Dreka im Bok Ekatak,

Consolidated Report for the Aggregates Study on Majuro and Ebeye

Republic of the Marshall Islands
Pacific Resilience Project Phase II

Pacific Community
Communauté du Pacifique

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Pacific Resilience Project Phase II[1]

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Contents

Abbreviations

ABLS	arcuate bight-like structures
ASM	artisanal and small-scale mining
CANCC	Coalition of Atoll Nations on Climate Change
COP	Conference of Parties
CSD	cutter suction dredge
EEZ	exclusive economic zone
EIA	environmental impact assessment
EMP	environmental management plans
EPA	environment protection authority
ESA	environmental and social assessment
ESAT	Environmentally Safe Aggregates for Tarawa
GDP	gross domestic product
GIS	geographic information system
KADA	Kwajalein Atoll Development Authority
KALGov	Kwajalein Atoll Local Government
LiDAR	light detection and ranging
MIMRA	Marshall Islands Marine Resources Authority
MJCC	The Marshalls Japan Construction Company
MSL	mean sea level
MWIU	Ministry of Works Infrastructure and Utilities
NAP	National Adaptation Plan
PII	Pacific International Inc
PMA	prospective mining areas
PREP	The Pacific Resilience Program Phase 2
RMI	Republic of the Marshall Islands
SIDS	Small Island Developing States
SLR	sea-level rise
SOPAC	South Pacific Applied Geoscience Commission
SPC	Pacific Community
TSHD	trailing suction hopper dredge
UN	The United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
UXO	unexploded ordinance
WWII	World War Two

List of Figures

List of Tables

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Executive Summary

Aggregates (sand and gravel) are critical materials needed for sustainable development globally. In the Republic of the Marshall Islands (RMI), aggregates are exceptionally critical for adaptation and resilience building against climate change impacts and coastal hazards. Significant volumes of aggregates are required for land reclamation, land raising, and shoreline protection, as outlined in RMI's National Adaptation Plan "Pāpjelmae". Aggregates are the primary materials needed for climate resilience and construction in RMI, therefore should be at the forefront of planning and the climate adaptation agenda. The scope of this study did not cover boulders.

However, current aggregate extraction practices in RMI are undermining efforts to strengthen resilience. Beach and reef mining have caused significant coastal erosion in Majuro and Ebeye. These extraction methodologies were first introduced during World War Two (WWII), when the focus was purely on sourcing materials as quickly as possible, with no or little regard for long-term sustainability or impacts. There is now a need to consider more sustainable options for sourcing aggregates.

Sustainability and renewability are different concepts and should not be conflated. Sustainability must be considered holistically, incorporating the environmental, social, and economic implications associated with both the extraction and use of aggregates across generations. Therefore, this study comprises an environment and social assessment; geophysical mapping, sampling, and testing of aggregates to determine volumes and composition; and a market assessment to better understand the demand and supply of aggregates. The study aims to support relevant stakeholders to make informed decisions regarding the sustainable management of aggregates resources in RMI.

Findings reveal that lagoon dredging is the most sustainable option for sourcing aggregates in Majuro and Ebeye, taking into account the need for further work and assessments. In simple terms, an atoll can be thought of as a bucket. The rim of the bucket represents the reef platform where most of the sediment is produced. Some of this sediment is deposited on the rim to form islands, and some sediment is lost inside the bucket. Lagoon dredging is effectively collecting the sediment from inside the bucket and therefore does not cause coastal erosion, provided that the dredging location is not connected to the beach or nearshore environment.

The study has estimated around 13.6 million yd^3 of lagoon aggregate resources across four sites in Majuro and 8.3 million yd^3 across six sites in Ebeye. The identified lagoon aggregate resources are predominantly sand sized, with varying amounts of gravel. These resources have the potential to improve the lives and livelihoods of the people of the Marshall Islands living on Ebeye and Majuro, as well as realise the principles of the "Pāpjelmae" regarding self-determination.

It is intended that this study will inform medium to long term development in RMI and further work is required should stakeholders decide to pursue extraction of the identified lagoon aggregate resources. As with any mining project, a staged approach is necessary, comprising the fundamental stages of exploration, development, production, and closure. The scope of this aggregates study comprises the exploration phase and some of the feasibility work required as part of the development phase. Therefore, further feasibility and design work is required prior to extraction taking place during the production phase.

Additional engineering property testing and field trials are recommended to assess the suitability of the aggregate resources for specific engineering applications. This should be coupled with the development of designs, standards, specifications, and guidelines using local lagoon aggregates. It is important that this work is guided by the composition of the carbonate sediment, as this is the fundamental factor controlling the properties of the material.

A detailed assessment and selection of the most appropriate dredging equipment and extraction methodologies is required. This should be conducted by the proponent seeking to undertake aggregate extraction, either a private sector actor, or potentially a state-owned enterprise should RMI wish to pursue this option. As part of the proponent's due diligence, it is recommended that a business plan be developed considering all operational and commercial matters.

It is essential that any prospective aggregate extraction is compliant with the relevant legal and policy framework in RMI, including the Earth Moving Regulations, the Environmental Impact Assessment (EIA) Regulations, the Historic Preservation Act, and the Coast Conservation Act. All necessary permits and approvals must be obtained prior to extraction taking place.

Of note, a site-specific EIA and environmental management plan are required to manage potential environmental and social impacts of any prospective dredging activity. The Majuro and Kwajalein lagoons provide ecosystem services and are used by the community for activities such as fishing, shipping, and swimming. Therefore, it is important that potential impacts of dredging are adequately managed. This should include robust consultations with relevant stakeholders and the public.

The environmental and social assessment conducted as part of this study identified opportunities to strengthen the existing legal and policy framework in RMI. To ensure the effective governance of the aggregates sector in RMI, it is recommended that government considers options regarding the legislation and capacity of relevant government agencies responsible for regulating the sector.

Pacific atoll nations, Tuvalu and Kiribati, have successfully implemented lagoon dredging initiatives. Notably the Tuvalu Coastal Adaptation Project and Borrow Pit Reclamation Project in Tuvalu, and the Environmentally Safe Aggregates for Tarawa Project in Kiribati. These experiences could be beneficial towards informing prospective lagoon dredging in the RMI.

The technical and strategic options for consideration by the Government of the Republic of the Marshall Islands include:

1. Recognising the potential for sourcing aggregates, that is sand and gravel, from the lagoons in Majuro and off Ebeye.
2. Developing and implementing plans for Ebeye and Majuro to transition away from (and prohibit) beach mining and reef mining and explore lagoon dredging as a more sustainable way of sourcing aggregates locally. This will require assessments, consultation and effective collaboration between Government, the private sector, donors, infrastructure development partners and impacted community stakeholders.
3. Developing local content policies for the RMI construction sector to preferentially use local lagoon aggregates, and only import aggregate where there is a specific quality requirement which cannot be met by local aggregates.
4. Engaging engineers and research institutes to conduct research and develop innovative designs, standards, and specifications using local lagoon aggregates.
5. Establishing geotechnical laboratories capable of aggregate testing and composition analysis in Majuro and Ebeye. This should involve training of local personnel to operate the laboratory.
6. Continuing to map and undertake further lagoon aggregate resource surveys to identify additional resources and sustainability issues in strategic locations for land reclamation and raising.
7. Strengthening the governance of the aggregates sector in RMI including the review of existing legislation and policy frameworks, introduction of new legislation, and strengthening the capacity of relevant government agencies responsible for regulating the sector.
8. Using economic incentives to encourage a transition towards environmentally sustainable practices of sourcing aggregates as well as compliance with existing regulations.
9. Convening a regional forum for Pacific atoll nations to share experiences and best practices regarding sourcing aggregates and land reclamation. This forum could also engage with countries in other regions including the Maldives to learn from their experiences.
10. Recognising the importance of aggregates and mineral security for disaster and climate resilience in Pacific Small Island Developing States, particularly the Republic of the Marshall Islands and advocating for new and additional resources to address the current mineral insecurity in the Pacific.
11. Recognising future opportunities such as the 4th International Conference on Small Island Developing States in May 2024 to review SIDS sustainable development progress and propose a new decade of partnerships and solutions to support a SIDS pathway towards resilient development
12. Advocating for mineral security to be highlighted at international fora such as the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) and aspire for its inclusion as a goal in the next iteration of the Sustainable Development Agenda beyond 2030.

1. Introduction

Figure 1: Location map of RMI, with Majuro and Kwajalein atolls shown in red rectangles.

The Pacific Resilience Program Phase 2 (PREP II) is a series of projects funded by the World Bank to protect the Republic of the Marshall Islands (RMI) from the effects of climate change, with the focus on strengthening early warning systems and establishing climate-resilient investments in shoreline protection, to better equip communities to manage the impacts of disasters and climate change, including rising sea levels.

The Pacific Community (SPC) received grant funding to implement key components under the Programme, which included the identification of sustainable sources of aggregates in the two main urban centres in RMI, namely 1) Majuro Atoll and 2) Ebeye Islet on Kwajalein Atoll (Figure 1). These investigative activities include geophysical mapping, sampling, and testing of aggregates to determine volumes and composition; an environment and social assessment; and a market assessment to better understand the demand and supply of aggregates. Collectively, these activities are known as 'The Aggregates Study', or 'Dreka im Bok Ekatak' in Marshallese.

This 'Consolidated Report' is the final deliverable of the Aggregates Study. The report seeks to contextualise, summarise, and integrate the findings of all the individual activity reports produced as part of the Aggregates Study. Given that the nature of this report is to summarise the collective findings, the reader should refer to the following relevant technical reports for further specific details:

1. Environmental and Social Assessment (ESA) of Sustainable Aggregate Extraction and Use in Majuro and Ebeye, the Republic of the Marshall Islands (2022)
2. Lagoon Geophysical Aggregate Resource Investigations, Majuro Atoll, Republic of the Marshall Islands (2023)
3. Lagoon Geophysical Aggregate Resource Investigations, Ebeye, Kwajalein Atoll, Republic of the Marshall Islands (2023)
4. Market Assessment of Aggregates in Marshall Islands (2024)
5. Assessment of Environmental and Social Risks and Mitigation Measures in Majuro and Ebeye, the Republic of the Marshall Islands: Annex to the Environmental and Social Assessment (ESA) of Sustainable Aggregate Extraction and Use in Majuro and Ebeye, the Republic of the Marshall Islands (2024).

The overall purpose of this aggregates study is to support relevant stakeholders to make informed decisions regarding the sustainable management of aggregates resources in RMI. It is intended that the study will inform all future construction in Majuro and Ebeye, including climate change adaptation planning.

2. Global Context

Globally, aggregates (sand, gravel, and crushed stone) are the second most consumed natural resource, after water. Aggregates are the foundational building blocks of civilisation and have been since the stone stage. Aggregates account for over 80% of global mineral production (Franks D. M., 2020). At present, the United Nations Environment Programme (UNEP) estimates that humanity consumes approximately 50 billion tonnes (T) of aggregates annually (UNEP, 2019), which equates to ~ 6 T of aggregates per person each year. Therefore, it is apparent that aggregates are the primary material underpinning economies, societies, and livelihoods.

Yet, paradoxically, aggregates (along with all other minerals) are neglected from the development agenda (UNEP, 2022). The United Nations (UN) '2030 Agenda for Sustainable Development' consists of 17 goals, 169 targets and a 15,000-word outcome document (United Nations, 2015). Within this Sustainable Development Agenda, the words 'minerals', 'mining' and 'miner' do not appear once. In contrast, other natural resources feature prominently in the agenda, including air, energy, fisheries, forests, genetic resources, pasture, water, and wildlife (Franks et al, 2022).

As a result of this neglect, numerous challenges have been overlooked, and insufficient resources have been allocated to enable the effective governance of the mining and quarrying sector (Peduzzi, 2014). Several stakeholders have recognised this issue and have subsequently advanced concepts, recommendations, and actions to help address the situation. These include the 'ACP-EU Development Minerals Programme' and UNEP's 'Sand and Sustainability: 10 Strategic Recommendations to Avert a Crisis' report (UNEP, 2022), which importantly calls for minerals to be at the forefront of the next iteration of the Sustainable Development Agenda.

The challenges facing the aggregates sector are varied and complex across the globe. Thus, it is critical that specific interventions are developed, implemented, and led at the local level, grounded by a robust understanding of local contexts and specific challenges. In this regard, this 'Aggregates Study' seeks to inform stakeholders in RMI, to support planning and decision-making related to addressing the challenges facing the aggregates sector in Majuro and Ebeye.

3. Important Concepts

3.1 Development Minerals

Franks et al (2016) defined the concept of 'development minerals' as:

"Minerals and materials that are mined, processed, manufactured, and used domestically in industries such as construction, manufacturing, infrastructure, and agriculture. Development minerals are economically important close to the location where the commodity is mined. In comparison to minimally processed export-minerals, they have closer links with the local economy with a more direct impact on poverty reduction".

In essence, development minerals are local minerals, mined and processed by local people, for local development. Development minerals play a particularly critical role in local development through two principle means:

1. their use in local communities, to build homes, schools, roads, coastal protection, and hospitals. Development minerals are literally the foundational building blocks of society.
2. the direct and indirect employment opportunities associated with their extraction, processing, and use. Such as miners, brick makers, truck drivers, mechanics, construction workers, and the plethora of jobs which depend on the workplaces created using Development Minerals.

Aggregates are the prime example of development minerals, as they are extracted, processed, and used domestically in the construction sector.

3.2 Mineral Security

Franks et al (2022) defined the concept of 'mineral security' as:

"when all people have sufficient and affordable access to the minerals necessary for human development, including for shelter, mobility, communication, energy and sustenance" .

This concept is aligned with the way we typically perceive other natural resources, for instance food security, water security and energy security. In fact, mineral security is closely linked to food, water, and energy security. For example, mineral fertilisers used in agriculture (food security), concrete used to make water reservoirs (water security), and concrete used in the foundations of solar panels and substations (energy security).

Where people do not have access to the minerals necessary for human development, they experience mineral insecurity (or mineral poverty), which inhibits access to essential infrastructure and services, such as coastal protection, housing, transport, and energy.

3.3 Sustainability

Given the numerous different definitions of sustainability, it is important to contextualise and define it for the purpose of this study.

The Brundtland Commission Report (1987) is a foundational document of the sustainable development agenda, defining sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This definition highlights a core principle of sustainability relevant to this study, meaning that RMI should seek to extract and utilise local aggregate resources to develop the nation of RMI and improve the standard of living for current and future generations, and thus improve the ability of future generations to meet their needs. While also mitigating potential negative environmental and social impacts associated with the extraction of aggregates, so that such impacts do not compromise the ability of future generations to meet their needs.

An important consideration for this study is that aggregate resources are typically non-renewable. They are extracted at rates exceeding their geological formation rates, and thus the resource base available for future generations is depleted. Except for certain isolated systems, such as braided rivers with enormous sediment loads, whereby gravel can be extracted below renewable rates. However, this is an exception and not the norm. The Brundtland Commission Report speaks to this issue of non-renewability as follows:

"As for non-renewable resources, like fossil fuels and minerals, their use reduces the stock available for future generations. But this does not mean that such resources should not be used. In general, the rate of depletion should take into account the criticality of that resource, the availability of technologies for minimizing depletion, and the likelihood of substitutes being available. Thus land should not be degraded beyond reasonable recovery. With minerals and fossil fuels, the rate of depletion and the emphasis on recycling and economy of use should be calibrated to ensure that the resource does not run out before acceptable substitutes are available. Sustainable development requires that the rate of depletion of non-renewable resources should foreclose as few future options as possible."

This same logic can be applied to this study as follows. The earth's crust is composed of vast resources of rock which are sufficient to supply humanity with aggregates perpetually and will never be depleted. The challenge is to locate economically extractable aggregate resources in proximity to the communities where there is a demand, so that the aggregates necessary for human development can be supplied to those communities at an affordable price. There will always be options to extract and transport aggregates from deeper or further away, however this will increase the price of aggregates and subsequently may cause mineral insecurity if the community cannot afford the increased price. In the context of RMI, even if a particular local aggregate resource is depleted from one location, future generations will always have access to additional aggregate resources (either locally or imported), though the cost of accessing those resources will likely be more expensive. Therefore, it is incumbent on present generations in RMI to utilise local aggregate resources responsibly, to improve the circumstances in RMI, so that future generations are better placed to afford potentially more expensive aggregate resources in the future.

The effective use of local aggregate resources to support economic growth and development in RMI is attainable, provided that environmental impacts associated with extraction are managed. Alternative resources should also be considered to reduce the demand for aggregates, including the use of substitute construction materials, and the recycling of aggregates, such as reusing waste concrete from demolished buildings.

Sustainability must be considered holistically, incorporating the environmental, social, and economic implications associated with both the extraction and use of aggregates across generations in RMI. Therefore, for the purpose of this study sustainability is defined as, "the optimization of environmental, social, and economic outcomes for present and future generations in RMI".

4. Historical context

Below is a brief history of aggregates in RMI, to give context and perspective to how the current situation has evolved, it is not intended to be exhaustive.

In traditional Marshallese society the demand for aggregates was very minimal. Traditional Marshallese houses consisted of wooden pole structures with thatched roofs as shown in Figure 2. These houses were primarily constructed from pandanus, coconut, wutilomar, konnat and other trees (Hermios, 2024; & Spennemann, 2000). The only aggregate required was for a layer of coral gravel spread inside on the floor, on top of which weaved mats were placed (WUTMI, 2009). Land transport infrastructure consisted of walking tracks where vegetation was cleared (Figure 2), hence there was no requirement for road aggregates in traditional Marshallese society (Spennemann, 2024).

Figure 2: Traditional housing on Majuro Atoll circa 1908-10 (left), and traditional track circa 1908-10 (right). Source: Spennemann, 2024.

Aggregates were utilised in relatively small quantities for other traditional practices. Including constructing fish traps on intertidal reef flats, by stacking coral boulders in traditional shapes as shown in Figure 3. Figure 3 also shows aggregates used to construct a traditional grave, with sand in the interior and coral boulders around the outside.

Figure 3: Traditional fish trap made from coral boulders (left), and traditional grave made from boulders and sand (right). Source: Curry, 2024, and Spennemann, 2024.

Spanish explorers in the 16th century were the first Europeans to visit the Marshall Islands. However, accounts from Russian explorer Otto von Kotzebue in 1817 noted few signs of western influence, with people continuing to live in traditional thatched houses (Hezel, 1983). Throughout the 19th century, increasing numbers of traders and missionaries began to reside in the Marshall Islands, bringing with them new construction materials and techniques (Hezel, 2003). This continued throughout the German colonial period (1885-1914) and Japanese colonial period (1914-1945). Imported timber and tin were the major materials used to construct buildings during this period, with minor amounts of concrete used, as shown in Figure 4 (Spennemann, 2024).

Figure 4: Colonial era housing; German (left) and Japanese (right). Source: Spennemann, 2024.

Transport infrastructure was also developed during this period to support the export of commodities such as copra. This included the construction of roads, wharfs, and light rail tracks. Jaluit wharf and a nearby coastal road is shown in Figure 5 below. The wharf has a timber pole seawall with stacked coral boulders around its periphery, and the interior is filled with aggregates with a light rail track on the surface. The nearby coastal road has a seawall constructed from stacked coconut logs and timber poles. Roads during this era appear to comprise areas cleared of vegetation, with minimal (if any) aggregate added.

