)

NIRC (2019d) Energy Economist Consultant: Request for Quote 13/19 In Norfolk Island Government Gazette No. 31, Friday 12 July 2019. Retrieved from: http://www.norfolkislander.com/images/2019_07_12_Gazette_No._31.pdf (accessed 12/11/2019)

NIRC (2019e) Media Release: Commercial Services Update. Retrieved from: http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/MediaReleases/2019_10_18%20MR%20-%20Commercial%20Services%20Update.pdf

NIRC (2019f) Mayor's Update 20/12/2019. Retrieved from http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/MediaReleases/2019_12_20%20MR%20-%20Mayor%27s%20Update.pdf

NIRC (2019g) Media Release: OVERVIEW OF COUNCIL MEETING 18 DECEMBER 2019. Retrieved from http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/MediaReleases/2019_12_20%20MR%20-%20Overview%20of%20Ordinary%20Council%20Meeting%2018%20December%202019.pdf

NIRC (2020a) Media Release: Commissioning of Council's Hotrot Composting Facility. Retrieved from http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/MediaReleases/2020_02_07%20MR%20-%20Commissioning%20of%20Council%27s%20Hotrot%20Composting%20System.pdf

NIRC (2020b) Media Release: Norfolk Telecom: Future proofing Norfolk Island's telecommunications. Retrieved from http://www.norfolkisland.gov.nf/sites/default/files/docs/NIRC/MediaReleases/2020_03_06%20MR%20-%204G%20Update%20of%20Rollout_0.pdf

NIRC (2020c) Draft Operational Plan 2020-2021. Retrieved from http://www.norfolkisland.gov.nf/file/59851/download?token=yLPAm8bt

NIRC (2020d). Invitation to tender 12/20 single source tender supply and install battery energy storage system. Retrieved from http://www.norfolkisland.gov.nf/file/nirc-rft-1220-invitation-tenderpdf

Norfolk Island Tourism (2013) *Norfolk Island Tourism Strategic Plan 2013-2023*. http://www.norfolkisland.gov.nf/sites/default/files/public/documents/Norfolk%20Island%20Tourism%20Strategic%20Plan%202013-2023.pdf (accessed 29/10/2019)

Norfolk Online News (2018) Designing a New Power System on Norfolk Island, http://www.norfolkonlinenews.com/_literature_241734/DESIGNING_A_NEW_POWER_SYSTEM_ON_NORFOLK_ISLAND (accessed 23/10/2019)

Norton Rose Fulbright. (2018). *Social Access Solar Gardens: Legal Report*. Retrieved from https://www.uts.edu.au/sites/default/files/article/downloads/SASG%20Legal%20Report.pdf

Office of Environment and Heritage (OEH) (2014) *Energy efficient lighting technology report* (Second edition 2014). Retrieved from https://www.environment.nsw.gov.au/resources/business/140017-energy-efficient-lighting-tech-rpt.pdf

OEH (2016) *Energy efficient lighting* [Fact Sheet]. Retrieved from https://www.environment.nsw.gov.au/resources/business/160349-lighting-factsheet.pdf

Orkney Islands Council (2019, May 31) £28.5m ReFLEX Orkney project to create a 'smart energy island'. Retrieved from https://www.orkney.gov.uk/OIC-News/285m-ReFLEX-Orkney-project-to-create-a-smart-energy-island.htm

Pacific Community (SPC) (May 9, 2019) Forty biogas digesters installed in the islands of Tuvalu bring community cleaner cooking stoves. Retrieved from https://www.spc.int/updates/news/2019/05/forty-biogas-digesters-installed-in-the-islands-of-tuvalu-bring-community

Palone, F., Portoghese, P., Buono, L., Necci, A., Rosati, C. and Rosati, D. (2017). Replacing diesel generators with hybrid renewable power plants: Giannutri Smart Island project. 1-6. 10.1109/EEEIC.2017.7977682.

Parkinson, G. (2017) Norfolk Island has “too much” solar, now it wants storage, Renew Economy https://reneweconomy.com.au/norfolk-island-has-too-much-solar-now-it-wants-storage-58159/ (accessed 23/10/2019)

Pina, A., Baptista, P., Silva, C., & Ferrão, P. (2014). Energy reduction potential from the shift to electric vehicles: The Flores island case study. *Energy Policy, 67*, 37–47. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.enpol.2013.07.120

Pingala. (n.d.-a). You can own solar. Sunny Roof not required. Buy a virtual plot in the Haystacks Solar Garden and have the energy it generates credited on your electricity bill. Retrieved from https://pingala.org.au/haystacks-solar-garden/

Pingala. (n.d.-b). Allambi Care solar project: In partnership with Lake Macquarie City Council and Pingala. Retrieved from https://pingala.org.au/solar-for-businesses/allambi-care/

Politopoulou, S. (2018) Net Metering In Greece, In South East Europe Workshop on Grid Integration of Variable Renewable Energy Sources, Vienna 7 November 2018. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Events/2018/Nov/SEE-workshop/Session-VI_HEDNO_NET-METERING-IN-GREECE.pdf?la=en&hash=7F0E2DD2BE0B9E83458B9EE833A75F783BD161EB

Ramos-Suárez, J. L., Ritter, A., Mata González, J., & Camacho Pérez, A. (2019). Biogas from animal manure: A sustainable energy opportunity in the Canary Islands. Renewable and Sustainable Energy Reviews, 104, 137–150. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.rser.2019.01.025

Renewables Networking Platform (n.d.) 100% renewable energy island – Samsø Island, Denmark. Retrieved from https://www.renewables-networking.eu/documents/DK-Samso.pdf

Renewables Now (2020, February 26) Azores island inaugurates hybrid renewables facility. Retrieved from https://renewablesnow.com/news/azores-island-inaugurates-hybrid-renewables-facility-688729/

Roberts, A. (2017, September 18). Community Energy, where communities take renewable energy into their own hands, CLEANaS, Tom Farrell Institute for the Environment. Retrieved from http://www.hbrmag.com.au/article/read/community-energy-where-communities-take-renewable-energy-into-their-own-hands-2503

Roberts, A. (2019, June 5). Newcastle City – Renewable, Sustainable, Smarter technology future. Retrieved from https://www.hei.org.au/event/newcastle-city-renewable-sustainable-smarter-technology-future/

Roberts**,** T**.,** Stace, N., Roberts, A., Conway, D., Van Nettern, J., & Woodard, N. (2016). Moving your campus Smartly to 100% renewable energy. *Proceedings of the 16th International Australasian Campuses Towards Sustainability (ACTS) Conference*, Sunshine Coast, Australia.

Roberts, A. & Roberts, T. (2016, March 6) Grass roots fertiliser for growth of green energy. Retrieved from http://www.theherald.com.au/story/3768743/grass-roots-fertiliser-for-growth-of-green-energy/

Roberts, A. & Roberts, T. (2017, May 15). Renewable energy island a community triumph. Retrieved from https://www.newcastleherald.com.au/story/4658820/renewable-energy-island-a-community-triumph/

Roberts, A. & Roberts, T. (2018, September 23). Solar gardens growing cheap electricity for renters. Retrieved from https://www.newcastleherald.com.au/story/5659970/solar-gardens-growing-cheap-electricity/

Rogulj, D. (2020, January 10) Krk Recognized Among 10 Energy Sustainable Islands in European Union. Retrieved from https://www.total-croatia-news.com/lifestyle/40707-krk

Roy, E. A. (2016, November 28) South Pacific island ditches fossil fuels to run entirely on solar power. Retrieved from https://www.theguardian.com/environment/2016/nov/28/south-pacific-island-ditches-fossil-fuels-to-run-entirely-on-solar-power

Ruggiero, S., Onkila, T., & Kuittinen, V. (2014). Realizing the social acceptance of community renewable energy: A process-outcome analysis of stakeholder influence. Energy Research and Social Science, 4 (December), 53-63. doi:10.1016/j.erss.2014.09.001

Rutovitz, J., McIntosh, L., Ison, N., Noble, E., Hicks, J., and Mey, F. (2018). Social Access Solar Gardens for Australia. Institute for Sustainable Futures, University of Technology Sydney. Retrieved from https://www.uts.edu.au/sites/default/files/article/downloads/SASG_summary_report.pdf

Selosse, S., Ricci, O., Garabedian, S., & Maïzi, N. (2018). Exploring sustainable energy future in Reunion Island. Utilities Policy, Elsevier, vol. 55(C), pages 158-166.

SGS Economics and Planning (2015) Norfolk Island Economic Development Strategy, Report for Department of Infrastructure and Regional Development. https://www.regional.gov.au/territories/publications/files/SGS_Norfolk_Island_Economic_Development_Strategy_Action_Plan.pdf (accessed 23/10/2019)

Shaw, M. & Ransan-Cooper, H. (2020, May 19) Energy Conversations: Developments in community-based battery storage [Video file]. Retrieved from https://www.youtube.com/watch?v=LQHNBVV-QjI

Smit, A. and Bondesen, O (2010) Norfolk Island: A SmallScale Distributed Unit? In International Institute for Industrial Environmental Economics (IIIEE). (2010). Distributed Treasure - Island Economies. Lund: IIIEE. Retrieved from: https://mespom.eu/sites/mespom.eu/files/basic_page/field_attachment/distributed-treasure-island-economies.pdf (accessed 12/11/2019)

Sperling, K. (2017). How does a pioneer community energy project succeed in practice? The case of the Samsø Renewable Energy Island. *Renewable & Sustainable Energy Reviews, 71,* 884–897. https://doi-org.ezproxy.newcastle.edu.au/10.1016/j.rser.2016.12.116

Spowart, N. (2020, February 9). Scottish island takes a step closer to being carbon neutral. Retrieved from https://www.thenational.scot/news/18221635.orkney-step-closer-carbon-neutral/

Stuart, R.P. (1979) Norfolk Island, 1846 : the accounts of Robert Pringle Stuart and Thomas Beagley Naylor, Brown, Prior & Anderson: Melbourne

SWISS-birdradar.com (n.d.) Migrating birds bats. Retrieved from https://swiss-birdradar.com/migrating-birds-bats.html

SwitchDin (n.d.-a). SwitchDin Technology overview. Retrieved from https://www.switchdin.com/how-it-works

SwitchDin (n.d.-b) Clean, affordable energy for regional microgrid: Solar & batteries offset diesel for Lockhart River. Retrieved from https://www.switchdin.com/lockhart-river-case-study

Tasmanian Government. (n.d.). Hydrogen. Retrieved from https://www.stategrowth.tas.gov.au/energy_and_resources/energy/hydrogen

Troman, S. (2013) Renewable Energy for Off Grid and Developing Communities, Australian Institute of Energy, Solar Seminar, 6 February 2013, Retrieved from: https://www.aie.org.au/data/pdfs/past_events/2013/CAN130206_Presentation_3.pdf (accessed 17/11/2019)

UNDP in the Pacific (2014, May 1). Koro Islands: leading in biofuel energy in Fiji. Retrieved from https://www.pacific.undp.org/content/pacific/en/home/presscenter/articles/2014/05/01/koro-islands-leading-in-biofuel-energy.html

UTS. (2018, December 19). Social Access Solar Gardens. Retrieved from https://www.uts.edu.au/research-and-teaching/our-research/institute-sustainable-futures/our-research/energy-and-climate/social-solar-gardens

Vannin, E. (2019, July 15) Climate change action 'is in Isle of Man's self-interest'. Retrieved from https://www.bbc.com/news/world-europe-isle-of-man-48994433

Vannin, E. (2020, January 9) Isle of Man commits to 75% renewable electricity by 2035. Retrieved from https://www.bbc.com/news/world-europe-isle-of-man-51041719

Viscidi, L., Graham, N., Madrigal, M., Masson, M., Prado, V.R., & Monticelli, J.C. (2020, February 11) Electrified Islands: The Road to E-Mobility in the Caribbean. Report for InterAmerican Dialogue, Inter-American Development Bank, & Organisation of American States. Retrieved from https://www.thedialogue.org/analysis/electrified-islands-the-road-to-e-mobility-in-the-caribbean/

Vorrath, S. (2019, September 25). Cattle Hill wind farm set to test new eagle protection technology. Retrieved from https://reneweconomy.com.au/cattle-hill-wind-farm-set-to-test-new-eagle-protection-technology-95828/

Vorrath, S. (2020, April 4) Australia’s biggest “solar garden” seeks to power 300 homes in NSW Riverina region. Retrieved from https://onestepoffthegrid.com.au/australias-biggest-solar-garden-seeks-to-power-300-homes-in-nsw-riverina-region/

Vulum, S. (2014, February 14). Low copra prices prompts Karkar’s bio-fuel diesel. Retrieved from https://www.islandsbusiness.com/submit-a-story-or-picture/item/1024-low-copra-prices-prompts-karkars-bio-fuel-diesel.html

Wärtsilä (2020, February 2) Wärtsilä technology enables Graciólica to increase the use of renewables from 15% to 65% in the Azores. Retrieved from https://www.wartsila.com/aze/media/news/21-02-2020-wartsila-technology-enables-graci%C3%B3lica-to-increase-the-use-of-renewables-from-15-to-65-in-the-azores-2646024

Watts, L. (2019, October 13) *Energy At The End Of The World: An Orkney Islands Saga [Virtual Island Summit]* [Video file]. Retrieved from https://www.youtube.com/watch?v=IQek08QSJdo

Webb, G.J. (2018). *Assessment of personal carbon goals for reducing obesity-related behaviour and carbon emissions in a remote island community: the Norfolk Island carbon and health evaluation study*, PhD thesis, Southern Cross University, Lismore, NSW. (Doctoral dissertation), Retrieved from: https://epubs.scu.edu.au/theses/614/ (accessed 12/11/2019)

Wettenhall, R. (2016). Decolonizing through integration: Australia's off-shore island territories. Island Studies Journal, (2), 715. Retrieved from http://search.ebscohost.com.ezproxy.newcastle.edu.au/login.aspx?direct=true&db=edsdoj&AN=edsdoj.00ca6dea3c50465cabce117d0527f34c&site=eds-live

Wild Singapore. (n.d.). Ubin micro-grid. Retrieved from http://www.wildsingapore.com/ubin/places/greenenergy.htm

Williams, R. & Crook, A. (2020, February 29). *Solar gardens allow renters and shaded households to access renewable energy* [Audio podcast]. Retrieved from https://www.abc.net.au/radionational/programs/scienceshow/solar-gardens-allow-renters-and-shaded-households-to-access-ren/12010666

WINDExchange. (n.d.). U.S. Average Annual Wind Speed at 30 Meters. Retrieved from https://windexchange.energy.gov/maps-data/325

Wu, Q., Larsen, E., Heussen, K., Binder, H., & Douglass, P. (2017). Remote Off-Grid Solutions for Greenland and Denmark: Using smart-grid technologies to ensure secure, reliable energy for island power systems. *IEEE Electrification Magazine, Electrification Magazine, IEEE, IEEE Electrific. Mag*, 5(2), 64–73. https://doi-org.ezproxy.newcastle.edu.au/10.1109/MELE.2017.2685959

Chapter 5

Aucoin, M. & Fry, Matthew. (2015). Growing local food movements: Farmers' markets as nodes for products and community. 56. 61-78. https://www.researchgate.net/publication/284746050

Australian National Audit Office (2019). Design, Implementation and Monitoring of Reforms to Services on Norfolk Island, viewed 22 February 2021, https://www.anao.gov.au/work/performance-audit/design-implementation-and-monitoring-reforms-to-services-norfolk-island

Caron, P., Ferrero y de Loma-Osorio, G., Nabarro, D. et al. (2018). Food systems for sustainable development: proposals for a profound four-part transformation. Agron. Sustain. Dev. 38, 41 https://doi.org/10.1007/s13593-018-0519-1

Commonwealth Grants Commission (2019). *2019 Norfolk Island Inquiry*, downloaded 14 March 2021, https://www.regional.gov.au/territories/norfolk_island/norfolk-island-economy/files/2019_Norfolk_Island_Inquiry_final_report.pdf

Crews, T. E., Carton, W., and Olsson, L. (2018), Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures, *Global Sustainability, 1*(e11), https://doi.org/10.1017/sus.2018.11

Department of Agriculture, Water and the Environment, *Drought and Rural Support*, viewed 3 March 2021, https://www.agriculture.gov.au/ag-farm-food/drought

Dickinson, P. (2013). Garden to Table Programme Final Evaluation Report. Massey University. https://www.gardentotable.org.nz/Research/Shore%20Whariki%20Garden%20to%20Table%20Prog%20Eval%20-%202013%20June.pdf

Invasive Species Council 2017. *Norfolk Island: protecting an ocean jewel,* viewed 17 March 2021, https://invasives.org.au/blog/norfolk-island-protecting-an-ocean-jewel/

Department of Agriculture, Water and the Environment 2021, *Biosecurity Business Grants program*, viewed 15 March 2021 https://www.communitygrants.gov.au/grants/biosecurity-business-grants-program

EcoAgricultures Partners, 2013. Defining Integrated Landscape Management for Policy Makers https://www.un.org/esa/ffd/wp-content/uploads/sites/2/2015/10/IntegratedLandscapeManagementforPolicymakers_Brief_Final_Oct24_2013_smallfile.pdf

Feenstra, Gail W. (1997). Local food systems and sustainable communities. *American Journal of Alternative Agriculture*, 12(1), 28–36. https://doi.org/10.1017/S0889189300007165

Food and Agriculture Organization of the United Nations (2017). Landscapes for life: Approaches to landscape management for sustainable food and agriculture. http://www.fao.org/3/i8324en/i8324en.pdf

Food and Agriculture Organization of the United Nations (2021). Local government planning for community food systems. http://www.fao.org/documents/card/en/c/cb3136en/

Htenas, Aira Maria (2017). *An overview of links between obesity and food systems: implications for the agriculture GP agenda (English).* Washington, D.C.: World Bank Group. http://documents.worldbank.org/curated/en/222101499437276873/An-overview-of-links-between-obesity-and-food-systems-implications-for-the-agriculture-GP-agenda

KPMG 2019, *Monitoring the Norfolk Island Economy*, downloaded 14 March 2021, https://www.regional.gov.au/territories/norfolk_island/norfolk-island-economy/files/Monitoring_the_Norfolk_Island_Economy.pdf

Landcare Research 2021, *Argentine Ants in New Zealand*, viewed 17 March 2021, https://argentineants.landcareresearch.co.nz/impacts.asp

Natural Resource Management 2018, *National Landcare Program Phase 2*, viewed 14 March 2021, http://www.nrm.gov.au/national-landcare-program

Norfolk Island Environment Strategy 2018–2023 (2018). *Norfolk Island Regional Council*

Olsson, Per & Bodin, Örjan & Folke, Carl. (2010). Building Transformative Capacity for Ecosystem Stewardship in Social–Ecological Systems. 10.1007/978-3-642-12194-4_13.

O'Farrell, Patrick & Anderson, Pippin. (2010). Sustainable multifunctional landscapes: A review to implementation. Current Opinion in Environmental Sustainability.

Petheram C, Taylor A, Hughes J, Philip S, Tavener N, Greenwood D, Taylor N, Wilson PR, Raiber M, Turnadge C, Yang A, Seo L, Davies P, Vanderzalm J, Davis A, Crane P, Gallant J, Ahmed W, Rogers L, Ticehurst C, Marvanek S, Christoph G, Bui E, Grice T, Crosbie R, Metcalfe S, Fitzpatrick R, Schepen A, Levick S, Nobbs C, Cahill K, Vaze J (2020) *Norfolk Island Water Resource Assessment*. A report to the Australian Government from the CSIRO Norfolk Island Water Resource Assessment team. CSIRO, Australia.

Pradyumna A. (2018). Planetary health and food systems: insights from global SDGs. Lancet Planet Health. https://pubmed.ncbi.nlm.nih.gov/30318095/

Rebecca Schiff PhD (2008). The Role of Food Policy Councils in Developing Sustainable Food Systems, Journal of Hunger & Environmental Nutrition. https://www.tandfonline.com/doi/full/10.1080/19320240802244017

Swenson, D. (2009). "Investigating the Potential Economic Impacts of Local Foods for Southeast Iowa". *Leopold Center Publications and Papers*. 66. https://lib.dr.iastate.edu/leopold_pubspapers/66

The Conversation (2019), *Invasive ants: federal budget takes aim but will it be a lethal shot?*, viewed 17 March 2021, https://theconversation.com/invasive-ants-federal-budget-takes-aim-but-will-it-be-a-lethal-shot-114818

Truman, E., Lane, D., Elliott, C. (2017), Defining food literacy: A scoping review, Appetite, Volume 116, Pages 365-371, ISSN 0195-6663, https://doi.org/10.1016/j.appet.2017.05.007

World Health Organisation (2021). Key Facts on Malnutrition. https://www.who.int/news-room/fact-sheets/detail/malnutrition

Appendix 1

Raw soil data from Chapter 1

RESULTS OF SOIL ANALYSIS

4 of 78 samples supplied by University of Newcastle on 11/10/2019. Lab Job No. i6765.
Samples submitted by Balaji Seshadri. Your Job: Norfolk Island
The University of Newcastle CALAGHAN NSW 2308

Parameter	Methods reference	Sample 75 N1 Taylors Road 1	Sample 76 N1 Taylors Road 2	Sample 77 N1 Taylors Road Swamp	Sample 78 N1 Arthur Vale Creek
	Job No.	i6765/75	i6765/76	i6765/77	i6765/78
PFOS/PFOA					
Perfluorobutanoic acid (PFBA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	0.0001	0.0002	<0.0001	<0.0001
Perfluoropentanoic acid (PFPeA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0005	<0.0005	<0.0005	<0.0005
Perfluorohexanoic acid (PFHxA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluoroheptanoic acid (PFHpA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorooctanoic Acid (PFOA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorononanoic acid (PFNA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorodecanoic acid (PFDA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluoroundecanoic acid (PFUnA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorododecanoic acid (PFDoA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorotridecanoic acid (PFTrDA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorotetradecanoic acid (PFTeDA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorohexadecanoic acid (PFHxDA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorobutane sulfonate (PFBS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluoropentane sulfonate (PFPeS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorohexane sulfonate (PFHxS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluoroheptane sulfonate (PFHpS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorooctane sulfonate (PFOS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	0.0005	0.0009	<0.0001
Sum of PFHxS and PFOS (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	0.0005	0.0009	<0.0001
Perfluorononane sulfonate (PFNS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorodecane sulfonate (PFDS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
Perfluorododecane sulfonate (PFDoS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.0001	<0.0001	<0.0001	<0.0001
1H,1H,2H,2H-Perfluorohexane sulfonate (4:2) (4:2 FTS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.001	<0.001	<0.001	<0.001
1H,1H,2H,2H-Perfluorooctane sulfonate (6:2) (6:2 FTS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.001	<0.001	<0.001	0.0050
1H,1H,2H,2H-Perfluorodecane sulfonate (8:2) (8:2 FTS) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.001	<0.001	<0.001	<0.001
Perfluoroctane sulfonamide (PFOSA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.001	<0.001	<0.001	<0.001
N-Methylperfluoroctane sulfonamide (N-MeFOSA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.001	<0.001	<0.001	<0.001
N-Ethylperfluoroctane sulfonamide (N-EtFOSA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.001	<0.001	<0.001	<0.001
2-(N-Methylperfluorooctane sulfonamido)-ethanol (N-MeFOSE) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.002	<0.002	<0.002	<0.002
2-(N-Ethylperfluorooctane sulfonamido)-ethanol (N-EtFOSE) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.002	<0.002	<0.002	<0.002
N-Methylperfluorooctanesulfonamidoacetic acid (N_MeFOSAA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.001	<0.001	<0.001	<0.001
N-Ethylperfluorooctanesulfonamidoacetic Acid (N-EtFOSAA) (mg/kg or ppm)	Subcontracted: SGS report SE 198743	<0.001	<0.001	<0.001	<0.001

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2
   Dissolved metals - samples filtered through 0.45µm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 µg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
7. ** NATA accreditation does not cover the performance of this service.
8. .. Denotes not requested.
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AGRICULTURAL SOIL ANALYSIS REPORT

78 samples supplied by University of Newcastle on 11th October, 2019. Lab Job No.i6765

Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

Parameter		Method reference	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
		Sample ID:	DAM 1	DAM 2	DAM 3	DAM 4	DAM 5
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter		**Method reference**	**i6765/1**	**i6765/2**	**i6765/3**	**i6765/4**	**i6765/5**
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	5.6	0.8	0.8	67.5	52
Ammonium Nitrogen (mg/kg N)			14	25	112	19	13
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	6.91	2.23	0.73	1.36	4.97
	(kg/ha)		3102	1002	326	609	2229
	(mg/kg)		1385	447	146	272	995
Exchangeable Magnesium	(cmol$_+$/kg)		7.76	1.47	1.23	1.42	5.00
	(kg/ha)		2113	399	336	386	1361
	(mg/kg)		943	178	150	172	608
Exchangeable Potassium	(cmol$_+$/kg)		1.13	0.37	0.67	0.78	1.91
	(kg/ha)		988	325	588	681	1675
	(mg/kg)		441	145	263	304	748
Exchangeable Sodium	(cmol$_+$/kg)		1.58	1.21	1.84	0.94	1.23
	(kg/ha)		815	625	948	483	634
	(mg/kg)		364	279	423	215	283
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	0.09	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		17	<1	<1	<1	<1
	(mg/kg)		8	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	1.52	6.07	5.64	<0.01
	(kg/ha)		<1	34	136	126	<1
	(mg/kg)		<1	15	61	56	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	17.47	6.81	10.55	10.13	13.11
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	39.6	32.8	6.9	13.4	37.9
Magnesium (%)			44.4	21.5	11.7	14.0	38.1
Potassium (%)			6.5	5.4	6.4	7.7	14.6
Sodium - ESP (%)			9.1	17.8	17.5	9.3	9.4
Aluminium (%)			0.5	0.0	0.0	0.0	0.0
Hydrogen			0.0	22.4	57.6	55.7	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	0.9	1.5	0.6	1.0	1.0
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	3.6	<0.5	<0.5	0.6	0.6
Manganese (mg/kg)			22	2.7	2.4	16	2.0
Iron (mg/kg)			226	187	251	156	328
Copper (mg/kg)			3.2	0.5	<0.1	<0.1	0.2
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	530	212	315	357	864
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	12	41	28	28	64
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	2.7	2.5	1.0	0.5	0.9

