Woja Causeway Project: Detailed Design and Monitoring Plan

Prepared for:

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: **Cover page: The Priority 1 most vulnerable part of the existing causeway road.**

Executive Summary

This report provides the second output for SPC contract CC/13/357, which has been developed to provide detailed engineering design and a monitoring plan for coastal protection works for Woja Island, Ailinglaplap Atoll, in the Republic of the Marshall Islands following the coastal processes and feasibility report. It is recommended that the feasibility study is read prior to reading this document if an in depth understanding of the design process is required. Specifically, the second stage of the project included:

1. Participation in consultation in Majuro, RMI, to present the results of the feasibility study and assist in the selection of priority coastal protection measures for Woja Island within the context of the project budget.
2. Preparation of a detailed design, costing and engineering drawings for the selected coastal protection measures, which combine hard and soft engineering measures where possible.
3. Design of a monitoring and evaluation framework for the selected coastal protection measures.

A visit to Majuro was undertaken between 25th and 28th February 2014, and the findings of the coastal processes and feasibility study were presented and several meetings attended to lead into the final design phase.

The feasibility study indicated that there are two areas of concern at the causeway; the southern and most vulnerable part of the causeway, some 70 m in length which is exposed to on-going erosion on the eastern/lagoon side (Priority 1 site), and a less vulnerable and more stable part of the causeway to the north that is some 150 m long that is flooded and impassable with vehicular traffic 1-2 hours either side of high tide (Priority 2 site).

Without intervention, continued erosion of the lagoon side beach and degradation of the beachrock reef on the western side will very likely lead to a permanent breach

dividing the island through this area on every high tide. Lifting and armouring the 2 vulnerable sections of the causeway is required to prevent this from occurring.

A source of armour rock for remediating the access issues at Woja Causeway was identified some 4 km to the north, on the north western exposed coast of the island. This area has abundant rock of 1.0 m diameter and larger, is accessible with vehicles and due to the very large number of rocks and the natural beach armouring with rocks and boulders; extraction of the relatively small volume of rocks for causeway remediation will have an insignificant impact on coastal processes. In addition, the smaller grade rocks can be used as fill if necessary.

From the assessment of available information and coastal hazards, as well as considering both the practicality of construction and the height of the surrounding island, a 3.0 m finished causeway height (above lowest astronomical tide (LAT)) was recommended in the feasibility study. This is an ‘Irish-Crossing’ type structure, i.e., rather than a primary piece of infrastructure for a densely populated coastal area, a robust structure that is designed to allow over-topping in the rarest and most extreme cases.

The extreme wave heights calculated from long-term wave data and empirical and numerical modelling were used in the calculations of rock sizes. The results of applying these maximum wave heights to the Hudson formula led to a Dn_{50} (median rock diameter) of 0.71 m for the Priority 1 new causeway road, with ~10% safety factor resulting in the specified 0.6-0.9 m limestone rocks at a gradient of 2:1 (H:V), which are reduced to 0.3-0.5 m diameter for the elevated road section (Priority 2).

At the Priority 1 southern site, the new causeway road will be set some 15-20 m to the west of the existing causeway road to provide an additional erosion buffer on the eroding eastern side of the causeway. The new elevated road in the northern Priority 2 area will run along its existing route. In addition to elevating and armouring the causeway road, planting out of the existing road in the Priority 1 area (which will be replaced by the new causeway 15-20 m to the west) will be undertaken to provide additional buffering from erosion, preventing wind-blown loss of sand and providing added natural erosion resistance. Additional soft-engineering in the form of planting around the site should also be applied, with mangrove in the low wet areas along the western side of the footpath, and additional Kone trees all around lower areas of the site that experience inundation. The exception to planting is around the tidal lagoon area on the south western side of the causeway, since this area is known as Diamond Kan and is a popular picnic area for the villagers.

Through the consultation and meetings undertaken in Majuro, the selection of the Priority 1 and Priority 2 resilience measures were agreed to by the participants as the most appropriate for the site. However, the discussions with Public Works led to several improvements, which have been incorporated into the detailed design. Namely:

- A 0.4 m barrier on either side of the elevated causeway road for safety, created by continuing the height of the armouring on either side of the causeway;
- A 1:100 slope across the road surface to allow for drainage, along with gaps in the barrier every 15 m to allow the water to run off the road;
- A passing bay for the 150 m long priority 2 section, located on the corner mid-way along this stretch, and;
- An alternative lower height Priority 2 road to try to incorporate a full solution into the capped construction budget.

These modifications and the lower height Priority 2 road have been incorporated into the detailed design.

The basics of the causeway design presented here (levels, rock sizes, components, etc.) can be applied to other similar sites in the Marshall Islands – open coast reef platforms and lagoon fetches restrict the incident wave heights on such structures, and so can be applied where these features similar to Ailinglaplap atoll occur. These components are as follows:

1. Road level of at least 3 m (higher is the surrounding topography allows);

2. Rock armour of at least 0.9 m diameter where close to the beach (either open ocean or lagoon side);
3. The use of geotextile filter cloth between the core of the structure and the armouring/road surface to prevent the winnowing of core material and chronic structural failure;
4. A robust toe to prevent undermining of the exposed armoured layer, and;
5. Consideration of incorporating safety factors and drainage measures.

Contractors in Majuro were requested to provide cost estimates based on a project brief developed during the feasibility study. The brief included preliminary plans and cross-sections of the proposed works for the Priority 1 and 2 areas, location photographs and maps, and a basic construction plan. The modifications to the design have resulted in increased volumes of construction materials and consequent increases in price. Based on this information, the following cost estimates were developed for the final designs:

- Priority 1 cost estimate total: USD519,373
- Priority 2 cost estimate total: USD400,953
- Mobilization/Demobilization: USD60,000
- Total estimated cost: USD980,326

Since the project has a capped amount of €500K (approximately US$690,00), which includes construction, tendering, supervision, monitoring, etc., there are not sufficient funds to undertake all of the works for both Priority 1 and 2 sites. While the plans for the preferred options have been developed in this report and can also be tendered for, an additional option has also been developed for the Priority 2 stretch of road. The Priority 2 stretch of road (150 m) is stable (i.e. not actively eroding and has a rock/gravel base), and not vulnerable to wave attack. However, it is currently up to 1.0 m below the spring high tide mark (MHWS), and so prevents access 1-2 hours either side of high tide. The alternative for this stretch of road to try to incorporate into the budget is to create a lower road set at MHWS + 0.3 m for sea level rise (i.e. 2.0 m above LAT). This significantly reduces the volume/cost of the structure:

Priority 1 + Priority 2b + Mobilization/Demobilization USD661,943

All coastal structures require maintenance. In the present case it is expected that maintenance will fall into 2 categories:

1. Local small-scale maintenance of the road surface, and;
2. Heavy machinery maintenance.

Heavy rain and/or over-topping during extreme events will likely damage the road surface. It is expected that the local people will be able to maintain the road surface by filling any depressions.