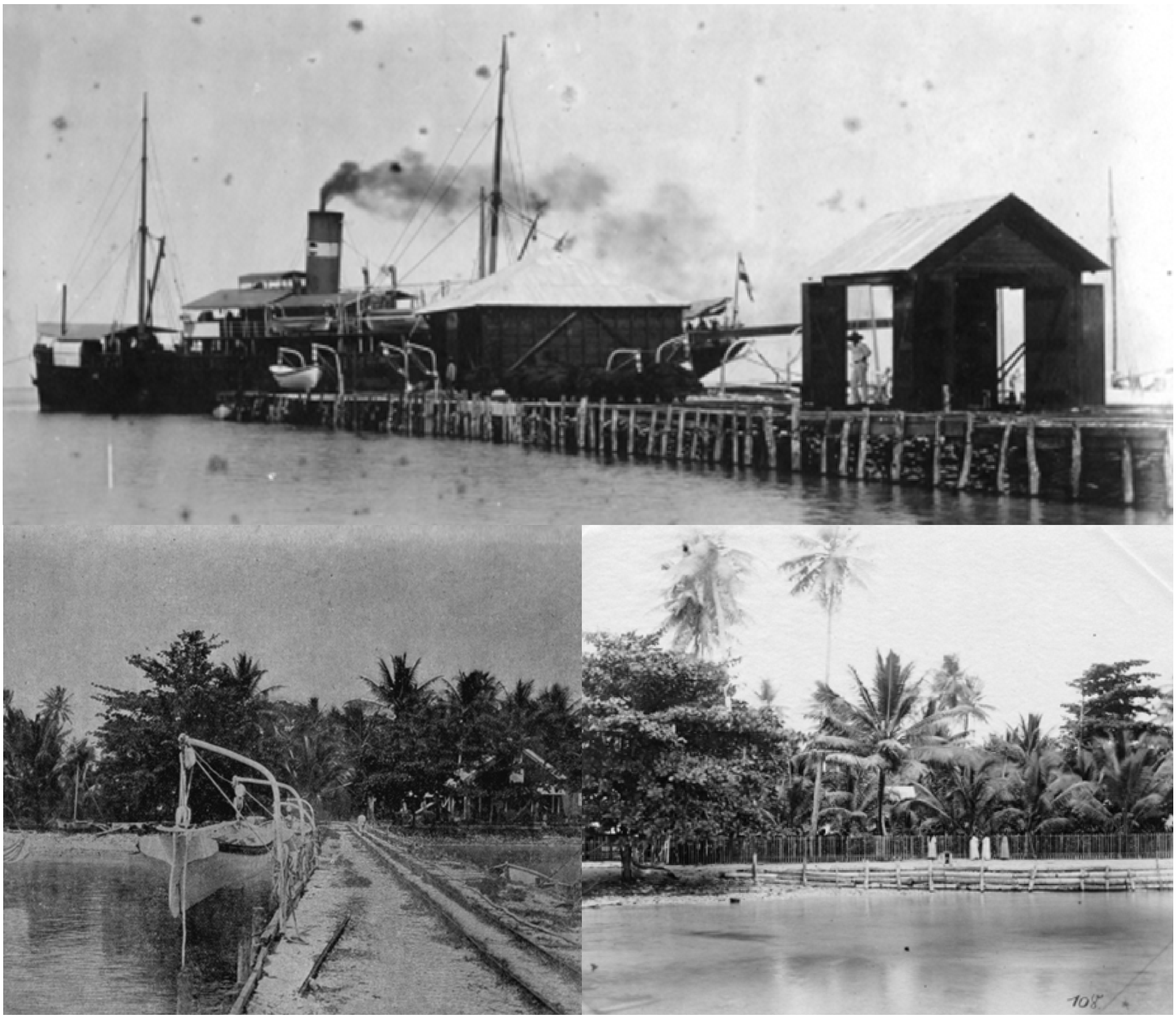

Figure 5: Colonial era transport infrastructure- Jaluit wharf (top & bottom left) and beach road with seawall (bottom right). Source: Spennemann 2024.

It wasn't until the onset of World War II (WWII) in 1939 that aggregate consumption substantially increased in RMI. The militaries of Japan and the United States of America (USA) imported explosives, and earth moving machinery such as excavators and bulldozers. This new earthmoving technology was used to dramatically transform several atolls in RMI. Military infrastructure including concrete wharves, runways, buildings, concrete bunkers, seawalls, and fortifications were constructed in a relatively short period of time (Figure 6).

Figure 6: Examples of WWII military infrastructure: runways on Majuro (top left) and Kwajalein (top right) atolls, a concrete bunker on Kwajalein atoll (bottom left), and wharfs, buildings, reclamations, seawalls, and various fortifications on Ebeye island (bottom right). Source: United States Army Air Force; & National Naval Aviation Museum

Of particular significance during WWII, several islets were connected by the construction of causeways, requiring vast volumes of aggregates. Figure 7 presents comparative maps of eastern Majuro from the start and end of WWII, which illustrate that several causeways connecting islets were constructed during WWII. All this wartime infrastructure required aggregates, and given the wartime context, the focus was on sourcing the aggregates as quickly as possible, therefore sustainability was not a consideration. Subsequently, aggregates were sourced from beach mining, nearshore dredging and using explosives to blast pits in the coral reef. The extraction of aggregates during this period transformed the environment in RMI, with permanent impacts to sediment dynamics and other coastal processes (Xue, 1997), which are discussed in more detail throughout this report.

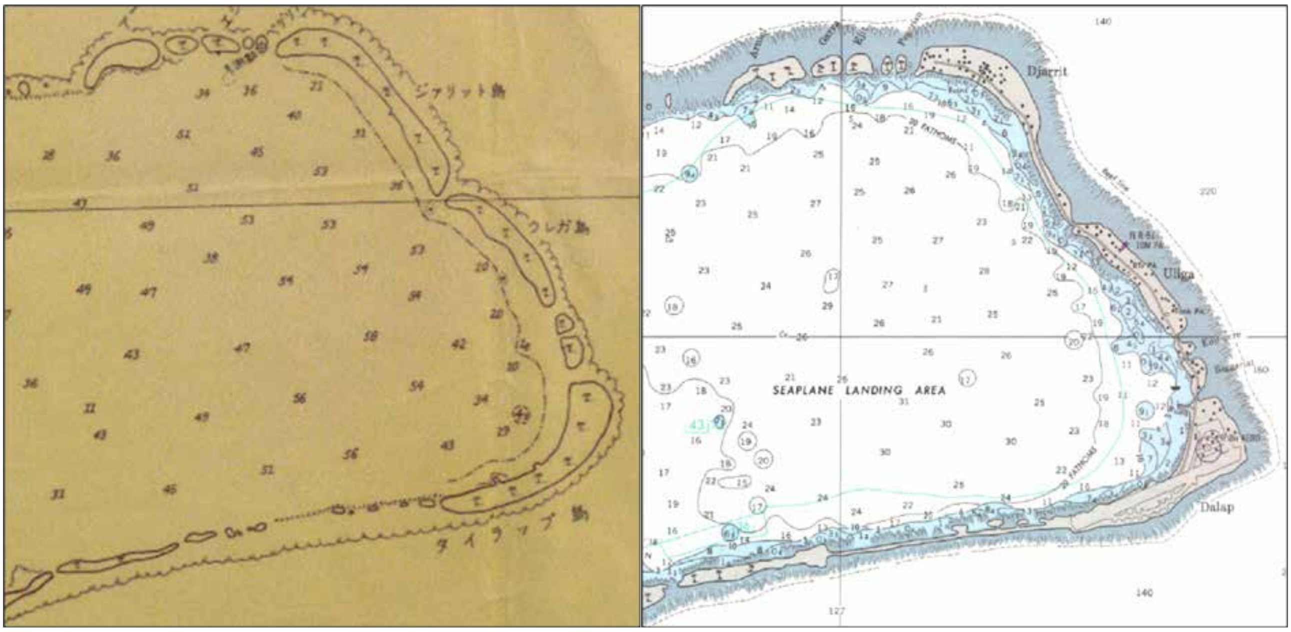

Figure 7: Eastern Majuro ~ 1940 at the start of WWII (left) and towards the end of WWII 1944 (right). Source: College of the Marshall Islands, 1940; & defence Mapping Agency Hydrographic/Topographic Centre, 1944.

Activity during WWII set a precedent for sourcing aggregates, with the same extraction methodologies continuing to present day. Throughout the postwar period the population in RMI has increased approximately 400% (Figure 8), with most of this population growth centred in Majuro and Ebeye (Graduate School USA, 2022). Prior to WWII the population in Majuro ranged between 1,000 and 2,000, with present estimates now at ~23,000 (SPC, 2023), postwar Majuro has experienced population growth of ~2,000%. The urban centre of Ebeye has experienced a similar trend.

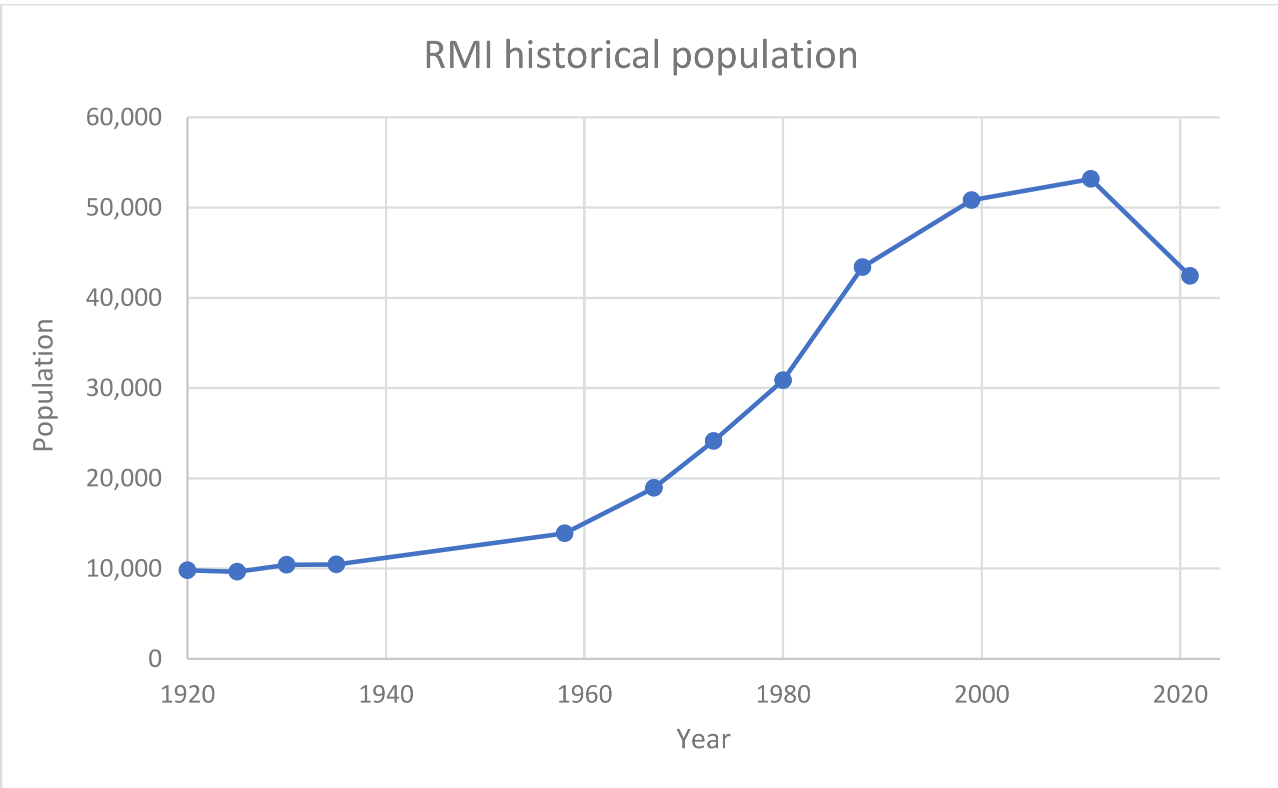

Figure 8: RMI historical population

Increasing quantities of aggregates were required as RMI developed and the population increased. This development included the construction of further causeways to connect islets, international airports, wharves, energy facilities, roads, water infrastructure, housing, schools, hospitals, hotels, commercial buildings, sports facilities, and the plethora of other infrastructure in the urban centres of contemporary RMI (Figure 9).

Figure 9: Examples of infrastructure developed in the postwar period; Majuro airport (top left), dense buildings and infrastructure on Ebeye (top right), causeway in Ebeye (bottom left), and stadium in Majuro (bottom right).
Source: Anderson Asphalt Limited, 2024; & Kwajalein Atoll Development Authority.

Of particular note, the expanding urban populations on the limited landmasses of Ebeye and Majuro have resulted in several land reclamations to create new space. These reclamations are aggregate intensive, as they require aggregate for fill material and aggregate for the construction of seawalls (such as the stadium shown in Figure 9 above). In the future, the demand for aggregates for reclamation will increase as RMI implements its recently endorsed National Adaptation Plan, "Pāpjelmae" (Republic of the Marshall Islands, 2023). Fellow atoll nation Tuvalu has begun to implement its long-term climate adaptation plan ("Te Lafiga o Tuvalu") based on elevating existing land and creating new elevated land. This plan is forecast to require approximately 1-olympic sized swimming pool full of aggregates per person. Thus, atolls nations are likely to have the highest aggregate demand per capita globally. This highlights the intense link between mineral security and climate security and demonstrates that aggregates provide the primary pathway for climate adaptation in atoll nations (Rogers et al, 2023).

5. Geology of RMI

The geology of RMI ultimately dictates which aggregate resources are available locally in RMI.

The exclusive economic zone (EEZ) of RMI encompasses a vast area of 1,774,280 km^2 (SPC, 2024). Approximately 98% of RMI's EEZ is ocean, meaning just ~2% is land, comprised of 29 atolls and 5 reef islands. RMI's EEZ is situated on the Pacific tectonic plate in an area comprised of some of the oldest oceanic crust on earth (~150mya) (Muller et all, 2008). Hence the majority of RMI's territory consists of deep ocean abyssal plains in excess of 4,000m water depth (GEBCO, 2024).

The land territory of RMI is associated with seamounts which rise from the deep ocean floor. These seamounts were formed by four hotspot seamount chains (Ratak, Ralik, Anewetak, and Ujlan) which formed volcanoes approximately 70-100 million years ago (mya) (Koppers et al, 2003). Some of these volcanoes ascended to elevations above the ocean's surface and formed islands. Over time, these volcanic islands subsided into the ocean and provided the foundations for reef constructing corals to grow vertically. Initially forming fringing reefs, then barrier reefs, and eventually atolls, as per the subsidence theory of atoll formation (Darwin, 1843). A schematic representation of this process is presented in Figure 10 below.

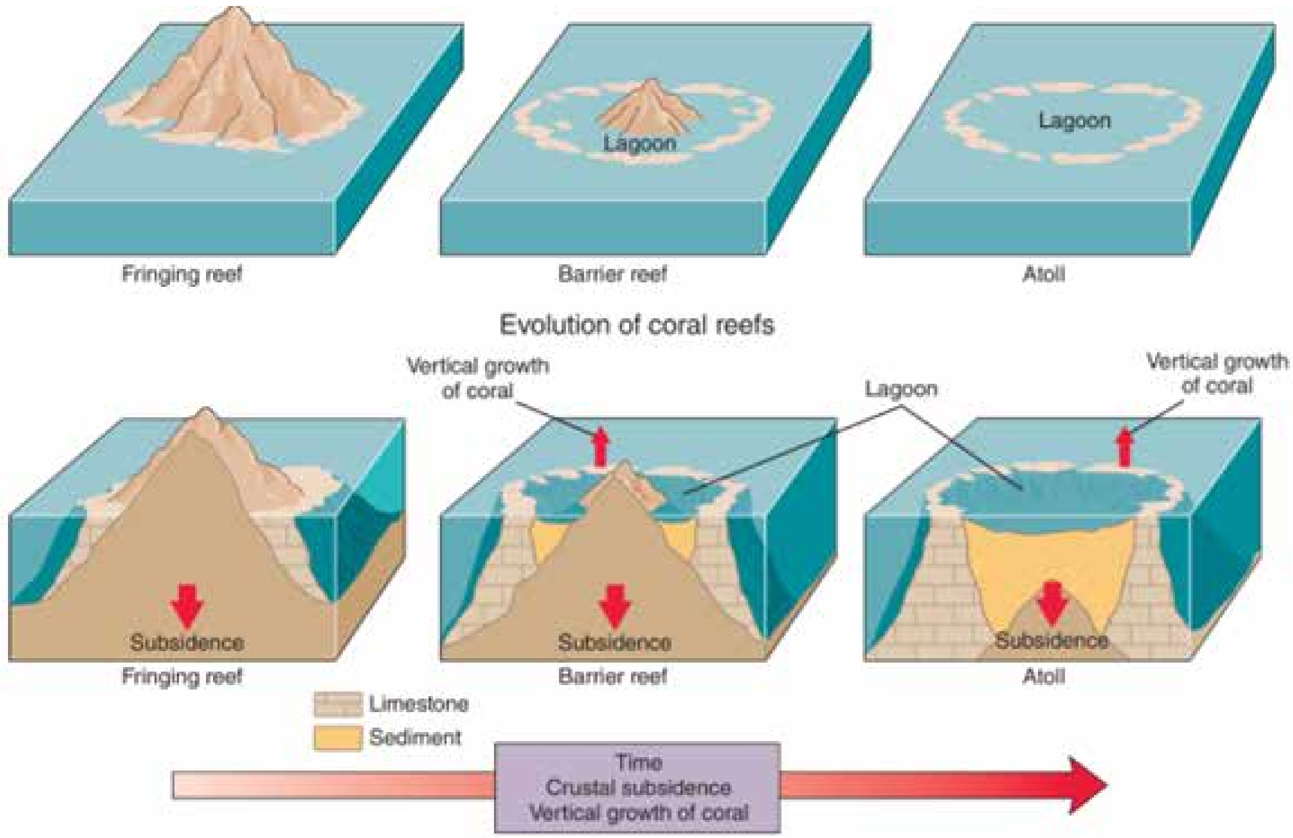

Figure 10: Evolution of an atoll; from a fringing reef, to a barrier, and finally to an atoll (Source: Jones & Bartlett Learning, 2009).

While this theory of atoll development is widely recognized, it was hypothesized before discussions on glaciation and associated sea level fluctuations were advanced (Woodroffe, 2008; Dickinson, 2009). Incorporating sea level oscillations to Darwin's theory provides a clearer understanding of how atolls form their irregular morphology or annular shape (Terry & Goff, 2012). Glacial eustasy driven by factors described by the Milankovitch theory caused sea levels to fall and rise multiple times throughout the Quaternary period (MacNeil, 1954; Berger, 1988). When sea levels dropped (during glacial periods), platform reefs emerged above the surface of the ocean and underwent subaerial erosion, creating saucer-shaped surfaces. As sea-level increased at the end of the last glaciation by approximately 120 m, the weathered saucer shaped surfaces became re-submerged, providing ideal substrates for coral growth to occur in an annular shape. Coral growth kept pace with the rising sea level and thus developed modern atoll islands (Dickinson, 1999), as shown in Figure 11. Additionally, in RMI sea level is estimated to have reached ~1.1 m to ~2.4 m higher than present-day levels during the mid-Holocene hydro-isostatic highstand 5000-2000 years ago (Dickinson, 2009, & Kench et al, 2014). This caused reef platforms to accrete to higher elevations than present day reef growth, influencing island formation processes and the timing of human migration.

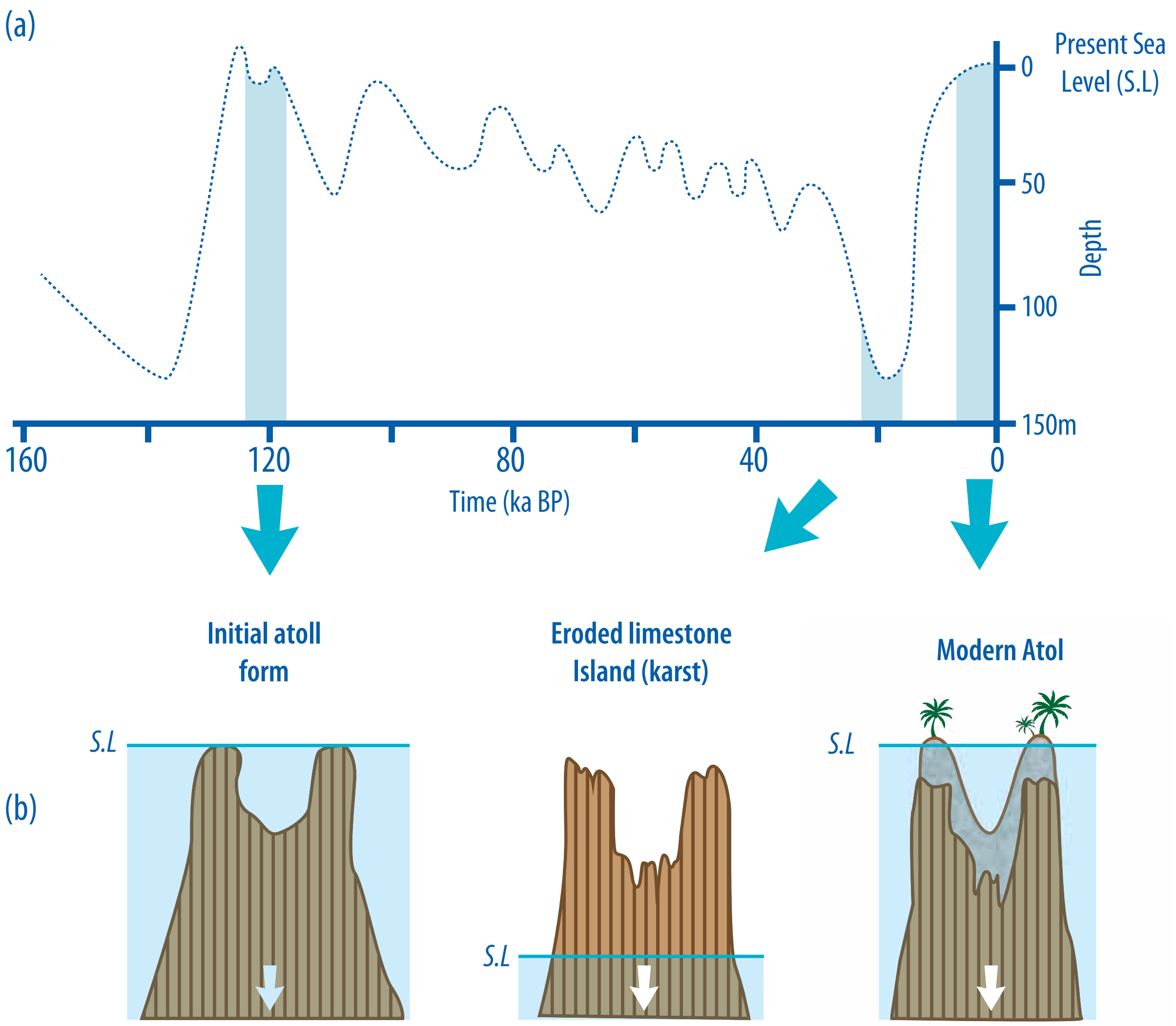

Figure 11: Schematic illustration of the late Quaternary history of an atoll with respect to (a) variations in sea level, showing (b) a gradually subsiding atoll. (Source: Woodroffe, 2008)

Figure 12 shows another important proccess influencing the shape of RMI's islands. Irregular morphologies or arcuate bight-like structures (ABLS) are the morphological expression of submarine failures that are frequent on the slopes of volcanic edifices. Such failures stem from structural weaknesses and unstable submarine deposits which promote slope instability and generate landslides and slumping (Terry & Goff, 2012). This can occur at any time during the process of atoll formation and heavily influences the modern shape of many atoll islands.