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AGRICULTURAL SOIL ANALYSIS REPORT

78 samples supplied by University of Newcastle on 11th October, 2019. Lab Job No.i6765

Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

			Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
		Sample ID:	DAM 1	DAM 2	DAM 3	DAM 4	DAM 5
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
	Parameter	Method reference	i6765/1	i6765/2	i6765/3	i6765/4	i6765/5

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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AGRICULTURAL SOIL ANALYSIS REPORT

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Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
Sample ID:	DAM 6	DAM 7(P)	DAM 8 D1	DAM 8 D2	DAM 8 D3
Crop:	N/G	N/G	N/G	N/G	N/G
Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri

Parameter		Method reference	i6765/6	i6765/7	i6765/8	i6765/9	i6765/10
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	54	2.4	2.7	0.9	0.2
Ammonium Nitrogen (mg/kg N)			12	3.8	18	13	9.8
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	8.99	2.47	1.05	2.13	3.86
	(kg/ha)		4035	1110	472	955	1733
	(mg/kg)		1801	495	211	427	774
Exchangeable Magnesium	(cmol$_+$/kg)		7.24	2.62	0.89	2.04	4.74
	(kg/ha)		1970	714	242	556	1289
	(mg/kg)		880	319	108	248	575
Exchangeable Potassium	(cmol$_+$/kg)		3.99	0.92	0.21	<0.12	<0.12
	(kg/ha)		3492	802	187	<112	<112
	(mg/kg)		1559	358	83	<50	<50
Exchangeable Sodium	(cmol$_+$/kg)		0.36	0.59	0.91	1.31	1.55
	(kg/ha)		184	305	470	673	796
	(mg/kg)		82	136	210	301	355
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	20.57	6.60	3.06	5.55	10.21
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	43.7	37.4	34.3	38.4	37.8
Magnesium (%)			35.2	39.7	29.0	36.8	46.4
Potassium (%)			19.4	13.9	7.0	1.2	0.7
Sodium - ESP (%)			1.7	9.0	29.8	23.6	15.1
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	1.2	0.9	1.2	1.0	0.8
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	6.3	<0.5	<0.5	9.7	1.9
Manganese (mg/kg)			14	1.0	3.8	13	11
Iron (mg/kg)			362	28	97	703	218
Copper (mg/kg)			5.4	1.0	<0.1	0.9	<0.1
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	1,680	400	139	120	144
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	108	8.6	37	16	50
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	0.4	1.2	0.4	0.2	0.1

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		Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
	Sample ID:	DAM 6	DAM 7(P)	DAM 8 D1	DAM 8 D2	DAM 8 D3
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/6	i6765/7	i6765/8	i6765/9	i6765/10

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
   Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium,
    122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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Parameter		Method reference	Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
		Sample ID:	100acresreserve1	100acresreserve(1)	100acresreserve(2)	100acresreserve(3)	Rocky Point Whites
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter		Method reference	i6765/11	i6765/12	i6765/13	i6765/14	i6765/15
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	29	33	42	46	82
Ammonium Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	5.8	6.3	5.3	5.8	7.1
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	5.13	3.48	4.29	2.98	5.13
	(kg/ha)		2302	1564	1928	1338	2302
	(mg/kg)		1027	698	860	597	1028
Exchangeable Magnesium	(cmol$_+$/kg)		7.15	6.00	9.25	8.90	7.83
	(kg/ha)		1945	1633	2518	2422	2131
	(mg/kg)		868	729	1124	1081	951
Exchangeable Potassium	(cmol$_+$/kg)		1.19	0.65	0.56	0.53	3.49
	(kg/ha)		1041	567	487	464	3054
	(mg/kg)		465	253	217	207	1363
Exchangeable Sodium	(cmol$_+$/kg)		8.70	8.67	15.56	16.53	5.62
	(kg/ha)		4483	4462	8011	8512	2897
	(mg/kg)		2001	1992	3576	3800	1293
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	22.17	18.80	29.65	28.94	22.07
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	23.1	18.5	14.5	10.3	23.2
Magnesium (%)			32.2	31.9	31.2	30.7	35.5
Potassium (%)			5.4	3.4	1.9	1.8	15.8
Sodium - ESP (%)			39.3	46.1	52.5	57.1	25.5
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	0.7	0.6	0.5	0.3	0.7
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	3.3	0.9	0.8	<0.5	2.0
Manganese (mg/kg)			7.3	6.0	2.7	1.9	4.3
Iron (mg/kg)			322	315	337	1512	365
Copper (mg/kg)			2.4	1.7	1.9	1.5	1.2
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	622	370	327	285	1,790
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	352	385	399	458	585
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	4.3	3.6	3.9	3.8	3.8

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		Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
	Sample ID:	100acresreserve1	100acresreserve(1)	100acresreserve(2)	100acresreserve(3)	Rocky Point Whites
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/11	i6765/12	i6765/13	i6765/14	i6765/15

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
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	Sample 16	Sample 17	Sample 18	Sample 19	Sample 20
Sample ID:	RP-WO-2	RP-WO+pine	T.EvanvsFarm1	T. EvansFarmD1	T. EvansFarmD2
Crop:	N/G	N/G	N/G	N/G	N/G
Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri

Parameter		Method reference	i6765/16	i6765/17	i6765/18	i6765/19	i6765/20
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	44	51	9.8	5.9	8.4
Ammonium Nitrogen (mg/kg N)			9.0	11	4.3	2.8	2.9
Exchangeable Calcium	(cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	24.31	23.45	6.72	3.59	2.60
	(kg/ha)		10911	10526	3015	1611	1169
	(mg/kg)		4871	4699	1346	719	522
Exchangeable Magnesium	(cmol+/kg)		13.33	17.40	3.14	2.46	1.52
	(kg/ha)		3630	4737	856	669	413
	(mg/kg)		1621	2115	382	299	184
Exchangeable Potassium	(cmol+/kg)		2.40	1.98	1.01	0.33	0.32
	(kg/ha)		2106	1732	887	291	281
	(mg/kg)		940	773	396	130	126
Exchangeable Sodium	(cmol+/kg)		2.32	5.46	0.30	0.51	0.37
	(kg/ha)		1197	2809	154	265	193
	(mg/kg)		534	1254	69	118	86
Exchangeable Aluminium	(cmol+/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	42.37	48.28	11.17	6.89	4.81
Calcium (%)		**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	57.4	48.6	60.1	52.1	54.1
Magnesium (%)			31.5	36.0	28.1	35.7	31.5
Potassium (%)			5.7	4.1	9.1	4.8	6.7
Sodium - ESP (%)			5.5	11.3	2.7	7.5	7.8
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol+/kg)	1.8	1.3	2.1	1.5	1.7
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	6.4	8.3	6.7	2.0	0.6
Manganese (mg/kg)			34	41	131	109	41
Iron (mg/kg)			27	63	149	37	18
Copper (mg/kg)			2.8	3.3	8.3	4.6	1.5
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	1,249	981	559	301	280
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	156	141	145	108	27
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	1.9	2.8	1.1	1.1	2.1

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		Sample 16	Sample 17	Sample 18	Sample 19	Sample 20
	Sample ID:	RP-WO-2	RP-WO+pine	T.EvanvsFarm1	T. EvansFarmD1	T. EvansFarmD2
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	**Method reference**	i6765/16	i6765/17	i6765/18	i6765/19	i6765/20

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
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			Sample 21	Sample 22	Sample 23	Sample 24	Sample 25
		Sample ID:	T. EvansFarmD3	RarmSite	DrainSite	RootyHill Right-1	RootyHill Right-2
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter		**Method reference**	**i6765/21**	**i6765/22**	**i6765/23**	**i6765/24**	**i6765/25**
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	47	8.8	21	3.4	2.2
Ammonium Nitrogen (mg/kg N)			2.6	8.8	7.2	5.7	3.7
Exchangeable Calcium	(cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	2.76	15.39	10.79	5.36	3.45
	(kg/ha)		1239	6906	4841	2407	1547
	(mg/kg)		553	3083	2161	1075	690
Exchangeable Magnesium	(cmol+/kg)		1.31	12.85	5.54	3.19	1.69
	(kg/ha)		356	3499	1507	867	459
	(mg/kg)		159	1562	673	387	205
Exchangeable Potassium	(cmol+/kg)		0.23	1.31	1.01	0.44	0.37
	(kg/ha)		197	1148	887	389	328
	(mg/kg)		88	513	396	174	146
Exchangeable Sodium	(cmol+/kg)		0.55	1.71	0.34	0.31	0.40
	(kg/ha)		283	878	178	160	203
	(mg/kg)		126	392	79	72	91
Exchangeable Aluminium	(cmol+/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	4.84	31.25	17.68	9.30	5.90
Calcium (%)		**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	57.0	49.2	61.0	57.6	58.4
Magnesium (%)			27.0	41.1	31.3	34.2	28.6
Potassium (%)			4.7	4.2	5.7	4.8	6.3
Sodium - ESP (%)			11.3	5.5	2.0	3.3	6.7
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol+/kg)	2.1	1.2	1.9	1.7	2.0
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	0.8	10	2.7	2.2	<0.5
Manganese (mg/kg)			24	47	22	2.6	0.4
Iron (mg/kg)			12	44	59	57	59
Copper (mg/kg)			0.7	3.2	2.3	0.9	0.2
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	209	711	541	266	244
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	14	111	24	4.4	3.1
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	1.8	1.9	0.7	1.4	2.4

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AGRICULTURAL SOIL ANALYSIS REPORT

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Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

		Sample 21	Sample 22	Sample 23	Sample 24	Sample 25
	Sample ID:	T. EvansFarmD3	RarmSite	DrainSite	RootyHill Right-1	RootyHill Right-2
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/21	i6765/22	i6765/23	i6765/24	i6765/25

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
   Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium,
    122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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		Sample 26	Sample 27	Sample 28	Sample 29	Sample 30
	Sample ID:	RootyHill Right-3	RootyHillLeft	Lyles Farm 1	Lyles Farm 2	Lyles Farm3- D1
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri

Parameter		Method reference	i6765/26	i6765/27	i6765/28	i6765/29	i6765/30
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	2.0	7.9	36	15	0.8
Ammonium Nitrogen (mg/kg N)			3.0	17	20	5.0	18
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	3.60	11.38	9.14	5.18	1.72
	(kg/ha)		1618	5108	4103	2325	773
	(mg/kg)		722	2281	1832	1038	345
Exchangeable Magnesium	(cmol$_+$/kg)		2.27	6.21	6.37	2.62	1.56
	(kg/ha)		619	1689	1733	713	424
	(mg/kg)		276	754	774	318	189
Exchangeable Potassium	(cmol$_+$/kg)		0.33	1.96	0.62	0.84	0.15
	(kg/ha)		285	1716	540	737	131
	(mg/kg)		127	766	241	329	58
Exchangeable Sodium	(cmol$_+$/kg)		0.29	0.85	0.23	0.18	1.25
	(kg/ha)		151	438	116	94	641
	(mg/kg)		68	195	52	42	286
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	6.50	20.39	16.35	8.82	4.67
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	55.5	55.8	55.9	58.7	36.8
Magnesium (%)			35.0	30.4	38.9	29.7	33.3
Potassium (%)			5.0	9.6	3.8	9.5	3.2
Sodium - ESP (%)			4.5	4.2	1.4	2.1	26.6
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	1.6	1.8	1.4	2.0	1.1
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	0.7	1.5	3.6	1.0	<0.5
Manganese (mg/kg)			0.8	18	47	25	10
Iron (mg/kg)			45	49	305	92	67
Copper (mg/kg)			0.5	1.0	3.2	1.7	0.7
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	215	930	399	468	135
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	3.5	6.1	22	6.3	8.4
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	1.7	1.2	0.3	0.8	1.2

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		Sample 26	Sample 27	Sample 28	Sample 29	Sample 30
	Sample ID:	RootyHill Right-3	RootyHillLeft	Lyles Farm 1	Lyles Farm 2	Lyles Farm3- D1
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/26	i6765/27	i6765/28	i6765/29	i6765/30

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
   Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium,
    122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
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Parameter		Method reference	Sample 31	Sample 32	Sample 33	Sample 34	Sample 35
		Sample ID:	Lyles Farm3- D2	HardersRoad D1	HardersRoadD2	HardersRoadD3	NewCascade Rd D1
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
			i6765/31	i6765/32	i6765/33	i6765/34	i6765/35
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	1.2	12	9.4	31	13
Ammonium Nitrogen (mg/kg N)			8.1	8.4	38	22	10
Exchangeable Calcium	(cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	2.17	9.32	2.64	1.93	1.12
	(kg/ha)		972	4183	1184	869	502
	(mg/kg)		434	1867	529	388	224
Exchangeable Magnesium	(cmol+/kg)		2.40	6.04	2.95	2.21	1.42
	(kg/ha)		654	1645	804	601	386
	(mg/kg)		292	734	359	268	172
Exchangeable Potassium	(cmol+/kg)		<0.12	1.29	1.81	1.53	1.06
	(kg/ha)		<112	1126	1588	1343	928
	(mg/kg)		<50	503	709	600	414
Exchangeable Sodium	(cmol+/kg)		1.65	0.20	0.82	0.66	0.41
	(kg/ha)		851	103	420	340	213
	(mg/kg)		380	46	188	152	95
Exchangeable Aluminium	(cmol+/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	6.29	16.85	8.22	6.34	4.01
Calcium (%)		**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	34.5	55.3	32.1	30.5	27.9
Magnesium (%)			38.2	35.9	35.9	34.8	35.4
Potassium (%)			1.0	7.6	22.1	24.2	26.4
Sodium - ESP (%)			26.3	1.2	9.9	10.4	10.3
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol+/kg)	0.9	1.5	0.9	0.9	0.8
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	0.7	0.6	<0.5	<0.5	<0.5
Manganese (mg/kg)			8.1	6.6	0.8	1.2	0.4
Iron (mg/kg)			24	24	69	1113	20
Copper (mg/kg)			0.8	0.5	0.1	0.3	<0.1
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	86	613	734	642	504
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	9.6	3.2	2.6	2.8	3.0
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	2.9	0.3	4.3	1.6	2.7

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		Sample 31	Sample 32	Sample 33	Sample 34	Sample 35
	Sample ID:	Lyles Farm3- D2	HardersRoad D1	HardersRoadD2	HardersRoadD3	NewCascade Rd D1
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/31	i6765/32	i6765/33	i6765/34	i6765/35

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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		Sample 36	Sample 37	Sample 38	Sample 39	Sample 40
Sample ID:		NewCascade Rd D2	NewCascade Rd D3	Mt Pitt Top	Mt Pitt Bottom	Taylors Rd Left D1
Crop:		N/G	N/G	N/G	N/G	N/G
Client:		B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	**Method reference**	**i6765/36**	**i6765/37**	**i6765/38**	**i6765/39**	**i6765/40**
Nitrate Nitrogen (mg/kg N)	**Inhouse S37 (KCl)	2.0	2.4	0.3	<0.1	8.1
Ammonium Nitrogen (mg/kg N)		7.3	5.1	7.8	12	4.4
Exchangeable Calcium (cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	1.05	3.61	0.22	0.18	10.01
Exchangeable Calcium (kg/ha)		472	1623	97	82	4494
Exchangeable Calcium (mg/kg)		211	724	43	37	2006
Exchangeable Magnesium (cmol+/kg)		1.03	2.96	0.46	0.53	1.94
Exchangeable Magnesium (kg/ha)		281	806	124	144	529
Exchangeable Magnesium (mg/kg)		126	360	55	64	236
Exchangeable Potassium (cmol+/kg)		0.84	0.97	<0.12	<0.12	0.58
Exchangeable Potassium (kg/ha)		737	851	<112	<112	508
Exchangeable Potassium (mg/kg)		329	380	<50	<50	227
Exchangeable Sodium (cmol+/kg)		0.36	0.33	1.65	0.42	1.25
Exchangeable Sodium (kg/ha)		186	170	848	216	642
Exchangeable Sodium (mg/kg)		83	76	379	97	287
Exchangeable Aluminium (cmol+/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable Aluminium (kg/ha)		<1	<1	<1	<1	<1
Exchangeable Aluminium (mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen (cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable Hydrogen (kg/ha)		<1	<1	<1	<1	<1
Exchangeable Hydrogen (mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)	**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	3.29	7.88	2.40	1.20	13.78
Calcium (%)	**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	32.0	45.9	9.0	15.2	72.6
Magnesium (%)		31.5	37.6	19.0	44.1	14.1
Potassium (%)		25.6	12.3	3.5	5.7	4.2
Sodium - ESP (%)		11.0	4.2	68.5	35.0	9.0
Aluminium (%)		0.0	0.0	0.0	0.0	0.0
Hydrogen		0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio	**Calculation: Calcium / Magnesium (cmol+/kg)	1.0	1.2	0.5	0.3	5.2
Zinc (mg/kg)	Rayment & Lyons 2011 - 12A1 (DTPA)	<0.5	1.0	<0.5	<0.5	<0.5
Manganese (mg/kg)		0.3	2.5	2.4	2.1	2.8
Iron (mg/kg)		19	15	2.1	1.7	3.0
Copper (mg/kg)		<0.1	0.2	<0.1	<0.1	0.3
Total Potassium (mg/kg)	Rayment & Lyons 2011 - 17C1 Aqua Regia	371	436	<50	<50	273
Phosphorus (mg/kg)	**Rayment & Lyons 2011 - 9C2b (Olsen)	2.1	3.0	5.0	1.9	9.1
Sodium Absorption Ratio	**Calculation (1:5 water): Sodium/Calcium+Magnesium	4.0	2.6	40.2	4.9	2.0

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		Sample 36	Sample 37	Sample 38	Sample 39	Sample 40
	Sample ID:	NewCascade Rd D2	NewCascade Rd D3	Mt Pitt Top	Mt Pitt Bottom	Taylors Rd Left D1
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/36	i6765/37	i6765/38	i6765/39	i6765/40

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
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5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
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	Sample 41	Sample 42	Sample 43	Sample 44	Sample 45
Sample ID:	Taylors Rd Left D2	Taylors Rd Left D3	Taylors Rd Right D1	Taylors Rd Right D2	Taylors Rd Right D3
Crop:	N/G	N/G	N/G	N/G	N/G
Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri

Parameter		Method reference	i6765/41	i6765/42	i6765/43	i6765/44	i6765/45
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	1.5	3.0	1.1	1.9	1.0
Ammonium Nitrogen (mg/kg N)			2.3	4.6	4.1	7.7	2.8
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	10.43	11.13	3.20	7.00	7.85
	(kg/ha)		4683	4996	1437	3144	3523
	(mg/kg)		2091	2230	641	1403	1573
Exchangeable Magnesium	(cmol$_+$/kg)		1.33	1.46	2.42	2.34	2.75
	(kg/ha)		362	398	658	637	749
	(mg/kg)		162	178	294	285	334
Exchangeable Potassium	(cmol$_+$/kg)		0.21	0.19	0.16	<0.12	<0.12
	(kg/ha)		186	165	139	<112	<112
	(mg/kg)		83	74	62	<50	<50
Exchangeable Sodium	(cmol$_+$/kg)		0.63	0.88	0.35	0.58	1.13
	(kg/ha)		323	454	178	297	582
	(mg/kg)		144	203	80	133	260
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	12.60	13.66	6.12	10.03	11.81
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	82.8	81.5	52.3	69.8	66.4
Magnesium (%)			10.6	10.7	39.5	23.4	23.3
Potassium (%)			1.7	1.4	2.6	1.0	0.7
Sodium - ESP (%)			5.0	6.4	5.6	5.8	9.6
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	7.8	7.6	1.3	3.0	2.9
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	<0.5	1.5	0.6	<0.5	<0.5
Manganese (mg/kg)			0.5	2.9	2.5	24	2.1
Iron (mg/kg)			3.1	4.7	15	18	7.3
Copper (mg/kg)			0.2	0.7	0.6	1.1	0.3
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	141	152	152	194	160
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	6.1	11	6.6	26	6.9
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	1.6	1.6	2.7	3.2	2.0

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Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

		Sample 41	Sample 42	Sample 43	Sample 44	Sample 45
	Sample ID:	Taylors Rd Left D2	Taylors Rd Left D3	Taylors Rd Right D1	Taylors Rd Right D2	Taylors Rd Right D3
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	**Method reference**	**i6765/41**	**i6765/42**	**i6765/43**	**i6765/44**	**i6765/45**

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
   Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium,
    122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
13. ** NATA accreditation does not cover the performance of this service.
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		Sample 46	Sample 47	Sample 48	Sample 49	Sample 50
	Sample ID:	Taylors Rd Drain 1	Taylors Middle Gate Rd	Taylors Rd Swamp	Raylors Rd Drain 2	Arthurvale Historic D1
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	**Method reference**	**i6765/46**	**i6765/47**	**i6765/48**	**i6765/49**	**i6765/50**
Nitrate Nitrogen (mg/kg N)	**Inhouse S37 (KCl)	0.9	9.7	2.6	6.6	3.8
Ammonium Nitrogen (mg/kg N)		4.2	4.1	14	19	4.4
Exchangeable Calcium (cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	7.06	12.65	29.95	34.55	3.13
Exchangeable Calcium (kg/ha)		3170	5677	13444	15510	1407
Exchangeable Calcium (mg/kg)		1415	2534	6002	6924	628
Exchangeable Magnesium (cmol+/kg)		1.73	2.25	5.49	14.57	3.48
Exchangeable Magnesium (kg/ha)		470	614	1495	3967	946
Exchangeable Magnesium (mg/kg)		210	274	667	1771	422
Exchangeable Potassium (cmol+/kg)		0.19	0.76	0.34	1.38	0.72
Exchangeable Potassium (kg/ha)		165	664	300	1206	631
Exchangeable Potassium (mg/kg)		74	297	134	538	282
Exchangeable Sodium (cmol+/kg)		0.75	0.68	3.73	9.67	1.03
Exchangeable Sodium (kg/ha)		385	350	1920	4980	531
Exchangeable Sodium (mg/kg)		172	156	857	2223	237
Exchangeable Aluminium (cmol+/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable Aluminium (kg/ha)		<1	<1	<1	<1	<1
Exchangeable Aluminium (mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen (cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable Hydrogen (kg/ha)		<1	<1	<1	<1	<1
Exchangeable Hydrogen (mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)	**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	9.73	16.34	39.51	60.17	8.36
Calcium (%)	**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	72.6	77.4	75.8	57.4	37.5
Magnesium (%)		17.8	13.8	13.9	24.2	41.6
Potassium (%)		1.9	4.6	0.9	2.3	8.6
Sodium - ESP (%)		7.7	4.2	9.4	16.1	12.3
Aluminium (%)		0.0	0.0	0.0	0.0	0.0
Hydrogen		0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio	**Calculation: Calcium / Magnesium (cmol+/kg)	4.1	5.6	5.5	2.4	0.9
Zinc (mg/kg)	Rayment & Lyons 2011 - 12A1 (DTPA)	<0.5	1.4	2.5	8.3	0.6
Manganese (mg/kg)		7.5	9.1	68	103	8.7
Iron (mg/kg)		11	9.8	120	280	78
Copper (mg/kg)		0.7	1.0	5.3	4.2	1.0
Total Potassium (mg/kg)	Rayment & Lyons 2011 - 17C1 Aqua Regia	189	425	236	670	364
Phosphorus (mg/kg)	**Rayment & Lyons 2011 - 9C2b (Olsen)	7.3	11	46	186	45
Sodium Absorption Ratio	**Calculation (1:5 water): Sodium/Calcium+Magnesium	3.3	1.9	1.4	2.0	3.4

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		Sample 46	Sample 47	Sample 48	Sample 49	Sample 50
	Sample ID:	Taylors Rd Drain 1	Taylors Middle Gate Rd	Taylors Rd Swamp	Raylors Rd Drain 2	Arthurvale Historic D1
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/46	i6765/47	i6765/48	i6765/49	i6765/50