There is the potential for larger scale damage to the structures (e.g. undermining of the toe, displacement of rock armour, etc.) following a very extreme event (e.g. a typhoon passing right over the site), or through chronic deterioration. Monitoring of the structures will include reporting to the government department responsible for the structure's maintenance any large scale maintenance requirements.

In order to consider the efficacy of each of the options, as well as to ensure that timely maintenance is achieved, a monitoring and evaluation framework has been prepared. The monitoring covers the construction of the coastal protection works and monitoring over at least a 3 year post-construction period. It is expected that monitoring will be carried out at regular intervals by local volunteers and government representatives when they are visiting Woja Island.

Once completed, the causeway will incorporate monitoring in order to assess:

1. Shoreline monitoring, and;
2. Structural integrity monitoring.

To monitor these components of the project, the following data will be collected:

- Beach profiles;

- Photographs, and;
- Field notes.

The initial beach profiles, site photographs and field notes (i.e. the feasibility study) will be used as the baseline data for monitoring.

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1 Background

SPC, specifically the Global Climate Change Alliance: Pacific Small Island States (GCCA:PSIS) project in the Strategic Engagement Policy and Planning Facility, has commissioned eCoast Marine Consulting and Research to provide engineering design and costing for coastal protection works for Woja Island, Ailinglaplap Atoll, in the Republic of the Marshall Islands (Figure 1.1).

This second report provides the final outputs for SPC contract CC/13/357, specifically:

1. Participation in consultation in Majuro, RMI, to present the results of the feasibility study and assist in the selection of priority coastal protection measures for Woja Island within the context of the project budget.
2. Preparation of a detailed design, costing and engineering drawings for the selected coastal protection measures, which combine hard and soft engineering measures where possible.
3. Design of a monitoring and evaluation framework for the selected coastal protection measures.

This report the detailed design based on the outcomes of the consultation and meetings undertaken in Majuro (point 1 above). It is recommended that the feasibility study is read prior to reading this document if an in depth understanding of the design process is required (Mead *et al*., 2014). The basics of the causeway design presented here (levels, rock sizes, components, etc.) can be applied to other similar sites in the Marshall Islands – open coast reef platforms and lagoon fetches restrict the incident wave heights on such structures, and so can be applied where these features similar to Ailinglaplap atoll occur.

In order to consider the efficacy of each component of the project, the monitoring and evaluation framework is critical, and covers the construction of the coastal protection works and monitoring over at least a 3 year post-construction period. The recommended monitoring procedure is also presented here, noting the limitations of the site with respect to usual monitoring methods. A thorough and quantified understanding of the efficacy of the project at Woja will lead to the development of sustainable and effective methods for these types of environments in other parts of the Marshall Islands and in the Pacific.

Figure 1.1. Location map of the project site on Woja Island, Ailinglaplap Atoll in the Republic of the Marshall Islands. (Source Google Earth 2014)

2 Summary of Preliminary Design

2.1 The Project Site

Figure 2.1 shows satellite images of the project site and the potential source for construction materials some 4 km to the north of the site.

Figure 2.1. Location of the project site and potential construction material area. (Source: Google Earth, 2014).

The project site is some 400 m from north to south, with a low beachrock reef on the western open ocean side and low limestone rock flats (near the low tide level) below a sandy beach on the eastern lagoon side (Figure 2.2). The area of low and friable beachrock reef on the western side of the site is the only part of the island's surrounding reef flat that is comprised of this type of rock and is distinctly lower than the reef platforms to the north and south of the area – the length of beachrock on the western reef flat adjacent to the causeway area is clearly visible in Figure 2.1.

Figure 2.2. Left: The low-crested, friable, beach rock reef on the western side of the project site. Right: the flat limestone reef flat near low tide on the eastern lagoon side of the project site.

There are two parts of the causeway that require protection and elevation to allow all weather access (presented in Figure 2.3):

1. The southern part is some 70 m long and located close to the eroding eastern lagoon side of the island – this site is considered the most vulnerable, and is located on a strip of land only 10 m wide between the lagoon-side beach and the small tidal lagoon inside the beach reef on the western side (Figure 2.4). This stretch is considered the first priority for the project.
2. The northern part is separated by a ~90 m long high area of the road (it is over 3 m above chart datum along some of this stretch), and is comprised of a low area of road some 150 m long that is flooded 1-2 hours either side of low-tide (Figure 2.5). However, while access is restricted during higher tidal levels, this section of the road is not vulnerable to erosion or wave attack. Thus, this section is considered the second priority for the project.

Figure 2.3. The project site is divided into 3 distinct areas – the first priority most vulnerable 70 m length of road in the south; the high central section of the site, and the second priority 150 m low stretch of road to the north.

Figure 2.4. The 70 m long Priority 1 southern part of the vulnerable road adjacent to the lagoon – to the left of the photograph (out of view) is the tidal lagoon that floods each high tide; only 10 m separates the east and west sides of the island at high water.

Figure 2.5. The 150 m long Priority 2 section of low road at the north of the project site during high tide (left) and low tide (right).

During high tides, the sea over-tops the low beachrock crest (Figure 2.6) and floods the northern part of the causeway over a ~150 m stretch of road, making it inaccessible to vehicles for 1-2 hours either side of high tide. There is a narrow footpath access on the eastern side of the site. However, it is not suitable for development into a road since it is very close to the lagoon beach and vulnerable to erosion, as is the southern part of the existing causeway.

Figure 2.6. Over-topping of the beachrock reef on the western side of the project area; during high tide, the northern 150 m of low road and the tidal lagoon adjacent to the Priority 1 area floods.