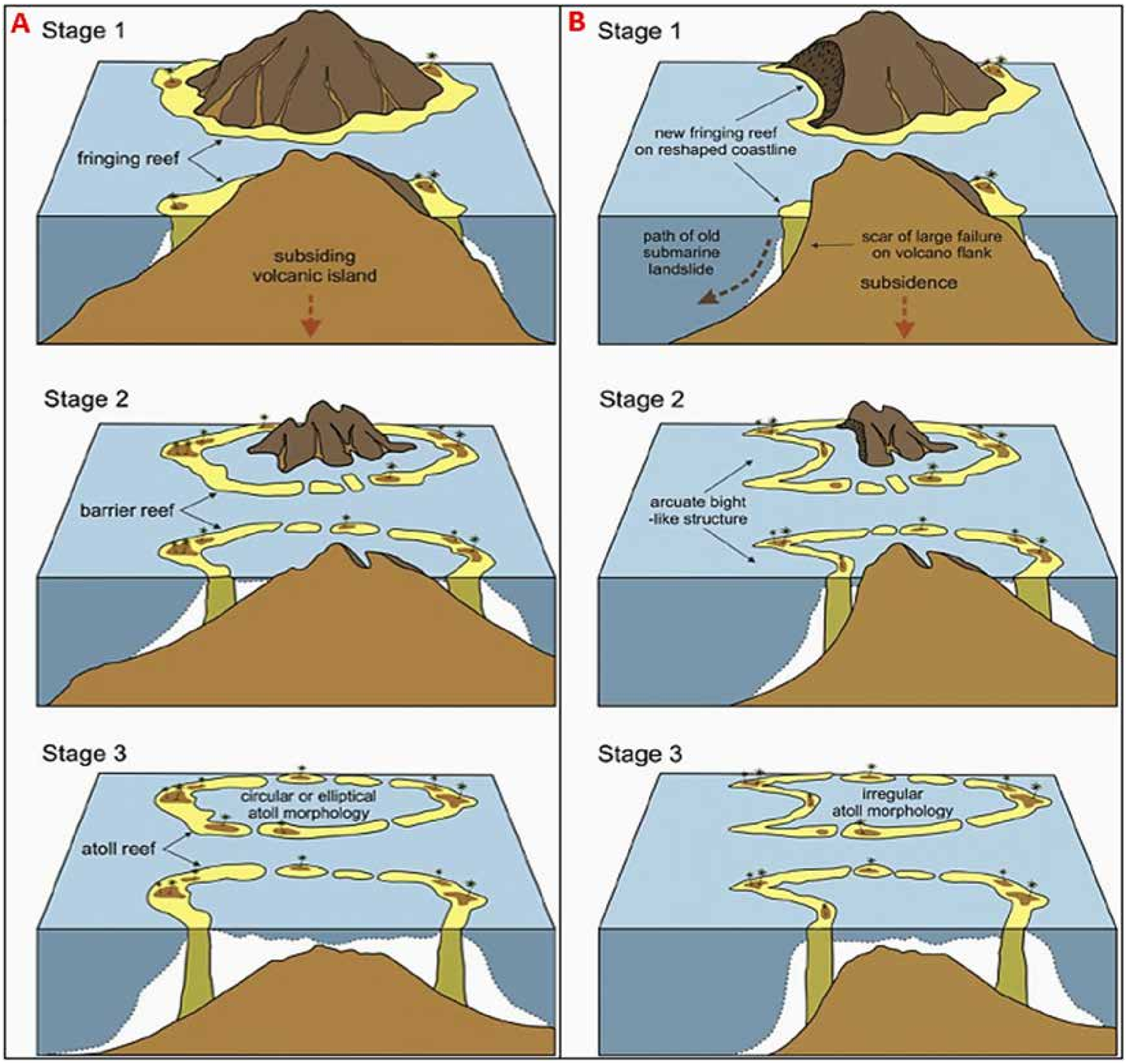

Figure 12: (A) Darwin's subsistence theory of atoll formation, showing the classic interpretation of the development of an elliptical atoll morphology. (B) Modified version to incorporate the formation of ABLS. (Source: Terry & Goff, 2012)

The discussion above outlines the long-term evolution of the islands in RMI. However, the current surface reef island morphology is the result of recent processes operating during the Holocene epoch since the end of the last glaciation (Woodroffe & Biribo, 2011). These processes can be broadly characterised as biogenic generation of calcareous sediment, erosion, sediment transportation, and sediment deposition on the reef platform to form the present-day islands. These processes have been operating since approximately 8-9 thousand years ago.

In simple terms the reef platform can be thought of as a factory producing sediment which is then transported by waves and currents to build the islands. This sediment is the skeletal remains of organisms living on the reef platform such as algae, molluscs, gastropods, foraminifera, crustaceans, and fragments of the coral reef itself. Different densities and types of organisms live in different parts of the platform, thus some areas form produce more sediment than others. Typically, the most productive part of the reef platform in RMI is the reef crest and reef flat close to the reef crest (Figure 13). This area is the habitat of large benthic foraminifera such as baculogypsina, calcarina, marginopora and amphistegina (Figure 14), and the skeletal remains of these organisms are the major contributor of sediment in RMI (Woodroffe & Biribo, 2011). Sediment also accumulates inside atoll lagoons via the transportation of sediment produced on the ocean side through channels between islets (including sediment eroded from islets), and directly through the production of sediment by organisms living inside the lagoon. Subsequently, atoll lagoons in RMI contain deposits of Holocene sediments overlying Pleistocene limestone and sediments, known as lagoon aggregates (as shown in the bottom right of Figure 13).

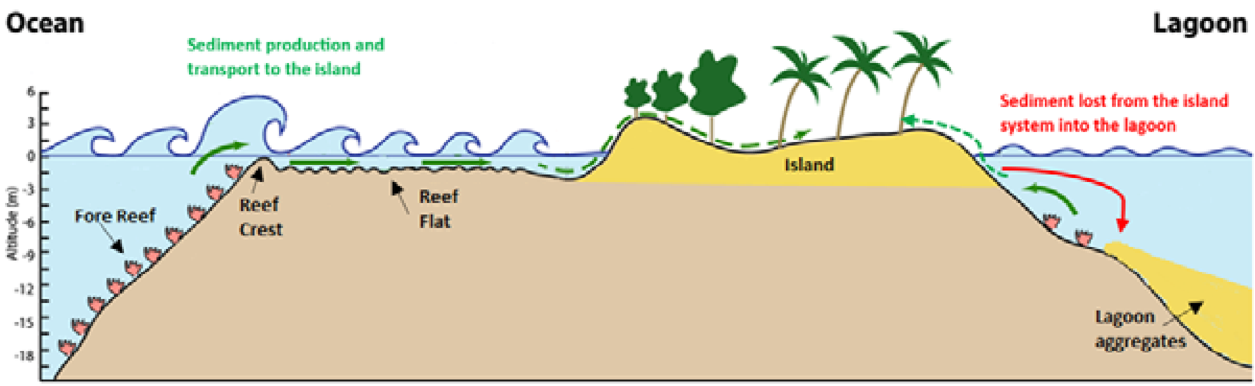

Figure 13: Schematic cross section of an atoll. Green arrows represent sediment transported to construct the island, and the red arrow represents sediment lost from the island system into the lagoon aggregate deposits. (Adapted from Duvat and Magnan, 2019).

Figure 14: Large benthic foraminifera commonly found in RMI: from left to right- baculogypsina, calcarina, marginopora and amphistegina.

6. Conceptual options for sourcing aggregates in RMI

Given the inherent geology discussed in the previous section, there are five conceptual options for sourcing aggregates in RMI: 1) beach mining, 2) reef mining, 3) land mining, 4) lagoon dredging, and 5) importation (see Figure 16). Each of these options has pros and cons across the environmental, social, and economic dimensions. All these options (except for importation) involve the extraction of carbonate sediment or coralline reef limestone, as these are the only geological resources in RMI within depths where extraction is commercially viable. The volcanic basement (basaltic rock) on the seamounts in RMI is more than 1,000m deep, as proven by drilling operations on Eniwetok atoll by the US Department of Interior in 1952, which encountered basalt in two holes at 1,405m and 1,267m as shown in Figure 15 (Ladd & Schlanger, 1960). Therefore, this aggregates study does not consider the option of mining basalt from the deep sea on the seamounts in RMI, as this option does not meet the fundamental mineral exploration criteria of 'reasonable prospects for economic extraction'.

Below we briefly discuss each of the five options at the conceptual level.

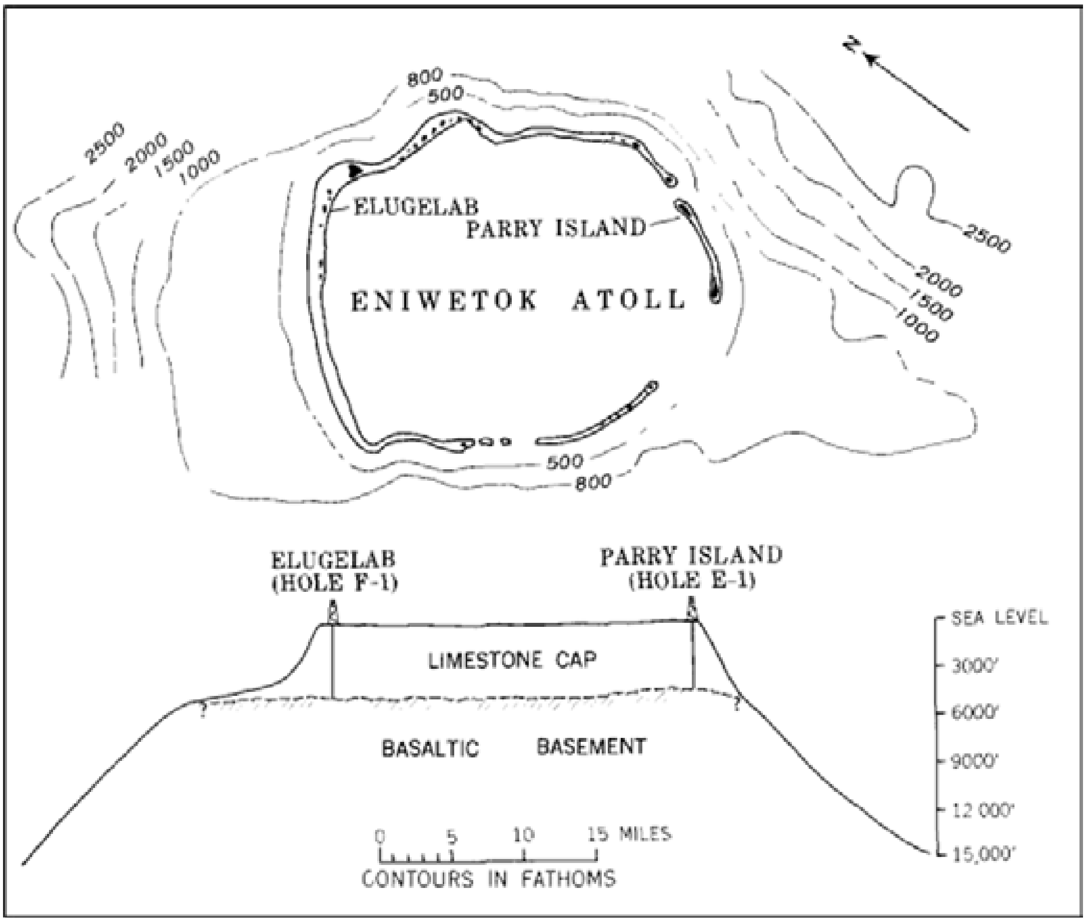

Figure 15: Plan and cross section of the two deep drill holes on Eniwetok atoll. Note- depths are in feet. Source: Ladd & Schlanger, 1960.

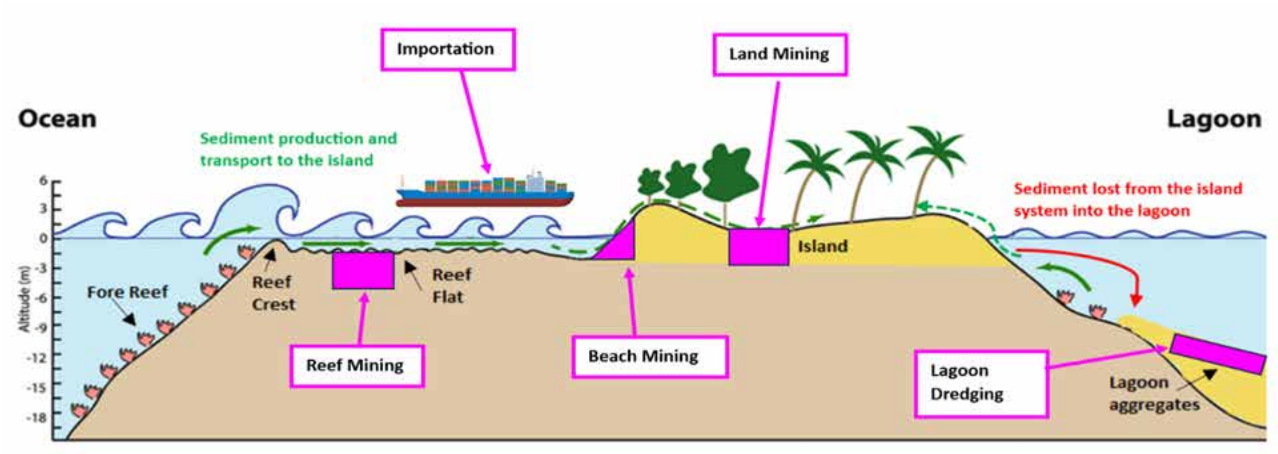

Figure 16: Conceptual options for sourcing aggregates in an atoll context, shown in purple.(Adapted from Duvat and Magnan, 2019).

6.1 Beach Mining

Figure 17: Beach sand mining in Tarawa, Kiribati, 1998. Source: Maharaj, 2000.

Beach mining is the process of extracting sand, gravel, or beachrock from the beach. This can either be done mechanically with an excavator or non-mechanically with hand tools. Beach mining is a relatively easy way to source aggregates. The option of using hand tools means that individuals and households can extract aggregates from the beach (Figure 17), and effectively source these materials for free. This practice extends back to the traditional era whereby households would harvest relatively small amounts of gravel from the beach to spread on the floor of traditional homes.

But in the modern era with population growth, increased demands for aggregates, and coastal resilience issues, the negative impacts from beach mining are severe (Myazoe, 2020). Coastal hazards and the impacts of climate change, such as sea level rise, are amongst the most critical challenges facing RMI. Consequently, actions to strengthen resilience against these challenges are a key priority in RMI. Such actions aim to safeguard RMI's coastlines and limited land. Beach mining directly undermines these efforts as it is literally human induced coastal erosion.

The islets in RMI can be considered as carbonate sediment cells, which can either accrete or erode, depending on the balance between 1) new sediment generated on the reef platform and deposited on the islet, and 2) sediment eroded from the islet and lost to the lagoon or oceanside. Beach mining directly removes sediment from this system and induces erosion. This erosion is not confined to the area of extraction, it can lead to erosion along the cost due to disrupted longshore processes.

Past studies have documented the adverse impacts of beaching mining and recommended that RMI prohibit beach mining and transition to more sustainable options (Xue, 1997; Mckenzie et al, 2006). However, as of 2024, transitioning away from beach mining has proved challenging and it continues to be practiced in RMI. SPC reiterates the previous recommendations to prohibit beach mining and recommend RMI transitions to more sustainable options as outlined in this report.

6.2 Reef Mining

Figure 18: Reef mining for the stadium in Majuro. Source: Google Earth.

Reef mining is the process of blasting the coral reef platform using explosives (on either the ocean-side or lagoon-side) and extracting boulders, gravel, and sand with an excavator (Figure 18). This practice requires personnel skilled with explosives and earthworks machinery and is therefore only practiced by commercial operators.

Reef mining was first practiced in RMI during WWII. The military possessed the necessary skilled personnel and technology, making reef mining a relatively quick way to source aggregate. This approach was purely adopted for the sake of expedience in the wartime context, with no regard for sustainability concerns. It is also the only way to source large boulders locally in RMI, therefore was favoured over the option of importation, which is costly, logistically challenging, and time consuming.

However, reef mining undermines efforts to strengthen coastal resilience. The very presence of islands in RMI is because coral reefs were able to grow vertically and keep pace with rising sea levels since the last glaciation, providing the foundations for island-building processes. Therefore, the ability of reefs to keep pace with current rising sea levels is a key factor which will determine the future resilience of islands in RMI. Ocean acidification, ocean warming, and anthropogenic stressors are significant concerns which threaten to inhibit reef growth. Reef mining is undoubtedly the most destructive anthropogenic stressor as it actively removes reef and lowers the platform level by meters.

Coral reefs serve as natural protective barriers to incident ocean wave energy, reducing coastal risks along reef fringed coastlines (Ferrario et al, 2014; & Beck et al, 2018). There is concern that sea level rise will outpace the capacity of coral reefs to grow and maintain their wave protection function, which will exacerbate coastal flooding, erosion of adjacent shorelines and threaten coastal communities (Kench et al, 2022). The reef crest and outer reef flat are the most important parts of the reef system providing this natural protective function (Kench et al, 2022). The physical footprint of existing reef mining pits in RMI is typically shoreward of this most important zone, nevertheless the associated impacts of mining (such as turbidity) will impact this important zone, however studies related to this are limited. Numerical modelling suggests that pits can either decrease or increase wave runup (Klaven et al, 2019). Quantifying the impacts of specific pits on ocean wave energy transformation across the reef flat would require detailed modelling, preferably informed by direct instrumentation prior to and after the excavation of a pit. A detailed assessment of current reef mining in RMI was outside the scope of this study, therefore such information is not available.

SPC observed some coral regrowth in several of the pits in Majuro and Ebeye. However, it was not particularly dense, being largely confined to remnant boulders and the edges of the pits, with algae being more abundant (Figure 19). The pits are used by community members for fishing and swimming. Some of the pits (notably younger pits) have relatively high turbidity, therefore impacting water quality, and potentially the health of fish, coral, and other organisms. Detailed marine biological surveys and water quality testing of pits was outside the scope of this study but is recommended to support the management of existing pits in RMI. This should extend to the reef around the pits, such as the important reef crest environment. This could include the installation and monitoring of Coral Reef Accretion Frames adjacent to pits and at control points away from any anthropogenic stressors, to measure respective reef accretion rates.

Figure 19: Example of coral regrowth in a reef mining pit on Majuro atoll. Note the coral is growing on remnant boulders and algae is abundant.

However, arguably the most serious impact of reef mining is the contribution to coastal erosion. As discussed previously in the geology section, the coral reef crest is the most productive area for sediment. Under natural conditions, this sediment is transported by waves and currents across the reef flat and is the primary material which has built the islands of RMI. Excavating pits on the reef flat creates a sediment sink whereby sediment is lost into the pits and thus does not reach the beach. See Figure 20 for an example of sand accumulating in the oceanside of a pit in Majuro. Therefore, reef mining induces erosion by cutting-off sediment supply to the island.