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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			Sample 51	Sample 52	Sample 53	Sample 54	Sample 55
		Sample ID:	Arthurvale Historic D2	Arthurvale Historic D3	Arthurvale Creek	Middlegate Rd D1	Middlegate Rd D2
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter		**Method reference**	**i6765/51**	**i6765/52**	**i6765/53**	**i6765/54**	**i6765/55**
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	8.6	3.4	1.3	0.8	1.6
Ammonium Nitrogen (mg/kg N)			6.0	4.2	18	3.6	4.4
Exchangeable Calcium	($cmol_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	7.26	3.76	4.18	12.76	12.60
	(kg/ha)		3261	1686	1877	5729	5655
	(mg/kg)		1456	753	838	2558	2525
Exchangeable Magnesium	($cmol_+$/kg)		4.17	5.07	6.57	2.66	2.31
	(kg/ha)		1136	1381	1788	725	630
	(mg/kg)		507	617	798	324	281
Exchangeable Potassium	($cmol_+$/kg)		0.59	0.66	0.81	0.91	0.69
	(kg/ha)		513	581	713	801	608
	(mg/kg)		229	259	318	358	271
Exchangeable Sodium	($cmol_+$/kg)		1.44	1.85	5.11	0.50	0.51
	(kg/ha)		743	951	2630	259	262
	(mg/kg)		332	425	1174	116	117
Exchangeable Aluminium	($cmol_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	($cmol_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) ($cmol_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H ($cmol_+$/kg)	13.47	11.34	16.67	16.85	16.11
Calcium (%)		**Base Saturation Calculations - Cation $cmol_+$/kg / ECEC x 100	53.9	33.1	25.1	75.8	78.2
Magnesium (%)			31.0	44.7	39.4	15.8	14.4
Potassium (%)			4.3	5.8	4.9	5.4	4.3
Sodium - ESP (%)			10.7	16.3	30.6	3.0	3.2
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium ($cmol_+$/kg)	1.7	0.7	0.6	4.8	5.4
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	3.8	1.5	5.6	1.0	3.7
Manganese (mg/kg)			11	2.5	17	3.1	1.9
Iron (mg/kg)			124	46	249	11	5.9
Copper (mg/kg)			3.1	3.5	3.9	0.7	0.6
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	354	330	419	477	380
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	56	51	56	8.9	6.1
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	3.3	10.2	3.7	0.9	0.8

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University Dr CALLAGHAN NSW 2308

		Sample 51	Sample 52	Sample 53	Sample 54	Sample 55
	Sample ID:	Arthurvale Historic D2	Arthurvale Historic D3	Arthurvale Creek	Middlegate Rd D1	Middlegate Rd D2
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/51	i6765/52	i6765/53	i6765/54	i6765/55

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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		Sample 56	Sample 57	Sample 58	Sample 59	Sample 60
Sample ID:		Middlegate Rd D3	NIindustries Left D1	NIindustries Left D2	NIindustries Left D3	Ball Bay Rd Landslide
Crop:		N/G	N/G	N/G	N/G	N/G
Client:		B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	**Method reference**	**i6765/56**	**i6765/57**	**i6765/58**	**i6765/59**	**i6765/60**
Nitrate Nitrogen (mg/kg N)	**Inhouse S37 (KCl)	0.9	9.5	3.0	6.0	1.6
Ammonium Nitrogen (mg/kg N)	**Inhouse S37 (KCl)	3.0	9.6	6.5	6.8	4.3
Exchangeable Calcium (cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	5.81	16.71	5.50	4.25	2.47
Exchangeable Calcium (kg/ha)		2608	7501	2470	1909	1110
Exchangeable Calcium (mg/kg)		1164	3349	1103	852	495
Exchangeable Magnesium (cmol+/kg)		1.56	9.62	2.87	2.29	3.12
Exchangeable Magnesium (kg/ha)		425	2620	780	623	851
Exchangeable Magnesium (mg/kg)		190	1170	348	278	380
Exchangeable Potassium (cmol+/kg)		0.94	1.97	0.95	0.64	0.55
Exchangeable Potassium (kg/ha)		825	1725	829	564	482
Exchangeable Potassium (mg/kg)		368	770	370	252	215
Exchangeable Sodium (cmol+/kg)		0.64	1.82	1.18	2.94	0.45
Exchangeable Sodium (kg/ha)		332	936	608	1515	230
Exchangeable Sodium (mg/kg)		148	418	271	676	103
Exchangeable Aluminium (cmol+/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable Aluminium (kg/ha)		<1	<1	<1	<1	<1
Exchangeable Aluminium (mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen (cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
Exchangeable Hydrogen (kg/ha)		<1	<1	<1	<1	<1
Exchangeable Hydrogen (mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)	**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	8.95	30.12	10.50	10.12	6.59
Calcium (%)	**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	64.9	55.5	52.4	42.0	37.5
Magnesium (%)		17.4	32.0	27.3	22.6	47.4
Potassium (%)		10.5	6.5	9.0	6.4	8.3
Sodium - ESP (%)		7.2	6.0	11.2	29.1	6.8
Aluminium (%)		0.0	0.0	0.0	0.0	0.0
Hydrogen		0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio	**Calculation: Calcium / Magnesium (cmol+/kg)	3.7	1.7	1.9	1.9	0.8
Zinc (mg/kg)	Rayment & Lyons 2011 - 12A1 (DTPA)	<0.5	9.5	<0.5	<0.5	<0.5
Manganese (mg/kg)		0.2	9.1	0.4	<0.1	<0.1
Iron (mg/kg)		5.0	32	177	2458	1318
Copper (mg/kg)		0.4	1.0	0.2	<0.1	0.2
Total Potassium (mg/kg)	Rayment & Lyons 2011 - 17C1 Aqua Regia	457	957	472	323	322
Phosphorus (mg/kg)	**Rayment & Lyons 2011 - 9C2b (Olsen)	4.1	13	3.9	2.3	3.5
Sodium Absorption Ratio	**Calculation (1:5 water): Sodium/Calcium+Magnesium	1.1	1.8	4.9	3.1	2.1

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		Sample 56	Sample 57	Sample 58	Sample 59	Sample 60
	Sample ID:	Middlegate Rd D3	NIindustries Left D1	NIindustries Left D2	NIindustries Left D3	Ball Bay Rd Landslide
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	**Method reference**	**i6765/56**	**i6765/57**	**i6765/58**	**i6765/59**	**i6765/60**

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
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7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
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12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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AGRICULTURAL SOIL ANALYSIS REPORT

78 samples supplied by University of Newcastle on 11th October, 2019. Lab Job No.i6765
Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

			Sample 61	Sample 62	Sample 63	Sample 64	Sample 65
		Sample ID:	Lyles Farm 4	Lyles Farm 5	Lyles Farm 6	Dereks Farm 1	Dereks Farm 2
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter		Method reference	i6765/61	i6765/62	i6765/63	i6765/64	i6765/65
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	43	14	12	36	23
Ammonium Nitrogen (mg/kg N)			7.8	5.3	4.9	13	10
Exchangeable Calcium	(cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	7.95	4.75	5.06	17.83	13.19
	(kg/ha)		3567	2131	2273	8005	5923
	(mg/kg)		1593	951	1015	3573	2644
Exchangeable Magnesium	(cmol+/kg)		3.12	2.66	2.56	5.35	5.56
	(kg/ha)		848	725	698	1458	1514
	(mg/kg)		379	324	312	651	676
Exchangeable Potassium	(cmol+/kg)		1.58	0.98	0.68	1.75	1.42
	(kg/ha)		1388	859	600	1533	1242
	(mg/kg)		620	383	268	684	554
Exchangeable Sodium	(cmol+/kg)		0.19	0.15	0.17	0.43	0.34
	(kg/ha)		99	77	87	222	173
	(mg/kg)		44	34	39	99	77
Exchangeable Aluminium	(cmol+/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	12.84	8.54	8.48	25.37	20.51
Calcium (%)		**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	61.9	55.6	59.7	70.3	64.3
Magnesium (%)			24.3	31.2	30.2	21.1	27.1
Potassium (%)			12.3	11.5	8.1	6.9	6.9
Sodium - ESP (%)			1.5	1.8	2.0	1.7	1.6
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol+/kg)	2.6	1.8	2.0	3.3	2.4
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	0.9	0.6	0.6	12	6.1
Manganese (mg/kg)			10	8.3	10	31	22
Iron (mg/kg)			81	121	84	61	45
Copper (mg/kg)			0.4	0.7	0.5	2.3	1.6
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	869	493	383	828	657
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	18	5.4	4.8	18	13
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	0.5	0.6	0.5	0.4	0.5

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Analysis requested by Balaji Seshadri. Your Job: Norfolk Island
University Dr CALLAGHAN NSW 2308

		Sample 61	Sample 62	Sample 63	Sample 64	Sample 65
	Sample ID:	Lyles Farm 4	Lyles Farm 5	Lyles Farm 6	Dereks Farm 1	Dereks Farm 2
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/61	i6765/62	i6765/63	i6765/64	i6765/65

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
   Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium,
    122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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Environmental Analysis Laboratory

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Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

			Sample 66	Sample 67	Sample 68	Sample 69	Sample 70
		Sample ID:	Emily Bay	Red Road D1	Red Road D2	Red Road D3	Airport Drain 1
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter		**Method reference**	**i6765/66**	**i6765/67**	**i6765/68**	**i6765/69**	**i6765/70**
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	13	1.6	1.6	0.8	5.5
Ammonium Nitrogen (mg/kg N)			9.5	4.8	3.2	5.2	4.5
Exchangeable Calcium	(cmol$_+$/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	24.40	5.66	3.54	0.84	14.54
	(kg/ha)		10951	2540	1589	376	6526
	(mg/kg)		4889	1134	709	168	2914
Exchangeable Magnesium	(cmol$_+$/kg)		13.90	2.03	2.07	0.94	2.41
	(kg/ha)		3785	552	564	256	656
	(mg/kg)		1690	247	252	114	293
Exchangeable Potassium	(cmol$_+$/kg)		0.85	0.22	0.47	0.17	0.32
	(kg/ha)		746	189	416	150	278
	(mg/kg)		333	84	186	67	124
Exchangeable Sodium	(cmol$_+$/kg)		3.30	0.39	0.35	0.23	0.17
	(kg/ha)		1701	199	181	119	89
	(mg/kg)		760	89	81	53	40
Exchangeable Aluminium	(cmol$_+$/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Exchangeable Hydrogen	(cmol$_+$/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	<0.01
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol$_+$/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol$_+$/kg)	42.46	8.29	6.44	2.18	17.44
Calcium (%)		**Base Saturation Calculations - Cation cmol$_+$/kg / ECEC x 100	57.5	68.3	55.0	38.5	83.4
Magnesium (%)			32.8	24.5	32.2	43.1	13.8
Potassium (%)			2.0	2.6	7.4	7.9	1.8
Sodium - ESP (%)			7.8	4.7	5.5	10.6	1.0
Aluminium (%)			0.0	0.0	0.0	0.0	0.0
Hydrogen			0.0	0.0	0.0	0.0	0.0
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol$_+$/kg)	1.8	2.8	1.7	0.9	6.0
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	14	<0.5	<0.5	2.1	26
Manganese (mg/kg)			31	14	<0.1	12	3.1
Iron (mg/kg)			145	28	1709	15816	37
Copper (mg/kg)			3.5	0.5	<0.1	1.6	0.4
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	550	174	219	126	239
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	48	2.6	2.0	2.0	4.7
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	1.7	1.0	0.7	1.1	0.3

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AGRICULTURAL SOIL ANALYSIS REPORT

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Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

			Sample 66	Sample 67	Sample 68	Sample 69	Sample 70
		Sample ID:	Emily Bay	Red Road D1	Red Road D2	Red Road D3	Airport Drain 1
		Crop:	N/G	N/G	N/G	N/G	N/G
		Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
	Parameter	**Method reference**	i6765/66	i6765/67	i6765/68	i6765/69	i6765/70

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013,
   Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium,
    122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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	Sample 71	Sample 72	Sample 73	Sample 74	Sample 75
Sample ID:	Airport Runoff	Airport Drain 2	Waste Treatment	Effluent	N1 Taylors Road 1
Crop:	N/G	N/G	N/G	N/G	N/G
Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri

Parameter		Method reference	i6765/71	i6765/72	i6765/73	i6765/74	i6765/75
Nitrate Nitrogen (mg/kg N)		**Inhouse S37 (KCl)	1.2	12	9.8	3.9	0.3
Ammonium Nitrogen (mg/kg N)			3.8	6.0	10	4.1	3.2
Exchangeable Calcium	(cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	0.94	12.57	18.26	24.92	4.63
	(kg/ha)		421	5642	8198	11185	2078
	(mg/kg)		188	2519	3660	4993	928
Exchangeable Magnesium	(cmol+/kg)		0.34	1.37	2.51	1.33	1.92
	(kg/ha)		94	373	682	361	524
	(mg/kg)		42	166	305	161	234
Exchangeable Potassium	(cmol+/kg)		0.33	0.48	1.00	0.15	0.23
	(kg/ha)		287	420	873	127	198
	(mg/kg)		128	187	390	57	89
Exchangeable Sodium	(cmol+/kg)		0.34	0.08	0.23	0.19	0.94
	(kg/ha)		173	44	116	99	486
	(mg/kg)		77	19	52	44	217
Exchangeable Aluminium	(cmol+/kg)	**Inhouse S37 (KCl)	<0.01	<0.01	<0.01	<0.01	0.03
	(kg/ha)		<1	<1	<1	<1	5
	(mg/kg)		<1	<1	<1	<1	2
Exchangeable Hydrogen	(cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	<0.01	<0.01	0.02
	(kg/ha)		<1	<1	<1	<1	<1
	(mg/kg)		<1	<1	<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)		**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	1.95	14.50	21.99	26.58	7.77
Calcium (%)		**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	48.3	86.7	83.0	93.7	59.6
Magnesium (%)			17.7	9.4	11.4	5.0	24.8
Potassium (%)			16.8	3.3	4.5	0.5	2.9
Sodium - ESP (%)			17.3	0.6	1.0	0.7	12.1
Aluminium (%)			0.0	0.0	0.0	0.0	0.4
Hydrogen			0.0	0.0	0.0	0.0	0.2
Calcium/Magnesium Ratio		**Calculation: Calcium / Magnesium (cmol+/kg)	2.7	9.2	7.3	18.8	2.4
Zinc (mg/kg)		Rayment & Lyons 2011 - 12A1 (DTPA)	<0.5	4.3	5.1	113	<0.5
Manganese (mg/kg)			0.4	7.1	3.4	3.2	18
Iron (mg/kg)			409	44	26	69	23
Copper (mg/kg)			<0.1	1.3	1.9	141	0.8
Total Potassium (mg/kg)		Rayment & Lyons 2011 - 17C1 Aqua Regia	183	270	557	188	201
Phosphorus (mg/kg)		**Rayment & Lyons 2011 - 9C2b (Olsen)	1.9	3.3	10	153	9.4
Sodium Absorption Ratio		**Calculation (1:5 water): Sodium/Calcium+Magnesium	1.7	0.1	0.2	0.0	0.9

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Analysis requested by Balaji Seshadri. Your Job: Norfolk Island

University Dr CALLAGHAN NSW 2308

		Sample 71	Sample 72	Sample 73	Sample 74	Sample 75
	Sample ID:	Airport Runoff	Airport Drain 2	Waste Treatment	Effluent	N1 Taylors Road 1
	Crop:	N/G	N/G	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	**Method reference**	i6765/71	i6765/72	i6765/73	i6765/74	i6765/75

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia.* CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
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		Sample 76	Sample 77	Sample 78
	Sample ID:	N1 Taylors Road 2	N1 Taylors Road Swamp	N1 Arthur Vale Creek
	Crop:	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	**Method reference**	**i6765/76**	**i6765/77**	**i6765/78**
Nitrate Nitrogen (mg/kg N)	**Inhouse S37 (KCl)	3.8	1.4	3.4
Ammonium Nitrogen (mg/kg N)	**Inhouse S37 (KCl)	15	28	4.8
Exchangeable Calcium (cmol+/kg)	Rayment & Lyons 2011 - 15D3 (Ammonium Acetate)	31.88	20.64	4.11
Exchangeable Calcium (kg/ha)		14310	9266	1845
Exchangeable Calcium (mg/kg)		6388	4137	824
Exchangeable Magnesium (cmol+/kg)		15.98	4.44	6.59
Exchangeable Magnesium (kg/ha)		4349	1209	1794
Exchangeable Magnesium (mg/kg)		1942	540	801
Exchangeable Potassium (cmol+/kg)		1.29	0.28	0.74
Exchangeable Potassium (kg/ha)		1133	248	649
Exchangeable Potassium (mg/kg)		506	111	290
Exchangeable Sodium (cmol+/kg)		12.59	2.68	5.11
Exchangeable Sodium (kg/ha)		6485	1381	2631
Exchangeable Sodium (mg/kg)		2895	617	1174
Exchangeable Aluminium (cmol+/kg)	**Inhouse S37 (KCl)	0.04	<0.01	<0.01
Exchangeable Aluminium (kg/ha)		8	2	1
Exchangeable Aluminium (mg/kg)		3	<1	<1
Exchangeable Hydrogen (cmol+/kg)	**Rayment & Lyons 2011 - 15G1 (Acidity Titration)	<0.01	<0.01	0.02
Exchangeable Hydrogen (kg/ha)		<1	<1	<1
Exchangeable Hydrogen (mg/kg)		<1	<1	<1
Effective Cation Exchange Capacity (ECEC) (cmol+/kg)	**Calculation: Sum of Ca,Mg,K,Na,Al,H (cmol+/kg)	61.78	28.06	16.58
Calcium (%)	**Base Saturation Calculations - Cation cmol+/kg / ECEC x 100	51.6	73.6	24.8
Magnesium (%)		25.9	15.8	39.7
Potassium (%)		2.1	1.0	4.5
Sodium - ESP (%)		20.4	9.6	30.8
Aluminium (%)		0.1	0.0	0.0
Hydrogen		0.0	0.0	0.1
Calcium/Magnesium Ratio	**Calculation: Calcium / Magnesium (cmol+/kg)	2.0	4.6	0.6
Zinc (mg/kg)	Rayment & Lyons 2011 - 12A1 (DTPA)	10.4	4.1	10.4
Manganese (mg/kg)		89	257	31
Iron (mg/kg)		797	300	465
Copper (mg/kg)		4.5	7.2	6.9
Total Potassium (mg/kg)	Rayment & Lyons 2011 - 17C1 Aqua Regia	708	224	406
Phosphorus (mg/kg)	**Rayment & Lyons 2011 - 9C2b (Olsen)	230	37	46
Sodium Absorption Ratio	**Calculation (1:5 water): Sodium/Calcium+Magnesium	2.1	2.0	4.1

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		Sample 76	Sample 77	Sample 78
	Sample ID:	N1 Taylors Road 2	N1 Taylors Road Swamp	N1 Arthur Vale Creek
	Crop:	N/G	N/G	N/G
	Client:	B. Seshadri	B. Seshadri	B. Seshadri
Parameter	Method reference	i6765/76	i6765/77	i6765/78

Notes:

1. All results presented as a 40°C oven dried weight. Soil sieved and lightly crushed to < 2 mm.
2. Methods from Rayment and Lyons, 2011. *Soil Chemical Methods - Australasia*. CSIRO Publishing: Collingwood.
3. Soluble Salts included in Exchangeable Cations - NO PRE-WASH (unless requested).
4. 'Morgan 1 Extract' adapted from 'Science in Agriculture', 'Non-Toxic Farming' and LaMotte Soil Handbook.
5. Guidelines for phosphorus have been reduced for Australian soils.
6. Indicative guidelines are based on 'Albrecht' and 'Reams' concepts.
7. Total Acid Extractable Nutrients indicate a store of nutrients.
8. National Environmental Protection (Assessment of Site Contamination) Measure 2013, Schedule B(1) - Guideline on Investigation Levels for Soil and Groundwater. Table 5-A Background Ranges.
9. Information relating to testing colour codes is available on sheet 2 - 'Understanding your agricultural soil results'.
10. Conversions for 1 $cmol_+/kg$ = 230 mg/kg Sodium, 390 mg/kg Potassium, 122 mg/kg Magnesium, 200 mg/kg Calcium
11. Conversions to kg/ha = mg/kg x 2.24
12. The chloride calculation of Cl mg/L = EC x 640 is considered an estimate, and most likely an over-estimate
13. ** NATA accreditation does not cover the performance of this service.
14. Analysis conducted between sample arrival date and reporting date.
15. This report is not to be reproduced except in full. Results only relate to the item tested.
16. All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions (refer scu.edu
17. This report was issued on 14/08/2019.

Quality Checked: Kris Saville
Agricultural Co-Ordinator KS

NATA
WORLD RECOGNISED ACCREDITATION
Accreditation No. 14960
Accredited for compliance with ISO/IEC 17025 - Testing

CRICOS Provider: 01241G

RESULTS OF SOIL ANALYSIS

78 samples supplied by University of Newcastle on 02/12/2019. Lab Job No. i6765.

Samples submitted by Balaji Seshadri. Your Job: Norfolk Island

The University of Newcastle CALAGHAN NSW 2308

SAMPLE CODES	PARAMETER	Pesticide analysis screen^see notes	Alpha BHC (mg/kg or ppm)	Hexachlorobenzene (HCB) (mg/kg or ppm)	Beta BHC (mg/kg or ppm)	Lindane (gamma BHC) (mg/kg or ppm)	Delta BHC (mg/kg or ppm)	Heptachlor (mg/kg or ppm)	Aldrin (mg/kg or ppm)	Heptachlor epoxide (mg/kg or ppm)	Gamma Chlordane (mg/kg or ppm)	Alpha Chlordane (mg/kg or ppm)	Alpha Endosulfan (mg/kg or ppm)	o,p'-DDE (mg/kg or ppm)	p,p'-DDE (mg/kg or ppm)	Dieldrin (mg/kg or ppm)	Endrin (mg/kg or ppm)	Beta Endosulfan (mg/kg or ppm)	o,p'-DDD (mg/kg or ppm)	p,p'-DDD (mg/kg or ppm)	Endosulfan sulphate (mg/kg or ppm)	o,p'-DDT (mg/kg or ppm)	p,p'-DDT (mg/kg or ppm)	Endrin ketone (mg/kg or ppm)	Methoxychlor (mg/kg or ppm)	trans-Nonachlor (mg/kg or ppm)
	METHODS REFERENCE/		*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*
	JOB NO.																									
DAM 1	*i6765/1*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 2	*i6765/2*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 3	*i6765/3*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 4	*i6765/4*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 5	*i6765/5*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 6	*i6765/6*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 7(P)	*i6765/7*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 8 D1	*i6765/8*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 8 D2	*i6765/9*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DAM 8 D3	*i6765/10*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
100acresreserve1	*i6765/11*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
100acresreserve(1)	*i6765/12*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
100acresreserve(2)	*i6765/13*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
100acresreserve(3)	*i6765/14*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Rocky Point Whites	*i6765/15*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RP-WO-2	*i6765/16*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RP-WO+pine	*i6765/17*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
T.EvanvsFarm1	*i6765/18*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
T. EvansFarmD1	*i6765/19*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
T. EvansFarmD2	*i6765/20*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
T. EvansFarmD3	*i6765/21*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RarmSite	*i6765/22*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
DrainSite	*i6765/23*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RootyHill Right-1	*i6765/24*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RootyHill Right-2	*i6765/25*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RootyHill Right-3	*i6765/26*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
RootyHillLeft	*i6765/27*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Lyles Farm 1	*i6765/28*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Lyles Farm 2	*i6765/29*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Lyles Farm3- D1	*i6765/30*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Lyles Farm3- D2	*i6765/31*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
HardersRoad D1	*i6765/32*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
HardersRoadD2	*i6765/33*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
HardersRoadD3	*i6765/34*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
NewCascade Rd D1	*i6765/35*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
NewCascade Rd D2	*i6765/36*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
NewCascade Rd D3	*i6765/37*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Mt Pitt Top	*i6765/38*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Mt Pitt Bottom	*i6765/39*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Rd Left D1	*i6765/40*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Rd Left D2	*i6765/41*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Rd Left D3	*i6765/42*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Rd Right D1	*i6765/43*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Rd Right D2	*i6765/44*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Rd Right D3	*i6765/45*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Rd Drain 1	*i6765/46*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Middle Gate Rd	*i6765/47*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Taylors Rd Swamp	*i6765/48*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Raylors Rd Drain 2	*i6765/49*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Arthurvale Historic D1	*i6765/50*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Arthurvale Historic D2	*i6765/51*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Arthurvale Historic D3	*i6765/52*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Arthurvale Creek	*i6765/53*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Middlegate Rd D1	*i6765/54*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Middlegate Rd D2	*i6765/55*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Middlegate Rd D3	*i6765/56*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
NIindustries Left D1	*i6765/57*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
NIindustries Left D2	*i6765/58*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
NIindustries Left D3	*i6765/59*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Ball Bay Rd Landslide	*i6765/60*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Lyles Farm 4	*i6765/61*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Lyles Farm 5	*i6765/62*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Lyles Farm 6	*i6765/63*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Dereks Farm 1	*i6765/64*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Dereks Farm 2	*i6765/65*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Emily Bay	*i6765/66*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Red Road D1	*i6765/67*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Red Road D2	*i6765/68*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Red Road D3	*i6765/69*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Airport Drain 1	*i6765/70*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Airport Runoff	*i6765/71*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Airport Drain 2	*i6765/72*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Waste Treatment	*i6765/73*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
Effluent	*i6765/74*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
N1 Taylors Road 1	*i6765/75*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
N1 Taylors Road 2	*i6765/76*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
N1 Taylors Road Swamp	*i6765/77*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1
N1 Arthur Vale Creek	*i6765/78*		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.2	<0.2	<0.1	<0.1	<0.2	<0.1	<0.1	<0.1	<0.1	<0.1

Notes:

1. Total metals - samples digested with nitric acid; Total available (acid soluble/ extractable) metals - samples acidified with nitric acid to pH <2;
   Dissolved metals - samples filtered through 0.45μm cellulose acetate and then acidified with nitric acid prior to analysis
2. Metals and salts analysed by Inductively Coupled Plasma - Mass Spectrometry (ICP-MS).
3. 1 mg/L (milligram per litre) = 1 ppm (part per million) = 1000 μg/L (micrograms per litre) = 1000 ppb (part per billion).
4. For conductivity 1 dS/m = 1 mS/cm = 1000 μS/cm.
5. Analysis performed according to APHA (2017) 'Standard Methods for the Examination of Water & Wastewater', 23rd Edition, except where stated otherwise.
6. Analysis conducted between sample arrival date and reporting date.
7. ** NATA accreditation does not cover the performance of this service.
8. .. Denotes not requested.
9. This report is not to be reproduced except in full.
10. All services undertaken by EAL are covered by the EAL Laboratory Services Terms and Conditions (refer scu.edu.au/eal or on request).
11. Results relate only to the samples tested.
13. This report was issued on 02/12/2019.