On the southern part of the project site, at the Priority 1 site, the high tide fills a tidal lagoon know as Diamond Kan (Figure 2.3), which results in this stretch of the island being only some 10 m wide at high tide (Figure 2.7). Discussions with locals indicate this area, and the area to the north where the Priority 2 stretch of road is submerged at high tide, have gotten lower over time (i.e. the water is deeper today over the road and in the lagoon than it was previously). However, it is not expected that this area will continue to erode, since there is little loose sand in the lagoon, and much of the road area is a compact layer of gravel and beachrock reef – Kone trees with their exposed roots are the also abundant in the northern area (Figure 2.8).

Figure 2.7. Looking north from the tidal lagoon on the western side of the Priority 1 site at mid-tide – the road is directly behind the trees on the right of the photograph, with the width of the island being only some 10 m along this stretch at high tide.

Figure 2.8. The compact gravel and beach rock northern section of road and Kone trees growing on exposed rock.

Detailed description of the data analysis and determination of the existing coastal processes is presented in the feasibility study (Mead *et al*., 2014). From the feasibility study it was concluded that without intervention, continued erosion of the lagoon side beach and degradation of the beachrock reef on the western side will very likely lead to a permanent breach dividing the island on every high tide. Lifting and armouring the 2 vulnerable sections of the causeway will prevent this from occurring.

2.2 Topographic Survey and Project Datum

During the site visit, personnel from RMI Lands and Survey undertook a topography survey of the project site using a total station. Since there were no existing benchmarks for the survey to be tied into, temporary benchmarks were developed for the survey, and the height of the tide was used to reduce all levels to Lowest Astronomical Tide (LAT), which is also Chart Datum (CD). By matching the predicted level of the tide at the time the survey marks of water level were taken, and offsetting the predicted level with the air pressure at the time of the survey (using the NCEP/NCAR Reanalysis – http://www.esrl.noaa.gov), the whole dataset could be reduced to heights relative to LAT. Detailed analysis of the tidal and water level data is presented in the feasibility study (Mead *et al*., 2014). LAT is used as project datum for any levels referred to in this report.

These corrected data were next supplemented with data captured at the site using a handheld GPS to further add detail with respect to both elevations (e.g. the location of the high-tide mark around the site) and site layout. The resulting data set was then used to develop a digital terrain model (DTM) of the site, as presented in Figure 2.9. The DTM has been used to extract long-sections and cross-section to estimate of distances and volumes and develop the engineering drawings for the development of the causeway (Appendix 1xx).

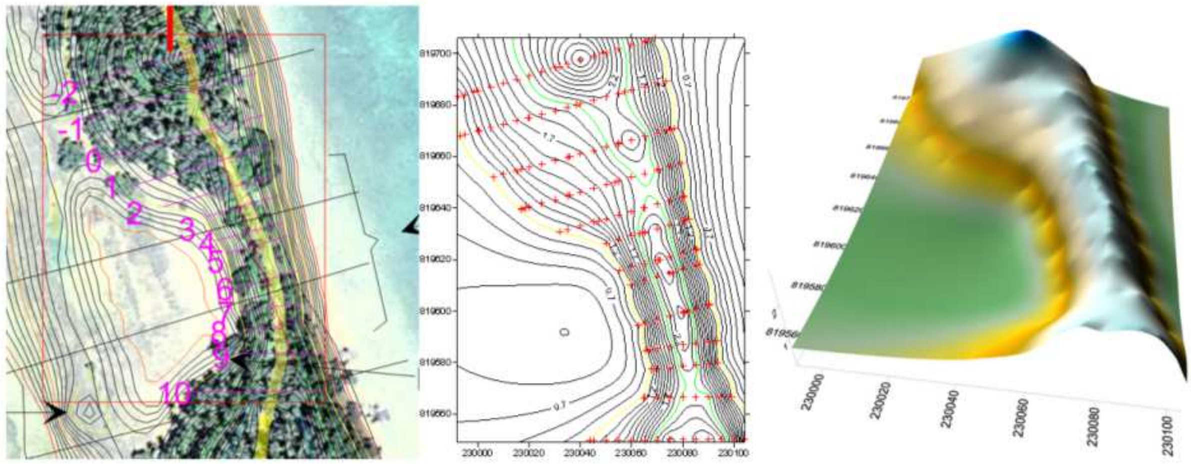

Figure 2.9. The height corrected and supplemented survey dataset was used to develop a digital terrain model (DTM), which was then used to develop cross-sections and long-sections and hence estimates of distances and volumes required for causeway development.

2.3 Source of Construction Material

Due to the isolation of the atoll, part of the site visit undertaken for the feasibility study was directed to identifying suitable construction material on the island, mainly large rocks for armouring the causeway. Suitably sized rock was identified on the northwestern coast of the island (Figure 2.1). This location includes an extensive area of large rocks (many >1.0 m in diameter) which were considered suitable for construction units – calculation of maximum wave heights and consequent rock sizes required for armouring are presented in the feasibility study (Mead *et al*., 2014).

The source of construction rocks (Figure 2.1) is some 4 km north of the project site, and access is available via a coastal road adjacent to the school. There are extensive volumes of rocks that are located on a flat reef platform, which make access to them relatively easy during lower tidal phases (Figure 2.10). These rocks have been broken off the outer edge of the platform reef during large wave events and thrown up onto the flats. Over time they are worked shoreward and slowly reduced to smaller and smaller boulders. An additional advantage of this source site is the abundance of smaller boulders armouring the beach (Figure 2.10), i.e. removal of a relatively low number of large rocks on the platform reef is unlikely to have any significant impact on coastal process (e.g. lead to erosion), and this material can be used as fill if required.

Figure 2.10. A very large supply of rock is available on the northwestern coast of Woja Atoll. The GPS on the rock in the righthand photo is 15 cm long (i.e. the rock it is sitting on is approximately 1.1 m diameter).

2.4 Rock Armour Sizing

Limestone rock (i.e. reef blocks located on the north western coast of the island - Figure 2.10) of 0.78 m diameter (i.e. nominally 0.6-0.9 m in diameter) at a gradient of 1.5:1 (H:V) has been specified for the Priority 1 southern causeway road based on the application of the Hudson formula (Mead *et al*., 2014). Smaller diameter rock is required for the elevated road (i.e. nominally 0.3-0.5 m diameter) at the northern Priority 2 site, since it is protected from direct wave attack by the beachrock reef to the west and is 40-80 m away from the eastern coast of the island.