Figure 20: Sand accumulation on the oceanside of a pit in Majuro.

Multiple past studies have documented the adverse impacts of reef mining and recommended that RMI prohibit reef mining and transition to more sustainable options (Xue, 1997; Mckenzie et al, 2006). The transition away from reef mining has proved challenging and it continues to be practiced in RMI. One reason for this difficulty is that alternative options do not exist locally for the extraction of large boulders (such as those used for coastal protection) and importation is cost prohibitive. A potential solution to this dilemma is to produce precast concrete armour units made from local sand and gravel, or adopt alternative coastal protection designs which do not use rock armour. There are several examples of this already being done in RMI. SPC's recommendation is to prohibit reef mining and transition to more sustainable options as per the previous studies. However, it is the role of local decision makers to determine whether to continue reef mining or not, balancing local environmental, social, and economic factors. In this regard, 80 years of history since reef mining first commenced and 27 years since SOPAC first recommended the practice be prohibited, suggests that the pressures from this local context have prevented the prohibition of reef mining. If reef mining continues to be practiced, new sites should be located far from any land or ocean habitat which RMI wishes to maintain, fully cognisant that such areas are sacrificial. But we emphasise that SPC's recommendation is to prohibit reef mining and transition to more sustainable alternatives as outlined in this study.

6.3 Land Mining

Figure 21: Pit on Funafuti atoll in Tuvalu following land mining to construct a runway during WWII.

Land mining is the practice of excavating (hand, mechanically or with explosives) sand, gravel, or rock resources located on land. This is a common practice globally and in most circumstances is the most responsible way to source aggregates, as the impacts are confined to a localised area with potential for rehabilitation after extraction. Additionally, from an economic perspective, it is a relatively simple and convenient way to source aggregates.

However, the islands of RMI are relatively small, therefore land is scarce and precious. Thus, pits left behind by land mining activities can exacerbate existing land scarcity issues, such as population density, coastal hazards, and climate impacts. For example, in Funafuti (Tuvalu), 8% of the land was rendered un-useable following pits excavated to source aggregates for runway construction during World War II. The pits became polluted ponds which were a health and environmental hazard (Figure 21). The damage in Funafuti was eventually rehabilitated by dredging sediment from the lagoon and infilling the pits, at a significant cost. This case study demonstrates the potential adverse consequences of land mining in an atoll context, particularly on an urban atoll with high population density, such as Majuro and Ebeye.

However, in the outer islands of RMI (with lower population densities and demands for aggregate) there is potential to consider land mining as a sustainable, circular-economy alternative to beach mining. Whereby pits could be designed and excavated to create productive assets for the community, such as traditional agricultural pits or fishponds, and the material extracted from the pits be utilised as aggregates. However, this approach is not viable on an urban atoll context such as Ebeye or Majuro.

6.4 Lagoon Dredging

Figure 22: Lagoon dredging for the Tuvalu Coastal Adaptation Project in Funafuti. Source: Hall Dredging.

Lagoon dredging involves the extraction of sand and gravel from inside the atoll lagoon. Dredging can be caried out by a variety of different dredging technologies, including, cutter-suction (as shown in Figure 22), trailing suction hopper, dragline, backhoe, clamshell, or bucket dredgers (CIRIA, 2018). The most appropriate dredging technology for any given dredging operation depends on site specific circumstances such as scale, budget, geology, and environmental circumstances.

In an atoll context, lagoon dredging is generally considered the most sustainable approach to sourcing aggregates. This is principally because lagoon aggregate deposits consist of material which has been lost from the island system (see Figure 13). Thus, these deposits are considered as 'sediment sinks'. In simple terms, an atoll can be thought of as a bucket. The outer rim of the bucket represents the reef crest where most of the sediment is produced. Some of this sediment is deposited on the rim of the bucket to form islands, and some sediment is eroded from the rim and lost inside the bucket. Lagoon dredging is effectively collecting the sediment from inside the bucket and putting it back up onto the rim. Therefore, extracting material from inside the lagoon will not lead to coastal erosion, provided the dredging location is not connected to the beach or nearshore environment.

Subsequently, lagoon dredging is the focus of this Aggregates Study and is assessed in detail in each of the respective technical reports produced. Several past studies have provided technical support towards establishing lagoon dredging in Majuro (Smith, 1995; Xue, 1997; Smith and Cullen, 2004; McKenzie et al, 2006; and Tawake & Kumar, 2008). This Aggregates Study seeks to build on the previous work in Majuro and undertake the first assessment of lagoon aggregate resources in Ebeye.

6.5 Importation

Figure 23: Aggregates from Fiji exported in shipping container.

Importation of aggregates involves the extraction of aggregates in another country and shipping it to RMI. From a perspective purely focused on the environment of RMI, this is the most favourable way to source aggregates as it does not involve any extraction in RMI.

However, when the social and economic dimensions are considered, importation is a less favourable approach. Importation removes the potential for local employment and the associated linkages to the local economy, thus undermines the concept of development minerals. Importation dramatically increases the price of aggregates and can cause mineral insecurity issues. RMI is one of the most remote nations in the world, with limited shipping services and facilities. Therefore, the cost of importing aggregates is relatively high and is unaffordable for the average household in RMI.

Nevertheless, aggregates are occasionally imported to RMI for specific purposes. The decision to import aggregate is typically made for two main reasons. Firstly, importation occurs when locally produced aggregates do not meet certain quality specifications required for a specific engineering design. For example, high strength concrete for multi-storey buildings. Secondly, for infrastructure funded by development partners, the decision to import aggregate is made during environmental and social safeguards assessment if it is determined that local aggregate suppliers do not comply with the respective safeguard standards.

Analysis of the options for importing aggregate to RMI was conducted as part of the Market Assessment component of this Aggregates Study.

7. Geophysical investigations

In 2023, SPC conducted geophysical investigations of aggregate resources in the lagoons of Majuro atoll and Kwajalein atoll (adjacent to Ebeye islet). These geophysical investigations purely focused on 'lagoon aggregate resources' because these resources represent the most sustainable option for sourcing aggregate in an atoll context, as highlighted in the prior section. A summary of the investigations is provided below. The reader should refer to the respective geophysical investigation reports for further details. The investigations comprised the following principal components:

- 72.48 line-kilometres of seismic reflection data
- 140 line-kilometres of gradiometer data
- 75 sediment samples collected for composition analysis and particle size distribution testing

Additionally, bathymetric-topographic LiDAR data and aerial imagery acquired in 2019 was an excellent baseline dataset for the geophysical investigations.

The investigations in Ebeye focused on six lagoon aggregate resources sites as shown in Figure 24.

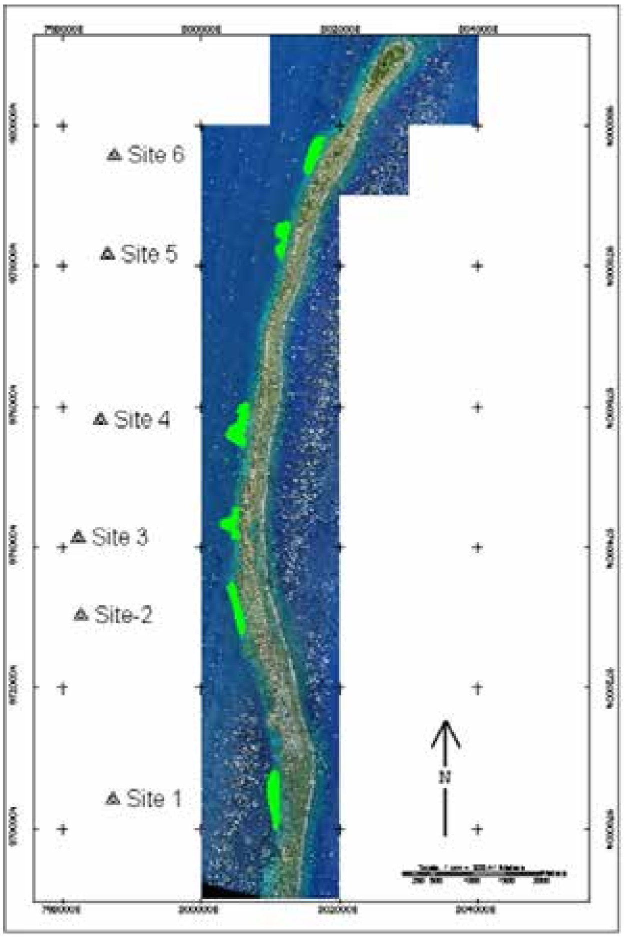

Figure 24: Lagoon aggregate resource site locations investigated in Ebeye, shown in green.

The investigations identified significant aggregate resources at all six site locations. An overview of the resource volumes is provided for the respective sites in the Table below. The total resource volumes presented for each site represent the totality of sediment at each respective location above the top of the second reflector on the seismic reflection data, maximum depths of this surface are provided in brackets. A total aggregate resource volume of 8.3 million yd^3 was identified across the six sites. Composition analysis revealed the sediment is dominated by foraminifera across all six sites, with varying inclusions of other carbonate sediment, including coral, bivalves, gastropods, and halimeda. Particle size distribution testing indicated the sediment is predominantly sand sized with varying amounts of gravel.

Table 1: Summary of aggregate resources identified in Ebeye.

EBEYE		
Site	**Depth (m below msl)**	**Resource volume yd^3 (m^3)**
Site 1	Total resource (-36 m)	1,534,836 (1,173,466)
Site 2	Total resource (-32 m)	979,502 (748,883)
Site 3	Total resource (- 20m)	1,132,315 (865,717)
Site 4	Total resource (-36 m)	2,333,035 (1,783,733)
Site 5	Total resource (-25 m)	1,294,803 (989,948)
Site 6	Total resource (-30 m)	992,544 (758,855)
Total resource volume (m^3)		**8,267,035 (6,320,602)**

The investigations in Majuro focused on four lagoon aggregate resource sites as shown in Figure 25.

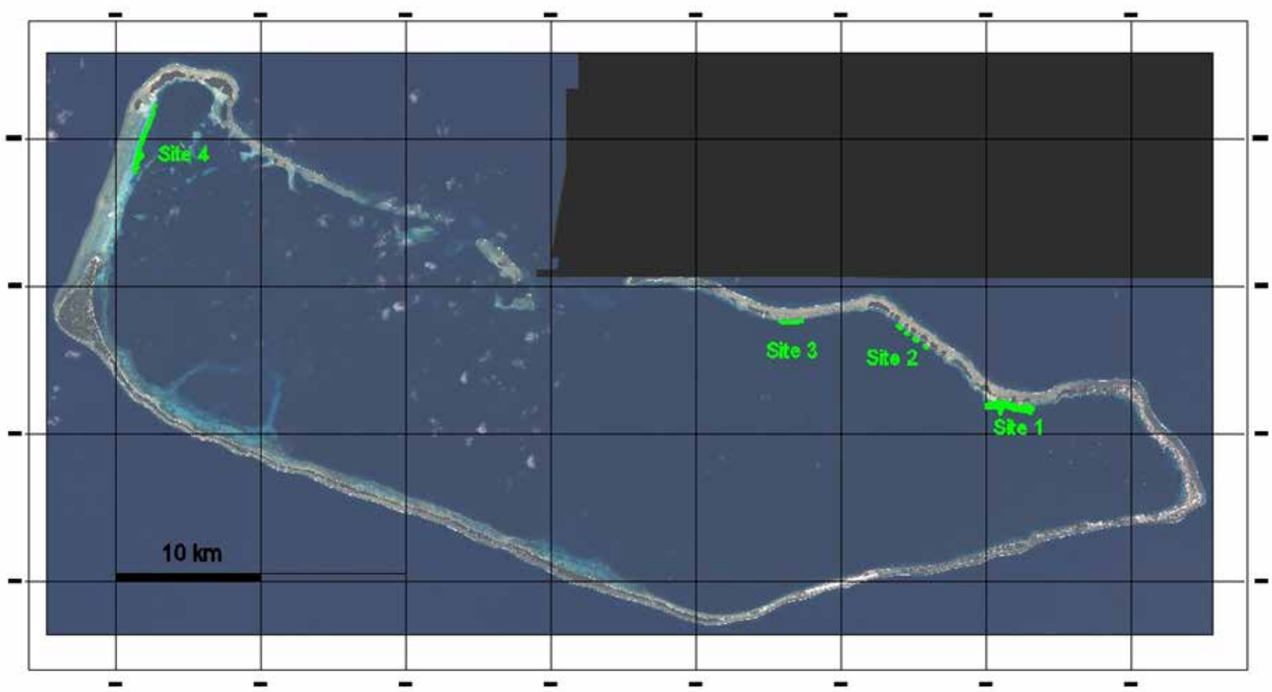

Figure 25: Lagoon aggregate resource site locations investigated in Majuro atoll.

The investigations identified significant aggregate resources at all four site locations. An overview of the resource volumes is provided for the respective sites in the Table below. The total resource volumes presented for each site represent the totality of sediment at each respective location above the top of the second reflector on the seismic reflection data, maximum depths of this surface are provided in brackets. A total aggregate resource volume of 13.6 million yd^3 was identified across the four sites. Composition analysis revealed the sediment is dominated by foraminifera across sites 1, 2 and 3, with varying inclusions of other carbonate sediment, including coral, bivalves, gastropods, and halimeda. Site 4 has varying compositions either dominated by coral, halimeda, or foraminifera. Particle size distribution testing indicated the sediment is predominantly sand sized with varying amounts of gravel, the sand is finer at Site 4 indicating a lower energy depositional environment.

Table 2: Summary of aggregate resources identified in Majuro.

MAJURO		
Site	**Depth (m below msl)**	**Resource volume yd^3 (m^3)**
Site 1	Total resource (-36 m)	6,028,477 (4,609,101)
Site 2	Total resource (-32 m)	1,617,799 (1,236,896)
Site 3	Total resource (- 20m)	1,606,949 (1,228, 601)
Site 4	Total resource (-36 m)	4,340,702 (3,318,705)
Total resource volume yd^3 (m^3)		**13,593,927 (9,164,702)**

*Note: according to the "Environmental and Social Assessment (ESA) of Sustainable Aggregate Extraction and Use in Majuro and Ebeye, the Republic of the Marshall Islands (2022)", Site 4 is located within an extraction exclusion area.

Gradiometer surveys were conducted to detect magnetic anomalies, to assist with the future management of risk associated with unexploded ordinance (UXO) from WWII. Identified magnetic anomalies represent potential UXO's, however the anomalies could represent any form of pollution containing iron. Inspection of detected anomalies by SCUBA was not conducted. A summary of the mapped anomalies for each site is presented in the Table below.

Table 3: Summary of magnetic anomalies detected in Majuro and Ebeye.

MAJURO		
Site name	**No. detected anomalies**	**Comments**
Site 1	2	2 minor isolated anomalies within the resource area
Site 2	3	3 isolated anomalies within the resource area
Site 3	2	2 isolated anomalies within the resource area
Site 4	2	2 isolated anomalies within the resource area
EBEYE		
Site name	**No. detected anomalies**	**Comments**
Site 1	12	Bulk of anomalies clustered in two specific locations
Site 2	15	4 minor anomalies scattered in the southern part of the resource area, but the bulk of anomalies are outside the resource area to the south
Site 3	4	4 minor isolated anomalies scattered throughout the resource area
Site 4	1	1 minor anomaly in the lagoon shelf edge in the centre of the resource
Site 5	4	4 minor isolated anomalies scattered throughout the resource area
Site 6	15	6 minor isolated anomalies within the resource area, and a large cluster of anomalies outside the resource area to the south

8. Environmental and Social Assessment

This assessment aims to inform the Aggregate Study on environmental and social factors that are important to consider before selecting the location of aggregate extraction. The ESA specifically reviews aggregate resources; the sustainability of aggregate mining; environmental impacts of dredging or mining; dredging types and capabilities; marine water quality; marine ecology, coastal processes; and coastal vulnerability to coastal hazards, sea-level rise (SLR), and climate change. Gendered assessments have also been carried out. Furthermore, geographically referenced information (GIS) consisting of an array of bathymetric, topographic, survey datasets, and environmental and social data has been produced.

An Annex to the ESA report was also developed that focuses on the sites subsequently investigated by the Geophysical and Market Assessments to further consider the sustainability of aggregate mining (noting the definition of sustainable aggregate extraction provided in the ESA and Section 3.3 of this report), potential environmental and social risks and impacts and how these can be mitigated and managed.

8.1 Environmental Assessment

8.1.1 The ESA Report

The environmental assessments for the ESA utilised existing data and reports, LiDAR surveys and collection of additional benthic information (substrate and benthic communities via drop-camera surveys (57 in Majuro lagoon and 39 in Ebeye lagoon).

From previous studies and undertaking drop camera surveys in Majuro and Ebeye, both ecological health and lagoon bed compositions were defined to determine preliminary locations of potential aggregate extraction. It was found that Majuro Atoll had a healthy, rich coral reef at some locations, with the most impacted areas located near Delap - Uliga–Djarrit and the stretch of reef along the southern side of the atoll, while the ocean side sites were observed to have high coral cover and diversity. Two previous studies of the ecological health of Ebeye provide evidence in support of the local assumption that the reefs at the northern end of Ebeye, and potentially other areas, are in a degraded ecological condition.

A general investigation into the environmental impacts of dredging was undertaken, with the findings showing that, if the right location and dredge technique are not selected, there are likely to be major negative impacts on benthic fauna due to sediment stress. This is particularly the case for fine sediments, which have been found to result in long recovery times for benthic communities (especially corals) and sometimes they do not recover at all. A previous study consisting of a 3D numerical simulation of Majuro Lagoon was analysed, with results indicating that dredge plumes within the surface layers would be directed toward and possibly out of the Calalin Channel, but this is plume size dependent. Importantly, if the dredge site were in the middle eastern part of the lagoon, plumes would not be directed towards corals reefs, located to the north, east, and south. There was no such study available for Ebeye.

In order to minimise the detrimental effects of dredge plumes, it is recommended that a hydraulic dredge is used. Encircling the dredging operations with turbidity curtains can be an effective method of containing plumes generated by dredging, although it is noted that these methods are difficult to apply in deep areas so are only recommended in the case that the final extraction locations are in relatively shallow waters.

The GIS database that was compiled contains all existing relevant GIS datasets (links to the GIS and metadata are included in the ESA report), which was used to inform the wider aggregate study on areas where aggregate can be mined in an ecologically and environmentally sustainable manner at both Majuro and Ebeye. The GIS also included sites of cultural, social and heritage significance. The combined data provided usage and exclusion mapping of Majuro and the Ebeye area of Kwajalein. This allowed for the classification of Prospective Mining Areas (PMAs) in the Majuro and Ebeye lagoon areas, where environmental/ecological and social/cultural values were found to be low, and Extraction Exclusion Area (EEA) for environmental/ecological and social/cultural reasons.

8.1.2 The Annex to the ESA

The Annex to the ESA was developed following the Geotechnical and Market Assessments. The Geotechnical Assessments investigated 4 sites on Majuro and 6 on Ebeye. 3 of the 4 sites at Majuro are considered suitable Prospective Mining Areas (PMAs), and all 6 sites at Ebeye are considered PMAs based on environmental, social and cultural exclusion mapping. Site 4 at Majuro is classified as an Extraction Exclusion Area (EEA) for environmental and social/cultural reasons (close proximity to marine ecological communities and a site of WWII relics), and also has finer sand fractions than the other 3 sites.

As noted in Section 7, magnetic anomalies (i.e., potential unexploded ordinances (UXOs) were found at all sites, with higher numbers found in the Ebeye sites; these will require consideration in terms of removal and/or exclusion.

Potential risks and impacts have been identified for the sites at Majuro and Ebeye, and measures to mitigate them have been recommended, noting that each site will likely require differing measures to mitigate risks and impacts; these can be developed through the EIA process and associated environmental management plans (EMPs). The recently developed 'Good Practice Guidelines in Environmental Impact Assessment for Coastal Engineering in the Pacific' (SPREP, 2022) has been appended to the Annex as a guide to developing site-specific EIA's, and provides the generic code of practise to guide downstream ESMP development, it considers environmental and social impacts, mitigation, monitoring, planning, etc., as well as a range of case studies.

8.2 Social Assessment

As part of the Environmental and Social Assessment (ESA) for Sustainable Aggregate in Majuro and Ebeye (Kwajalein) undertaken in 2021, multiple methods of stakeholder engagements were undertaken to gather data regarding key issues and concerns. The methods included public community consultations in selected communities in both Majuro (Ajeltake, Delap, & Laura), and Ebeye, the distribution of survey questionnaires with responses from various communities (Marjuro: Ajeltake, Delap, Laura, and Jeirok & Kwajalein: Ebeye, Tobukle, Bouj, Jablur, and Lole), one on one interviews and focus group discussions, meetings with the Steering Committee, field work, surveys, specific information requests from authorities through questionnaires, desktop research and literature reviews.