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checked: ....
Graham Lancaster
Laboratory Manager

Endrin aldehyde (mg/kg or ppm)	Isodrin (mg/kg or ppm)	Mirex (mg/kg or ppm)		Dichlorvos (mg/kg or ppm)	Dimethoate (mg/kg or ppm)	Diazinon (Dimpylate) (mg/kg or ppm)	Fenitrothion (mg/kg or ppm)	Malathion (mg/kg or ppm)	Chlorpyrifos (Chlorpyrifos Ethyl) (mg/kg or ppm)	Parathion-ethyl (Parathion) (mg/kg or ppm)	Bromophos Ethyl (mg/kg or ppm)	Methidathion (mg/kg or ppm)	Ethion (mg/kg or ppm)	Azinphos-methyl (mg/kg or ppm)		Arochlor 1016 (mg/kg or ppm)	Arochlor 1221 (mg/kg or ppm)	Arochlor 1232 (mg/kg or ppm)	Arochlor 1242 (mg/kg or ppm)	Arochlor 1248 (mg/kg or ppm)	Arochlor 1254 (mg/kg or ppm)	Arochlor 1260 (mg/kg or ppm)	Arochlor 1262 (mg/kg or ppm)	Arochlor 1268 (mg/kg or ppm)
Subcontracted: SGS report SE 198743	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*		*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*		*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*	*Subcontracted: SGS report SE 198743*
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
<0.1	<0.1	<0.1		<0.5	<0.5	<0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.5	<0.2	<0.2		<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

checked: ....
Graham Lancaster
Laboratory Manager

Appendix 2

Raw rainfall data from Chapter 2

Appendix 2

Table A.1: Average rainfall per catchment for the period 1999 – 2019 (kL).

Catch	Area km^2	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual
1	0.239	21,987	24,468	24,071	21,253	25,249	28,090	27,206	24,171	17,388	11,975	16,044	20,822	262,724
2	0.048	4,447	4,948	4,868	4,298	5,106	5,681	5,502	4,888	3,516	2,422	3,245	4,211	53,132
3	0.066	6,102	6,790	6,680	5,898	7,007	7,795	7,550	6,707	4,825	3,323	4,452	5,778	72,907
4	0.129	11,934	13,281	13,065	11,536	13,704	15,246	14,766	13,119	9,438	6,500	8,708	11,301	142,598
5	0.122	11,254	12,523	12,320	10,878	12,923	14,377	13,925	12,371	8,900	6,129	8,212	10,657	134,469
6	0.120	11,089	12,340	12,140	10,719	12,734	14,167	13,721	12,190	8,769	6,040	8,092	10,501	132,502
7	0.808	74,487	82,891	81,544	72,001	85,535	95,159	92,165	81,883	58,905	40,568	54,353	70,538	890,029
8	0.214	19,762	21,992	21,635	19,103	22,694	25,247	24,453	21,725	15,628	10,763	14,421	18,715	236,138
9	0.155	14,267	15,877	15,619	13,791	16,384	18,227	17,654	15,684	11,283	7,771	10,411	13,511	170,479
10	0.724	66,727	74,256	73,050	64,500	76,624	85,246	82,564	73,353	52,769	36,342	48,690	63,190	797,311
11	0.299	27,557	30,667	30,168	26,637	31,645	35,205	34,098	30,293	21,793	15,009	20,108	26,096	329,276
12	0.260	23,953	26,656	26,223	23,154	27,506	30,601	29,639	26,332	18,943	13,046	17,479	22,684	286,216
13	0.219	20,193	22,471	22,106	19,519	23,188	25,797	24,985	22,198	15,969	10,998	14,734	19,122	241,280
14	0.378	34,852	38,784	38,154	33,689	40,021	44,525	43,124	38,313	27,561	18,982	25,431	33,005	416,441
15	1.070	98,661	109,794	108,010	95,368	113,295	126,043	122,078	108,458	78,023	53,735	71,993	93,432	1,178,890
16	0.034	3,109	3,460	3,404	3,005	3,570	3,972	3,847	3,418	2,459	1,693	2,269	2,944	37,150
17	0.188	17,333	19,289	18,976	16,755	19,904	22,144	21,447	19,054	13,707	9,440	12,648	16,415	207,112
18	0.185	17,009	18,928	18,621	16,441	19,532	21,730	21,046	18,698	13,451	9,264	12,411	16,107	203,238
19	0.539	49,703	55,311	54,413	48,044	57,075	63,498	61,500	54,639	39,306	27,070	36,268	47,069	593,896
20	0.105	9,302	10,755	10,006	9,317	11,164	12,288	12,164	10,883	8,291	5,507	6,943	8,983	115,603

21	0.073	6,459	7,468	6,948	6,470	7,752	8,533	8,447	7,557	5,758	3,824	4,821	6,238	80,275
22	1.178	108,566	120,816	118,853	104,943	124,670	138,697	134,334	119,347	85,856	59,129	79,220	102,812	1,297,243
23	0.979	90,198	100,375	98,744	87,188	103,577	115,231	111,606	99,154	71,330	49,125	65,817	85,417	1,077,762
24	0.344	30,411	35,162	32,713	30,460	36,498	40,173	39,768	35,580	27,108	18,004	22,700	29,369	377,946
25	0.238	21,065	24,356	22,659	21,099	25,281	27,827	27,546	24,645	18,777	12,471	15,724	20,343	261,793
26	0.420	37,119	42,919	39,929	37,179	44,549	49,035	48,541	43,429	33,087	21,976	27,708	35,847	461,318
27	0.767	67,825	78,422	72,959	67,934	81,401	89,597	88,695	79,354	60,458	40,154	50,627	65,501	842,927
28	0.299	26,387	30,510	28,384	26,429	31,668	34,857	34,506	30,872	23,521	15,622	19,696	25,482	327,934
29	0.173	15,297	17,687	16,455	15,321	18,359	20,207	20,004	17,897	13,635	9,056	11,418	14,773	190,109
30	2.492	229,672	255,586	251,433	222,006	263,738	293,414	284,182	252,477	181,628	125,088	167,590	217,497	2,744,311
31	6.405	590,368	656,982	646,306	570,665	677,936	754,217	730,488	648,991	466,872	321,537	430,790	559,075	7,054,227
32	0.821	72,574	83,914	78,068	72,691	87,100	95,871	94,905	84,911	64,691	42,966	54,172	70,087	901,950
33	2.578	227,866	263,470	245,116	228,234	273,476	301,014	297,982	266,601	203,115	134,903	170,089	220,058	2,831,924
34	0.106	9,789	10,893	10,716	9,462	11,241	12,506	12,112	10,761	7,741	5,331	7,143	9,270	116,965
35	0.791	69,926	80,852	75,220	70,039	83,923	92,373	91,443	81,813	62,331	41,398	52,196	67,530	869,044
36	1.937	178,501	198,642	195,415	172,544	204,978	228,042	220,867	196,226	141,161	97,219	130,252	169,040	2,132,887
37	0.234	17,740	22,235	19,415	19,003	22,364	24,911	25,279	22,989	15,903	10,974	14,505	18,482	233,800
38	0.513	47,285	52,620	51,765	45,707	54,298	60,408	58,507	51,980	37,393	25,753	34,504	44,778	564,998
39	0.211	19,443	21,637	21,285	18,794	22,327	24,839	24,058	21,374	15,376	10,589	14,188	18,413	232,323
40	0.597	45,224	56,681	49,494	48,443	57,011	63,505	64,443	58,605	40,539	27,974	36,977	47,116	596,012
41	4.695	355,934	446,108	389,540	381,267	448,702	499,814	507,193	461,245	319,064	220,170	291,026	370,825	4,690,888
42	0.299	26,396	30,521	28,394	26,439	31,680	34,870	34,518	30,883	23,529	15,627	19,703	25,492	328,052
43	1.349	124,306	138,332	136,084	120,157	142,744	158,805	153,809	136,649	98,303	67,702	90,706	117,717	1,485,314
44	0.188	14,247	17,856	15,592	15,261	17,960	20,006	20,301	18,462	12,771	8,813	11,649	14,843	187,761

45	0.057	5,288	5,884	5,789	5,111	6,072	6,755	6,543	5,813	4,182	2,880	3,858	5,007	63,182
46	0.189	16,744	19,360	18,011	16,771	20,095	22,118	21,896	19,590	14,925	9,913	12,498	16,170	208,091
47	0.126	11,615	12,925	12,715	11,227	13,338	14,838	14,372	12,768	9,185	6,326	8,475	10,999	138,783
48	0.628	47,570	59,622	52,062	50,956	59,969	66,800	67,786	61,645	42,643	29,426	38,895	49,561	626,935

Total	34.590	3,057,543	3,497,316	3,335,137	3,027,706	3,597,567	3,994,301	3,917,565	3,499,995	2,531,806	1,730,527	2,283,859	2,952,823	37,426,145

Table A.2: Household water demand per catchment (kL).

Catch	Number of dwellings	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual
1	3	30	27	30	29	30	29	30	30	29	30	29	30	353
2	1	10	9	10	10	10	10	10	10	10	10	10	10	119
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	15	150	135	150	145	150	145	150	150	145	150	145	150	1,765
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	10	9	10	10	10	10	10	10	10	10	10	10	119
10	16	160	144	160	154	160	154	160	160	154	160	154	160	1,880
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1	10	9	10	10	10	10	10	10	10	10	10	10	119
14	7	70	63	70	68	70	68	70	70	68	70	68	70	825
15	4	40	36	40	39	40	39	40	40	39	40	39	40	472
16	3	30	27	30	29	30	29	30	30	29	30	29	30	353
17	5	50	45	50	48	50	48	50	50	48	50	48	50	587
18	4	40	36	40	39	40	39	40	40	39	40	39	40	472
19	1	10	9	10	10	10	10	10	10	10	10	10	10	119
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1	10	9	10	10	10	10	10	10	10	10	10	10	119
22	5	50	45	50	48	50	48	50	50	48	50	48	50	587
23	15	150	135	150	145	150	145	150	150	145	150	145	150	1,765
24	20	199	180	199	193	199	193	199	199	193	199	193	199	2,345
25	10	100	90	100	96	100	96	100	100	96	100	96	100	1,174
26	22	219	198	219	212	219	212	219	219	212	219	212	219	2,579
27	35	349	315	349	338	349	338	349	349	338	349	338	349	4,110
28	22	219	198	219	212	219	212	219	219	212	219	212	219	2,579
29	8	80	72	80	77	80	77	80	80	77	80	77	80	940
30	69	688	621	688	666	688	666	688	688	666	688	666	688	8,101
31	206	2,054	1,855	2,054	1,987	2,054	1,987	2,054	2,054	1,987	2,054	1,987	2,054	24,181
32	66	658	594	658	637	658	637	658	658	637	658	637	658	7,748
33	132	1,316	1,189	1,316	1,274	1,316	1,274	1,316	1,316	1,274	1,316	1,274	1,316	15,497
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0

35	29	289	261	289	280	289	280	289	289	280	289	280	289	3,404
36	40	399	360	399	386	399	386	399	399	386	399	386	399	4,697
37	9	90	81	90	87	90	87	90	90	87	90	87	90	1,059
38	36	359	324	359	347	359	347	359	359	347	359	347	359	4,225
39	10	100	90	100	96	100	96	100	100	96	100	96	100	1,174
40	7	70	63	70	68	70	68	70	70	68	70	68	70	825
41	135	1,346	1,216	1,346	1,302	1,346	1,302	1,346	1,346	1,302	1,346	1,302	1,346	15,846
42	14	140	126	140	135	140	135	140	140	135	140	135	140	1,646
43	51	508	459	508	492	508	492	508	508	492	508	492	508	5,983
44	14	140	126	140	135	140	135	140	140	135	140	135	140	1,646
45	5	50	45	50	48	50	48	50	50	48	50	48	50	587
46	15	150	135	150	145	150	145	150	150	145	150	145	150	1,765
47	5	50	45	50	48	50	48	50	50	48	50	48	50	587
48	38	379	342	379	367	379	367	379	379	367	379	367	379	4,463
Total	1,080	10,772	9,723	10,772	10,422	10,772	10,422	10,772	10,772	10,422	10,772	10,422	10,772	126,815

Table A.3: Simulated household rainwater consumption per catchment (kL).

Catch	Number dwellings	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual
1	3	27	25	34	30	33	36	33	33	26	22	26	28	353
2	1	9	8	11	10	11	12	11	11	9	7	9	9	118
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	15	135	124	170	152	163	181	164	166	132	108	129	139	1,763
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	9	8	11	10	11	12	11	11	9	7	9	9	118
10	16	144	133	181	162	174	193	175	177	141	115	138	148	1,881
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	1	9	8	11	10	11	12	11	11	9	7	9	9	118
14	7	63	58	79	71	76	84	77	78	62	50	60	65	823
15	4	36	33	45	40	44	48	44	44	35	29	34	37	470
16	3	27	25	34	30	33	36	33	33	26	22	26	28	353
17	5	45	41	57	51	54	60	55	55	44	36	43	46	588

18	4	36	33	45	40	44	48	44	44	35	29	34	37	470
19	1	9	8	11	10	11	12	11	11	9	7	9	9	118
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	1	10	8	11	10	11	12	11	11	9	7	9	9	118
22	5	45	41	57	51	54	60	55	55	44	36	43	46	588
23	15	135	124	170	152	163	181	164	166	132	108	129	139	1,763
24	20	193	160	216	199	217	239	220	224	180	143	173	184	2,350
25	10	97	80	108	99	109	119	110	112	90	72	87	92	1,175
26	22	213	176	238	219	239	263	242	247	198	157	191	203	2,585
27	35	338	280	379	348	380	418	385	392	316	251	303	323	4,113
28	22	213	176	238	219	239	263	242	247	198	157	191	203	2,585
29	8	77	64	87	80	87	95	88	90	72	57	69	74	940
30	69	622	572	782	698	751	831	755	764	608	495	595	638	8,111
31	206	1,858	1,707	2,336	2,084	2,242	2,479	2,255	2,282	1,815	1,476	1,775	1,904	24,215
32	66	638	528	714	656	717	788	727	740	595	472	572	609	7,756
33	132	1,276	1,056	1,429	1,312	1,435	1,575	1,454	1,480	1,190	945	1,143	1,218	15,513
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	29	280	232	314	288	315	346	319	325	261	208	251	268	3,408
36	40	361	331	454	405	435	481	438	443	352	287	345	370	4,702
37	9	82	68	92	92	105	113	102	105	81	61	72	83	1,056
38	36	325	298	408	364	392	433	394	399	317	258	310	333	4,232
39	10	90	83	113	101	109	120	109	111	88	72	86	92	1,176
40	7	64	53	72	71	81	88	79	81	63	47	56	65	822
41	135	1,237	1,017	1,385	1,377	1,569	1,697	1,532	1,570	1,215	914	1,087	1,246	15,845
42	14	135	112	152	139	152	167	154	157	126	100	121	129	1,645
43	51	460	423	578	516	555	614	558	565	449	366	439	471	5,995
44	14	128	105	144	143	163	176	159	163	126	95	113	129	1,643
45	5	45	41	57	51	54	60	55	55	44	36	43	46	588
46	15	145	120	162	149	163	179	165	168	135	107	130	138	1,763
47	5	45	41	57	51	54	60	55	55	44	36	43	46	588
48	38	348	286	390	388	442	478	431	442	342	257	306	351	4,460
Total	1,080	10,009	8,686	11,832	10,878	11,898	13,069	11,927	12,123	9,627	7,659	9,208	9,973	126,908

Table A.4: Simulated household water consumption per catchment (mm) and annual percentage of rainfall

Catch	Jan	Feb	Mar	Apr	May	Jun	Jul	Ago	Sep	Oct	Nov	Dec	Annual	Rainfall %
1	0.11	0.1	0.14	0.13	0.14	0.15	0.14	0.14	0.11	0.09	0.11	0.12	1.48	0.13
2	0.19	0.17	0.23	0.21	0.23	0.25	0.23	0.23	0.19	0.15	0.19	0.19	2.46	0.22
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0.17	0.15	0.21	0.19	0.2	0.22	0.2	0.21	0.16	0.13	0.16	0.17	2.17	0.2
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0.06	0.05	0.07	0.06	0.07	0.08	0.07	0.07	0.06	0.05	0.06	0.06	0.76	0.07
10	0.2	0.18	0.25	0.22	0.24	0.27	0.24	0.24	0.19	0.16	0.19	0.2	2.58	0.24
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0.04	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.04	0.04	0.53	0.05
14	0.17	0.15	0.21	0.19	0.2	0.22	0.2	0.21	0.16	0.13	0.16	0.17	2.17	0.2
15	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.03	0.42	0.04
16	0.8	0.74	1.01	0.89	0.98	1.07	0.98	0.98	0.77	0.65	0.77	0.83	10.47	0.95
17	0.24	0.22	0.3	0.27	0.29	0.32	0.29	0.29	0.23	0.19	0.23	0.24	3.11	0.28
18	0.2	0.18	0.24	0.22	0.24	0.26	0.24	0.24	0.19	0.16	0.18	0.2	2.55	0.23
19	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.22	0.02
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0.14	0.11	0.15	0.14	0.15	0.16	0.15	0.15	0.12	0.1	0.12	0.12	1.61	0.15
22	0.04	0.03	0.05	0.04	0.05	0.05	0.05	0.05	0.04	0.03	0.04	0.04	0.51	0.05
23	0.14	0.13	0.17	0.16	0.17	0.18	0.17	0.17	0.13	0.11	0.13	0.14	1.8	0.16
24	0.56	0.46	0.63	0.58	0.63	0.69	0.64	0.65	0.52	0.42	0.5	0.53	6.81	0.62
25	0.41	0.34	0.45	0.42	0.46	0.5	0.46	0.47	0.38	0.3	0.37	0.39	4.95	0.45
26	0.51	0.42	0.57	0.52	0.57	0.63	0.58	0.59	0.47	0.37	0.45	0.48	6.16	0.56
27	0.44	0.36	0.49	0.45	0.5	0.54	0.5	0.51	0.41	0.33	0.39	0.42	5.34	0.49
28	0.71	0.59	0.8	0.73	0.8	0.88	0.81	0.83	0.66	0.53	0.64	0.68	8.66	0.79
29	0.44	0.37	0.5	0.46	0.5	0.55	0.51	0.52	0.42	0.33	0.4	0.43	5.43	0.49
30	0.25	0.23	0.31	0.28	0.3	0.33	0.3	0.31	0.24	0.2	0.24	0.26	3.25	0.3
31	0.29	0.27	0.36	0.33	0.35	0.39	0.35	0.36	0.28	0.23	0.28	0.3	3.79	0.34
32	0.78	0.64	0.87	0.8	0.87	0.96	0.89	0.9	0.72	0.57	0.7	0.74	9.44	0.86
33	0.49	0.41	0.55	0.51	0.56	0.61	0.56	0.57	0.46	0.37	0.44	0.47	6	0.55
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0

35	0.35	0.29	0.4	0.36	0.4	0.44	0.4	0.41	0.33	0.26	0.32	0.34	4.3	0.39
36	0.19	0.17	0.23	0.21	0.22	0.25	0.23	0.23	0.18	0.15	0.18	0.19	2.43	0.22
37	0.35	0.29	0.39	0.39	0.45	0.48	0.44	0.45	0.35	0.26	0.31	0.35	4.51	0.45
38	0.63	0.58	0.8	0.71	0.76	0.84	0.77	0.78	0.62	0.5	0.6	0.65	8.24	0.75
39	0.43	0.39	0.54	0.48	0.52	0.57	0.52	0.53	0.42	0.34	0.41	0.44	5.59	0.51
40	0.11	0.09	0.12	0.12	0.14	0.15	0.13	0.14	0.11	0.08	0.09	0.11	1.39	0.14
41	0.26	0.22	0.29	0.29	0.33	0.36	0.33	0.33	0.26	0.19	0.23	0.27	3.36	0.34
42	0.45	0.38	0.51	0.47	0.51	0.56	0.52	0.53	0.42	0.33	0.41	0.43	5.52	0.5
43	0.34	0.31	0.43	0.38	0.41	0.46	0.41	0.42	0.33	0.27	0.33	0.35	4.44	0.4
44	0.68	0.56	0.77	0.76	0.87	0.94	0.85	0.87	0.67	0.51	0.6	0.69	8.77	0.88
45	0.78	0.71	0.99	0.89	0.94	1.05	0.96	0.96	0.77	0.63	0.75	0.8	10.23	0.93
46	0.77	0.63	0.86	0.79	0.86	0.94	0.87	0.89	0.71	0.56	0.69	0.73	9.3	0.85
47	0.36	0.33	0.45	0.4	0.43	0.48	0.44	0.44	0.35	0.29	0.34	0.37	4.68	0.42
48	0.55	0.46	0.62	0.62	0.7	0.76	0.69	0.7	0.54	0.41	0.49	0.56	7.1	0.71
Norfolk	0.29	0.25	0.34	0.31	0.34	0.38	0.34	0.35	0.28	0.22	0.27	0.29	3.66	0.34

Table A.5: Accommodation properties details

Accommodation properties	Units	Beds	Bedrooms	Catchment	Roof Area (m2)	Storage(L)	Notes
A – Frame Chalets @ Mokutu	12	52	26	33	942	573,572.5	updated survey 2002
Aataren Villas	4	16	8	31	640	260,000	min requirement
Ahstyk Cottage	1	5	2	31	160	65,000	min requirement
Aloha Apartments	34	136	68	31	4,759	1,392,660	updated survey 2002
Anson Bay Lodge	5	20	10	10	436	133,836	updated survey 2002
Auwas Island Holiday Home	1	6	3	31	240	97,500	min requirement
Ball Bay House	1	6	3	46	240	97,500	min requirement
Broad Leaf Villas	5	15	7	41	560	227,500	min requirement
Bucks Point House	1	6	3	32	292	75,700	2002 survey
Burnt Pine Boutique Apartment	10	24	12	41	960	390,000	min requirement
By The Bay	1	6	3	32	252	70,350	updated survey 2002
Callam Court Ocean View Apartments	8	27	13	31	666	303,200	updated survey 2002
Cascade Garden Apartments	5	17	8	31	340	31,794	2002 survey
Castaway Norfolk Island	20	44	22	41	1,337	37,850	updated survey 2002
Cavendish Apartments	2	8	4	30	320	130,000	min requirement
Channers on Norfolk Gardenside Apartments	7	26	13	41	716	289,625	updated survey 2002
Christian's of Bucks Point	1	6	3	32	240	97,500	min requirement
Coast Norfolk Island	15	40	20	38	1,600	650,000	min requirement
Cobbys of Crystal Pool	1	4	2	43	211	37,850	2002 survey
Cumberland Resort and Spa	10	34	17	41	1,048	446,120	updated survey 2002
(*) Da Shed	2	3	1		80	32,500	min requirement
Daydreamer Apartments	12	32	16	31	1,131	473,270	updated survey 2002
Dii Elduu House and Cottage	2	10	5	10	303	75,700	2002 survey
Dolphin Inn	6	22	11	31	390	75,700	2002 survey
Endeavour Lodge	7	24	12	44	732	235,980	updated survey 2002
Feawa - Forever	1	4	2	41	160	65,000	min requirement
Five Pines Holiday Home	2	14	7	30	560	227,500	min requirement
Fletcher Christian Apartments	13	32	16	31	1,340	75,700	updated survey 2002
Forrester Court Cliff Top Cottages	3	10	5	27	400	162,500	min requirement
(*) Frangipani	1	6	3		240	97,500	min requirement
Girlies Holiday Home	1	6	3	32	240	97,500	min requirement
Governor's Lodge Resort Hotel	55	120	60	41	4,800	1,665,400	2002 survey
Hamish's Cottages	3	10	5	31	400	162,500	min requirement
Haydanblair House	1	7	3	31	443	94,625	2002 survey