2.5 Causeway Road Level

Based on the investigations described above (detailed in Mead *et al*., 2014), an 'Irish crossing' type causeway, i.e. a robust structure that is designed to allow over-topping in the rarest and most extreme cases, with a finished road level of 3.0 m above LAT is considered the most practical solution for the site. This approach is considered appropriate relative to the height of the surrounding land, the position of the causeway road in relation to the beachrock reef crest on the western side of the site, and population and traffic pressure that the causeway road will experience. A higher road (i.e. above the total coastal hazard levels identified by Mead *et al*., (2014)) is not considered to provide additional benefits at the site in terms of accessibility, since if the causeway at 3.0 m above LAT is being over-topped, other areas of the island and stretches of the road will also be experiencing over-topping (e.g. there are 2 stretches of road north of the site (100 and 300 m long) which are within 10-20 of the beach). In addition, there is significant cost savings due to reduced volume at 3.0 m compared to higher levels, i.e. because the level of the road is not set higher than the rare and most extreme events.

2.6 Causeway Road Position and Planting

The existing causeway road position needs to be considered, since it has had to be moved in the recent past and any resilience remediation should attempt to ensure that future movement is not required. The northern low section of the road was previously located along the narrow strip of land to the east on the margin of the lagoon that is today the foot path (Figure 2.11). It was abandoned due to erosion and over-topping making it impassable during higher tides and large wave events. At present, the Priority 1 southern area is vulnerable to on-going erosion and over-topping and so moving it away from the eastern coast will provide further future protection for this section of causeway.

At the Priority 1 southern site, the new causeway road will be set some 15-20 m to the west of the existing causeway road to provide an additional erosion buffer on the eroding eastern side of the causeway (Figure 2.11). The new elevated road in the northern Priority 2 area will run along its existing route (Figure 2.11). In addition to elevating and armouring the causeway road, planting out of the existing road in the Priority 1 area (which will be replaced by the new causeway 15-20 m to the west) will be undertaken to provide additional buffering from erosion, preventing wind-blown loss of sand and providing added natural erosion resistance. Additional soft-engineering in the form planting around the site should also be applied, with mangrove in the low wet areas along the western side of the footpath, and additional

Kone trees all around lower areas of the site. The exception to planting is the area around the tidal lagoon area on the southwestern side of the causeway, since this area is known as Diamond Kan and is a popular picnic area for the villagers.

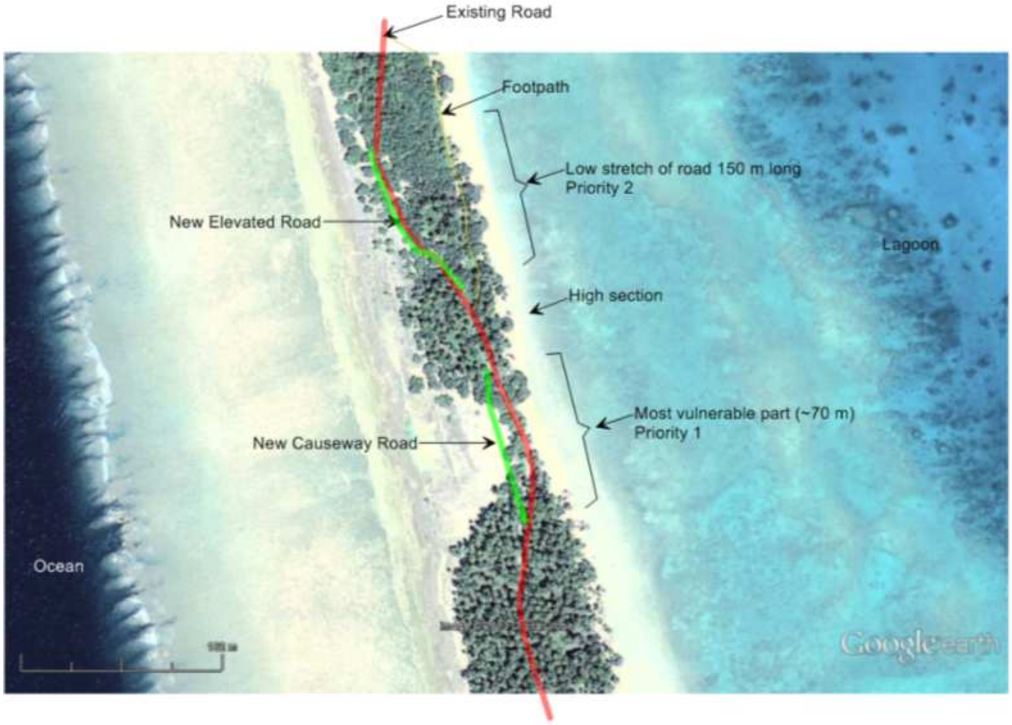

Figure 2.11. The existing road is shown in red – the northern section previously ran along the eastern edge adjacent to the lagoon, where there is now a footpath; it was abandoned due to erosion and over-topping making it impassable during higher tides and large wave events. In the Priority 1 southern areas, the new causeway road will be set some 15-20 to the west of the existing causeway road (shown with the green line) to provide an additional erosion buffer on the eroding eastern side of the causeway. The new elevated road in the northern Priority 2 area will run along its existing route (also shown with a green line).

2.7 New Causeway Road – Priority 1 Preliminary Design

Figure 2.12 shows the location and a generic cross-section of the new causeway for the southern Priority 1 area presented in the feasibility study. The new causeway is located 15-20 m west of the existing road and has a finished road level of 3.0 m. The existing road will be planted out to provide additional buffering from erosion, preventing wind-blown loss of sand and providing added natural erosion resistance.

2.8 Elevated Road – Priority 2 Preliminary Design

Figure 2.13 shows the location and a generic cross-section of the new elevated road for the northern Priority 2 area presented in the feasibility study. The new elevated road is to be located in the same position as the existing road and has a finished road level of 3.0 m. Additional planting around the site will also be applied, with mangrove in the low wet areas along the western side of the footpath (i.e. between the elevated road and the eastern side of the causeway area), and additional Kone trees all around lower areas of the site.