Below outlines the key findings of the Social Assessment.

8.2.1 Community

The need for aggregate is great in both Majuro and Ebeye, not only for current and future development projects but to also construct new (and strengthen existing) coastal protections. Issues with inundation and coastal erosion were highlighted as serious concerns by all stakeholders through the various engagements.

Women traditionally delegated their authority regarding land matters to a male family member; however, the women and their children are now taking a more active role and have more "social influence" as they continue to receive higher education and generate income.

Aggregate extraction can affect men and women economically. Any effects that hinder their access and use of the foreshore, nearshore, or offshore areas would affect their livelihoods and ability to generate income.

Displacement of a stakeholder either physically or economically should also be avoided where possible. Economic displacement can occur if, for example, extraction occurred within a local traditional fishing zone, for land access through private property to the foreshore, or near a private resort with ocean dependent activities.

While the surveyed households during the Social Assessment were outside the sites investigated by the Geotechnical Assessment (4 Sites in Majuro and 6 Sites in Kwajalein), the general information gathered is still relevant in forming the impacts and mitigation measures identified for the preferred sites. Additional potential risks and impacts have been further identified for the selected sites at Majuro and Ebeye, and measures to mitigate them have been recommended. However, it is to be noted that site specific information including land ownership and extraction and transportation methodologies will require further consultation during the site-specific EIAs to determine the key issues, concerns, and mitigation measures to be observed by the contractor. In particular, areas of cultural and ecological significance requiring protection or buffers, and areas of interest which supports their tourism activities and the livelihoods of the locals and businesses.

8.2.2 Land

Marshallese cultural and ownership traditions are considered the fundamental basis of Marshallese society, and have for the most part, been legally upheld through the Constitution of the Marshall Islands 1979. The tradition is so strong that 99% of RMI land is owned under customary tenure, the most of any small Pacific Island nation. However, interpretation of various Acts relating to land ownership (private, public and lease land) have created confusion on who owns what land. This confusion has led to years of complicated land ownership contentions and has left a gap between the legal land and resource ownership rights, and practical and daily experience of land use within RMI. The gap, therefore, can be seen as a potential risk if there is a dispute with the use of land and the aggregate resources and what legal processes have to be followed to obtain the necessary permits/licences.

Plans and compensation with respect to land acquisition, both voluntary and necessary, are also detailed in RMI laws and regulations, and the policies of development partners such as the World Bank, to ensure that fair and swift compensation is available.

However, it is recommended that an extensive public awareness campaign on the legislative requirements for land and the foreshore & marine environment ownership, development, and management beyond the high-water mark to the low-water mark, as well as in the lagoon and deep seas, is undertaken to ensure clarity on these critical and sensitive issues.

8.2.3 Legislation

For sustainable aggregate extraction, it is recommended that the legal framework for the process work within the current legislative context. It is noted that the current Earth Moving Regulations administered by the Environment Protection Authority (EPA) do not fully address the full suite of legal concerns relevant to aggregate extraction. Therefore, it is recommended that the existing regulations be reviewed to address current gaps, alternatively a new policy specific to sustainable aggregate extraction could be developed. This review (or new policy development) should ensure that the following aspects are addressed; the purpose or reason for extraction, quantity of aggregate extracted, timeframes for quantities, potential impacts, mitigation measures and penalties, environmental bonds), and compliance with existing regulations (e.g., the Environmental Impact Assessment (EIA) Regulations, the Historic Preservation Act, the Coast Conservation Act 1988, etc.).

It is vital that an institutional arrangement with the key stakeholders of EPA, Marshall Islands Marine Resources Authority (MIMRA), Ministry of Works, Infrastructure and Utilities (MWIU), Central Implementation Unit – Ministry of Finance (CIU), the Local Councils and the Office of the Chief Secretary come together to provide inputs and monitoring to ensure roles and responsibilities are clear and coordinated, with information being shared for better cohesive decision making on the future of aggregate extraction in RMI. This collaborative monitoring approach is key to establishing current baselines and setting future parameters to ensure the sustainable management of aggregate resources in RMI.

9. Market Assessment

The market assessment report provides a snapshot of the aggregate sector in Marshall Islands, investigating the sources of demand and supply for aggregates by local extraction or external sources. The report takes into consideration key findings of the Geotechnical Report mapping the aggregate resource in the Ebeye and Majuro lagoons, undertaken by SPC, and the environment and social assessment report developed by eCoast Consultants.

9.1 Profile of Aggregate Sector

The Geotechnical Reports identify significant volumes of aggregates at 8.3 million yd^3 at selected sites in the Ebeye lagoon and 13.6 million yd^3 in the Majuro lagoon. The Annex to the ESA Report categorises 3 sites on Majuro atoll as prospective mining areas and 6 sites on Ebeye atoll. This comprises a significant resource with current extraction rate estimated at 72,000 yd^3 per year. The resource is primarily rich in foram, halimeda and coral that form the main composition of concrete structures in Marshall Islands.

9.2 Supply Side

Extraction is primarily through beach mining, nearshore lagoon dredging and ocean side reef platform quarrying. Beach mining has been the traditional mode of obtaining sand, gravel, and beach rock for domestic needs and is the most destructive method of aggregate extraction practised mostly by the informal sector. Nearshore lagoon dredging provides access to greater volume of material usually using a crane and dragline but not sustainable as replenishment is diminished. Ocean-side reef blasting and removing coral rock, and debris, from the quarry holes or pits is also practiced to access large boulders.

Production of sand and gravel in Majuro and Ebeye is dominated by Pacific International Inc. (PII) extraction from its own quarry and import for compliance with stricter building standards such as the runway upgrade. The commercial prices of sand and gravel produced by PII are US\$70/yd^3 (US\$53.52/m^3) and US\$74/yd^3 (US\$56.58/m^3) respectively. AD Company is a smaller operator supplying aggregates on Ebeye Island with sand and gravel prices retailing at US\$80/ yd^3 (US\$61.16/m^3) and US\$90/ yd^3 (US\$68.81/m^3) respectively.

9.3 Demand Side

Aggregates extracted on Majuro and Ebeye including concrete blockmaking, and as an ingredient in concrete for construction. The Marshalls Japan Construction Company (MJCC) produces up to 500 blocks per day or up to 10,000 blocks per month and sells them at US\$3 for 4", and US\$4 for 6". Other hardware companies have imported concrete blocks but can't compete profitably with the locally produced blocks. AD Company produces about 300 blocks per day and sells at US\$3 for 4", and US\$3.5 for 6", and US\$4.25 for 8".

The Marshall Islands Government implements several construction projects and is the main client for aggregates. On Kwajalein, the local Kwajalein Atoll Development Authority (KADA) implements a few construction projects and with the recent extension of the Compact of Free Association agreement more public infrastructure projects are likely to be implemented. The Kwajalein Atoll Local Government (KALGov) indicated current aggregate usage rate at 6,500 yd^3 (5,000 m^3) per year. The national Government has a few large pipeline construction related projects over the next 5 years that include the Urban Resilience Project and upgrades to the main hospital, airport terminal and Capitol Building.

9.4 Contribution to the Economy

The mining and quarrying sector accounts for an almost negligible part of the national income of the Marshall Islands contributing 0.0% of total GDP. The construction sector's contribution to the economy dropped slightly from around 6% to 5% of total GDP in 2021. With high urbanisation and annual population growth, demand for aggregates is expected to increase.

9.5 National Policy Frameworks

The National Adaptation Plan (NAP) charts the country's response to the impacts of climate change and sea-level rise projections. For the period 2040 to 2050, the NAP's pathway plans for "decisions regarding which atolls to protect" and the need to reclaim land and build protection infrastructure to protect people and livelihoods. The NAP draws attention to the amount of filler material that will be needed to cover the reclamation work. The sea-level rise policy recommends progressively, high-grade coastal protections such as sea walls and revetments to address up to 20 in (0.5m) of sea level rise projected to occur between 2070 and 2090.

9.6 Aggregate Imports

Aggregates are imported from Fiji, Federated States of Micronesia, Nauru and Asia for specific projects. Landed Prices from Fiji for Sand: US$350/ yd^3 (US$267.58/m^3) Gravel: US$380/yd^3 (US$290.52/ m^3). Importing aggregates from Nauru and Federated States of Micronesia are too expensive due to shipping costs. Landed price for aggregates from Taiwan is around US$152 yd^3 and there could be a market for importation of Sland from New Caledonia.

9.7 Accessing Offshore Aggregates

The SPC geotechnical surveys identify environmentally sustainable source of aggregate from within the lagoon basin. The environmental costs of lagoon basin dredging can be reasoned to be outweighed by the costs and increased vulnerability caused by continued near-shore mining. In general, the operational costs of offshore aggregate mining are higher than nearshore mining.

Hydraulic Dredging Systems – These suck a mixture of dredged material and water from the seabed bottom. The hopper dredge is for dredging materials ranging from soft mud/silt to dense sands/clay and can transit quickly to dredging sites under its own power without the need for towing. A cutter suction dredge (CSD) sucks dredged material through the intake pipe at one end and directly discharges through a floating pipeline onto the placement site so can be very cost-efficient. For comparison purposes, the estimated cost for land reclamation in Tuvalu, as part of their climate adaptation initiative, is around US$15 million extending the land area by 6.1 Ha.

Mechanical Dredging Systems - Clamshell dredges can operate in restricted areas and work in all types of material including blasted rock. Various bucket and jaw designs are available to cope with a variety of bottom materials from soft mud to blasted rock. Dredging depth is limited by the amount of wire rope on the winch drums and leave an irregular bottom profile.

Dragline Dredging Systems - Uses wire ropes from the top and base of the boom to the bucket, casts the bucket forward and then pulls the bucket back through the material to be excavated. The bucket is a scoop and cannot close around the load which is a disadvantage due to washout. It is frequently used in small scale dredging operations of coarse sand or cobble operating from shore disposing material in the near-shore area. The backhoe or hydraulic digger combine the agility of the clam shell and the digging force of a power shovel.

9.8 Options to Access Offshore Aggregates

The Government will need to consider options to access the offshore aggregates at sites identified in the geophysical survey, through dredging, taking into consideration environment & social issues covered in the technical reports. In the Majuro lagoon, sites surveyed are located at a distance to the main Majuro urban centre so need to be transported across the lagoon for stockpiling. In the case of Ebeye, surveyed sites are adjaecent to where they are required and therefore easilytransported. The cost of dredging will differ and require more detailed analysis depending on the method of extraction and transportation.

Option 1 – To allow local private operators respond to market demand and supply of aggregates for construction by dredging at identified sites based on thresholds identified in the mining permit. This will require substantial capital investment with possibly one or two companies in the local market capable of investing in such an operation. Tax incentives can be considered for local companies who may be interested to invest however the risk of one company monopolising the market is to be considered as companies extracting aggregates are also involved in construction.

Option 2 - Contract an outside company to bring in their own dredging equipment for a specified period to supply a fixed volume. The cost of mobilising and demobilising to and from Marshall Islands is estimated at US$2.5 million so initial startup cost is relatively high. The operational cost is dependent on number of days and volume extracted estimated at US$8,000 per week (Ciria, 2018). This could be more appropriate for supplying one-off large volumes possibly for land reclamation.

Option 3 - Establish a state-owned enterprise for accessing the offshore aggregates similar to the operation in Kiribati. It will involve procuring a landing craft, outfitted with a dredging machine, including land-based logistical support and storage space. This will create opportunities for local employment and more fair distribution of aggregates at affordable market prices. A smaller mobile operation, that can easily be managed, with the advantage of deploying to other sites in Marshall Island group as needed. Start-up capital including 3 years operational cost could be in the range of USD5.6 million.

10. Discussion

A fundamental consideration in any mineral resource project is the difference between resources and reserves. A 'mineral resource' is "a concentration or occurrence of solid material of economic interest in or on the earth's crust in such form, grade or quality and quantity that there are reasonable prospects for eventual economic extraction". Whereas a 'mineral reserve' is "the economically mineable part of a mineral resource. It includes diluting materials and allowances for losses, which may occur when the material is mined or extracted and is defined by studies at pre-feasibility or feasibility level as appropriate that include application of Modifying Factors. Such studies demonstrate that, at the time of reporting, extraction could reasonably be justified" (CIM, 2014).

Accordingly, it is important to note that the volumes of aggregate presented in Geophysical Reports for Majuro and Ebeye are resources and not reserves. Therefore, the final reserve volumes available for extraction will be smaller than the reported resource volumes. The reserve volumes will need to be calculated in future by the entity seeking to extract aggregates from the identified resources, and the volumes will vary depending on the specific circumstances such as the equipment used, the dredge profile design, and conditions of approval for the site specific environmental and social impact assessment.

Below we have calculated indicative reserve volumes for Area 2 in Ebeye to illustrate this point and demonstrate how the transition from resources to reserves may reduce the volume of aggregate available. We emphasise that these calculations are indicative, and final reserve estimations will need to be calculated in future by the entity seeking to extract aggregates at any given location.

For the indicative resource volume calculations for Site 2 in Ebeye, we used two bench depths, one at 10m water depth and another at 15m, as shown in the cross section presented in Figure 26. The other important factor to consider is the angle of response for the slope on the shoreward side of the dredge excavation. For this exercise we have selected an angle of 30 degrees. This angle was informed by analysis of the existing slope angles in Area 2, which show natural slopes of up to 40 degrees (Figure 27). 2019 LiDAR data from Funafuti was also analysed to identify actual post-dredging slope angles at areas dredged in 2015. This analysis revealed post-dredging slopes between 45 and 47degrees as shown in Figure 28. Therefore, we interpret 30 degrees as a relatively conservative angle as it is shallower than the existing slope at Site 2 and actual post-dredge slopes in Tuvalu. A comparison between the reserve volumes and resource volumes in presented in the Table below, with reserves approximately 20% lower than resource volumes.

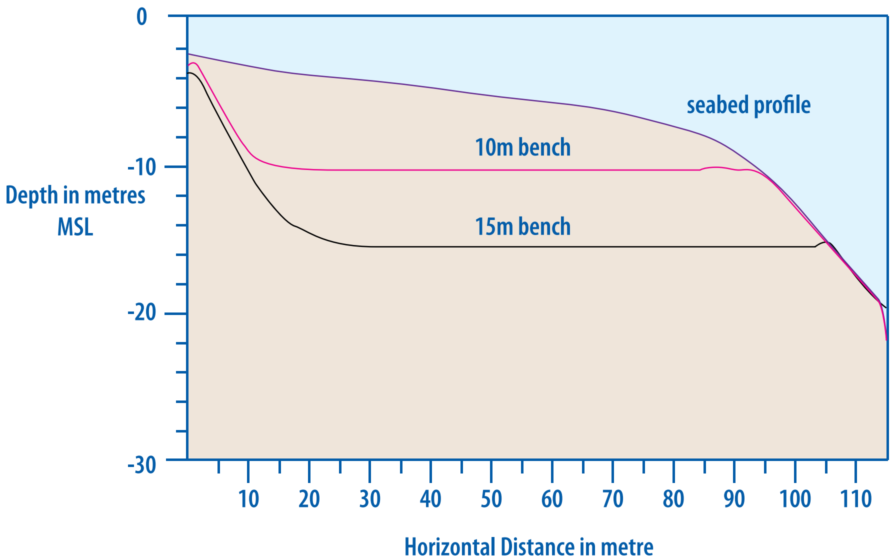

Figure 26: Cross section showing indicative reserves for Area 2 in Ebeye.

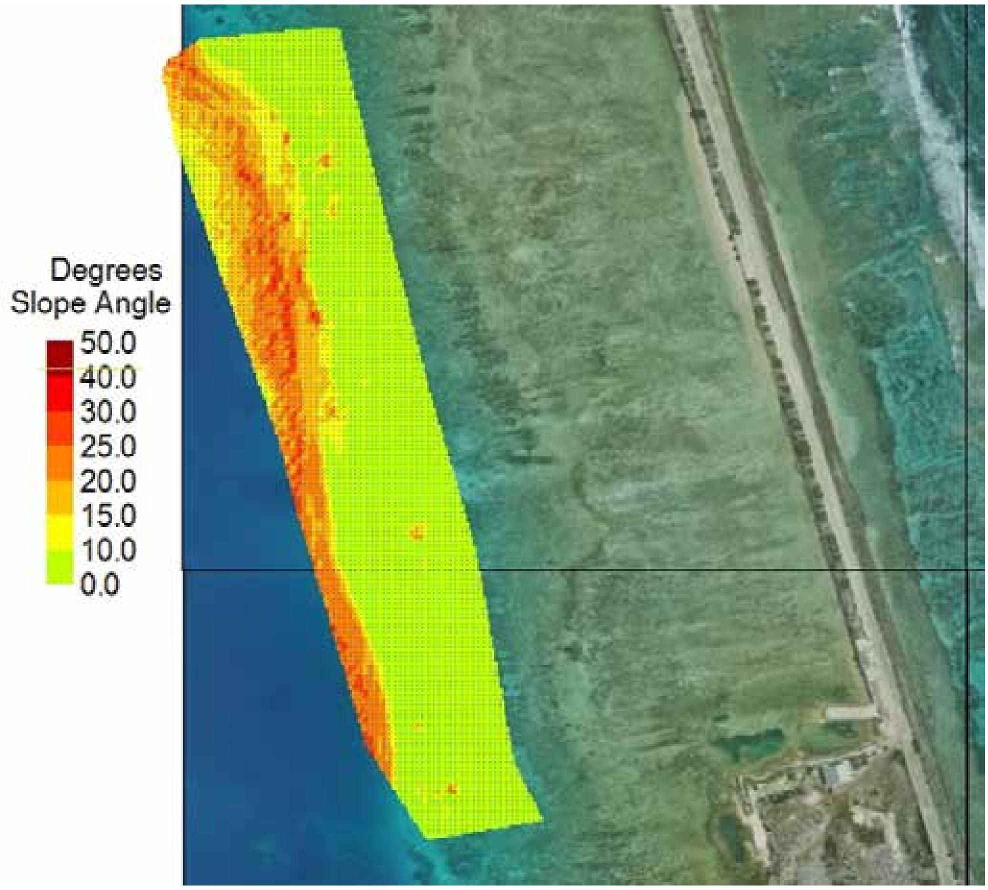

Figure 27: Existing slope angle map for Site 2 in Ebeye.

Table 4: Resource and reserve estimates for Site 2 in Ebeye to 10 m and 15 m bench depths

Bench Level wrt to MSL	Resource volume yd³	Reserve volume yd³	% change resource vs reserve
-10 m	224,687	183,442	-18.36%
-15 m	537,343	424,721	-20.96%

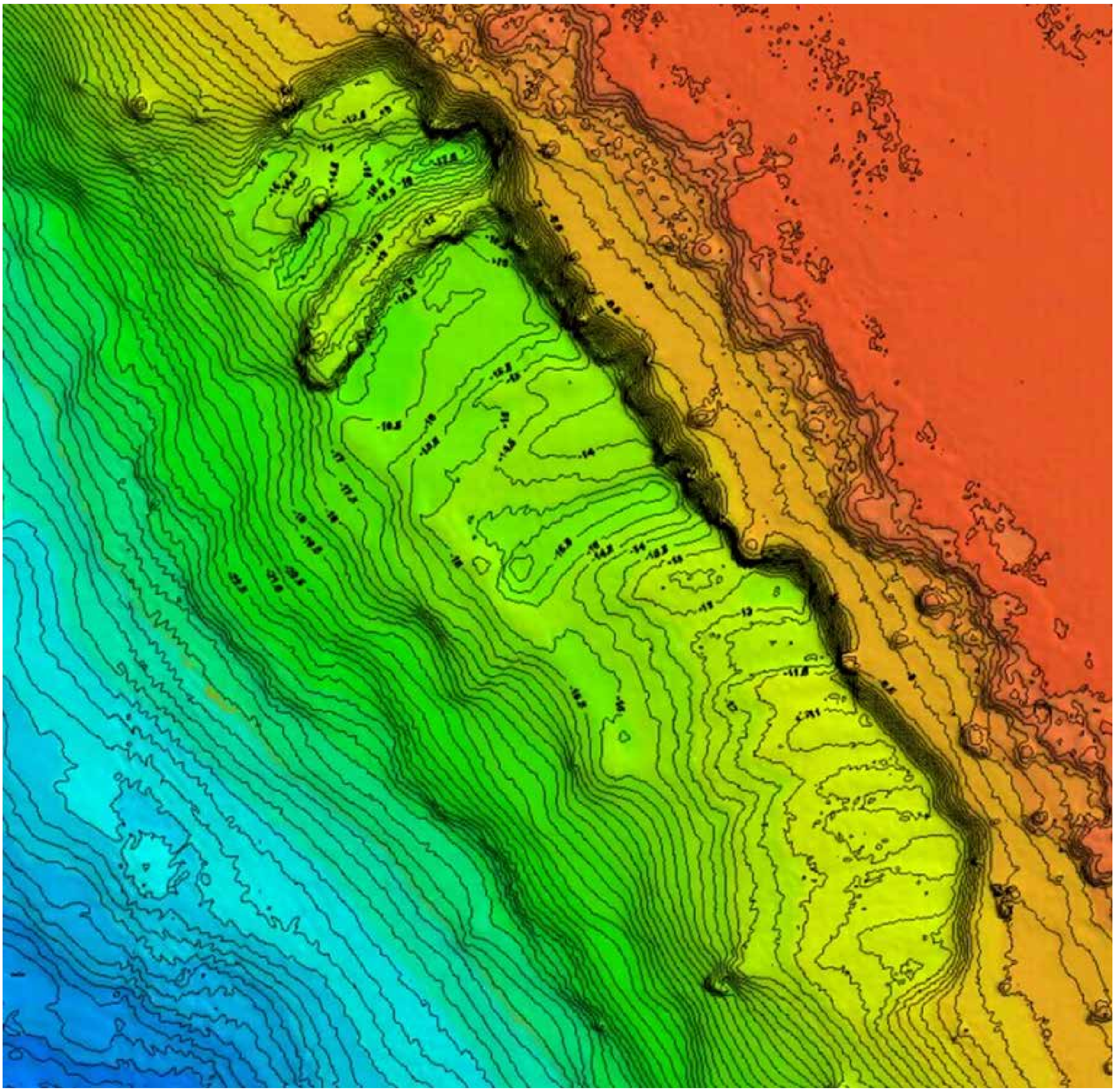

Figure 28: Post-dredging bathymetry in Funafuti, showing slopes between 45 and 47 degrees. The dredging was carried out in 2015 and the LiDAR bathymetry was collected in 2019.