Hibiscus Crown Apartments	9	37	18	31	949	330,350	updated survey 2002
Hibiscus Regal Apartments	8	24	12	31	516	286,495	updated survey 2002
Hideaway Retreat	9	29	14	30	1,120	455,000	min requirement
Highlands	2	14	7	31	516	113,550	updated survey 2002
Islander Lodge Apartments	5	10	5	41	402	0	2002 survey
Jacaranda Park Holiday Cottages	5	10	5	33	400	162,500	min requirement
Jemimas @ Tau Gardens	1	2	1	41	80	32,500	min requirement
Kentia Holiday Accommodation	5	25	12	44	822	238,200	updated survey 2002
King Tide House	1	4	2	23	160	65,000	min requirement
Kingston Cottages	3	10	5	41	351	151,400	2002 survey
Lavendula Garden Cottage	1	4	2	31	170	81,705	updated survey 2002
Norfolk Holiday Apartments	12	33	16	41	907	348,220	2002 survey
Nuffka Studio Apartments	6	17	8	30	372	226,845	updated survey 2002
Ocean Breeze Cottages	12	24	12	31	900	465,300	updated survey 2002
Oceanview Apartments	2	4	2	31	160	56,775	2002 survey
Palms By the Sea (Pacific Palms)	2	8	4	10	221	37,850	2002 survey
Panorama Seaside Apartments	12	35	17	41	494	56,775	updated survey 2002
Paradise Hotel & Resort	48	99	49	31	3,920	1,592,500	min requirement
(*) Philly’s Place	1	5	2		160	65,000	min requirement
Pine Valley Apartments	13	38	19	31	677	0	2002 survey
Poinciana Cottages	5	15	7	30	662	246,025	2002 survey
(*) Polynesian Apartments	13	27	13	31	1,013	0	updated survey 2002
Pomona	1	6	3		240	97,500	min requirement
Rainbows End	1	6	3	44	240	97,500	min requirement
Ranston Farm BnB	1	4	2	15	160	65,000	min requirement
Riggers Retreat	1	3	1	31	82	37,850	2002 survey
Rocky Point Lodge	1	7	3	36	240	97,500	min requirement
Saints Holiday Apartments	4	13	6	31	302	175,420	updated survey 2002
Selwyn Cottage	1	2	1	31	98	37,850	2002 survey
Seaview Hotel & Cottages	9	27	13	41	1,040	422,500	min requirement
Shearwater Scenic Villas	7	20	10	43	794	319,905	updated survey 2002
Shiralee Executive Cottages	6	20	10	31	739	124,905	updated survey 2002
South Pacific Resort Hotel	68	145	72	41	5,465	1,987,850	updated survey 2002
Tau Gardens	4	18	9	23	477	207,265	updated survey 2002
TheArk	1	4	2	31	160	65,000	min requirement
The Bounty Lodge	5	12	6	30	781	143,830	2002 survey
The Bounty Lodge – ‘Fig Tree Cottage’	1	6	3	30	240	97,500	min requirement

The Crest Apartments	14	46	23	48	1,260	289,552.5	2002 survey
The House @ Puppy's Point	1	4	2	31	160	65,000	min requirement
The Tin Sheds – Norfolk Island	3	6	3	31	240	97,500	min requirement
The White House	1	10	5	32	400	162,500	min requirement
Tintoela of Norfolk	3	22	11	31	832	262,147.5	updated survey 2002
(*) Touchwood	1	4	2		160	65,000	min requirement
Trade Winds Country Cottages	5	24	12	24	1,064	474,384	updated survey 2002
Tudor Apartments	5	22	11	31	559	207,920	updated survey 2002
Viewrest Inn	3	11	5	31	270	35,957.5	updated survey 2002
Wattle Cottage	1	2	1	31	80	32,500	min requirement
Whalers Watch	1	6	3	31	240	97,500	min requirement
Whispering Pines	7	28	14	31	729	102,195	2002 survey
Whitewood Sea	1	5	2	38	160	65,000	min requirement

(*) Properties that could not be located

Table A.6: Rainwater consumed by touristic accommodations per catchment. Average year for period 1999-2019. (a) in (kL), (b) equivalent mm) and rainfall percentage

Catch.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
10	84	92	90	85	102	111	110	92	68	48	65	84	1,028
15	14	11	14	13	16	16	16	14	10	8	11	13	155
23	59	63	63	55	67	75	73	62	45	32	43	56	692
24	89	79	88	82	103	106	100	92	74	54	70	80	1,016
27	34	33	34	32	41	41	40	37	29	21	26	32	399
30	348	304	359	330	417	431	415	342	268	204	273	328	4,018
31	2,106	2,147	2,175	1,997	2,521	2,690	2,615	2,242	1,666	1,196	1,602	2,079	25,035
32	118	99	119	112	139	140	141	128	101	73	94	109	1,372
33	119	137	128	119	142	157	155	139	106	70	89	115	1,474
36	22	22	22	20	25	28	26	22	17	12	16	21	254
38	153	142	156	144	183	192	187	153	117	88	118	145	1,779
41	1,389	1,505	1,417	1,408	1,748	1,902	1,948	1,656	1,201	859	1,136	1,447	17,615
43	84	67	89	79	100	105	97	81	66	51	68	80	966
44	136	149	139	139	171	186	191	164	118	84	111	142	1,730
46	20	19	20	19	24	24	25	22	17	12	16	19	238
48	92	106	96	101	120	130	136	117	84	59	78	100	1,219
Total	4,866	4,975	5,009	4,735	5,920	6,332	6,274	5,362	3,985	2,870	3,814	4,846	58,990

(a)

Catch.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	% Rainfall
10	0.12	0.13	0.12	0.12	0.14	0.15	0.15	0.13	0.09	0.07	0.09	0.12	1.43	0.13
15	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.14	0.01
23	0.06	0.06	0.06	0.06	0.07	0.08	0.07	0.06	0.05	0.03	0.04	0.06	0.7	0.06
24	0.26	0.23	0.26	0.24	0.3	0.31	0.29	0.27	0.21	0.16	0.2	0.23	2.96	0.27
27	0.04	0.04	0.04	0.04	0.05	0.05	0.05	0.05	0.04	0.03	0.03	0.04	0.5	0.05
30	0.14	0.12	0.14	0.13	0.17	0.17	0.17	0.14	0.11	0.08	0.11	0.13	1.61	0.15
31	0.33	0.34	0.34	0.31	0.39	0.42	0.41	0.35	0.26	0.19	0.25	0.32	3.91	0.36
32	0.14	0.12	0.14	0.14	0.17	0.17	0.17	0.16	0.12	0.09	0.11	0.13	1.66	0.15
33	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.05	0.04	0.03	0.03	0.04	0.57	0.05
36	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.12	0.01
38	0.3	0.28	0.3	0.28	0.36	0.37	0.36	0.3	0.23	0.17	0.23	0.28	3.46	0.31
41	0.3	0.32	0.3	0.3	0.37	0.41	0.41	0.35	0.26	0.18	0.24	0.31	3.75	0.38
43	0.06	0.05	0.07	0.06	0.07	0.08	0.07	0.06	0.05	0.04	0.05	0.06	0.72	0.07
44	0.72	0.79	0.74	0.74	0.91	0.99	1.02	0.87	0.63	0.45	0.59	0.75	9.2	0.92

46	0.11	0.1	0.11	0.1	0.13	0.13	0.13	0.12	0.09	0.06	0.08	0.1	1.26	0.11
48	0.15	0.17	0.15	0.16	0.19	0.21	0.22	0.19	0.13	0.09	0.12	0.16	1.94	0.19
Norfolk	0.14	0.14	0.14	0.14	0.17	0.18	0.18	0.16	0.12	0.08	0.11	0.14	1.7	
% Rainfall	0.16	0.14	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.17	0.16	0.16	

(b)

Table A.7: Simulated results. Average year for period 1999-2019. (a) Rainwater actually consumed by touristic accommodations per catchment (kL), (b) Remaining touristic accommodation's water demand (kL)

Catch.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
10	75	77	103	88	106	99	96	104	103	68	50	65	1,034
15	10	11	17	14	11	12	11	12	16	17	14	13	157
23	50	48	65	57	66	64	59	63	74	62	44	46	698
24	75	80	101	87	85	75	68	80	91	106	93	86	1,026
27	29	32	40	32	34	30	29	32	37	43	35	31	403
30	289	313	383	331	333	319	287	336	382	432	334	316	4,054
31	1,789	1,765	2,248	2,106	2,281	2,219	2,033	2,282	2,569	2,569	1,685	1,665	25,209
32	101	106	134	114	112	103	98	112	123	149	127	106	1,384
33	117	114	136	131	154	150	141	147	143	88	81	91	1,492
36	19	20	23	21	24	21	20	21	25	25	20	19	257
38	130	139	169	146	150	140	127	151	170	188	145	141	1,795
41	1,335	1,179	1,518	1,421	1,611	1,549	1,463	1,645	1,819	1,824	1,145	1,251	17,760
43	67	73	94	84	77	75	69	78	91	105	85	78	974
44	122	113	152	144	161	155	148	169	185	165	109	121	1,744
46	19	19	26	24	21	18	17	20	21	27	24	21	256
48	90	86	113	102	118	120	120	130	122	84	60	82	1,226
Total	4,316	4,174	5,319	4,900	5,344	5,148	4,785	5,380	5,971	5,950	4,050	4,130	59,469

(a)

Catch.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
10	42	49	66	62	34	21	12	22	40	102	98	80	627
15	1	1	2	3	2	0	0	0	0	1	2	3	15
23	18	24	31	31	13	4	3	8	9	35	45	38	260
24	1	0	4	8	3	1	0	0	0	0	3	5	25
27	2	2	6	7	3	0	0	0	0	2	5	7	35
30	27	21	58	68	35	2	1	3	0	11	62	67	355
31	475	619	910	799	367	59	28	140	158	604	1,176	1,092	6,426
32	5	6	19	23	11	1	1	0	0	3	12	19	100
33	77	91	135	115	74	43	35	60	90	185	165	144	1,214
36	3	4	7	7	3	1	0	1	2	5	9	7	48
38	13	10	26	33	16	1	0	2	0	8	34	32	175
41	322	569	793	692	331	120	50	118	172	497	953	763	5,378
43	5	4	12	14	8	1	0	1	0	1	8	14	67
44	50	68	88	77	39	17	7	15	21	75	110	87	655

46	0	0	1	1	1	0	0	0	0	0	1	1	6
48	55	66	88	83	50	24	14	25	49	118	120	93	785
Total	1,096	1,536	2,246	2,023	991	293	150	395	540	1,648	2,801	2,451	16,170

(b)

Figure A.1: Touristic accommodation's water demand per catchment in an average year (kL/month). Period 1999-2019.

Table A.8: Water consumption of cattle in (kL) per catchment. Based on average number of cattle.

Catch.	Number cattle head	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	11	33	30	24	23	24	23	24	24	23	24	23	33	308
2	2	6	5	4	4	4	4	4	4	4	4	4	6	53
7	33	100	91	72	69	72	69	72	72	69	72	69	100	927
9	2	6	5	4	4	4	4	4	4	4	4	4	6	53
10	24	73	66	52	50	52	50	52	52	50	52	50	73	672
13	2	6	5	4	4	4	4	4	4	4	4	4	6	53
14	12	36	33	26	25	26	25	26	26	25	26	25	36	335
15	4	12	11	9	8	9	8	9	9	8	9	8	12	112
16	2	6	5	4	4	4	4	4	4	4	4	4	6	53
17	9	27	25	20	19	20	19	20	20	19	20	19	27	255
18	9	27	25	20	19	20	19	20	20	19	20	19	27	255
19	4	12	11	9	8	9	8	9	9	8	9	8	12	112
20	22	67	60	48	46	48	46	48	48	46	48	46	67	618
21	1	3	3	2	2	2	2	2	2	2	2	2	3	27
22	48	146	132	104	101	104	101	104	104	101	104	101	146	1,348
23	41	125	113	89	86	89	86	89	89	86	89	86	125	1,152
24	16	49	44	35	34	35	34	35	35	34	35	34	49	453
25	12	36	33	26	25	26	25	26	26	25	26	25	36	335
26	19	58	52	41	40	41	40	41	41	40	41	40	58	533
27	35	106	96	76	74	76	74	76	76	74	76	74	106	984
28	14	43	38	30	29	30	29	30	30	29	30	29	43	390
29	6	18	16	13	13	13	13	13	13	13	13	13	18	169
30	84	255	230	182	176	182	176	182	182	176	182	176	255	2,354
31	205	623	563	445	431	445	431	445	445	431	445	431	623	5,758
32	36	109	99	78	76	78	76	78	78	76	78	76	109	1,011
33	124	377	340	269	260	269	260	269	269	260	269	260	377	3,479
35	80	243	220	174	168	174	168	174	174	168	174	168	243	2,248
36	80	243	220	174	168	174	168	174	174	168	174	168	243	2,248
37	11	33	30	24	23	24	23	24	24	23	24	23	33	308
38	21	64	58	46	44	46	44	46	46	44	46	44	64	592
39	6	18	16	13	13	13	13	13	13	13	13	13	18	169
40	28	85	77	61	59	61	59	61	61	59	61	59	85	788
41	225	684	617	488	473	488	473	488	488	473	488	473	684	6,317
42	14	43	38	30	29	30	29	30	30	29	30	29	43	390

43	57	173	156	124	120	124	120	124	124	120	124	120	173	1,602
44	9	27	25	20	19	20	19	20	20	19	20	19	27	255
45	2	6	5	4	4	4	4	4	4	4	4	4	6	53
46	9	27	25	20	19	20	19	20	20	19	20	19	27	255
47	3	9	8	7	6	7	6	7	7	6	7	6	9	85
48	28	85	77	61	59	61	59	61	61	59	61	59	85	788
Total	1,350	4,099	3,703	2,932	2,834	2,932	2,834	2,932	2,932	2,834	2,932	2,834	4,099	37,897

Table A.9: Water consumption of cattle in (mm) per catchment and rainfall percentage. Based on average number of cattle.

Catch.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	% Rainfall
1	0.14	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	1.29	0.12
2	0.12	0.10	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.12	1.10	0.10
7	0.12	0.11	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.12	1.15	0.10
9	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.34	0.03
10	0.10	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.10	0.93	0.08
13	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.24	0.02
14	0.10	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.10	0.89	0.08
15	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.10	0.01
16	0.18	0.15	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.18	1.57	0.14
17	0.14	0.13	0.11	0.10	0.11	0.10	0.11	0.11	0.10	0.11	0.10	0.14	1.36	0.12
18	0.15	0.14	0.11	0.10	0.11	0.10	0.11	0.11	0.10	0.11	0.10	0.15	1.38	0.13
19	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.02	0.21	0.02
20	0.64	0.57	0.46	0.44	0.46	0.44	0.46	0.46	0.44	0.46	0.44	0.64	5.87	0.53
21	0.04	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.37	0.03
22	0.12	0.11	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.12	1.14	0.10
23	0.13	0.12	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.13	1.18	0.11
24	0.14	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	1.32	0.12
25	0.15	0.14	0.11	0.10	0.11	0.10	0.11	0.11	0.10	0.11	0.10	0.15	1.41	0.13
26	0.14	0.12	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	1.27	0.12
27	0.14	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	1.28	0.12
28	0.14	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	1.31	0.12
29	0.10	0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.10	0.98	0.09
30	0.10	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.10	0.94	0.09
31	0.10	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.10	0.90	0.08
32	0.13	0.12	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.13	1.23	0.11
33	0.15	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.15	1.35	0.12
35	0.31	0.28	0.22	0.21	0.22	0.21	0.22	0.22	0.21	0.22	0.21	0.31	2.84	0.26
36	0.13	0.11	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.13	1.16	0.11
37	0.14	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	1.32	0.13
38	0.12	0.11	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.12	1.15	0.10
39	0.09	0.08	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.09	0.80	0.07
40	0.14	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	1.32	0.13
41	0.15	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.15	1.35	0.13
42	0.14	0.13	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	1.31	0.12

43	0.13	0.12	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.13	1.19	0.11
44	0.14	0.13	0.11	0.10	0.11	0.10	0.11	0.11	0.10	0.11	0.10	0.14	1.36	0.14
45	0.10	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.10	0.92	0.08
46	0.14	0.13	0.11	0.10	0.11	0.10	0.11	0.11	0.10	0.11	0.10	0.14	1.35	0.12
47	0.07	0.06	0.06	0.05	0.06	0.05	0.06	0.06	0.05	0.06	0.05	0.07	0.67	0.06
48	0.14	0.12	0.10	0.09	0.10	0.09	0.10	0.10	0.09	0.10	0.09	0.14	1.26	0.13

Norfolk	0.12	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.12	1.10	0.10

Table A.10: Estimated intercepted rainfall by forest (kL). Average year, period 1999-2019.

Catch	% Forest	Jan kL/m	Feb kL/m	Mar kL/m	Apr kL/m	May kL/m	Jun kL/m	Jul kL/m	Aug kL/m	Sep kL/m	Oct kL/m	Nov kL/m	Dec kL/m	Annual kL/y
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	23.8	290	323	318	281	334	371	359	319	230	158	212	275	3,471
4	38.7	923	1,027	1,011	892	1,060	1,179	1,142	1,015	730	503	674	874	11,030
5	83.2	1,872	2,083	2,049	1,809	2,150	2,391	2,316	2,058	1,480	1,020	1,366	1,773	22,367
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	5.8	870	968	952	841	999	1,111	1,077	956	688	474	635	824	10,396
8	5.8	231	257	253	223	265	295	286	254	183	126	168	219	2,758
9	71.6	2,044	2,275	2,238	1,976	2,347	2,612	2,529	2,247	1,617	1,113	1,492	1,936	24,426
10	24.1	3,217	3,580	3,522	3,110	3,694	4,110	3,981	3,536	2,544	1,752	2,347	3,046	38,440
11	74.9	4,129	4,594	4,520	3,991	4,741	5,274	5,109	4,539	3,265	2,249	3,013	3,910	49,332
12	47.7	2,287	2,545	2,504	2,211	2,627	2,922	2,830	2,514	1,809	1,246	1,669	2,166	27,330
13	64.6	2,608	2,903	2,856	2,521	2,995	3,332	3,227	2,867	2,063	1,421	1,903	2,470	31,167
14	48.9	3,408	3,793	3,731	3,294	3,914	4,354	4,217	3,747	2,695	1,856	2,487	3,227	40,723
15	52.5	10,369	11,539	11,351	10,023	11,907	13,247	12,830	11,399	8,200	5,647	7,566	9,819	123,897
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	82.3	8,185	9,109	8,961	7,912	9,399	10,457	10,128	8,998	6,473	4,458	5,973	7,751	97,802
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	46	9,980	11,106	10,926	9,647	11,461	12,750	12,349	10,971	7,893	5,436	7,283	9,451	119,254
23	25.5	4,593	5,111	5,028	4,440	5,274	5,868	5,683	5,049	3,632	2,502	3,352	4,350	54,881
24	13.2	805	931	866	806	966	1,064	1,053	942	718	477	601	778	10,006
25	13.9	584	675	628	585	701	771	764	683	521	346	436	564	7,258
26	14.6	1,087	1,257	1,170	1,089	1,305	1,436	1,422	1,272	969	644	812	1,050	13,512
27	19.1	2,593	2,998	2,789	2,597	3,112	3,426	3,391	3,034	2,311	1,535	1,936	2,504	32,227
28	14	741	857	797	742	889	979	969	867	661	439	553	716	9,210
29	33.1	1,013	1,171	1,090	1,015	1,216	1,338	1,325	1,185	903	600	756	978	12,590
30	24.3	11,168	12,428	12,227	10,796	12,825	14,268	13,819	12,277	8,832	6,083	8,149	10,576	133,449
31	14.4	16,969	18,884	18,577	16,403	19,486	21,679	20,997	18,654	13,420	9,242	12,383	16,070	202,765
32	7.5	1,095	1,266	1,178	1,097	1,314	1,447	1,432	1,281	976	648	817	1,057	13,609
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	66.6	1,304	1,451	1,427	1,260	1,497	1,665	1,613	1,433	1,031	710	951	1,235	15,577

35	14.1	1,974	2,283	2,124	1,978	2,370	2,608	2,582	2,310	1,760	1,169	1,474	1,907	24,538
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	17.5	619	776	678	663	781	870	882	803	555	383	506	645	8,162
38	5.6	530	590	581	513	609	678	656	583	419	289	387	502	6,338
39	48.1	1,869	2,080	2,046	1,807	2,147	2,388	2,313	2,055	1,478	1,018	1,364	1,770	22,336
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	24.7	1,305	1,509	1,404	1,307	1,567	1,724	1,707	1,527	1,164	773	974	1,261	16,223
43	6.5	1,615	1,798	1,768	1,561	1,855	2,064	1,999	1,776	1,277	880	1,179	1,530	19,301
44	43.7	1,244	1,559	1,362	1,333	1,568	1,747	1,773	1,612	1,115	770	1,017	1,296	16,396
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	18.1	606	701	652	607	727	801	793	709	540	359	452	585	7,532
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	6.1	582	730	637	624	734	818	830	755	522	360	476	607	7,674
Total	16.3	102,709	115,157	112,221	99,954	118,836	132,044	128,383	114,227	82,674	56,686	75,363	97,722	1,235,977

Table A.11: Estimated intercepted rainfall by forest. In (mm) and rainfall percentage Average year, period 1999-2019.

Catch	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	% Rainfall
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4.38	4.88	4.8	4.24	5.05	5.6	5.42	4.82	3.47	2.39	3.2	4.15	52.4	4.76
4	7.13	7.93	7.81	6.89	8.19	9.11	8.82	7.84	5.64	3.88	5.21	6.75	85.2	7.74
5	15.33	17.06	16.78	14.82	17.61	19.58	18.97	16.86	12.12	8.35	11.19	14.52	183.19	16.64
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	1.08	1.2	1.18	1.04	1.24	1.37	1.33	1.18	0.85	0.59	0.79	1.02	12.87	1.17
8	1.08	1.2	1.18	1.04	1.24	1.38	1.33	1.18	0.85	0.59	0.78	1.02	12.87	1.17
9	13.2	14.7	14.46	12.77	15.16	16.87	16.34	14.52	10.45	7.19	9.64	12.51	157.81	14.33
10	4.44	4.95	4.87	4.3	5.1	5.68	5.5	4.88	3.51	2.42	3.24	4.21	53.1	4.82
11	13.81	15.37	15.12	13.35	15.86	17.64	17.09	15.18	10.92	7.52	10.08	13.08	165.02	14.99
12	8.8	9.79	9.64	8.51	10.11	11.24	10.89	9.67	6.96	4.79	6.42	8.33	105.15	9.55
13	11.9	13.25	13.04	11.51	13.67	15.21	14.73	13.09	9.42	6.49	8.69	11.27	142.27	12.92
14	9.01	10.03	9.87	8.71	10.35	11.51	11.15	9.91	7.13	4.91	6.58	8.53	107.69	9.78
15	9.69	10.78	10.6	9.36	11.12	12.38	11.99	10.65	7.66	5.28	7.07	9.17	115.75	10.51
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	15.18	16.89	16.62	14.67	17.43	19.39	18.78	16.69	12	8.27	11.08	14.37	181.37	16.47
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	8.47	9.43	9.28	8.19	9.73	10.82	10.48	9.31	6.7	4.62	6.18	8.02	101.23	9.19
23	4.69	5.22	5.14	4.54	5.39	6	5.81	5.16	3.71	2.56	3.43	4.45	56.1	5.1
24	2.34	2.71	2.52	2.34	2.81	3.09	3.06	2.74	2.09	1.39	1.75	2.26	29.1	2.65
25	2.45	2.83	2.63	2.45	2.94	3.23	3.21	2.87	2.19	1.45	1.83	2.37	30.45	2.77
26	2.59	2.99	2.79	2.59	3.11	3.42	3.39	3.03	2.31	1.53	1.93	2.5	32.18	2.93
27	3.38	3.91	3.63	3.38	4.06	4.46	4.42	3.95	3.01	2	2.52	3.26	41.98	3.82
28	2.48	2.87	2.67	2.49	2.98	3.28	3.25	2.9	2.21	1.47	1.85	2.4	30.85	2.81
29	5.85	6.77	6.3	5.86	7.03	7.73	7.66	6.85	5.22	3.47	4.37	5.65	72.76	6.63
30	4.48	4.99	4.91	4.33	5.15	5.73	5.55	4.93	3.54	2.44	3.27	4.24	53.56	4.86
31	2.65	2.95	2.9	2.56	3.04	3.38	3.28	2.91	2.1	1.44	1.93	2.51	31.65	2.87
32	1.33	1.54	1.43	1.34	1.6	1.76	1.74	1.56	1.19	0.79	0.99	1.29	16.56	1.51
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	12.28	13.66	13.44	11.86	14.1	15.68	15.19	13.49	9.71	6.69	8.95	11.63	146.68	13.32

35	2.49	2.89	2.68	2.5	3	3.3	3.26	2.92	2.22	1.48	1.86	2.41	31.01	2.82
36	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	2.65	3.32	2.9	2.83	3.34	3.72	3.77	3.43	2.37	1.64	2.16	2.76	34.89	3.49
38	1.03	1.15	1.13	1	1.19	1.32	1.28	1.14	0.82	0.56	0.75	0.98	12.35	1.12
39	8.86	9.86	9.7	8.57	10.18	11.32	10.96	9.74	7.01	4.83	6.47	8.39	105.89	9.62
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	4.37	5.05	4.7	4.38	5.25	5.77	5.72	5.11	3.9	2.59	3.26	4.22	54.32	4.95
43	1.2	1.33	1.31	1.16	1.38	1.53	1.48	1.32	0.95	0.65	0.87	1.13	14.31	1.3
44	6.62	8.3	7.25	7.09	8.34	9.3	9.43	8.58	5.93	4.1	5.41	6.9	87.25	8.73
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	3.2	3.7	3.44	3.2	3.84	4.23	4.19	3.74	2.85	1.89	2.39	3.09	39.76	3.62
47	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0.93	1.16	1.02	0.99	1.17	1.3	1.32	1.2	0.83	0.57	0.76	0.97	12.22	1.22
Norfolk	2.97	3.33	3.24	2.89	3.44	3.82	3.71	3.3	2.39	1.64	2.18	2.83	35.74	
% Rainfall	3.38	3.3	3.38	3.28	3.31	3.32	3.28	3.27	3.27	3.28	3.3	3.33	3.31	

Table A.12: Estimated Potential Evapotranspiration (mm/month) per catchment. Average year, period 1999-2019.