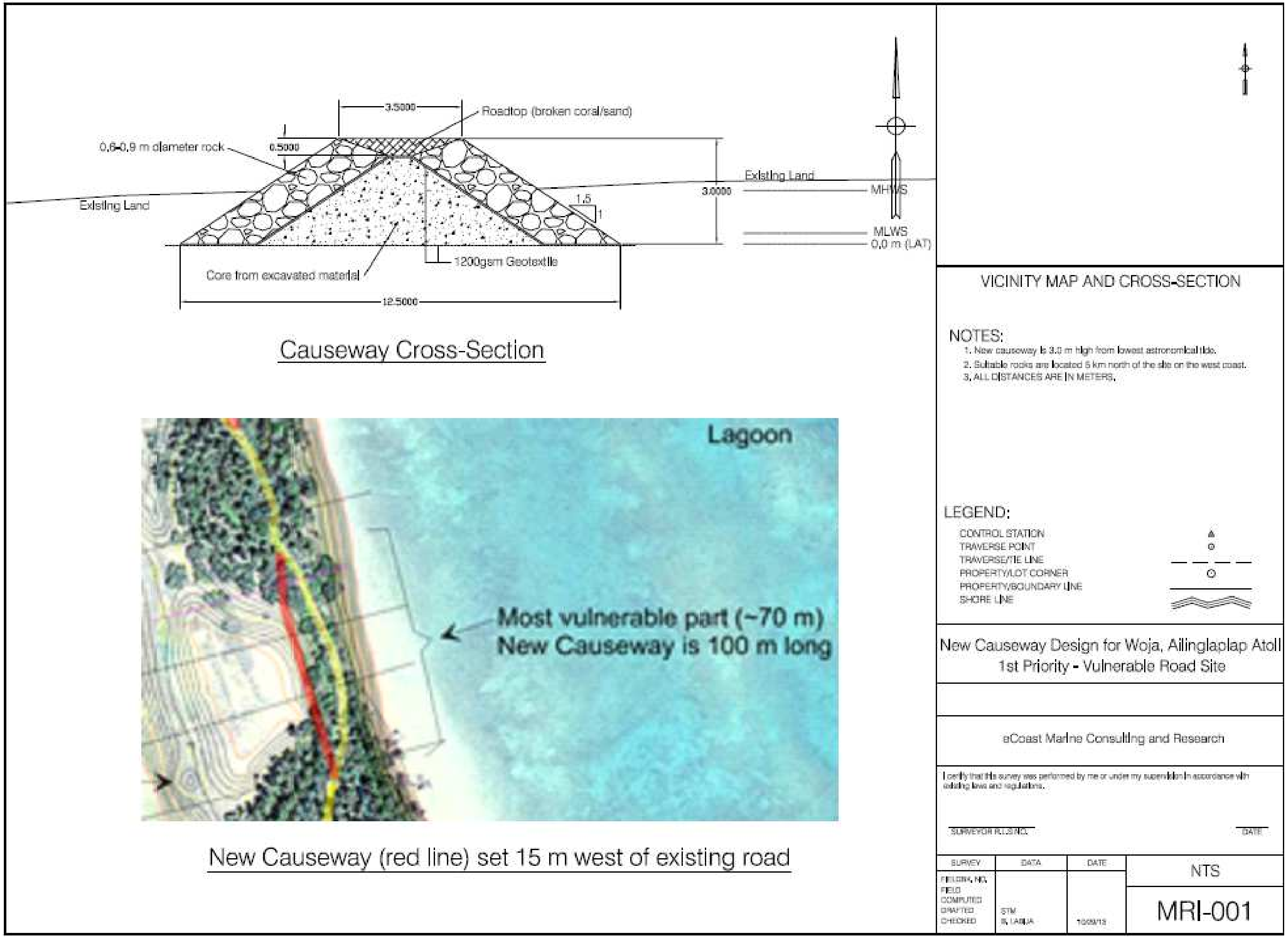

Figure 2.12. Location and cross-section for Priority 1 southern causeway road.