As highlighted in the Ebeye Geophysical Report, Site 2 has potential to supply the material needed for a proposed land reclamation on the adjacent reef flat immediately north of Ebeye island. Importantly, the estimated reserve volumes presented in the table above indicate that sufficient reserves are available to meet the 376,920 yd^3 required for this land reclamation with a dredge depth of 15m. It should be noted that the reclamation material volume of 376,920 yd^3 is an estimate, and the final volume of material needed for the proposed reclamation will depend on the specific design geometry and compaction requirements. Likewise, the estimated reserve volume will vary depending on the bench depth, angle of repose, and dredge boundary area.

Another important consideration for lagoon aggregate resources is that the resource volume is dynamic. Over time new sediment will be generated and deposited on the resources, meaning the resource volumes can increase over time. The rate of sedimentation is dependent on the complex biophysical processes which generate and transport sediment. These processes are not linear and are typically episodic with relatively large influxes of sediment occurring during high wave energy events capable of transporting sediment from the ocean side into by the lagoon. For this reason, lagoon aggregate resources can be considered to have an element of renewability.

Quantifying this sedimentation at the resource scale requires monitoring through recurrent bathymetric surveys. Sediment traps are also a useful tool to quantify sedimentation at specific locations over a period of deployment. Fortunately, Site 1 in Majuro has two bathymetric surveys, a 2002 multibeam survey, and a 2019 LIDAR survey, which can be compared to assess the change in resource volume over this 17-year period. For this comparison.

Site 1 is comprised of multiple fan deposits associated with sediment transported through gaps between the islets on the northern rim of Majuro atoll. Therefore, to assess sedimentation rates of the individual fans of Site 1, three polygons were drawn on the respective fans (Figure 29). Bathymetric surfaces from the 2002 and 2019 datasets were derived and compared across these three areas. The results of this exercise are presented below and 2D cross sections from each polygon are presented for illustrative purposes. The calculations are based on constructed 3D models over the entire area of the polygons.

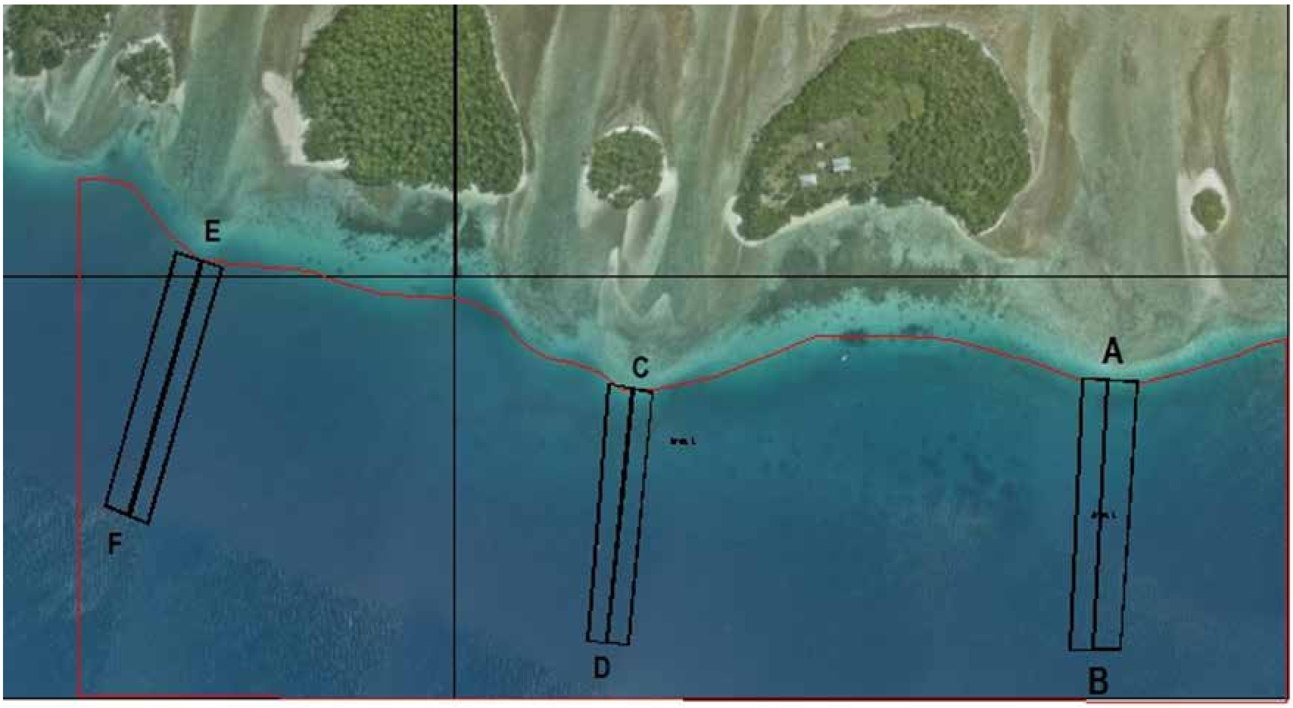

Figure 29: Polygons drawn on Site 1 in Majuro for the purpose of comparing bathymetric between 2002 and 2019.

The comparison between the 2019 and 2002 surfaces for polygon A-B sees a net volume gain of 5,198 yd^3 (3,974 m^3). This equates to an average of 33cm of sediment added to the slope across the area of polygon A-B, which gives an average sedimentation rate of 2cm/y between 2002 and 2019.

An illustrative cross section for polygon A-B is presented below.

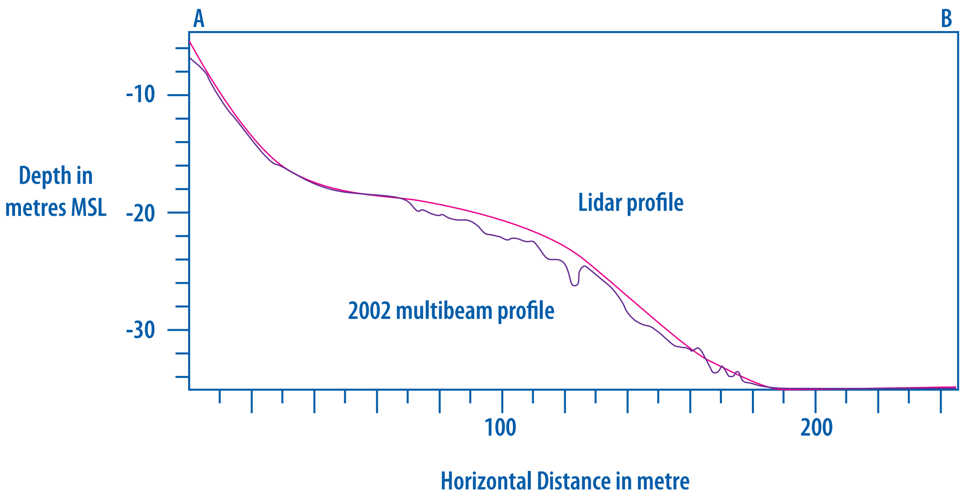

Figure 30: illustrative cross section showing the change in bathymetry in polygon A-B between 2002 and 2019.

The comparison between the 2019 and 2002 surfaces for polygon C-D sees a net volume gain of 4,666 m^3. This equates to an average of 51.2cm of sediment added to the slope across the area of polygon C-D, which gives an average sedimentation rate of 3.04 cm/y between 2002 and 2019.

An illustrative cross section for polygon C-D is presented below.

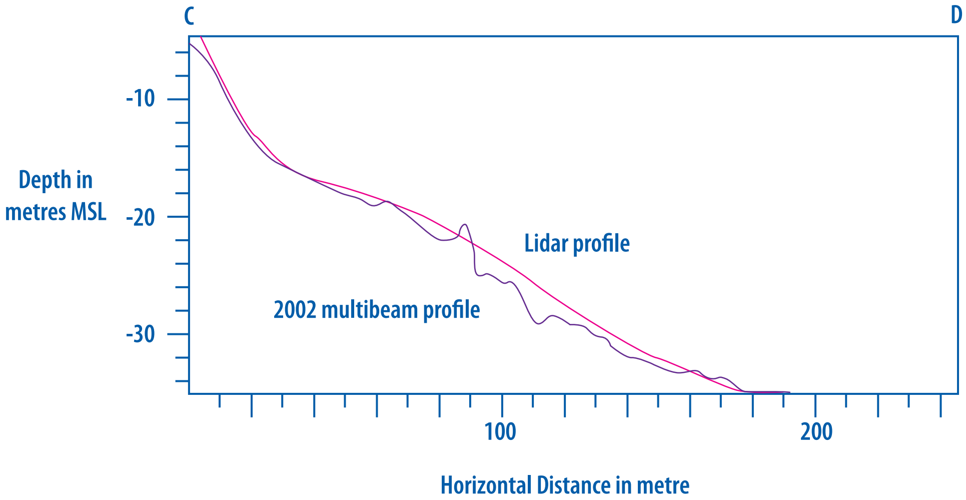

Figure 31: illustrative cross section showing the change in bathymetry in polygon C-D between 2002 and 2019.

The comparison between the 2019 and 2002 surfaces for polygon E-F sees a net volume gain of 5366.1m^3. This equates to an average of 51.8cm of sediment added to the slope across the area of polygon E-F which gives an average sedimentation rate of 3.05cm/y between 2002 and 2019.

An illustrative cross section for polygon E-F is presented below.

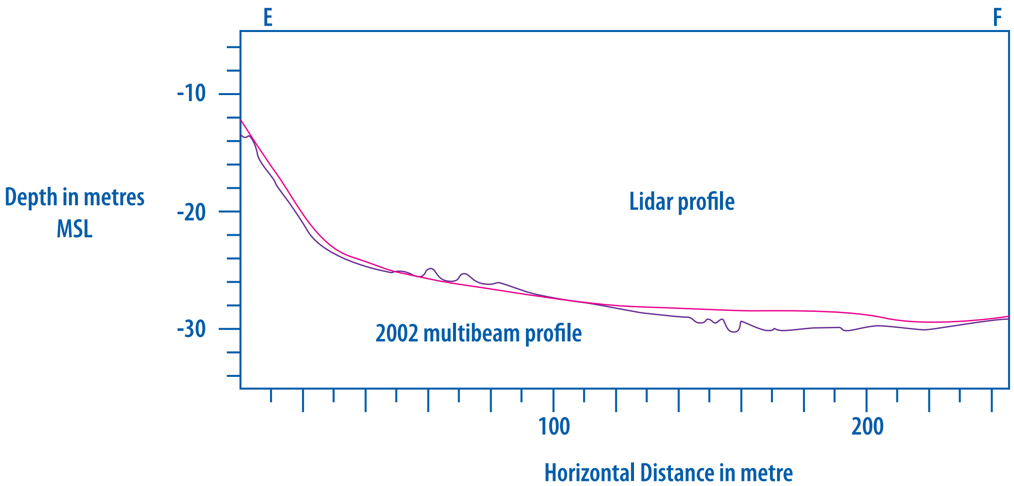

Figure 32: illustrative cross section showing the change in bathymetry in polygon E-F between 2002 and 2019.

This analysis demonstrates that new sediment is being transported through gaps between the islets, leading to increasing resource volumes for Site 1. This is indicative of the scale of sedimentation likely occurring at the lagoon aggregate resources in Majuro atoll. In Ebeye, sites 1 and 6 are likely also experiencing similar sedimentation processes. However, sites 2, 3, 4 and 5 have had causeways constructed on the adjacent reef flat to connect islets, which has cutoff sediment transport from the oceanside to the lagoon. Hence, these resources are likely to be experiencing much lower sedimentation rates, purely consisting of sediment generated in the lagoon.

These sedimentation rates are an important consideration in terms of the potential long-term resource and reserve volumes available. It is recommended that periodic bathymetric surveys be conducted to allow for further sedimentation analysis, to support the management of lagoon aggregate resources in Ebeye and Majuro. However, this element of renewability should not be conflated with sustainability and should not be a target for extraction rates. No country on earth issues permits for mineral extraction projects based on the target of renewability (except for very specific cases, such as river gravel extraction), as geological resources are inherently non-renewable in nature. Therefore, setting extraction thresholds based on renewability is an unrealistic target for RMI which would undoubtedly create mineral insecurity issues and undermine the broader context of sustainability. Therefore, even though sites 2 to 5 in Ebeye have ongoing sediment transport from the oceanside cut-off by causeways, this does not mean that aggregate extraction should be prohibited in these areas.

Depleting specific aggregate resources is standard practice globally and is considered sustainable so long as the environmental and social impacts associated with the extraction phase are managed appropriately, and the site is rehabilitated so that it is left in a state which is not a liability to people or the environment after the extraction phase (e.g. once the resource is depleted). Once a particular aggregate resource is depleted, the community which depended on that resource will subsequently need to source aggregates from another location. In most instances the replacement location is further away, subsequently incurring higher prices associated with transportation costs. Therefore, as highlighted earlier in this report, it is incumbent on present generations in RMI to utilise local aggregate resources wisely, to improve the circumstances in RMI, such as the economy and infrastructure, so that future generations are better placed to afford potentially more expensive aggregate resources sourced from further away.

To demonstrate this point, it is useful to apply this logic to a specific example in RMI. In this regard, there is a proposal to carry out a land reclamation project on the reef flat adjacent to Site 2 in Ebeye. The purpose of this reclamation is twofold, 1) create new land to alleviate population density issues, and 2) create elevated land resilient to the impacts of climate change and coastal hazards. This study has identified a geological reserve of 424,722 yd^3 (324,723m^3) at Site 2 (to a dredge depth of 15m), and an initial aggregate volume requirement for the reclamation is 376,921 yd^3 (288,177m^3). Hypothetically, let us assume that stakeholders in Ebeye decide to proceed with this reclamation and extract 376,921 yd^3 for use as fill material. Furthermore, a portion of this reclamation is designated as an aggregate storage area, and the remaining 47,800 yd^3 (36,546m^3) of Site 2 reserve is extracted and stockpiled on the reclamation for use in future construction projects in Ebeye. Is this considered unsustainable because the reserve was extracted at a rate exceeding its natural replenishment rate and subsequently the reserve has been depleted? According to the definition of sustainability applied to this study - the optimization of environmental, social, and economic outcomes for present and future generations in RMI – this hypothetical activity is clearly sustainable, provided the environmental and social impacts of dredging are managed during the extraction phase and the post-dredge bathymetry is appropriately designed. It is a pragmatic use of Ebeye's aggregate resources to create resilient land and economic opportunities for current and future generations in Ebeye. The aggregates were not sourced by beach or reef mining, which would create erosion issues and thereby undermine the efforts to create coastal resilience. The aggregates were sourced from the identified lagoon aggregate resources, which are the most responsible locations to source aggregates in an atoll context, as they are sediment sinks, and subsequently their extraction will not lead to coastal erosion. As such, this hypothetical scenario is an exemplary sustainable use of aggregates, as it epitomises the optimization of environmental, social, and economic outcomes for present and future generations in RMI.

Conversely, if the threshold of renewability was applied, this project would not go ahead. Meaning that current and future generations in RMI would be deprived of the opportunities presented by this reclamation and would be unnecessarily subjected to negative impacts from climate change, coastal hazards, and population density issues. Even if aggregates were to be imported from another country at exorbitant cost, the aggregate would not be renewable. For example, if aggregate were imported from quarries in Guam or Hawaii this material would have been extracted at rates far exceeding the geological processes which formed the rock (see Figure 33). This is why no country on earth applies a target of renewability for aggregate resources, as it would lead to catastrophic mineral insecurity issues and the decimation of the construction sector. Thus, renewability is an unattainable and harmful target when applied to aggregates and should certainly not be applied in RMI.

Figure 33: Quarry in Hawaii (left) and quarry in Guam (right).

Nevertheless, RMI has relatively limited geological resources by virtue of being an atoll nation. Therefore, it is critical that aggregate resources are managed and utilised responsibility through long-term planning. This will require effective collaboration between government, private sector, and the public. A summary of estimated aggregate reserves for the sites mapped during this study are presented in the tables 5 and 6 below. These estimates are calculated based on a depth of 20m below msl (which is a typical dredge depth for a mid-sized cutter suction operation) and a 20% reduction factor (from resource to reserve) informed by the earlier analysis in this discussion.

Table 5: Estimated aggregate reserves for Majuro.

MAJURO		
Site	**Bench Level: m below msl**	**Reserve volume yd^3 (m^3)**
Site 1	- 20 m	1,400,338 (1,070,636)
Site 2	- 20 m	923,315 (705,926)
Site 3	- 20 m	808,363 (618,039)
Site 4*	- 20 m	3,247,444 (2,482,852)
Total reserve volume yd^3 (m3)		**6,379,460 (4,877,453)**

*Note: according to the "Environmental and Social Assessment (ESA) of Sustainable Aggregate Extraction and Use in Majuro and Ebeye, the Republic of the Marshall Islands (2022)", Site 4 is located within an extraction exclusion area.

Table 6: Estimated aggregate reserves for Ebeye.

EBEYE		
Site	**Bench Level: m below msl**	**Reserve volume yd³ (m³)**
Site 1	- 20 m	1,126,523 (861,290)
Site 2	- 20 m	721,135 (551,348)
Site 3	- 20 m	905,850 (692,573)
Site 4	- 20 m	1,004,081 (767,676)
Site 5	- 20 m	792,669 (606,040)
Site 6	- 20 m	848,554 (648,767)
Total reserve volume yd³ (m3)		**5,398,818 (4,127,697)**

The total reserve estimate (to a dredge depth of 20 m) is 6.4 million yd^3 for the four aggregate resources mapped in Majuro, and 5.4 million yd^3 for the six aggregate resources mapped in Ebeye. Current aggregate consumption in Ebeye and Majuro is discussed in the Market Assessment section of this report. Future aggregate consumption will depend on specific future construction activity, which is unknown. Hence, it is not possible to accurately estimate the projected future consumption of aggregate in Ebeye and Majuro and subsequently how long the identified reserves could last before being depleted. However, the most significant future demand for aggregate is related to potential climate adaptation works involving land reclamation. Therefore, we have assessed the potential for the identified aggregate reserves to supply the material needed for some of the proposed reclamation works.

It is important to note that the reserve volumes presented above are only to 20 m water depth, based on a typical operating depth of a mid-sized cutter suction or clamshell dredge. However, it is possible to dredge to significantly deeper depths with larger dredging equipment. For example, a larger cutter section dredge can operate at 30 m, if a pump is installed on the dragarm of a trailer suction hopper dredge it is practical to dredge at depths of 60 m, and some larger systems are designed to operate at depths exceeding 100 m. The total resource estimates for Majuro and Ebeye are 13.6 million yd^3 and 8.3 million yd^3 respectively. Therefore, the reserve estimates presented in the tables above account for just 53% of the total resource in Majuro and 65% of the total resource in Ebeye. Hence, the reserve estimates presented above are conservative and could be increased substantially should deeper dredging technology be considered. It should be noted that the sediment in deeper locations will likely become halimeda rich and finer grained, which may not be suitable for some construction applications such as concrete manufacturing but is a useful material for land reclamation.