Catch	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	123	102	104	86	74	63	64	72	81	101	112	116	1098
2	121	101	103	85	73	63	64	71	80	100	111	114	1086
3	120	100	101	84	73	62	63	71	79	99	109	113	1074
4	111	93	94	78	68	57	58	66	74	92	102	106	999
5	109	91	93	77	67	57	58	65	73	90	100	104	984
6	113	94	96	79	68	58	59	66	75	93	103	107	1011
7	120	100	102	84	73	62	63	71	80	99	109	113	1076
8	113	94	96	80	69	58	59	67	75	93	103	107	1014
9	111	93	94	78	68	58	59	66	74	92	102	106	1001
10	112	93	95	79	68	58	59	66	75	92	102	106	1005
11	109	91	92	77	66	56	57	64	73	90	99	103	977
12	110	91	93	77	67	57	58	65	73	90	100	104	985
13	112	94	95	79	69	58	59	67	75	93	103	107	1011
14	115	96	98	81	70	60	61	68	77	95	105	109	1035
15	115	96	97	81	70	59	60	68	76	95	105	109	1031
16	122	101	103	85	74	63	64	72	80	100	111	115	1090
17	117	97	99	82	71	60	61	69	78	96	107	111	1048
18	118	98	100	83	71	61	62	69	78	97	107	111	1055
19	110	92	93	77	67	57	58	65	73	91	100	104	987
20	124	103	105	87	75	64	65	73	82	102	113	117	1110
21	122	102	103	86	74	63	64	72	81	101	111	115	1094
22	116	97	98	82	71	60	61	69	77	96	106	110	1043
23	115	95	97	81	70	59	60	68	76	94	104	108	1027
24	121	100	102	85	73	62	63	71	80	100	110	114	1081
25	120	100	102	85	73	62	63	71	80	99	110	114	1079
26	118	99	100	83	72	61	62	70	79	98	108	112	1062
27	110	92	93	78	67	57	58	65	73	91	101	104	989
28	116	96	98	82	70	60	61	68	77	96	106	110	1040
29	117	97	99	82	71	60	61	69	77	96	106	110	1045
30	112	93	95	79	68	58	59	66	74	92	102	106	1004
31	113	94	96	79	68	58	59	67	75	93	103	107	1012
32	109	91	93	77	66	56	57	64	73	90	100	103	979
33	109	90	92	76	66	56	57	64	72	89	99	103	973
34	112	94	95	79	68	58	59	66	75	93	102	106	1007
35	115	95	97	81	69	59	60	68	76	94	105	108	1027

36	119	99	101	84	72	62	63	70	79	98	109	113	1069
37	117	97	99	82	71	60	61	69	77	96	107	110	1046
38	108	90	91	76	65	56	57	63	72	89	98	102	967
39	107	89	90	75	65	55	56	63	71	88	97	101	957
40	120	99	101	84	72	62	63	70	79	98	109	113	1070
41	115	96	97	81	70	59	60	68	76	95	105	109	1031
42	118	98	100	83	71	61	62	69	78	97	107	111	1055
43	110	91	93	77	67	57	58	65	73	91	100	104	986
44	98	82	83	69	59	51	51	58	65	81	89	93	879
45	121	100	102	85	73	62	63	71	80	99	110	114	1080
46	116	97	98	82	70	60	61	68	77	96	106	110	1041
47	119	99	101	84	72	61	62	70	79	98	109	113	1067
48	105	88	89	74	64	54	55	62	70	87	96	100	944

Total	114	94	96	80	69	59	60	67	75	94	104	107	1019

Table A.13: Estimated Potential Evapotranspiration (kL/month) per catchment. Average year, period 1999-2019.

Catch	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1	29,258	24,294	24,787	20,522	17,704	15,093	15,353	17,212	19,389	24,061	26,673	27,631	261,977
2	5,849	4,858	4,954	4,103	3,539	3,019	3,068	3,443	3,870	4,811	5,332	5,520	52,366
3	7,925	6,598	6,715	5,570	4,807	4,095	4,161	4,675	5,255	6,532	7,228	7,493	71,054
4	14,417	12,012	12,221	10,154	8,757	7,439	7,569	8,498	9,613	11,883	13,150	13,668	129,381
5	13,312	11,154	11,297	9,404	8,142	6,900	7,022	7,897	8,895	11,032	12,172	12,660	119,887
6	13,590	11,268	11,509	9,547	8,206	6,985	7,105	7,965	9,048	11,148	12,369	12,850	121,590
7	96,989	80,578	82,181	68,060	58,732	50,044	50,915	57,082	64,322	79,799	88,440	91,649	868,791
8	24,303	20,167	20,583	17,078	14,689	12,501	12,715	14,260	16,177	19,952	22,127	22,985	217,537
9	17,198	14,391	14,590	12,136	10,500	8,909	9,063	10,191	11,473	14,236	15,717	16,336	154,740
10	81,219	67,582	68,829	57,114	49,259	41,905	42,627	47,838	54,023	66,884	74,063	76,882	728,225
11	32,534	27,230	27,604	22,972	19,871	16,846	17,145	19,273	21,740	26,931	29,733	30,929	292,808
12	28,484	23,755	24,150	20,077	17,322	14,704	14,964	16,802	19,017	23,495	25,989	27,029	255,788
13	24,619	20,584	20,881	17,362	15,016	12,747	12,967	14,578	16,408	20,365	22,492	23,368	221,387
14	43,559	36,358	36,930	30,678	26,510	22,536	22,914	25,754	28,972	35,980	39,770	41,282	391,243
15	122,901	102,620	104,214	86,576	74,843	63,597	64,684	72,687	81,797	101,552	112,236	116,529	1,104,236
16	4,101	3,407	3,473	2,877	2,481	2,117	2,150	2,414	2,712	3,374	3,737	3,870	36,713
17	22,036	18,295	18,660	15,466	13,322	11,360	11,543	12,957	14,599	18,113	20,074	20,804	197,229
18	21,716	18,022	18,389	15,246	13,124	11,185	11,369	12,757	14,407	17,839	19,777	20,511	194,342
19	59,109	49,521	50,163	41,748	36,149	30,637	31,185	35,063	39,496	48,981	54,049	56,214	532,315
20	13,051	10,840	11,051	9,156	7,894	6,736	6,841	7,683	8,630	10,735	11,893	12,314	116,824
21	8,936	7,422	7,567	6,269	5,405	4,612	4,684	5,260	5,910	7,350	8,143	8,432	79,990
22	136,590	113,949	115,830	96,155	83,123	70,634	71,888	80,700	90,934	112,780	124,727	129,488	1,226,798

23	112,136	93,351	95,021	78,847	68,030	57,906	58,871	66,111	74,480	92,398	102,273	106,099	1,005,523
24	41,562	34,564	35,222	29,176	25,196	21,466	21,836	24,493	27,557	34,231	37,915	39,285	372,503
25	28,693	23,865	24,304	20,152	17,384	14,819	15,055	16,911	19,004	23,629	26,161	27,105	257,082
26	49,770	41,379	42,174	34,958	30,160	25,681	26,126	29,303	33,049	40,967	45,385	47,066	446,018
27	84,682	70,473	71,746	59,507	51,349	43,741	44,455	49,929	56,158	69,768	77,229	80,060	759,097
28	34,642	28,805	29,350	24,332	20,990	17,880	18,179	20,404	22,981	28,518	31,586	32,746	310,413
29	20,179	16,816	17,103	14,193	12,258	10,432	10,606	11,914	13,400	16,646	18,415	19,100	181,062
30	278,395	231,743	235,891	195,751	168,871	143,749	146,130	164,117	184,891	229,370	253,887	263,386	2,496,181
31	724,511	602,554	613,732	508,980	438,946	374,018	380,075	426,847	480,348	596,512	660,519	684,702	6,491,744
32	89,734	74,549	76,003	63,025	54,299	46,266	47,024	52,784	59,536	73,793	81,765	84,792	803,570
33	280,209	232,662	237,286	196,647	169,428	144,494	146,814	164,804	185,584	230,359	255,293	264,523	2,508,103
34	11,896	9,949	10,091	8,391	7,258	6,161	6,267	7,046	7,931	9,843	10,870	11,294	106,997
35	90,772	75,499	76,891	63,761	54,997	46,873	47,624	53,493	60,148	74,747	82,759	85,767	813,331
36	231,080	191,913	195,706	162,118	139,783	119,233	121,166	135,990	152,947	190,054	210,604	218,116	2,068,710
37	27,369	22,773	23,185	19,228	16,590	14,138	14,365	16,137	18,136	22,546	24,958	25,864	245,289
38	55,413	46,013	46,932	38,920	33,514	28,548	29,024	32,567	36,797	45,541	50,479	52,370	496,118
39	22,508	18,792	19,083	15,855	13,703	11,646	11,842	13,311	14,976	18,596	20,552	21,337	202,201
40	71,393	59,295	60,459	50,090	43,182	36,839	37,426	42,018	47,239	58,718	65,061	67,378	639,098
41	540,483	448,841	457,752	379,202	326,926	278,832	283,378	318,015	357,840	444,477	492,571	510,210	4,838,527
42	35,144	29,262	29,777	24,703	21,323	18,160	18,456	20,733	23,308	28,968	32,057	33,233	315,124
43	148,502	123,366	125,778	104,282	89,858	76,574	77,831	87,359	98,495	122,124	135,320	140,304	1,329,793
44	18,363	15,331	15,569	12,936	11,180	9,502	9,662	10,860	12,218	15,171	16,767	17,407	164,966
45	6,930	5,754	5,868	4,864	4,190	3,573	3,630	4,075	4,591	5,696	6,313	6,543	62,027
46	21,989	18,297	18,631	15,447	13,333	11,359	11,547	12,965	14,577	18,116	20,056	20,786	197,103

47	15,015	12,463	12,715	10,541	9,076	7,736	7,862	8,823	9,958	12,337	13,676	14,180	134,382
48	66,155	54,945	56,029	46,464	40,018	34,095	34,656	38,896	43,907	54,384	60,270	62,514	592,333

Total	3,929,220	3,268,161	3,328,873	2,760,639	2,381,235	2,028,317	2,061,839	2,314,895	2,606,741	3,235,343	3,582,634	3,714,610	35,212,507

Table A.14: Annual water balance components in mm. Average year, period 1999-2019.

Catch.	PP	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
1	1,101	1.5	0.0	1.3	2.8	0.0	1098	98	242	758	110	890
2	1,101	2.5	0.0	1.1	3.6	0.0	1086	98	242	757	110	889
3	1,101	0.0	0.0	0.0	0.0	52.4	1074	98	242	761	110	893
4	1,101	0.0	0.0	0.0	0.0	85.2	999	98	242	761	110	893
5	1,101	0.0	0.0	0.0	0.0	183.2	984	98	242	761	110	893
6	1,101	0.0	0.0	0.0	0.0	0.0	1011	98	242	761	110	893
7	1,101	2.2	0.0	1.1	3.3	12.9	1076	98	242	757	110	889
8	1,101	0.0	0.0	0.0	0.0	12.9	1014	98	242	761	110	893
9	1,101	0.8	0.0	0.3	1.1	157.8	1001	98	242	760	110	892
10	1,101	2.6	1.4	0.9	4.9	53.1	1005	98	242	756	110	888
11	1,101	0.0	0.0	0.0	0.0	165.0	977	98	242	761	110	893
12	1,101	0.0	0.0	0.0	0.0	105.2	985	98	242	761	110	893
13	1,101	0.5	0.0	0.2	0.8	142.3	1011	98	242	760	110	892
14	1,101	2.2	0.0	0.9	3.1	107.7	1035	98	242	758	110	890
15	1,101	0.4	0.1	0.1	0.7	115.8	1031	98	242	760	110	892
16	1,101	10.5	0.0	1.6	12.0	0.0	1090	98	242	749	110	881
17	1,101	3.1	0.0	1.4	4.5	0.0	1048	98	242	756	110	888
18	1,101	2.6	0.0	1.4	3.9	0.0	1055	98	242	757	110	889
19	1,101	0.2	0.0	0.2	0.4	181.4	987	98	242	760	110	892
20	1,098	0.0	0.0	5.9	5.9	0.0	1110	98	242	753	110	884
21	1,098	1.6	0.0	0.4	2.0	0.0	1094	98	242	757	110	888
22	1,101	0.5	0.0	1.1	1.7	101.2	1043	98	242	759	110	891
23	1,101	1.8	0.7	1.2	3.7	56.1	1027	98	242	757	110	889
24	1,098	6.8	3.0	1.3	11.1	29.1	1081	98	242	747	110	879
25	1,098	5.0	0.0	1.4	6.4	30.5	1079	98	242	752	110	884
26	1,098	6.2	0.0	1.3	7.4	32.2	1062	98	242	751	110	883
27	1,098	5.3	0.5	1.3	7.1	42.0	989	98	242	751	110	883
28	1,098	8.7	0.0	1.3	10.0	30.9	1040	98	242	749	110	880
29	1,098	5.4	0.0	1.0	6.4	72.8	1045	98	242	752	110	884
30	1,101	3.3	1.6	0.9	5.8	53.6	1004	59	242	794	110	926
31	1,101	3.8	3.9	0.9	8.6	31.7	1012	69	242	781	110	913
32	1,098	9.4	1.7	1.2	12.3	16.6	979	98	242	746	110	878
33	1,098	6.0	0.6	1.3	7.9	0.0	973	60	242	788	110	920
34	1,101	0.0	0.0	0.0	0.0	146.7	1007	98	242	761	110	893
35	1,098	4.3	0.0	2.8	7.1	31.0	1027	98	242	751	110	883
36	1,101	2.4	0.1	1.2	3.7	0.0	1069	73	242	782	110	915
37	999	4.5	0.0	1.3	5.8	34.9	1046	89	220	684	100	804
38	1,101	8.2	3.5	1.2	12.9	12.4	967	98	242	748	110	880

39	1,101	5.6	0.0	0.8	6.4	105.9	957	98	242	754	110	886
40	999	1.4	0.0	1.3	2.7	0.0	1070	89	220	687	100	807
41	999	3.4	3.8	1.3	8.5	0.0	1031	152	220	619	100	739
42	1,098	5.5	0.0	1.3	6.8	54.3	1055	98	242	752	110	883
43	1,101	4.4	0.7	1.2	6.3	14.3	986	98	242	754	110	886
44	999	8.8	9.2	1.4	19.3	87.3	879	140	220	620	100	740
45	1,101	10.2	0.0	0.9	11.2	0.0	1080	98	242	749	110	882
46	1,098	9.3	1.3	1.3	11.9	39.8	1041	98	242	747	110	878
47	1,101	4.7	0.0	0.7	5.4	0.0	1067	98	242	755	110	887
48	999	7.1	1.9	1.3	10.3	12.2	944	89	220	680	100	800

Table A.15: Annual water balance components in % rainfall. Average year, period 1999-2019.

Catch.	Household	Tourism	Cattle	WU	Interception	PET	SR	GR1	ET1	GR2	ET2
1	0.13	0.00	0.12	0.25	0.0	99.7	8.9	22.0	68.8	10.0	80.8
2	0.22	0.00	0.10	0.32	0.0	98.6	8.9	22.0	68.8	10.0	80.7
3	0.00	0.00	0.00	0.00	4.8	97.5	8.9	22.0	69.1	10.0	81.1
4	0.00	0.00	0.00	0.00	7.7	90.7	8.9	22.0	69.1	10.0	81.1
5	0.00	0.00	0.00	0.00	16.6	89.4	8.9	22.0	69.1	10.0	81.1
6	0.00	0.00	0.00	0.00	0.0	91.8	8.9	22.0	69.1	10.0	81.1
7	0.20	0.00	0.10	0.30	1.2	97.7	8.9	22.0	68.8	10.0	80.7
8	0.00	0.00	0.00	0.00	1.2	92.1	8.9	22.0	69.1	10.0	81.1
9	0.07	0.00	0.03	0.10	14.3	90.9	8.9	22.0	69.0	10.0	81.0
10	0.23	0.13	0.08	0.45	4.8	91.3	8.9	22.0	68.6	10.0	80.7
11	0.00	0.00	0.00	0.00	15.0	88.7	8.9	22.0	69.1	10.0	81.1
12	0.00	0.00	0.00	0.00	9.6	89.5	8.9	22.0	69.1	10.0	81.1
13	0.05	0.00	0.02	0.07	12.9	91.8	8.9	22.0	69.0	10.0	81.0
14	0.20	0.00	0.08	0.28	9.8	94.0	8.9	22.0	68.8	10.0	80.8
15	0.04	0.01	0.01	0.06	10.5	93.6	8.9	22.0	69.0	10.0	81.0
16	0.95	0.00	0.14	1.09	0.0	99.0	8.9	22.0	68.0	10.0	80.0
17	0.28	0.00	0.12	0.41	0.0	95.2	8.9	22.0	68.7	10.0	80.7
18	0.23	0.00	0.13	0.36	0.0	95.8	8.9	22.0	68.7	10.0	80.7
19	0.02	0.00	0.02	0.04	16.5	89.6	8.9	22.0	69.0	10.0	81.0
20	0.00	0.00	0.53	0.53	0.0	101.1	8.9	22.0	68.5	10.0	80.5
21	0.15	0.00	0.03	0.18	0.0	99.6	8.9	22.0	68.9	10.0	80.9
22	0.05	0.00	0.10	0.15	9.2	94.7	8.9	22.0	68.9	10.0	80.9
23	0.16	0.06	0.11	0.33	5.1	93.3	8.9	22.0	68.7	10.0	80.7
24	0.62	0.27	0.12	1.01	2.7	98.5	8.9	22.0	68.1	10.0	80.1
25	0.45	0.00	0.13	0.58	2.8	98.3	8.9	22.0	68.5	10.0	80.5
26	0.56	0.00	0.12	0.68	2.9	96.7	8.9	22.0	68.4	10.0	80.4
27	0.49	0.05	0.12	0.65	3.8	90.1	8.9	22.0	68.4	10.0	80.4
28	0.79	0.00	0.12	0.91	2.8	94.7	8.9	22.0	68.2	10.0	80.1
29	0.49	0.00	0.09	0.58	6.6	95.2	8.9	22.0	68.5	10.0	80.5
30	0.30	0.15	0.09	0.53	4.9	91.2	5.4	22.0	72.1	10.0	84.1
31	0.34	0.36	0.08	0.78	2.9	91.9	6.3	22.0	70.9	10.0	82.9
32	0.86	0.15	0.11	1.12	1.5	89.2	8.9	22.0	68.0	10.0	80.0
33	0.55	0.05	0.12	0.72	0.0	88.6	5.5	22.0	71.8	10.0	83.8
34	0.00	0.00	0.00	0.00	13.3	91.5	8.9	22.0	69.1	10.0	81.1
35	0.39	0.00	0.26	0.65	2.8	93.5	8.9	22.0	68.4	10.0	80.4
36	0.22	0.01	0.11	0.34	0.0	97.1	6.6	22.0	71.1	10.0	83.1
37	0.45	0.00	0.13	0.58	3.5	104.7	8.9	22.0	68.5	10.0	80.5
38	0.75	0.31	0.10	1.17	1.1	87.8	8.9	22.0	67.9	10.0	79.9

39	0.51	0.00	0.07	0.58	9.6	86.9	8.9	22.0	68.5	10.0	80.5
40	0.14	0.00	0.13	0.27	0.0	107.1	8.9	22.0	68.8	10.0	80.8
41	0.34	0.38	0.13	0.85	0.0	103.2	15.2	22.0	62.0	10.0	74.0
42	0.50	0.00	0.12	0.62	4.9	96.1	8.9	22.0	68.5	10.0	80.4
43	0.40	0.07	0.11	0.58	1.3	89.6	8.9	22.0	68.5	10.0	80.5
44	0.88	0.92	0.14	1.93	8.7	88.0	14.0	22.0	62.1	10.0	74.1
45	0.93	0.00	0.08	1.01	0.0	98.1	8.9	22.0	68.1	10.0	80.1
46	0.85	0.11	0.12	1.08	3.6	94.8	8.9	22.0	68.0	10.0	80.0
47	0.43	0.00	0.06	0.49	0.0	96.9	8.9	22.0	68.6	10.0	80.6
48	0.71	0.19	0.13	1.03	1.2	94.5	8.9	22.0	68.0	10.0	80.1

Appendix 3

Regulatory Frameworks from Chapter 3

APPENDIX 3 - REGULATORY FRAMEWORKS

FEDERAL LEGISLATION IN NORFOLK ISLAND

The Norfolk Island act 1979 (CTH)

The Norfolk Island Act 1979 (Cth) states that unless otherwise specified Federal legislation extends to Norfolk Island, and the Federal Minister has the power to make Ordinances and Instruments for Norfolk Island. This Act and sub-ordinate regulations underwent significant changes in 2015 that came into effect through the Norfolk Island Legislation Amendment Act 2015 (Cth). From 2016, Commonwealth taxation, social security, immigration, biosecurity, customs and health arrangements, including Medicare and the Pharmaceutical Benefits Scheme, were extended to Norfolk Island.

The Environment Protection and Biodiversity Conservation Act 1999 (Cth)

The Environment Protection and Biodiversity Conservation Act 1999 (Cth) has been enforced in Norfolk Island since 1999. This Act is a key piece of federal environmental legislation as it provides a legal framework to protect and manage nationally and internationally significant flora, fauna, ecological communities and heritage places (these are defined in the EPBC Act as matters of national environmental significance (MNES). MNES on Norfolk Island include world heritage properties, nationally threatened species and ecological communities, migratory species, and Commonwealth marine areas. Under this Act, any action that has the potential to significantly impact a MNES must be assessed for referral to the Australian Government Department of Environment and Energy.

The national environmental protection act 1994

The National Environmental Protection Act 1994 dictates that that the development and implementation of environmental policy and programs by all levels of Government should protect the environment and maintain ecological processes whilst also allowing for sustainable development that improves quality of life for both Australian and international communities. Sound environmental practices, inter-generational conservation of biological diversity and ecological integrity, and improved valuation, pricing and incentive mechanisms (i.e., the polluter pays principle) are fundamental considerations. All states and Territory jurisdictions have been bound to uphold this Act.

Product stewardship act 2011

The Product Stewardship Act 2011 provides the framework to effectively manage the environmental, health and safety impacts of products, and in particular those impacts associated with the disposal of products and their associated waste. Through voluntary, co-regulatory and mandatory Extended Producer Responsibility (EPR) schemes, this Act aims to involve industry in taking greater responsibility for the environmental impacts of the entire lifecycle of their products from manufacturing to ultimate disposal. An annual product list of problematic wastes for attention is provided by all jurisdictions. The Act also supports the National Television and Computer Recycling Scheme (NTCRS) through the *Product Stewardship (Televisions and Computers) Regulations 2011*. In 2018 the first review of the Act since its implementation was carried out resulting in 26 recommendations for action aimed at further improving Australia's management of end-of-life products and transition to a circular economy. This Act has now been absorbed into the Recycling and Waste Reduction Act 2020.

Product stewardship (televisions & computers) regulations 2011

The Product Stewardship (Televisions & Computers) Regulations 2011 were introduced for the management of specified electronic wastes in Australia. This legislation places requirements on the manufacturers of televisions (TVs) and computers to provide for the end-of-life recycling of these products, including computer peripherals. Councils are encouraged to enter into partnerships with the computer and TV industry under an Approved Co-Regulatory Arrangement to provide collection points for these materials. Administration has set specific industry targets for the sector to reach with the first annual recycling target of 30% in 2012–13 rising incrementally to 80% in 2021–22. A review of these regulations was carried out as part of the 2018 review of the Product Stewardship Act 2011. In this review many submissions called for the current National Television and Computer Recycling Scheme (NTCRS) scheme to be expanded to cover an increased scope of electronic and electrical products and for schemes to be developed for other products such as batteries. These regulations have significant financial implications for Norfolk Island as the costs of the freight for recycling is born by the manufacturer.

2018 national waste policy: less waste, more resources

The 2018 National Waste Policy: Less Waste, More Resources provides a national framework for waste and resource recovery in Australia until 2030. It outlines roles and responsibilities for collective action by businesses, governments, communities and individuals. The policy identifies five overarching principles underpinning waste management in a circular economy. These include:

- Avoid waste
- Improve resource recovery
- Increase use of recycled material and build demand and markets for recycled products
- Better manage material flows to benefit human health, the environment and the economy
- Improve information to support innovation, guide investment and enable informed consumer decisions.

This policy recognises the current global shift towards circular economy approaches with Australia's trade partners, businesses and government recognising the opportunities waste materials provide and the economic value they retain. This policy acknowledges that applying circular economy principles to waste management in Australia requires changes to product design, production, use and reuse, recycling and disposal. It is a whole-of-system approach that requires accounting of the full cost and life cycle of materials. It is also an approach that will help to minimise reliance on virgin materials and maximise the economic value of resources.