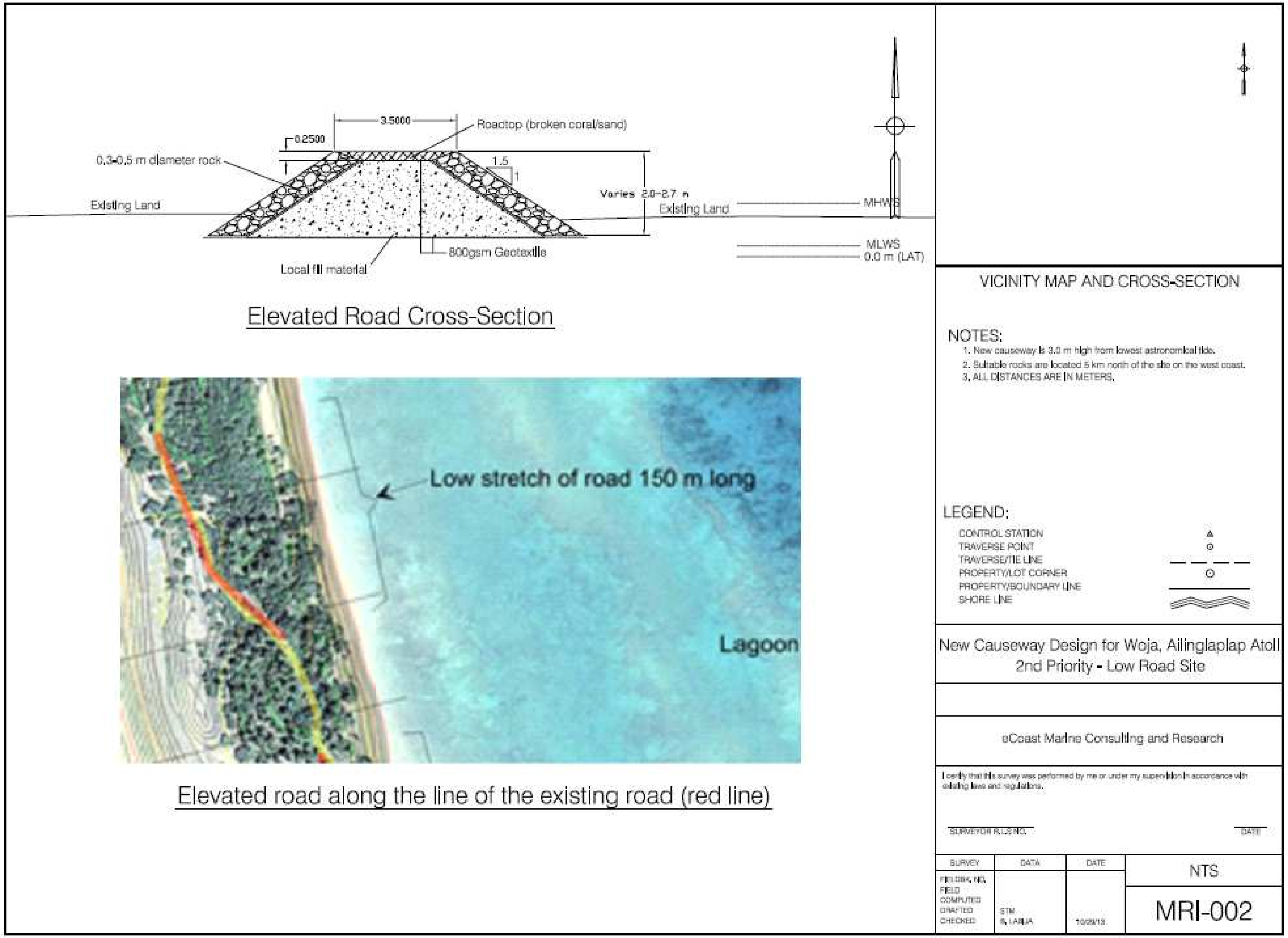

Figure 2.13. Location and cross-section for Priority 2 northern elevated road.

2.9 Summary

A visit to Majuro was undertaken between 25th and 28th February 2014, and the findings of the coastal processes and feasibility study indicated that there are two areas of concern at the causeway; the southern and most vulnerable part of the causeway, some 70 m in length which is exposed to on-going erosion on the eastern/lagoon side (Priority 1 site), and a less vulnerable and more stable part of the causeway to the north that is some 150 m long and is flooded and impassable with vehicular traffic 1-2 hours either side of high tide (Priority 2 site).

Without intervention, continued erosion of the lagoon side beach and degradation of the beachrock reef on the western side will very likely lead to a permanent breach dividing the island through this area on every high tide. Lifting and armouring the 2 vulnerable sections of the causeway is required to prevent this from occurring.

A source of armour rock for remediating the access issues at Woja Causeway was identified some 4 km to the north on the north western exposed coast of the island. This area has abundant rock of 1.0 m diameter and larger, is accessible with vehicles and due to the very large number of rocks and the natural beach armouring with rocks and boulders, extraction of the relatively small volume of rocks for causeway remediation will have an insignificant impact on coastal processes.

From the assessment of available information and coastal hazards, as well as considering both the practicality of construction and the height of the surrounding island, a 3.0 m finished causeway height was recommended in the feasibility study. This is an 'Irish-Crossing' type structure, i.e., rather than a primary piece of infrastructure for a densely populated coastal area, a robust structure that is designed to allow over-topping in the rarest and most extreme cases.

The extreme wave heights calculated from long-term wave data and empirical and numerical modelling were used in the calculations of rock sizes. The results of applying these maximum wave heights to the Hudson formula led to a Dn_{50} (median rock diameter) of 0.71 m for the Priority 1 new causeway road, with ~10% safety factor resulting in the specified 0.6-0.9 m limestone rocks at a gradient of 1.5:1 (H:V), which are reduced to 0.3-0.5 m diameter for the elevated road section (Priority 2).

At the Priority 1 southern site, the new causeway road will be set some 15-20 m to the west of the existing causeway road to provide an additional erosion buffer on the eroding eastern side of the causeway. The new elevated road in the northern Priority 2 area will run along its existing route. In addition to elevating and armouring the causeway road, planting out of the existing road in the Priority 1 area (which will be replaced by the new causeway 15-20 m to the west) will be undertaken to provide additional buffering from erosion, preventing wind-blown loss of sand and providing added natural erosion resistance. Additional soft-engineering in the form planting around the site will also be applied, with mangrove in the low wet areas along the western side of the footpath, and additional Kone trees all around lower areas of the site that also get inundated. The exception to planting is around the tidal lagoon area on the south western side of the causeway, since this area is known as Diamond Kan and is a popular picnic area for the villagers.

3 Detailed Design, Specifications and Costs

3.1 Detailed Design

Through the consultation and meetings undertaken in Majuro, while alternative options were discussed, the selection of the Priority 1 and Priority 2 areas was agreed to by the participants. However, the discussions with Public Works led to several improvements, which have been incorporated into the detailed design. Namely:

- A 0.4 m barrier on either side of the elevated causeway road for safety, created by continuing the height of the armouring on either side of the causeway;
- A 1:100 slope across the road surface to allow for drainage, along with gaps in the barrier every 15 m to allow the water to run off the road;
- A passing bay for the 150 m long priority 2 section, located on the corner mid-way along this stretch, and;
- An alternative lower height Priority 2 road to try to incorporate a full solution into the capped construction budget.

These modifications and the lower height Priority 2 road have been incorporated into the detailed design, which is presented in Appendix 1 (engineering drawings), with specifications of geotextiles provided in Appendix 2.

Since the project has a capped amount of €500K (approximately US$690,000), which includes construction, tendering, supervision, monitoring, etc., there are not sufficient funds to undertake all of the works for both Priority 1 and 2 sites. While the plans for the preferred options have been developed and so can also be tendered for (Appendix 1), the additional option has also been developed for the Priority 2 stretch of road. The Priority 2 stretch of road (150 m) is stable (i.e. not actively eroding and has a rock/gravel base), and not vulnerable to wave attack. However, it is currently up to 1.0 m below the spring high tide mark (MHWS) in the lowest section, and so prevents access 1-2 hours either side of high tide. The alternative for this stretch of road to try to incorporate into the budget is to create a lower road set at MHWS + 0.3

m for sea level rise (i.e. 2.0 m above LAT). This results in a significantly reduction in the volume/cost of the Priority 2 structure.

In addition, as described in the feasibility study (Mead *et al*., 2014), ribbons of sand on the reef flat below the beach rock reef were observed below both the breaches in the beach rock reef, which supports the likelihood that sand is being loss from the causeway site out of these gaps and leading to the lowering of the areas of the northern low road and lagoon. However, it is not expected that the road or lagoon will continue to deepen greatly since there is little loose sand in the lagoon, and much of the road area is a compact layer of gravel and beachrock reef. Even so, simple measures to reduce the potential further loss of sand in these areas can be undertaken during construction, which will entail plugging the 9 m wide gap in the beachrock reef crest (Figure 2.3) with 0.9-1.1 m diameter rock.