It is also important to recognise that the estimates presented in the tables above do not represent the totality of lagoon aggregate resources available in Majuro and Ebeye. These figures are only for the aggregate resources identified during this study. There are undoubtedly additional aggregate resources present in the lagoons on Majuro and Kwajalein, which if mapped would significantly increase the local aggregate resource base. Therefore, we recommend that additional investigations be conducted in future to understand the totality of the aggregate resource base in Majuro and Ebeye. For perspective, the total area of Majuro lagoon is approximately 324 km^2 (124 mile^2) and the total area of the 4 resource areas in Majuro is 0.92 km^2 (0.32 mile^2), representing just 0.3% of the total lagoon area. Likewise, the total area of Kwajalein lagoon is 2,850 km^2 (1,100 mile^2) and the total area of the six resource areas in Ebeye is 0.48 km^2 (0.19 mile^2), just 0.02% of the total lagoon area. It is also important to bear these numbers in mind when considering extent of the environmental footprint of any future extraction.

Additional resource mapping is particularly recommended to inform proposed reclamation works as RMI's climate adaptation planning progresses. In terms of dredging costs, it is cost effective to identify aggregate resources relatively close to the reclamation site, to avoid the need for booster pumping stations over longer distances. Experience from reclamation works in Funafuti using a cutter suction dredge suggests it is beneficial to identify resources within 1km of the reclamation, however specific distance-cost implications are dependent on the dredging technology.

The 'Atoll Study' conducted by Deltares and Tonkin & Taylor has identified areas in Majuro and Ebeye for reclaiming new land and raising existing land, as shown in Figure 34, Figure 35, and Figure 36. SPC survey locations were not informed by the Atoll Study, subsequently the investigations did not target strategically located aggregate resources for these proposed adaptation options. The sites were selected on the premise of identifying materials required for baseline construction needs in RMI, following interpretation of the LiDAR data and previous studies. However, the aggregate resources identified in Ebeye are in strategic locations to supply material for this proposed reclamation and land raising. Likewise, Site 4 in Majuro is strategically located to supply material needed for the proposed land reclamation and land raising in the western margin of Majuro near Laura. However, the aggregate resources mapped along the northern margin of Majuro atoll (Site 1, 2 and 3) are not in locations suitable to support the proposed reclamation. These resources were explored with the intention that they could replace existing extraction practices in Majuro and supply aggregate needed for baseline construction works, such as block manufacturing, concrete, and roadworks. Therefore, further mapping of aggregates along the southern margin of Majuro atoll would be required to identify resources needed for the proposed reclamation and land raising in this area.

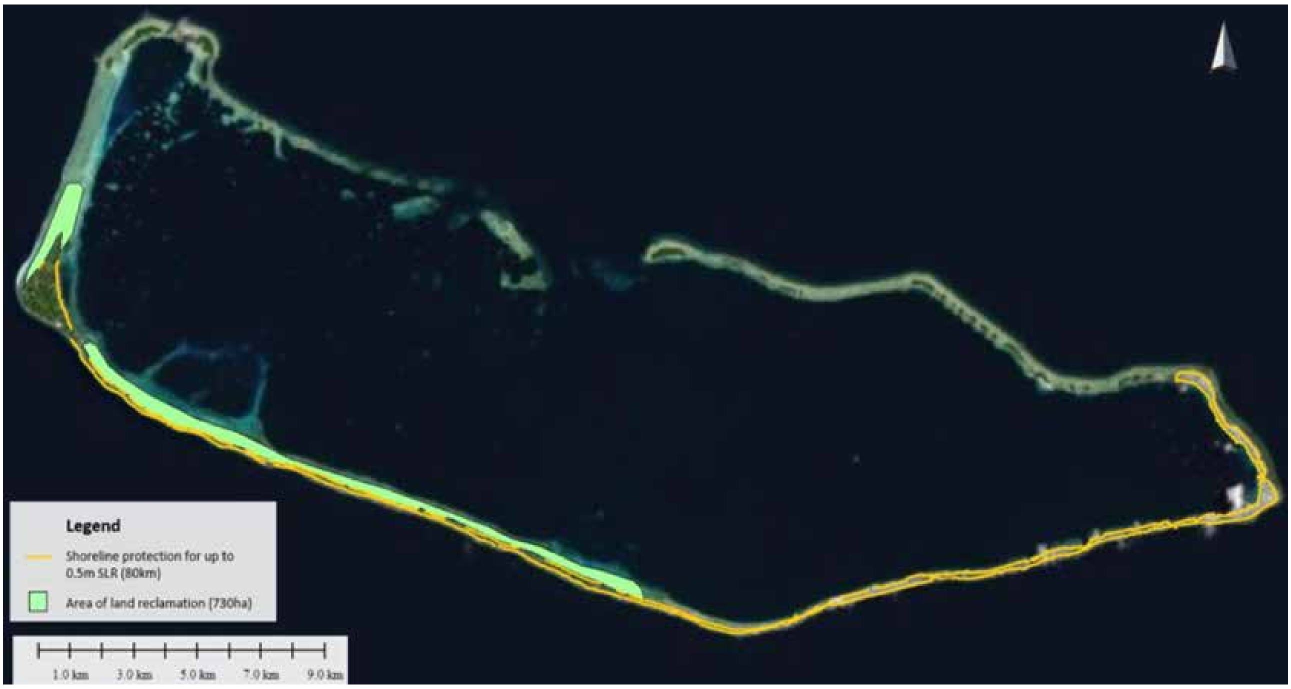

Figure 34: Proposed climate adaptation option for Majuro, comprising 730 Ha of new reclaimed land, and 80 km of shoreline protection. Source: Deltares and Tonkin & Taylor, 2021.

Figure 35: Proposed climate adaptation option for Majuro, comprising 730 Ha of new reclaimed land, and 80 km of shoreline protection. Source: Deltares and Tonkin & Taylor, 2021.

Figure 36: Proposed climate adaptation option for Ebeye, comprising 60 Ha of raised existing land, 100 Ha of new reclaimed land, and 19 km of shoreline protection. Source: Deltares and Tonkin & Taylor, 2021.

The Atoll Study does not provide any estimates on the volumes required for the proposed reclamation and land raising. Therefore, we have estimated volumes of aggregate required for the proposed reclamation areas adjacent to Ebeye island based on the LiDAR data as presented in Figure 37. These estimates are based on a reclamation elevation of 2 m above msl as outlined in the Atoll Study. This analysis reveals that Area 1 and 4 are located on reef flat areas with relatively shallow bathymetry, whereas Area 2 and 3 are in areas with relatively deep bathymetry up to ~10m depth. Subsequently, Area 1 and 4 superior reclamation locations in terms of the efficient use of aggregate resources, as they provide an opportunity to create 2.5 and 2.4 Ha of new land per 100,000 yd^3 of aggregate respectively. Conversely, Area 2 and 3 are relatively wasteful areas to locate reclamations as they only create 1.0 and 1.3 Ha of land per 100,000 yd^3 of aggregate.

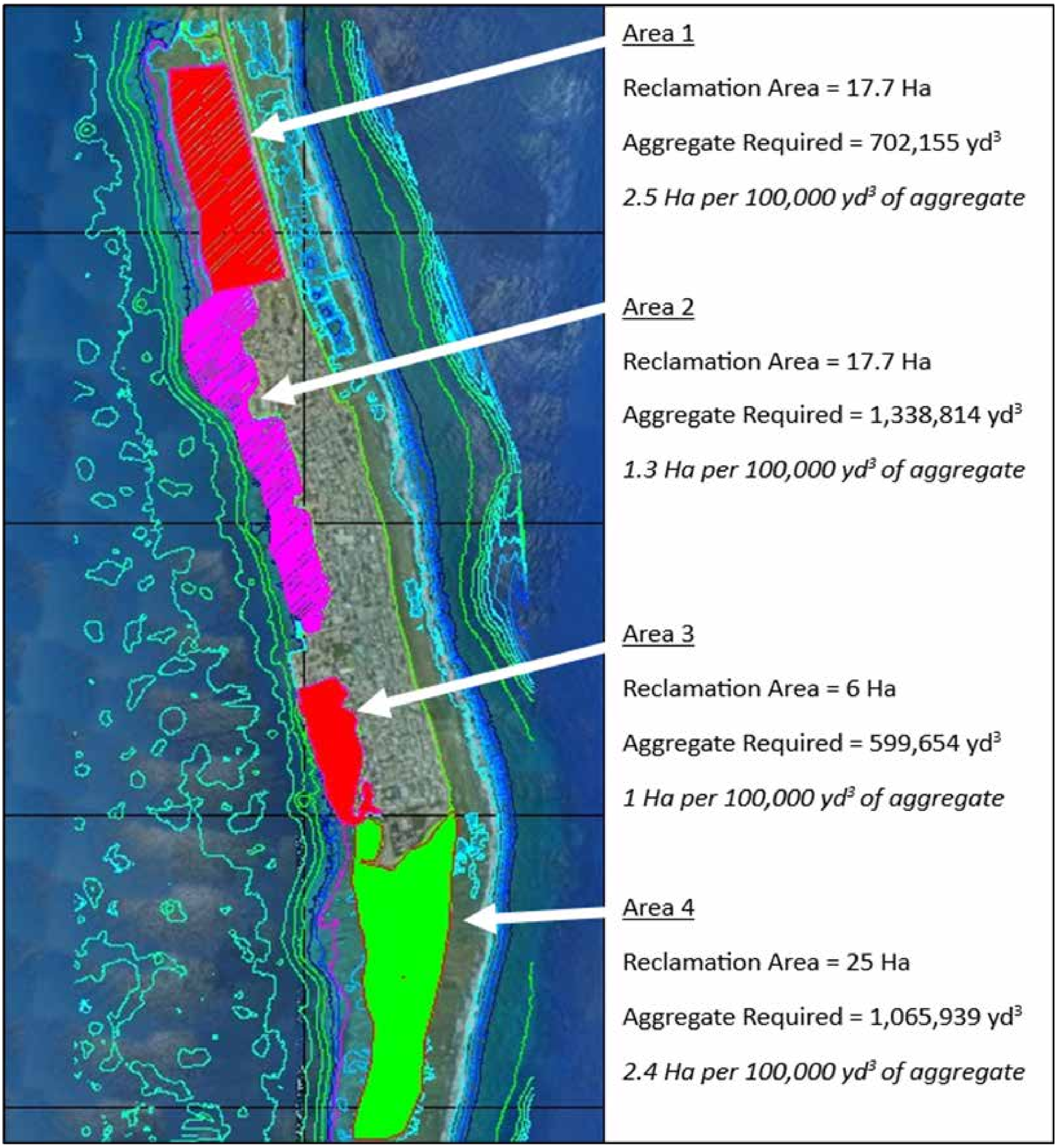

Figure 37: Analysis of the aggregate volumes required for the proposed reclamation areas in Ebeye.

We recommend that the efficient use of aggregate resources is at the forefront of RMI's long-term climate adaptation planning. In this regard, Area 1 and 2 represent the most efficient locations for land reclamation adjacent to Ebeye. The aggregate resources identified at Sites 1 and 2 are conveniently located to these areas and have sufficient volumes for these proposed reclamations (Figure 38). Site 1 is estimated to have aggregate reserves of 1,126,523 yd^3 at a dredge depth of 20m, and the Area 2 reclamation is estimated to require 1,065,939 yd^3. Site 2 is estimated to have aggregate reserves of 721,135 yd^3 at a dredge depth of 20 m, and the Area 1 reclamation is estimated to require 702,155 yd^3.

Figure 38: Aggregate resource locations with respect to proposed reclamation areas in Ebeye.

Site 4 in Majuro is located within close proximity to the proposed reclamation in the west of Majuro atoll, adjacent to Laura. The proposed reclamation has an area of 155 Ha and requires ~ 5,914,112 yd^3 of aggregate for an elevation of 2m above msl. This proposed reclamation is in an area with relatively shallow bathymetry and presents the opportunity to create 2.6 Ha of land per 100,000 yd^3 of aggregate. This is a relatively efficient use of aggregate resources. The adjacent aggregate resource at Site 4 has an estimated reserve volume of 6,155,084 yd^3 for a dredge depth of 25 m, sufficient to complete this reclamation. According to the ESA, Site 4 is located in an extraction exclusion area due to its proximity to marine ecological communities and a site of WWII relics. Therefore, if the proposed reclamation in Laura is seriously considered, there will be a need to assess the option of refining the boundary of the extraction exclusion area to allow for dredging of the resource at Site 4, provided sufficient mitigation measures are implemented.

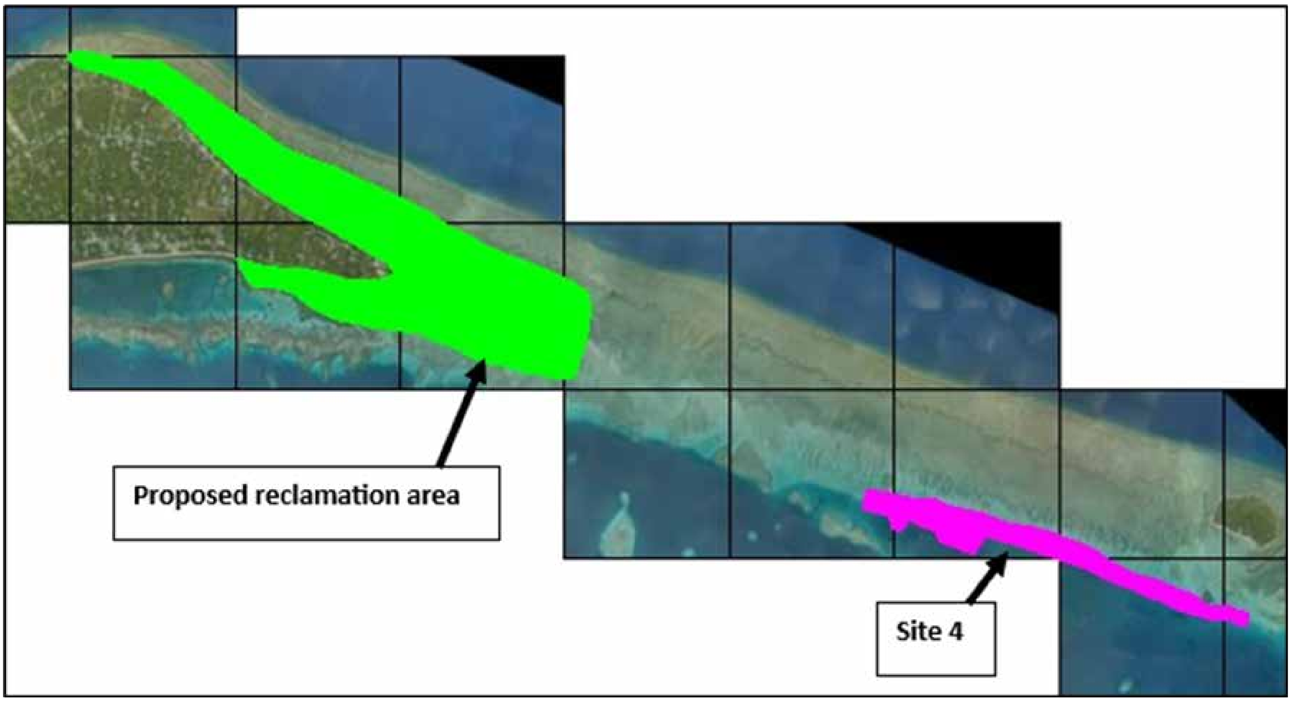

Figure 39: Proposed reclamation area in the west of Majuro atoll, with respect to Site 4.

We recommend that Government develops and implements plans for Ebeye and Majuro to transition away from (and prohibit) beach mining, reef mining, and nearshore dredging, and commence lagoon dredging as a more sustainable alternative. In Majuro, PII has an existing lagoon dredging operation on the south side of the lagoon using Sauerman equipment, which is extracting aggregate from the sediment sink in the lagoon down to a depth of ~27m. This site is the only existing lagoon dredging operation and is therefore considered to be the only existing sustainable aggregate extraction operation. It should be noted that this interpretation is based on the conceptual nature of the site and SPC has not carried out a detailed assessment of the environmental records and controls related to the site. Aside from this single lagoon dredging site, there are also several existing reef mining and beach mining operations supplying aggregates to the market in Majuro. Whereas in Ebeye there are no existing lagoon dredging operations, with all local aggregates currently sourced via beach mining, nearshore dredging and reef mining using an excavator. Given this context, an abrupt ban on beach mining, reef mining, and nearshore dredging would likely lead to mineral insecurity issues. Yet is vital that this transition is implemented as a matter of urgency, to avoid interruptions to the construction sector and to avoid additional adverse impacts of further beach mining and reef mining. It is important that any such plan is developed in consultation with the private sector with the expectation that the private sector be an active partner in this transition. If possible, we recommend that no new permits are issued for beach mining and reef mining, while opportunities be explored to establish lagoon dredging operations.

Should RMI decide to implement this transition, it will require effective collaboration between stakeholders and the development of a comprehensive plan. Successful implementation of this plan will not be easy, and it will require time and dedicated resources. But it certainly is possible, as evidenced by the Republic of Kiribati. Prior to 2008, sand and gravel were traditionally mined from the beaches of Tarawa, the most populated atoll in the Republic of Kiribati. This practice was recognised as being unsustainable, due to greatly exacerbated coastal erosion problems which were compromising communities and infrastructure in an environment already under threat from coastal hazards and climate change. Subsequently, between 2008 and 2016, the Government of Kiribati and partners implemented a comprehensive plan to protect Tarawa's beaches and transition to a sustainable source of aggregates, named the Environmentally Safe Aggregates for Tarawa (ESAT) Project. The project identified an alternative sustainable source of aggregate located in a sediment sink in the Tarawa lagoon, conducted robust environmental and social assessments, supported artisanal and small-scale mining (ASM) beach miners to transition, banned beach mining, and successfully established a state-owned dredging operation to source sustainable aggregates from the lagoon. Kiribati's success serves as an inspiration for RMI and other communities around the world to implement transitions to sustainable sources of aggregate.

This case study from Kiribati highlights the opportunity to establish a regional forum for Pacific atoll nations to share experiences and best practices regarding sourcing aggregates and land reclamation. If practical, this forum should seek to integrate under the auspices of any established collaboration mechanisms. The forum could also seek to learn from the experiences of the Maldives, through the Coalition of Atoll Nations on Climate Change (CANCC).

Further work is required prior to extraction of the identified lagoon aggregate resources. As with any mining project, a staged approach is necessary, comprising the fundamental stages of exploration, development, production, and closure (NRGI, 2015). The scope of this aggregates study comprises the exploration phase and some of the feasibility work of the development phase. Therefore, further feasibility and design work is required prior to extraction taking place during the production phase.

Donors and infrastructure development partners should support RMI with this transition to a sustainable supply of local aggregates. A successful transition to a sustainable supply of local aggregates will require effective collaboration between government, private sector, and development partners. In this regard, we recommend that infrastructure development partners and government develop local content policies to preferentially use local lagoon aggregates.

Nevertheless, the need to import aggregates in certain circumstances for engineering quality reasons will undoubtedly remain. However, we recommend that engineers undertake research to develop engineering designs, standards, specifications and guidelines using local lagoon aggregate resources, which are fit for purpose in RMI. Such designs, standards, specifications and guidelines should seek to minimise the need for importing aggregates and preferentially utilise local aggregates. In circumstances where local materials cannot meet a specific quality requirement, options should consider combining local and imported aggregates. To assist with this, bulk sampling of the aggregate resources identified during this study is recommended. RMI may explore the potential of hiring a dredge from the US Army Garrison on Kwajalein atoll or the clamshell dredge from Tarawa (as shown in Figure 40) to obtain large samples suitable for a full suite of testing and field trials.

Figure 40: Te Atinimarawa clamshell dredging operation in Tarawa.

Larger and deeper samples collected by the clamshell would likely indicate the presence of more gravel sized sediment than the existing particle size distribution results presented in the geotechnical reports. This is because the samples collected during the geotechnical investigation were collected using a Van Veen grab sampler, which collects relatively small samples compared to a full-scale clamshell dredge. Comparative evidence from dredging operations in Kiribati and Tuvalu suggests the presence of more gravel sized sediment than is reflected in the surface Van Veen grab samples collected during this study. This exercise would also be of significant value in terms of due diligence to demonstrate the feasibility of lagoon dredging prior to investing in dredging equipment.