Recycling and waste reduction act 2020

The Recycling and Waste Reduction Act 2020 provides a framework to regulate the export of certain types of waste materials (including glass, plastic, tyres, paper/cardboard, and hazardous waste) from Australia to prevent it from having a negative impact on human health and/or the environment in the receiving country. Under the Act, bans will be implemented on the export of unprocessed plastic, paper, glass, and tyre waste, and a license will be required to export certain types of processed waste. Gradual changes to regulations and processes are planned to come into effect for different waste streams between January 2021 and July 2024. This legislation also incorporates the existing Product Stewardship Act 2011 with improvements to encourage companies to take greater responsibility for the waste they generate, including through better product design and increased recovery and reuse of waste materials.

NEW SOUTH WALES LEGISLATION IN NORFOLK ISLAND

Local government act 1993 (nsw) (ni)

The Local Government Act 1993 (NSW) (NI) primarily deals with the governance of councils in New South Wales and Norfolk Island. One of the aims of this Act is the avoidance of unnecessary State Government intervention in local affairs, whilst ensuring that councils, their elected bodies and their staff, remain properly accountable to the public. For Norfolk Island, this Act provides the framework for strategic planning and integrated planning and reporting by councils. The Act also provides specific requirements for State of the Environment reporting for Norfolk Island. The Norfolk Island Regional Council operates under this Act.

Norfolk Island Applied Laws Ordinance 2016 (Cth)

It was planned that NSW laws and regulations be applied to Norfolk Island as subordinate Commonwealth Legislation using the Norfolk Island Applied Laws Ordinance 2016 (Cth). The Ordinance also allows the Federal Minister to repeal or make changes to any New South Wales legislation before or after it is applied to Norfolk Island. While some State legislation has already been applied to Norfolk Island, the operation of most NSW laws was suspended until 2021. However, the Queensland State Government is now in discussion with the Federal Government with regard to taking over Norfolk Island's service contract from NSW (which expires in June 2021).

NORFOLK ISLAND LEGISLATION

There are several Norfolk Island specific Acts and Regulations with significant environmental relevance including: Bores and Wells Act 1996, Environment Act 1990, Noxious Weeds Act 1916, Norfolk Island Heritage Act 2002, Norfolk Island Plan 2002, Planning Act 2002, Public Reserves Act 1997, Subdivision Act 2002, Trees Act 1997, Waste Management Act 2003, Public Health Act 1996, Stock Diseases Act 1936, Migratory Birds Act 1980, Animals (Importation) Act 1983 and the Electricity Supply Act 1985.

Norfolk Island Regional Council has also developed an Environment Strategy (2018-2023) which provides information and guidelines to ensure a sustainable environment for future generations. This Plan complements the strategic plans under the Integrated Planning and Reporting Framework for Norfolk Island, to meet the operational target to develop an Environment Strategy, and to provide a monitoring and reporting framework for State of the Environment Reporting required under the NSW Local Government Act 1993 (NSW) (NI).

Environment act 1990

The Environment Act 1990 makes provision for the protection of the environment and vegetation and provides rules for environmental sanitation and physical planning and development. This Act promotes the conservation of the natural environment and landscape beauty of Norfolk Island and ensures, so far as is practicable, that physical works and other activities result in no detriment to the natural environment. In regard to environmental health, this Act makes provision for, among other things: sewerage and sewage deposit; drainage; protection of freshwater resources; garbage collection and disposal; prevention of nuisance; the keeping of animals; and acquisition of easements for sewerage.

Planning act 2002 (NI) and planning regulations 2004 (NI)

Land use and development in Norfolk Island is managed under the Norfolk Island Plan 2002 which is prepared and implemented under the Planning Act 2002 (NI).

The Act promotes the conservation of the natural environment, landscape beauty and cultural heritage of Norfolk Island. The Act requires a Norfolk Island plan (Norfolk Island Plan 2002) to be adopted by the Legislative Assembly. This Plan promotes the objects of this Act by indicating planning objectives and development and environmental standards for Norfolk Island generally and for designated land use zones. The executive member may prepare a draft development control plan. The Act sets out the development approval process. Under this Act all Development Applications submitted are received and assessed by the Norfolk Island Regional Council before being either approved, refused, or referred back to the Norfolk Island Regional Council General Manager with directions for specific actions.

Waste Management Act 2003

The Waste Management Act 2003 makes provision for the Norfolk Island Regional Council and management of waste collection and disposal operations in Norfolk Island and defines offences for purposes of pollution control. It also concerns the removal and disposal of asbestos. The executive member may publish Guidelines for the operation, use and management of the Waste Management Centre and other places used to dispose of waste or waste management facilities designated by the executive member. A person must not deposit waste at a Centre except in accordance with the Guidelines. The Act grants regulation-making powers to the Administrator.

Waste management regulations 2004

The Waste Management Regulations 2004 implement provisions of the Waste Management Act 2003 by: imposing a levy on imported good and imposing a levy on each container of equine or bovine animals imported into Norfolk Island whether by sea or by air; by establishing the amount of prescribed waste disposal fee under section 10 for disposal of asbestos, asbestos product and material containing asbestos at the Waste Management Centre; and by prescribing the form and consistency of receptacles used for disposal of asbestos.

Norfolk Island environment strategy 2018-2023

The overarching goals for waste management under the Norfolk Island Regional Council Delivery Program (2016-2020) were:

- Cease ocean disposal of waste by 2018
- Investigate advanced waste technologies for the future
- Provide ongoing and consistent educative recycling information to the community on a minimum of a quarterly basis
- Develop a Waste Management Implementation Action Plan to:
    - ⇒ Track and report progress in implementation of the Waste Management Strategic Plan 2015 at least annually
    - ⇒ Conduct a baseline waste audit to characterise and quantify current waste streams/volumes and determine per capita production, recycling, avoidance, disposal rates/methods, etc.

⇒ Measure and record all waste streams coming through the WMC

⇒ Estimate and record types and volumes of other waste streams not coming through the WMC

⇒ Record types and volumes of all waste exported

⇒ Monitor and record user trips to the WMC (count vehicles using the traffic counter at WMC)

⇒ Record waste management fees collected (count and record number and value of tickets collected at the ticket office daily)

⇒ Develop a complaints system for reporting of illegal dumping, nuisance complaints of backyard burning and other waste related complaints

The 2018 targets for waste management enhancement set out in the adopted Norfolk Island Delivery Program 2016-2020 have not been met, mainly due to shipping delays. Other challenges include the remoteness of Norfolk Island from potential recyclable markets and final disposal facilities, and funding constraints.

GUIDING PRINCIPLES

Ecologically sustainable development (ESD)

The principles of Ecologically Sustainable Development (ESD) have been extremely useful in the design and implementation of waste management strategies and provide useful guidance on the management of waste facilities.

The principles of ESD are:

- The precautionary principle
- Intergenerational equity
- Conservation of biological diversity and ecological integrity
- Polluter pays principle

These four principles aim to govern waste management by ensuring that:

- Waste does not cause negative or unintended consequences to the wider environment
- Waste does not affect biodiversity and ecological integrity
- Waste is the burden of the current generation and not shifted onto the future
- The full cost of the treatment and management is the responsibility of the generator

The waste hierarchy

The Waste Hierarchy is an internationally accepted guide for prioritising waste management practices that ranks methods for waste management from most-to-least-preferred using the six categories depicted below.

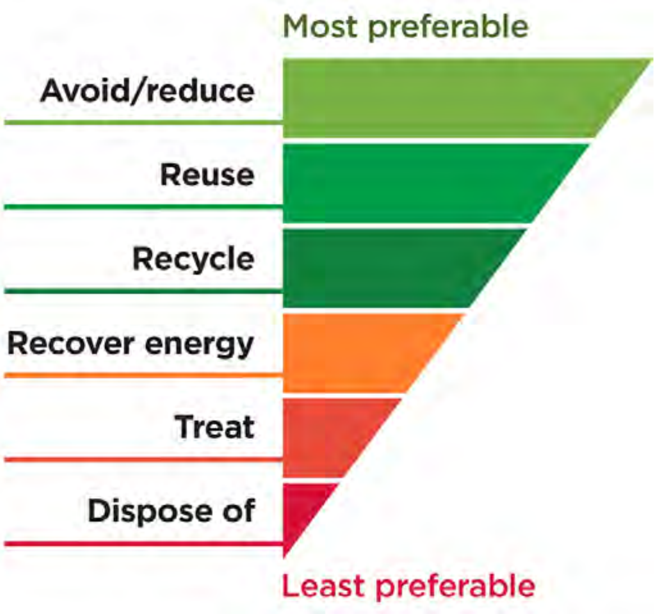


Figure 1: *The Waste Hierarchy - Source: https://www.planning.nsw.gov.au/Assess-and-Regulate/State-Significant-Projects/Energy-from-waste*

The three priorities of the Waste Hierarchy are:

- Avoidance including action to reduce the amount of waste generated by households, industry and all levels of government,
- Resource recovery including re-use, recycling, reprocessing and energy recovery, consistent with the most efficient use of the recovered resources, and
- Disposal including management of all disposal options in the most environmentally responsible manner.

While the Waste Hierarchy is very useful it is important to note that it is conceptually linear and only really considers waste at disposal which is the final stage of its lifecycle.

Appendix 4

GHG calculations from Chapter 4

Appendix 4: Calculation of GHG Emissions

GHG Emissions are estimated as follows:

$$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1\ 000}$$

(Department of Environment and Energy, 2017)

Where:

E_{ij} is emissions of gas type (j) released from the combustion of fuel type (i) from the operation of the facility

Q_i is the quantity of the fuel type (i) combusted from the operation of the facility during the year measured in kL

EC_i is the energy content factor of fuel type (i)

For Diesel Oil used for stationary energy purposes:

EC_i = 38.6 GJ/kL

EF_{oxij} is the emission factor for each gas type (j) released from the operation of the facility during the year (which includes the effect of a default oxidation factor) measured in kilograms CO2- e per gigajoule of the fueltype (i).

For fueltype (i) = Diesel for stationary energy purposes:

Where gas type j = CO_2, EF_{oxij} = 69.9 **kg CO_2-e/GJ**
Where gas type j = CH_4, EF_{oxij} = 0.1 **kg CO_2-e/GJ**
Where gas type j = N_2O, EF_{oxij} = 0.2 **kg CO_2-e/GJ**

(Department of Environment and Energy, 2017).

In 2017, 1,496,118 L of Diesel fuel was consumed for Diesel Power Generation at the Powerhouse on Norfolk Island (Hydro Tasmania, 2018a).

Therefore, with Q_i = 1,4196.118 kL

GHG Emissions of CO_2 = (1,4196.118 x 38.6 x 69.9)/1 000
= 38,303 t CO2-e

GHG Emissions of CH_4 = (1,4196.118 x 38.6 x 0.1)/1 000
= 55 t CO2-e

GHG Emissions of N_2O = (1,4196.118 x 38.6 x 0.2)/1 000

= 110 t CO2-e

Total GHG Emissions s (CO_2, CH_4 and N_2O) in tonnes of CO2-e from Diesel fuel consumption in 2017

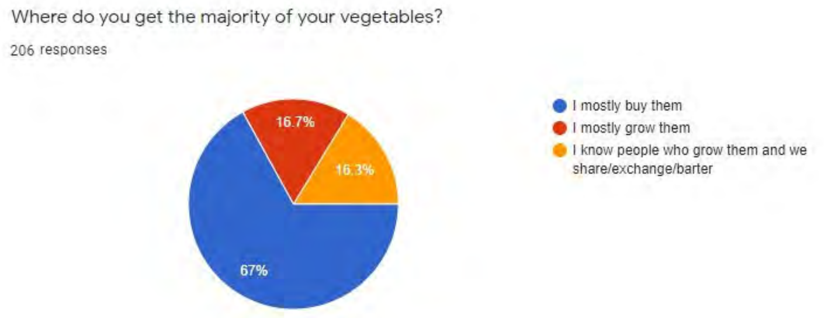
= 38,303 + 55 + 110

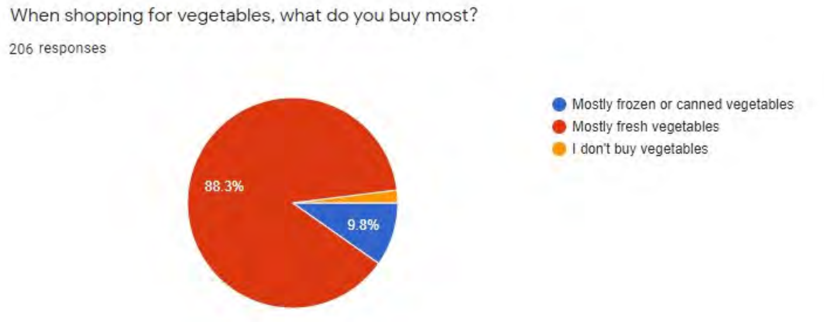
= 38,468 t CO2-e

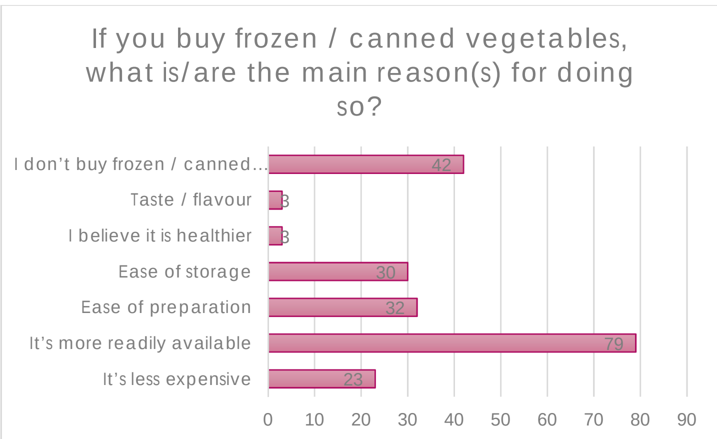
Appendix 5

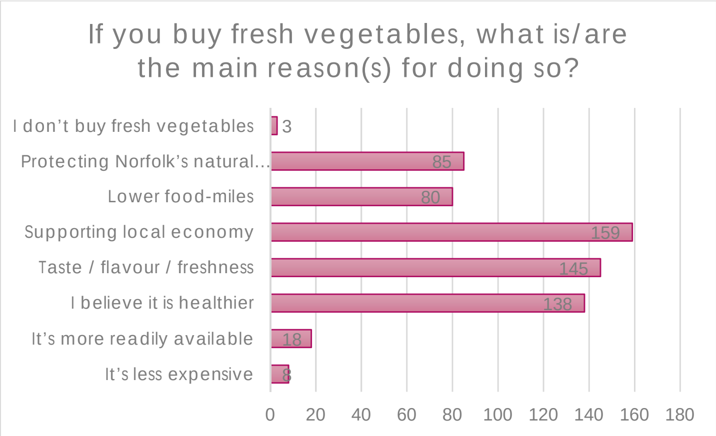
Food surveys from Chapter 5

Appendix 5A: Online Survey Results – Consumers



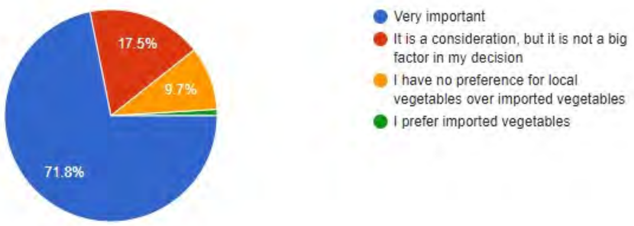


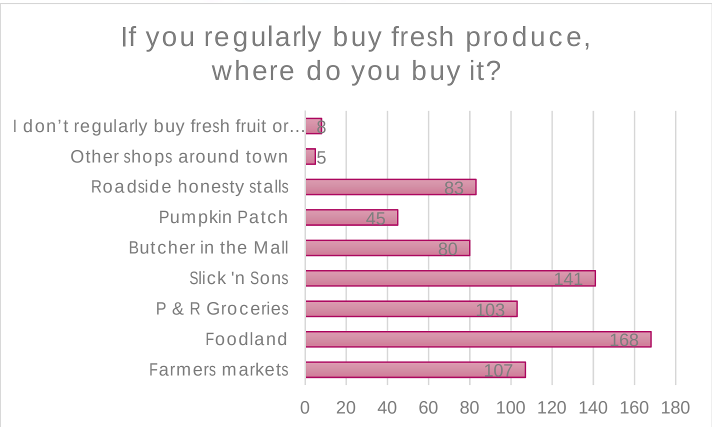


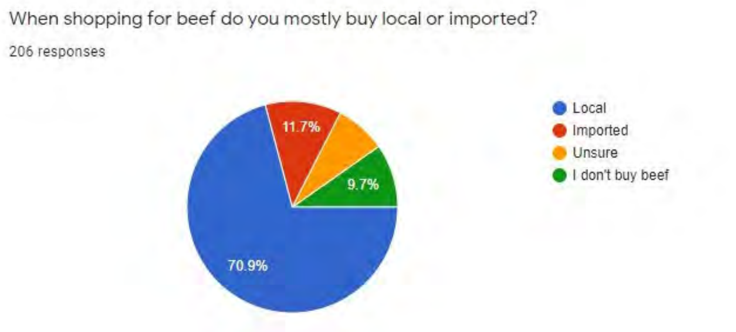


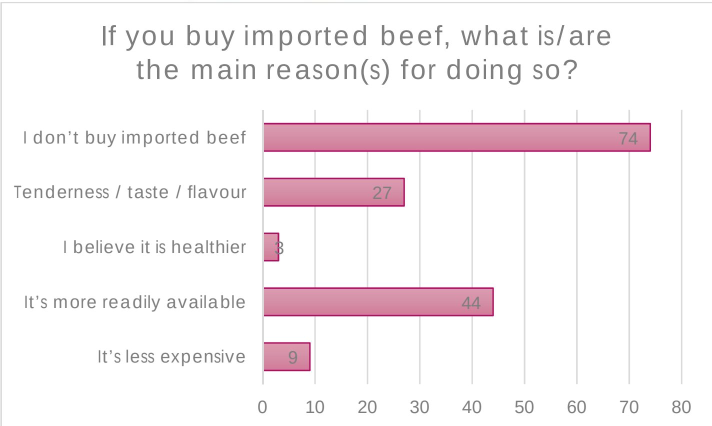
When choosing vegetables, how important to you is it that it is locally grown?

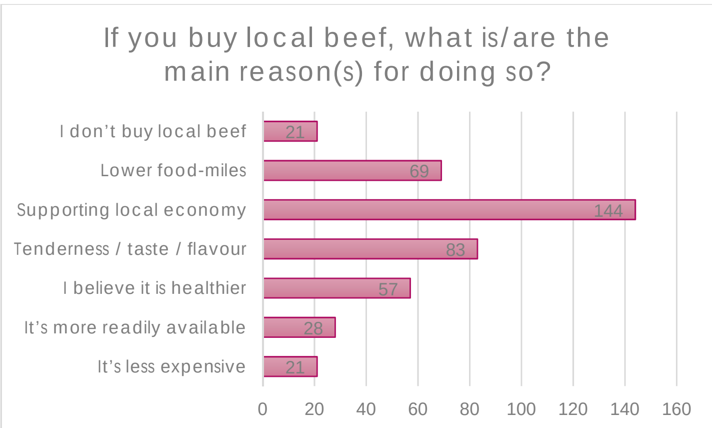
206 responses





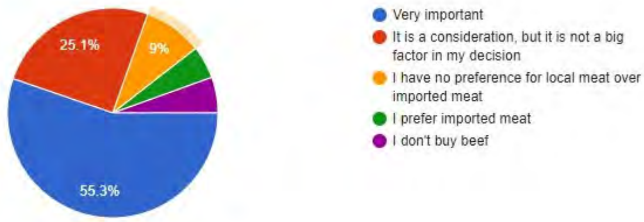

When shopping for beef do you mostly buy local or imported?
206 responses
Local
Imported
Unsure
I don't buy beef
11.7%
9.7%
70.9%


If you buy imported beef, what is/are the main reason(s) for doing so?
I don't buy imported beef
Tenderness / taste / flavour
I believe it is healthier
It's more readily available
It's less expensive
74
27
3
44
9
0
10
20
30
40
50
60
70
80


If you buy local beef, what is/are the main reason(s) for doing so?
I don't buy local beef
Lower food-miles
Supporting local economy
Tenderness / taste / flavour
I believe it is healthier
It's more readily available
It's less expensive
21
69
144
83
57
28
21
0
20
40
60
80
100
120
140
160

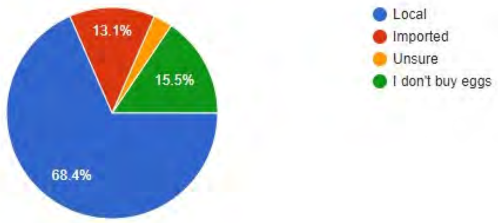
When choosing beef, how important to you is it that it is locally produced?

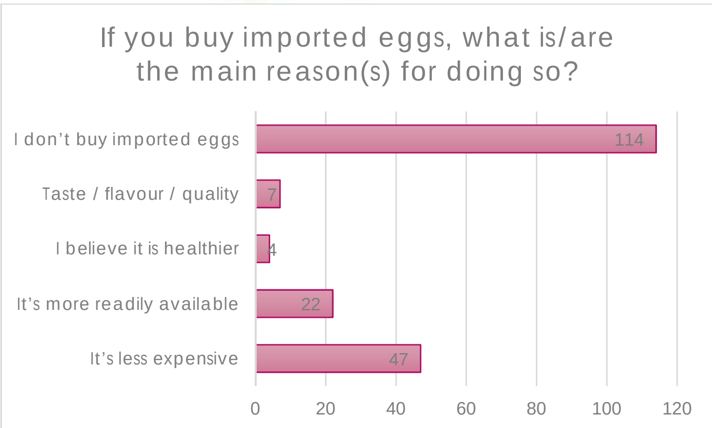
206 responses

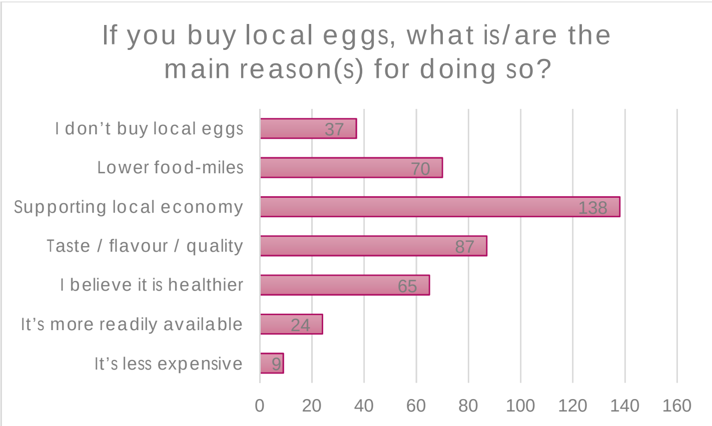


When shopping for eggs, do you mostly buy local or imported?

206 responses

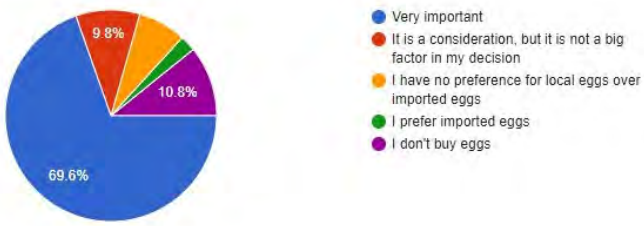






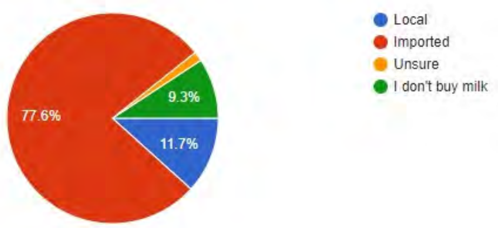
When choosing eggs, how important to you is it that it is locally produced?

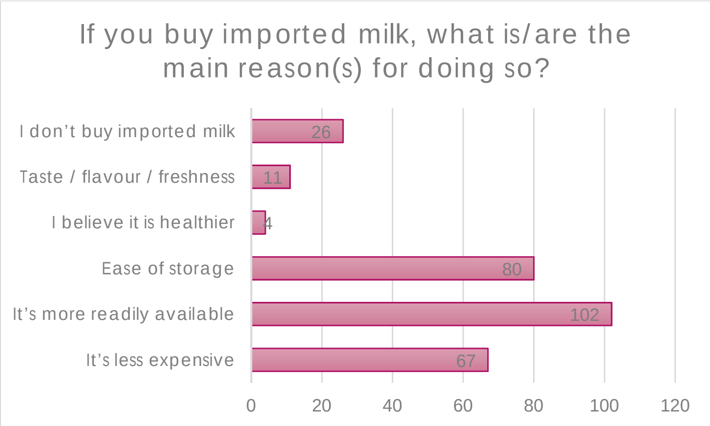
206 responses

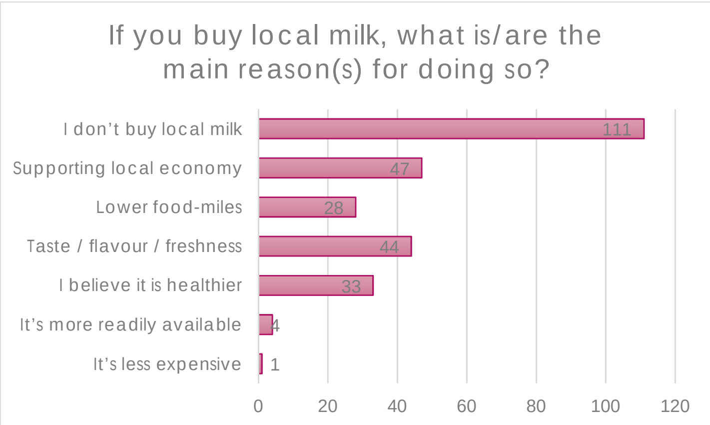


When shopping for milk, do you mostly buy local or imported?