The basics of the causeway design presented here (levels, rock sizes, components, etc.) can be applied to other similar sites in the Marshall Islands – open coast reef platforms and lagoon fetches restrict the incident wave heights on such structures, and so can be applied where these features similar to Ailinglaplap atoll occur. These components are as follows:

1. Road level of at least 3 m (higher is the surrounding topography allows);
2. Rock armour of at least 0.9 m diameter where close to the beach (either open ocean or lagoon side);
3. The use of geotextile filter cloth between the core of the structure and the armouring/road surface to prevent the winnowing of core material and chronic structural failure;
4. A robust toe to prevent undermining of the exposed armoured layer, and;
5. Consideration of incorporating safety factors and drainage measures.

3.2 Costing

Contractors in the Majuro were requested to provide cost estimates based on the brief supplied in feasibility study. The brief included preliminary plans and cross-sections of the proposed works for the Priority 1 and 2 areas, location photographs and maps, and a basic construction plan (Appendix 4). Based on this information, the cost estimates were developed for the Priority 1 and 2 areas. However, the modifications to the design described above led to increases in construction volumes, which are presented in Table 3.1. This information has then been applied to estimating the costs of updated causeway designs and the additional lower height Priority 2 road, which are presented in Table 3.2, Table 3.3 and Table 3.4.

Table 3.1. Updated construction material volumes

	Rock volume (m3)	Excavation Volume (m3)	Core Volume (m3)	Roadtop volume (m3)	Geofabric (m2)
Priority 1	800	1,320	1,140	115	2,770
Priority 2	550	75	1,530	130	3,570
Priority 2b	80	0	110	90	1650

Table 3.2. Priority 1 cost estimate.

Item	Quantity	Cost (USD)
Armour rock acquisition/placement	800 m^3	343,376
Excavation	1,320 m^3	52,364
Core Fill	1,140 m^3	70,976
Road Top	115 m^3	7,672
Geofabric	2,770 m^2	44,985
Total		519,373

Table 3.3. Priority 2 cost estimate.

Item	Quantity	Cost (USD)
Armour rock acquisition/placement	550 m^3	236.071
Excavation	75 m^3	2,975
Core Fill	1,530 m^3	80,950
Road Top	130 m^3	8,672
Geofabric	3,570 m^2	57,977
Total		400,953

Mobilization/Demobilization 60,000

Priority 1 + 2 Grand Total (USD) **980,326**

Table 3.4. Priority 2b cost estimate.

Item	Quantity	Cost (USD)
Armour rock acquisition/placement	100 m^3	42,922
Excavation	0 m^3	0
Core Fill	110 m^3	6,848
Road Top	90 m^3	6,004
Geofabric	1,650 m^2	26,796
Total		82,570

Mobilization/Demobilization 60,000

Priority 1 + 2b Grand Total (USD) **661,943**

3.3 Maintenance

All coastal structures require maintenance. In the present case it is expected that maintenance will fall into 2 categories:

1. Local small-scale maintenance of the road surface, and;
2. Heavy machinery maintenance.

Heavy rain and/or over-topping during extreme events will likely damage the road surface. It is expected that the local people will be able to maintain the road surface by filling any depressions.

There is the potential for larger scale damage to the structures (e.g. undermining of the toe, displacement of rock armour, etc.) following a very extreme event (e.g. a typhoon passing right over the site), or through chronic deterioration. Monitoring of the structures will include reporting to the government department responsible for the structure’s maintenance any large scale maintenance requirements.

4 Monitoring and Evaluation

In order to consider the efficacy of each of the options, as well as to ensure that timely maintenance is achieved, this monitoring and evaluation framework has been prepared. The monitoring covers the construction of the coastal protection works and monitoring over at least a 3 year post-construction period. It is expected that monitoring will be carried out by local volunteers and government representatives when they are visiting Woja Island.

4.1 Methods

Once completed, the causeway will incorporate monitoring in order to assess:

1. Shoreline monitoring, and;
2. Structural integrity monitoring.

To monitor these components of the project, the following data should be collected:

- Beach profiles;
- Photographs, and;
- Field notes.

The best monitoring designs to measure coastal change that is due to modifications (e.g. the addition of structures) from within the natural variation of a coast is a BACI design – Before/After Control/Impact. BACI considers the sites modified (the Impact), Before and After construction, as well as Control sites (i.e. sites away from the Impact of the modification) Before and After construction. In this way, natural variations are recorded at the Control sites, and the variations/changes at the Impact sites can be compared to both the Control sites (natural variation) and Before data to determine the extent of change due to existing natural processes and the extent due to the construction of the options.

In the present case, the things to consider include the structure's integrity and the state of the beach/land on either side of the structures, as well as on the beach (east) and beachrock reef (west) away from the structures. In a case like this it is noted that there is not really a 'control' site available, since the causeways are being built set-back from the active beach and measures to induce changes to the beach (e.g. sand-retention structures, renourishment of the beach, etc.) are not incorporated in the design. The only 'control' site is the beach area north and south of the project on the eastern/lagoon side (the western side is a beachrock reef, with limestone reef and perched beaches to the north and south), and photographic monitoring to assess the state of this area (i.e. eroding/accreting) will be collected.

The survey work, photographs and field notes taken during the feasibility study serve as 'before' pre-construction monitoring.

4.1.1 Beach Profiles

The survey data (corrected to LAT) and photographs of the site have been archived in a zip file for future use in the monitoring programme. Future beach profiles should be measured at the same locations as measured in the feasibility study (Figure 4.1). It is noted that local monitoring will not be able to incorporate beach profile monitoring, and that this activity will be restricted to intermittent visits by government representatives.