Additionally, we recommend local geotechnical laboratories capable of performing relevant aggregate testing and composition analysis are established in Majuro and Ebeye to improve understanding of local aggregate resources, and support quality control and assurance for the construction sector. This should involve training of local personnel to operate the laboratories. The JICA funded Solar Electricity Generation System in Ebeye Island Project has established a small laboratory on site capable of testing concrete compressive strength for their own quality control purposes, and likewise in Majuro PII has a small laboratory. However, in most cases, samples need to be sent to laboratories overseas (such as Guam, Singapore, and Philippines) at significant cost and time. This is a barrier for local aggregate producers and concrete block manufacturers to sell their products on larger projects. Therefore, establishing local laboratories will assist local producers to produce products to the required specifications and sell their products on larger projects.

According to SPC's records, the last regional workshop focused on best practices for concrete construction using coral aggregates was conducted in 1982 (New Zealand Concrete Research Association, 1982). This is over 40 years ago, highlighting the need for renewed research in this space to support infrastructure development in the Pacific region.

From a first principles perspective, the fundamental factor influencing the quality of aggregates in any atoll context is the sediment composition e.g. what the individual grains of sand or gravel are made from. Different compositions of aggregate have different engineering properties and are therefore useful for different applications. Therefore, we recommend that the research to develop engineering designs, standards, and specifications focuses on testing aggregates of different compositions and assessing their respective suitability for different uses. The sand fraction of the lagoon aggregate resources in RMI typically have two primary sediment compositions 1) halimeda rich, and 2) foraminifera rich (see Figure 41), while the gravel sized fraction is predominantly coral fragments. Halimeda is a macroalgae, its leaves and stems become sediment when it dies. This material is relatively weak and can be easily abraded or crushed to form finer sediment. Experimentation during the borrow-pit infilling project in Funafuti found halimeda rich sediment to be an excellent material for land reclamation (Eade, 1994). However, the relatively weak nature of the sediment raises concerns regarding its suitability for other applications such as concrete manufacturing. Conversely, foraminifera are single cell organisms and when they die their tests (skeletons) become sediment. Foraminifera tests are typically relatively strong and do not breakdown easily. The current lagoon dredging site in southern Majuro is producing halimeda-rich sand, whereas all the resources identified as part of this study are foraminifera rich, except for Site 4 in Majuro. Therefore, in addition to the particle size distribution testing and composition analysis presented in the geotechnical reports, we conducted some preliminary laboratory testing to compare the differences in concrete strength between concrete produced from foraminifera rich sand and halimeda rich sand (see Appendix 1). Four concrete cylinders were produced for compressive concrete strength testing at Geotech Testing Limited's laboratory in Suva. Three of these cylinders were made from foraminifera rich sand collected from Site 2 in Majuro, and one was made using halimeda rich sand produced from the existing lagoon dredging operation in Majuro (sampled from a stockpile at one of the block manufacturers). The purpose of this testing was purely to compare the difference in strength between concrete made from halimeda-rich sediment and concrete made from foraminifera-rich sediment. The halimeda-rich cylinder was tested after 28 days and had a compressive strength of 17 MPa. One of the foraminifera-rich cylinders was tested after 7 days, and the other two foraminifera-rich cylinders were tested after 28 days. The 7-day result was 16.5 MPa, virtually the same strength as the 28-day equivalent for the halimeda-rich concrete. The 28-day results were 21.5 MPa and 20.0 MPa, 26.5% to 17.6% higher compressive strength than the halimeda-rich concrete. The results of this testing indicate that the newly mapped foraminifera rich sand can produce higher strength concrete than the existing halimeda-rich sand which is being used for concrete construction and block making in Majuro. Therefore, transitioning to the newly identified sites has potential to increase the quality of concrete and construction in Majuro.

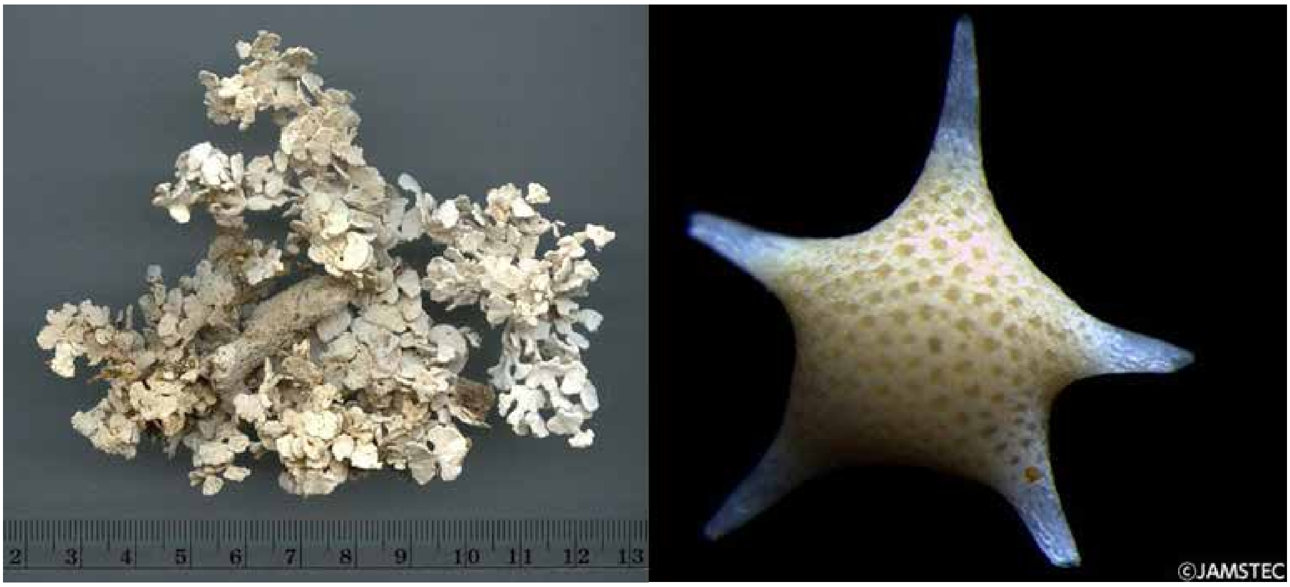

Figure 41: Halimeda (left) and Baculogypsina foraminifera (right).

There are numerous examples in RMI and other atoll nations demonstrating that infrastructure can be built with local aggregates. The infrastructure constructed during WWII provides some of the best examples to demonstrate the longevity of local aggregates. For example, the seawall on the oceanside of Gugeegue islet on Kwajalein atoll was constructed ~80 years ago during WWII (Figure 42). This wall is built from local aggregates and has been exposed to relatively large wave energy events for ~80 years, yet it is in remarkable condition, showing no notable signs of failure. The wall clearly overtops, and the design could no doubt be improved, but from the standpoint of the resilience of the materials, this seawall clearly demonstrates that local aggregates can be resilient.

Figure 42: ~80-year-old seawall on Gugeegue islet constructed with local aggregates.

As previously mentioned, the solar project on Ebeye has established a small laboratory to conduct concrete testing. The engineers have used this lab to trial different concrete mixes using local aggregates and have managed to develop a concrete design using local aggregates which meets relatively stringent Japanese standards. It should be noted that this has been achieved using the existing halimeda rich sand, and the foraminifera rich sands identified in this study would likely produce higher strength concrete. There are no doubt numerous examples of this approach being adopted - experimentation with local aggregates to meet design specifications – however this is currently occurring at the project level. We recommend that the same approach is adopted at the national level to develop guidelines and best practices for constructors to use local lagoon aggregates.

It is important that this work is informed by the specific composition of the respective lagoon aggregate resources in RMI, as this is what controls the quality from a first principles perspective. However, this work should also draw upon global research related to the use of carbonate and coral aggregates (Zhou et al, 2020; Liu et al, 2017). This research indicates that concrete made from carbonate aggregates has higher early strength due to chloride ions, however long-term strength is typically lower, and tensile strength is typically slightly higher (compared to normal aggregates). Fiber reinforcement is identified as a potential solution for further strength improvement. Research indicates that the porosity of the aggregate is a major factor influencing concrete properties. The porosity of the different sediment compositions found in RMI is variable, therefore this should be investigated further. Concrete structures often experience corrosion of steel reinforcing and structural degradation due to high concentrations of chloride ions. Research indicates that washing aggregate to reduce chloride content is possible, but this requires freshwater which is a scare resource in RMI (Kenyon, 2012). Stockpiling aggregate to allow for flushing by rainwater is a best practice to reduce chloride content. However, during drought periods this may not be possible therefore it is necessary to consider alternative solutions to this issue. In this regard, mineral additions and fiber reinforcement are effective methods to improve the resistance of concrete to chloride ion penetration, and fibre-reinforced polymer reinforcing is a corrosion-resistant substitute to traditional steel reinforcing (Zhou et al, 2020).

There are 48 existing reef mining pits on the oceanside in Majuro, with an estimated extracted volume of 522,442 yd^3. Most of the pits are located close to areas of housing and critical infrastructure. For example, in the 1 km stretch of reef from the bridge eastwards towards the oil terminal, 80% of the reef flat surface has been mined. Previous studies have documented the coastal erosion associated with this practice and recommended that reef mining be prohibited. One reason for the continued propensity of reef mining (see Figure 44 for an example) is that this is the only method of sourcing large boulders for coastal protection locally in RMI, and importing boulders is cost prohibitive. The production of precast concrete armour units made from local sand and gravel is a potential solution to this issue. Examples of this were observed in RMI and the lagoon dredging operation in Kiribati is also producing units (Figure 45). Another alternative option is to design coastal protection solutions which do not require large boulders or pre-cast concrete units (Figure 46). We recommend that both these options are evaluated by qualified coastal engineers, with the focus on creating innovative coastal protection designs made from local lagoon aggregate resources.

Figure 43: Extent of reef mining pits near the bridge on Majuro (Source: Google Earth).

Figure 44: Reef mining pits excavated to construct the new sports stadium in Majuro.

Figure 45: Examples of pre-cast concrete armour units observed in Ebeye (left) and produced by the lagoon dredging operation in Kiribati (right).

Figure 46: example of a concrete seawall constructed from local sand and gravel resources.

The most appropriate dredging equipment to extract aggregate from any of the identified lagoon aggregate resources will depend on specific circumstances such as scale and budget. In the case of land reclamation, this requires dredging a relatively large amount material in a short period of time. The most efficient equipment for land reclamation is either a cutter suction dredge (CSD) or a trailing suction hopper dredge (TSHD). CSD's dredge material via a suction pipe which is submerged on the seabed, and the dredged material is typically pumped via pipelines directly to the reclamation area. CSD's are most appropriate when the aggregate resource is relatively close the reclamation area as they allow for direct pumping of material via pipelines. A CSD was used to complete the reclamation in Tuvalu (Figure 47), and this is likely the most appropriate type of equipment for the proposed reclamation works in Ebeye and Majuro. TSHD have the added ability to store material in an internal hull, therefore this equipment is particularly useful if the dredged material needs to be transported from the aggregate resource area to the reclamation area. For example, if RMI was to explore the potential of dredging material from Arno Atoll for land reclamation in Majuro atoll, a TSHD would be the most appropriate equipment for this purpose.

Figure 47: Cutter suction dredge (top) used to complete 6.1 Ha of land reclamation in Funafuti atoll (bottom).

If reclamation is carried out, we recommend that a portion of the new land is allocated as an 'aggregate stockpile area' and that additional material be dredged and stockpiled to supply baseline construction needs. We also recommend exploring the potential of stockpiling additional aggregate in other areas, such as the existing aggregate production companies in Majuro and Ebeye. For baseline construction needs, the market assessment estimates current extraction rates of approximately

73,000 yd^3 per year. The most efficient equipment to extract material at this rate is a mechanical system, such as the Te Atinimarawa clamshell dredging operation established in Kiribati as part of the Environmentally Safe Aggregates for Tarawa project (Figure 48). This operation has the ability to produce approximately ~80,000 yd^3 of aggregate per annum. A similar operation would likely be the most appropriate equipment to extract aggregate from Site 1, 2 and 3 in Majuro, to supply aggregates for Majuro's baseline construction needs. Likewise a similar system could be used to extract aggregate from all six sites in Ebeye. Given the close proximity of the resources in Ebeye to the populated islets, there could also be the potential to explore the use of a dragline operation based on land or a pontoon mounted backhoe system. However, this would require management plans including buffer zones adjacent to the coast to ensure that dredging is note carried out in the nearshore environment where it could cause coastal erosion.

Figure 48: Te Atinimarawa clamshell dredging operation in Kiribati.

To reduce the demand for aggregate extraction, there is potential embrace circular economy principles. Where derelict concrete structures require demolition, it is recommended that this material be reused and not disregarded as waste (see Figure 49 for an example in Ebeye). Concrete can be crushed and reused for road construction or reclamation fill materials. There are several best practice guidance documents for reusing concrete debris, which have been developed for repurposing concrete debris following disaster events (Brown et al, 2016). Additionally, when wave inundation events deposit sand and gravel on roads and other infrastructure, this material should be stockpiled during clean-up efforts and reused as construction aggregate. This is particularly relevant where causeway structures have interrupted natural sediment transport pathways. These structures can trap sediment on the oceanside which is subsequently deposited on the road during storm events. This is an ongoing issue for motorists in Ebeye as shown in Figure 50. Local operators are currently reusing the material cleared from the road after inundation events, and we recommend this practice continues. We do not recommend extracting sediment deposited on coastal berm systems after inundation events, as this material is part of a natural accretion process whereby the berm level elevates and can provide protection against future inundation events.

Figure 49: Example of derelict concrete structure on Ebeye, highlighting the potential to recycle concrete.

Figure 50: Sand debris deposited on the road on the causeway to Gugeegue following inundation events.

11. Options for consideration

The technical and strategic options for consideration by the Government of the Republic of the Marshall Islands include:

1. Recognising the potential for sourcing aggregates, that is sand and gravel, from the lagoons in Majuro and off Ebeye.
2. Developing and implementing plans for Ebeye and Majuro to transition away from (and prohibit) beach mining and reef mining and explore lagoon dredging as a more sustainable way of sourcing aggregates locally. This will require assessments, consultation and effective collaboration between Government, the private sector, donors, infrastructure development partners and impacted community stakeholders.
3. Developing local content policies for the RMI construction sector to preferentially use local lagoon aggregates, and only import aggregate where there is a specific quality requirement which cannot be met by local aggregates.
4. Engaging engineers and research institutes to conduct research and develop innovative designs, standards, and specifications using local lagoon aggregates.
5. Establishing geotechnical laboratories capable of aggregate testing and composition analysis in Majuro and Ebeye. This should involve training of local personnel to operate the laboratory.
6. Continuing to map and undertake further lagoon aggregate resource surveys to identify additional resources and sustainability issues in strategic locations for land reclamation and raising.
7. Strengthening the governance of the aggregates sector in RMI including the review of existing legislation and policy frameworks, introduction of new legislation, and strengthening the capacity of relevant government agencies responsible for regulating the sector.
8. Using economic incentives to encourage a transition towards environmentally sustainable practices of sourcing aggregates as well as compliance with existing regulations.
9. Convening a regional forum for Pacific atoll nations to share experiences and best practices regarding sourcing aggregates and land reclamation. This forum could also engage with countries in other regions including the Maldives to learn from their experiences.
10. Recognising the importance of aggregates and mineral security for disaster and climate resilience in Pacific Small Island Developing States, particularly the Republic of the Marshall Islands and advocating for new and additional resources to address the current mineral insecurity in the Pacific.
11. Recognising future opportunities such as the 4th International Conference on Small Island Developing States in May 2024 to review SIDS sustainable development progress and propose a new decade of partnerships and solutions to support a SIDS pathway towards resilient development
12. Advocating for mineral security to be highlighted at international fora such as the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP) and aspire for its inclusion as a goal in the next iteration of the Sustainable Development Agenda beyond 2030.

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Annex I – Concrete compressive strength report.

CONCRETE COMPRESSIVE STRENGTH REPORT

GEOTECH TESTING PTE LTD
"Specialize in Aggregate & Soil Testing"
Geotech Testing Fiji
Vatuwaqa Laboratory
78 Ackland Street Vatuwaqa Suva
Phone: 9494 506
Email: geotechtestingfiji@hotmail.com

Report Number:	**P23550-1**
Issue Number:	2 - *This version supersedes all previous issues*
Reissue Reason:	*28 Days*
Date Issued:	19/01/2024
Client:	SECETARIATE OF THE PACIFIC COMMUNITY
Project:	P23550 - TRIAL MIX
Project Location:	MARSHAL ISLANDS
Work Request:	3417
Sample Number:	23-3417
Date Sampled:	22/12/2023
Sampling Method:	NZS 4407.2.4.6.2.1 - Stockpile of uniformly graded aggregate - Hand Method
Location in Structure:	TRIAL MIX

Accredited for compliance with ISO/IEC 17025

Approved Signatory: Geotech Testing
Director

Accreditation Number: 1344

Test results indicated as not accredited are outside the scope of the laboratory's accreditation

Compression Cylinders

Id	Slump Ordered (mm)	Slump Actual (mm)	Delivery Docket # / Truck #	Time Batched / Moulded	Mix Code	Spec. Id	Initial Cure (h)	Stand. Moist Curing (days)	Date of Test	Age at Test (days)	Specimen Height (mm)	Specimen Av. Dia (mm)	Mass/Unit Volume (kg/m³)	Comp. Strength (MPa)	Char. Strength (MPa)	Cap Type	Break Type	Remarks / Location in Structure
1	-	-	- / -	1:40 / 1:47	**	B	**	N/A	19/01/24	28	198	100.0	1780	**21.5**	**	R	N	SAMPLE FROM: MAJURO SAMPLE NO: FORAMS
2	-	-	- / -	1:52 / 1:57	**	B	**	N/A	19/01/24	28	198	100.2	1860	**17.0**	**	R	N	SAMPLE FROM: MAJURO SAMPLE NO: HALIMEOA
3	-	-	- / -	2:05 / 2:10	**	B	**	N/A	19/01/24	28	197	100.2	1760	**20.0**	**	R	N	SAMPLE FROM: MAJURO SAMPLE NO: 3.1,3.2 & 3.3

NOTE: Unless otherwise stated to the contrary the following apply:

1. Sampling and casting were conducted by our staff.
2. The composite sample was made from 3 portions taken during the load.
3. Slump Test in accordance with AS 1012.3.1
4. Capping: R - Rubber
5. Break Type: N - Normal
6. Cylinders compacted by Hand rodding, in accordance with AS 1012.8.1
7. Compression specimens are 100x200 cylinders.
8. Curing in accordance with AS 1012.8.1 9.3(a) Standard Temperate Zone
9. Density in accordance with AS 1012.12.1 with Moisture Condition SSD
10. Compressive Strength in accordance with AS 1012.9

Report Number: P23550-1

Page 1 of 1

Annex I – Concrete compressive strength report.

CONCRETE COMPRESSIVE STRENGTH REPORT

GEOTECH TESTING PTE LTD
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Vatuwaqa Laboratory
78 Ackland Street Vatuwaqa Suva
Phone: 9494 506
Email: geotechtestingfiji@hotmail.com

Accredited for compliance with ISO/IEC 17025

Approved Signatory: Geotech Testing
Director

Accreditation Number: 1344

Test results indicated as not accredited are outside the scope of the laboratory's accreditation

Report Number: P23550-1
Issue Number: 1
Date Issued: 30/12/2023
Client: SECETARIATE OF THE PACIFIC COMMUNITY

Project: P23550 - TRIAL MIX
Project Location: MARSHAL ISLANDS
Work Request: 3417
Sample Number: 23-3417
Date Sampled: 22/12/2023
Sampling Method: NZS 4407.2.4.6.2.1 - Stockpile of uniformly graded aggregate - Hand Method
Location in Structure: TRIAL MIX

						Compression Cylinders												
Id	Slump Ordered (mm)	Slump Actual (mm)	Delivery Docket # / Truck #	Time Batched / Moulded	Mix Code	Spec. Id	Initial Cure (h)	Stand. Moist Curing (days)	Date of Test	Age at Test (days)	Specimen Height (mm)	Specimen Av. Dia (mm)	Mass/Unit Volume (kg/m³)	Comp. Strength (MPa)	Char. Strength (MPa)	Cap Type	Break Type	Remarks / Location in Structure
1	-	-	- -	1:40 1:47	**	A	**	N/A	29/12/23	7	199	100.2	1760	**16.5**	**	R	N	SAMPLE FROM: MAJURO SAMPLE NO: FORAMS
2	-	-	- -	1:52 1:57	**	Slump Only												SAMPLE FROM: MAJURO SAMPLE NO: HALIMEOA
3	-	-	- -	2:05 2:10	**	Slump Only												SAMPLE FROM: MAJURO SAMPLE NO: 3.1,3.2 & 3.3

NOTE: Unless otherwise stated to the contrary the following apply:
1. Sampling and casting were conducted by our staff.
2. The composite sample was made from 3 portions taken during the load.
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9. Density in accordance with AS 1012.12.1 with Moisture Condition SSD
10. Compressive Strength in accordance with AS 1012.9