206 responses

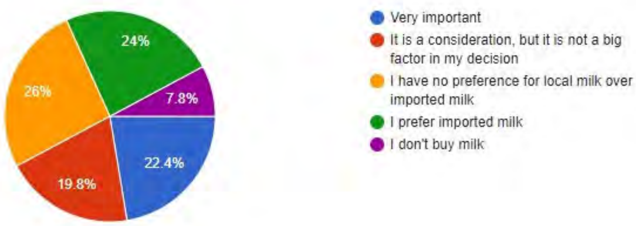






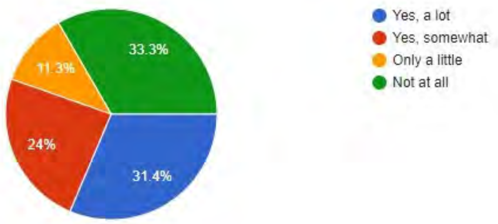
In choosing which milk to buy, how important to you is it that it is locally produced?

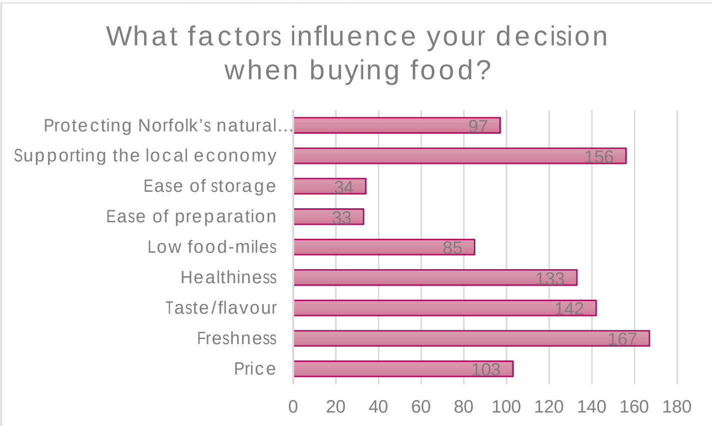
206 responses



When deciding where to dine out, does the source of the food (local vs imported) influence your decision much?

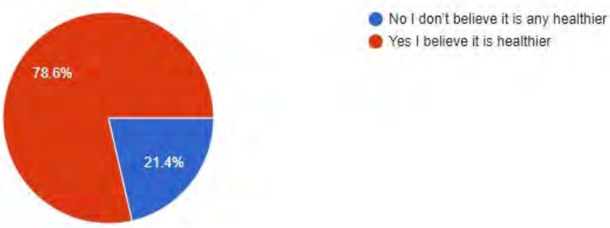
206 responses

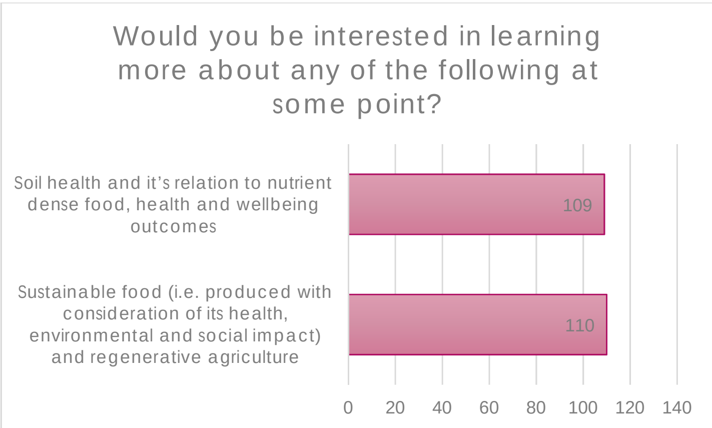




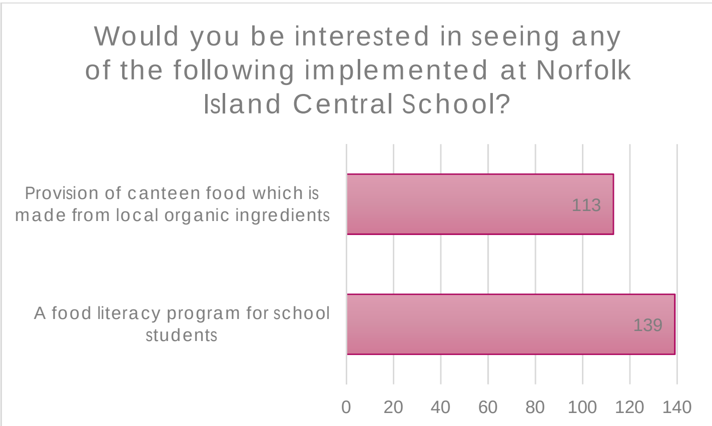
Do you believe eating local produce is healthier than imported food?

206 responses



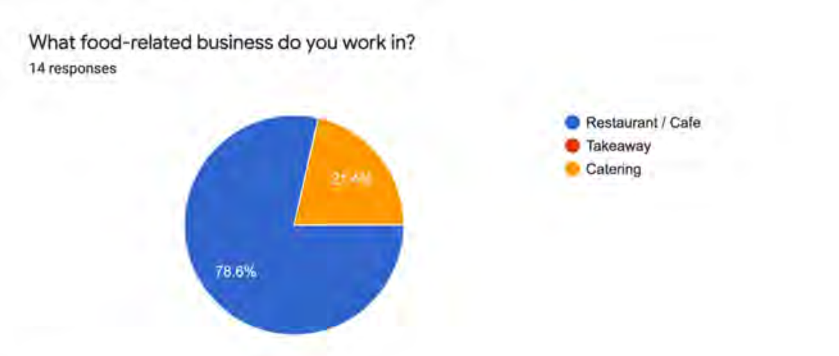


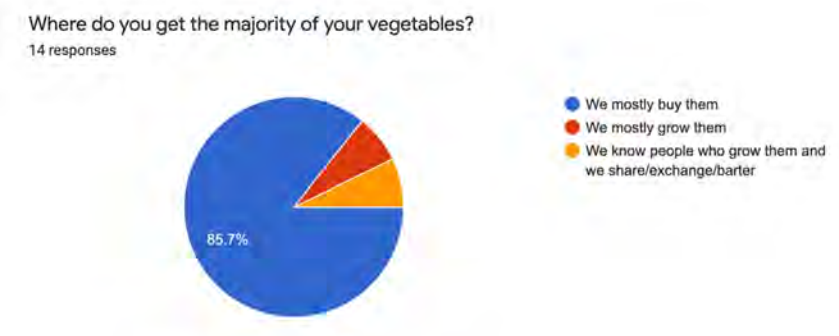
Would you be interested in learning more about any of the following at some point?
Soil health and it's relation to nutrient dense food, health and wellbeing outcomes
109
Sustainable food (i.e. produced with consideration of its health, environmental and social impact) and regenerative agriculture
110
0
20
40
60
80
100
120
140

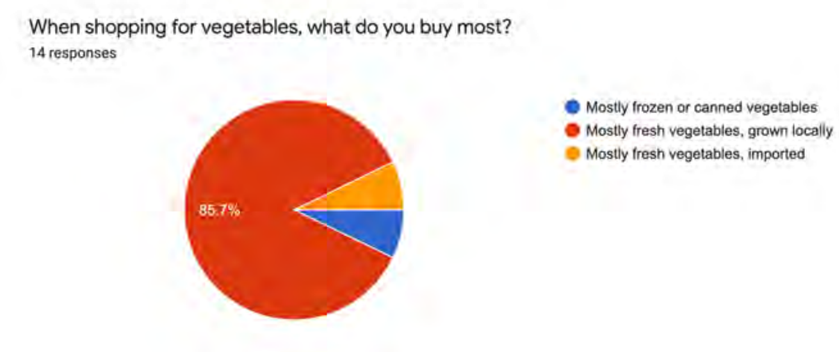


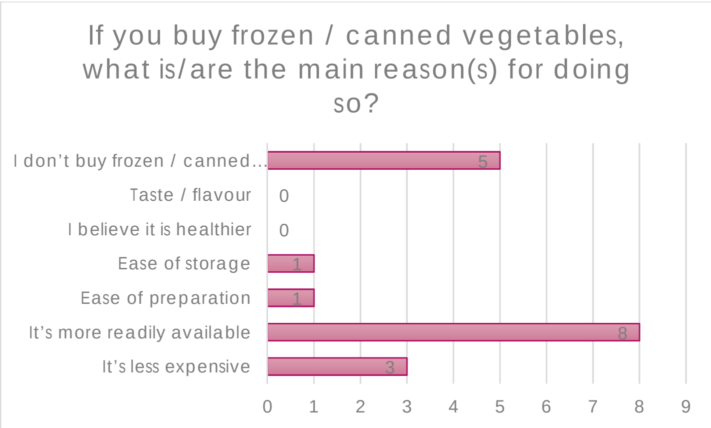
Would you be interested in seeing any of the following implemented at Norfolk Island Central School?
Provision of canteen food which is made from local organic ingredients
113
A food literacy program for school students
139
0
20
40
60
80
100
120
140

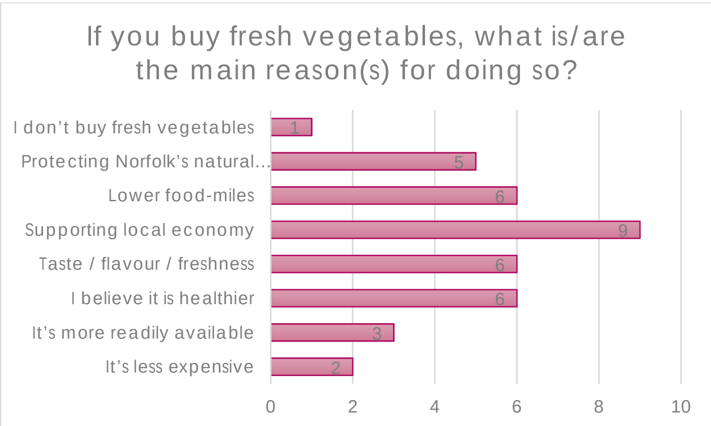
Appendix 5B: Online Survey Results: Commercial Operators

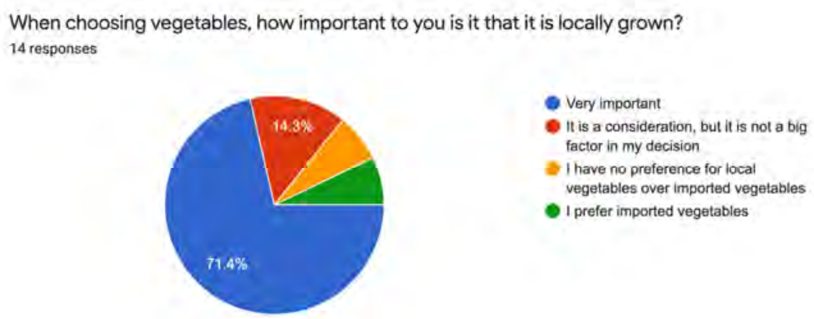


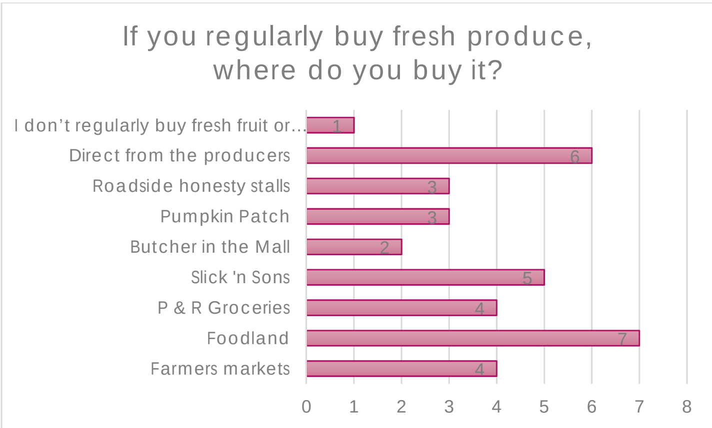


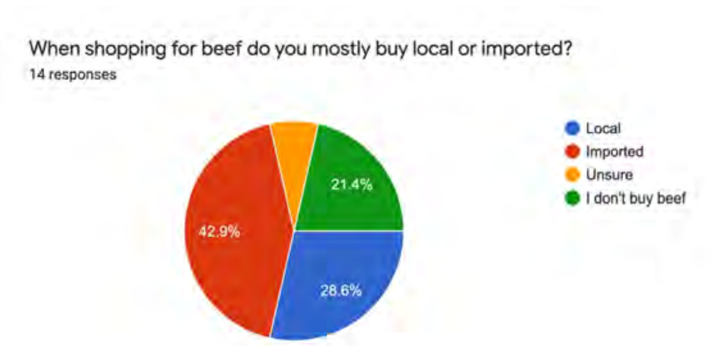


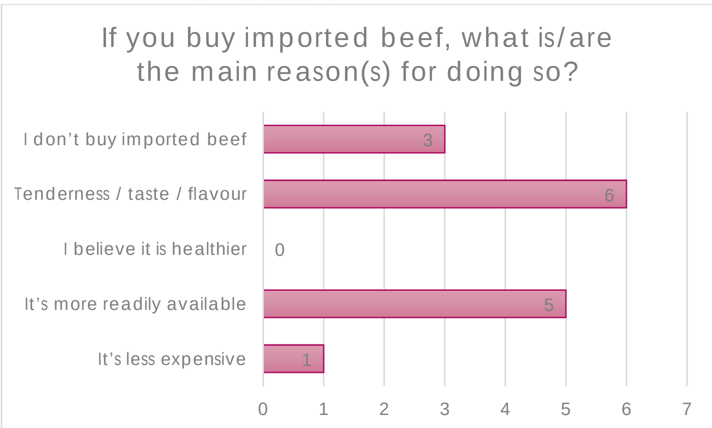

If you buy frozen / canned vegetables, what is/are the main reason(s) for doing so?
I don't buy frozen / canned...
Taste / flavour
I believe it is healthier
Ease of storage
Ease of preparation
It's more readily available
It's less expensive
5
0
0
1
1
8
3
0 1 2 3 4 5 6 7 8 9

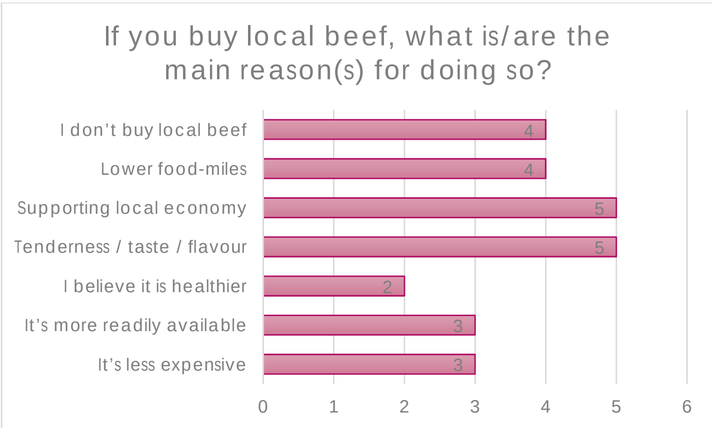

If you buy fresh vegetables, what is/are the main reason(s) for doing so?
I don't buy fresh vegetables
Protecting Norfolk's natural...
Lower food-miles
Supporting local economy
Taste / flavour / freshness
I believe it is healthier
It's more readily available
It's less expensive
1
5
6
9
6
6
3
2
0 2 4 6 8 10


When choosing vegetables, how important to you is it that it is locally grown?
14 responses
14.3%
71.4%
Very important
It is a consideration, but it is not a big factor in my decision
I have no preference for local vegetables over imported vegetables
I prefer imported vegetables

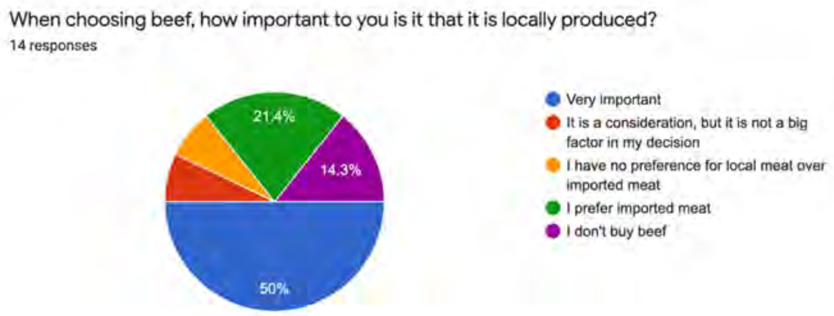

If you regularly buy fresh produce, where do you buy it?
I don't regularly buy fresh fruit or...
Direct from the producers
Roadside honesty stalls
Pumpkin Patch
Butcher in the Mall
Slick 'n Sons
P & R Groceries
Foodland
Farmers markets
1
6
3
3
2
5
4
7
4
0 1 2 3 4 5 6 7 8


When shopping for beef do you mostly buy local or imported?
14 responses
Local
Imported
Unsure
I don't buy beef
21.4%
42.9%
28.6%

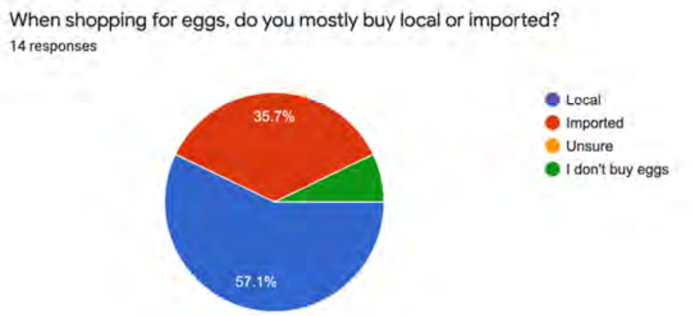

If you buy imported beef, what is/are the main reason(s) for doing so?
I don't buy imported beef
Tenderness / taste / flavour
I believe it is healthier
It's more readily available
It's less expensive
3
6
0
5
1
0 1 2 3 4 5 6 7



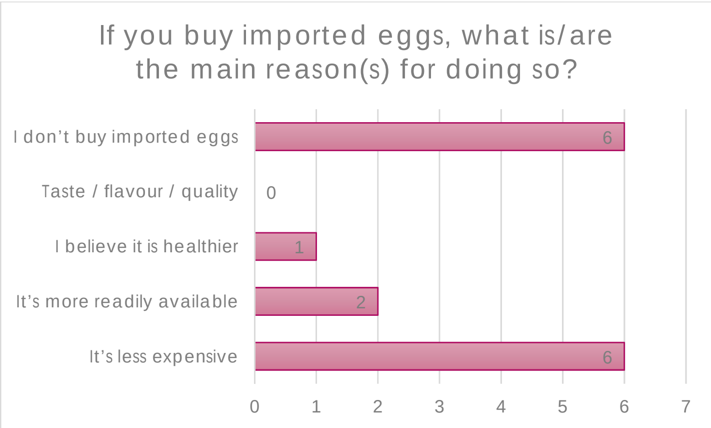
If you buy local beef, what is/are the main reason(s) for doing so?
I don't buy local beef
Lower food-miles
Supporting local economy
Tenderness / taste / flavour
I believe it is healthier
It's more readily available
It's less expensive
4
4
5
5
2
3
3
0
1
2
3
4
5
6



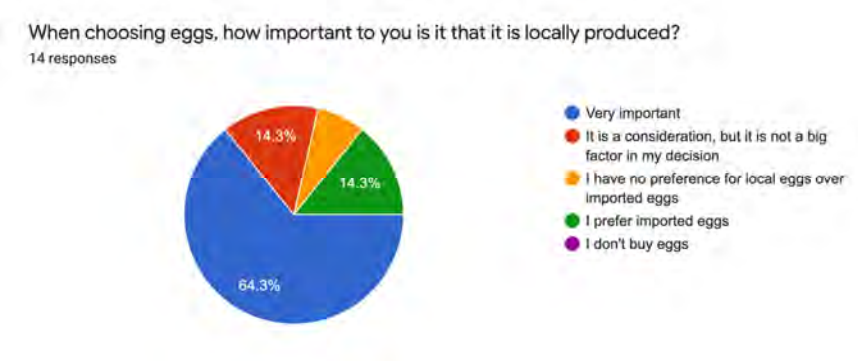
When choosing beef, how important to you is it that it is locally produced?
14 responses
21.4%
14.3%
50%
Very important
It is a consideration, but it is not a big factor in my decision
I have no preference for local meat over imported meat
I prefer imported meat
I don't buy beef

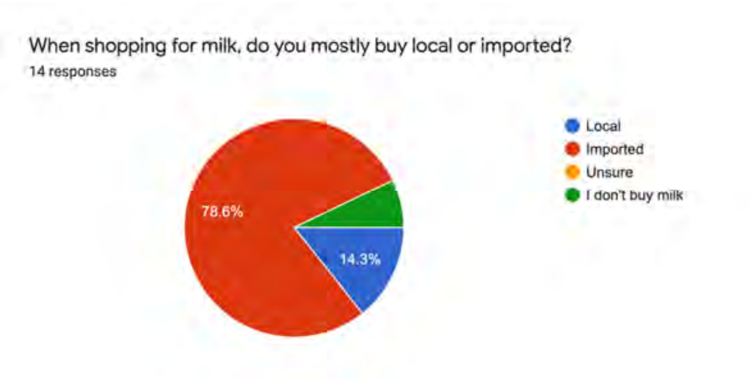


When shopping for eggs, do you mostly buy local or imported?
14 responses
35.7%
57.1%
Local
Imported
Unsure
I don't buy eggs

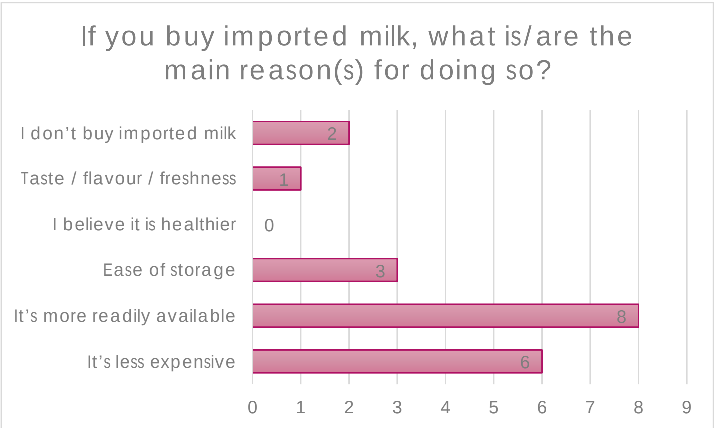

If you buy imported eggs, what is/are the main reason(s) for doing so?
I don't buy imported eggs
Taste / flavour / quality
I believe it is healthier
It's more readily available
It's less expensive
6
0
1
2
6
0
1
2
3
4
5
6
7


If you buy local eggs, what is/are the main reason(s) for doing so?
I don't buy local eggs
Lower food-miles
Supporting local economy
Taste / flavour / quality
I believe it is healthier
It's more readily available
It's less expensive
2
5
9
6
2
2
0
0
2
4
6
8
10

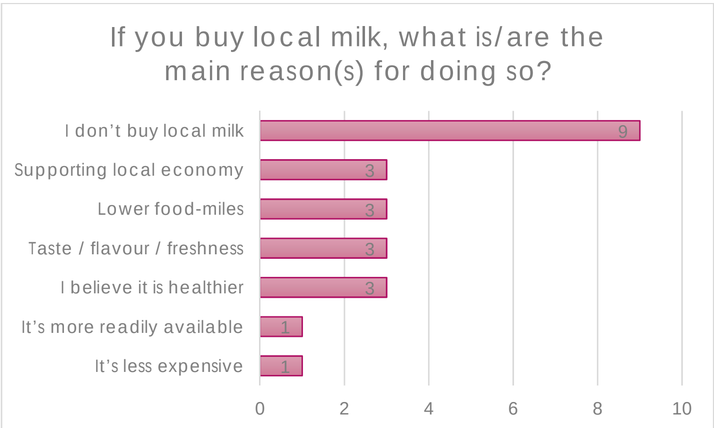

When choosing eggs, how important to you is it that it is locally produced?
14 responses
14.3%
14.3%
64.3%
Very important
It is a consideration, but it is not a big factor in my decision
I have no preference for local eggs over imported eggs
I prefer imported eggs
I don't buy eggs



When shopping for milk, do you mostly buy local or imported?
14 responses
Local
Imported
Unsure
I don't buy milk
78.6%
14.3%



If you buy imported milk, what is/are the main reason(s) for doing so?
I don't buy imported milk
2
Taste / flavour / freshness
1
I believe it is healthier
0
Ease of storage
3
It's more readily available
8
It's less expensive
6
0 1 2 3 4 5 6 7 8 9



If you buy local milk, what is/are the main reason(s) for doing so?
I don't buy local milk
9
Supporting local economy
3
Lower food-miles
3
Taste / flavour / freshness
3
I believe it is healthier
3
It's more readily available
1
It's less expensive
1
0 2 4 6 8 10

In choosing which milk to buy, how important to you is it that it is locally produced?
14 responses