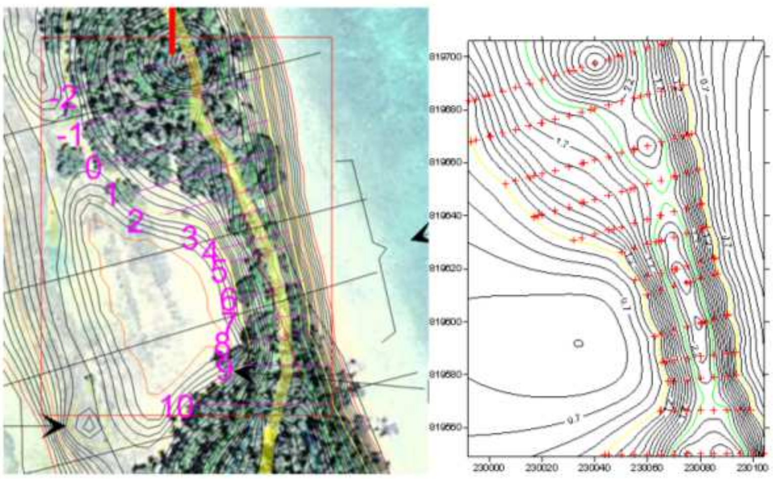

Figure 4.1. Profile measurements from the feasibility study. Profile monitoring should be taken along the same profiles as measured during the feasibility study.

4.1.2 Photographs

Photographs and field notes can be collected by local representatives for the purpose of monitoring – a digital camera may need to be purchased for the Woja Island community to undertake this monitoring. A guide to the locations of monitoring photographs are shown in Figure 4.2 and Figure 4.3 – these sites are considered a guide, since the local topography and vegetation may restrict the field of view in some cases, and there are probably other locations that will provide better fields of view. These photograph locations relate to existing archived photographs collected during the feasibility study. It is important that photographs are taken from a similar location with a similar field of view each time monitoring is undertaken. Additional locations and more photographs can be taken – the important aspect of the monitoring is repeating the same fields of view each time the monitoring is done.

Figure 4.2. A guide to photograph locations for the Priority 1 site. The stars indicate the location and the red-cones the field of view.

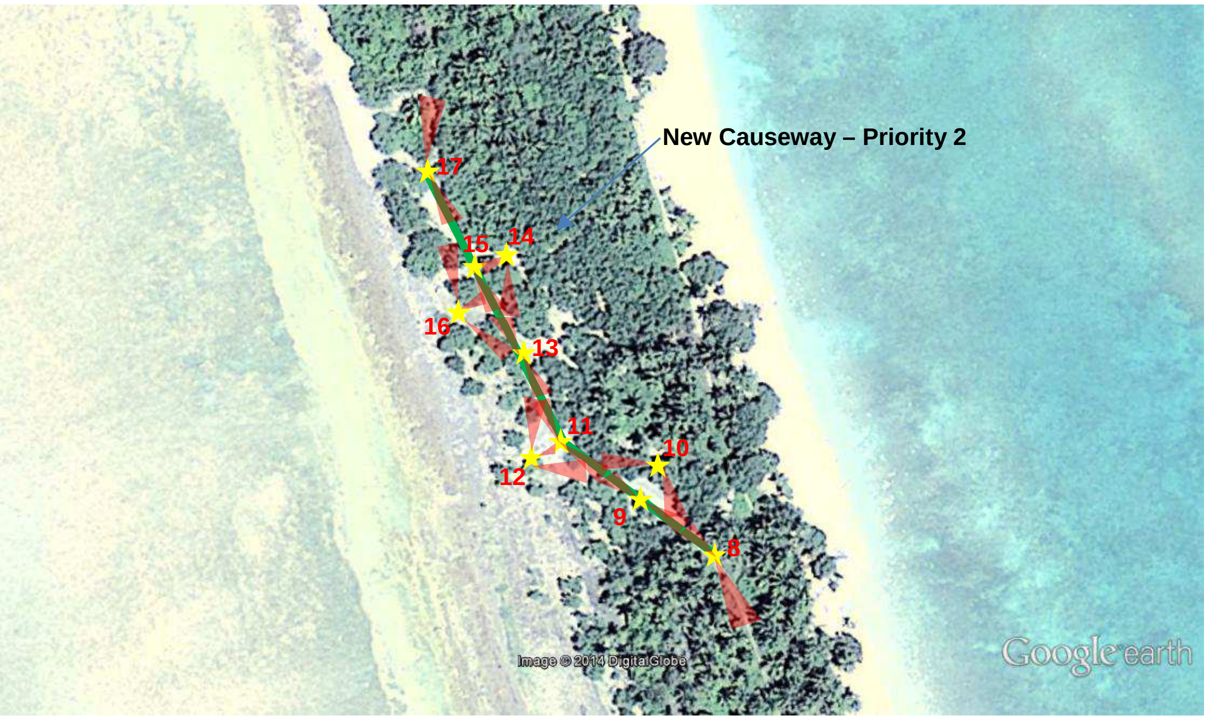

Figure 4.3. A guide to photograph locations for the Priority 2 site. The stars indicate the location and the red-cones the field of view.

4.1.3 Field Notes

Field notes should be taken each time photographic monitoring is undertaken. These notes should include:

1. Time/date of monitoring survey.
2. General comments about the integrity of the structures.
3. General comments about the state of the eastern/lagoon beach and the western beachrock reef crest.
4. General comments about the health and growth of the planted areas.
5. Specific comments about particular areas of the project site (e.g. undermining, beach erosion, plant failure/success, road-surface issues, etc.).

4.2 Monitoring Programme and Results Presentation

The monitoring programme has been designed to provide the following information:

1. Record the stability of the structures;
2. Record the changes to the beach and beachrock reef;
3. Learn the impacts of the different structures/planting trials;
4. Adapt the trials for better outcomes;
5. Apply to other parts of the project site and of the Republic of the Marshal Islands in the Future, and;
6. Use to determine maintenance requirements.

Monitoring of project should be undertaken at the following intervals:

- Before construction
- 2 months after completion
- 4 months after completion
- Quarterly for 2 years thereafter
- Bi-annually for 2 years thereafter

However, it is again noted that local monitoring will not be able to incorporate beach profile monitoring, and that this activity will be restricted to intermittent visits by government representatives. Therefore, the above monitoring schedule refers to the local monitoring.

It is expected that the photographing and taking of field notes will take no more than a half a day each time. Photographs must be labelled in reference to the position from which they are taken (location number from Figure 4.2 or Figure 4.3). Field notes should include beach health, structural integrity and state of planted areas (referenced to structure, location, etc.).

Beach profile monitoring will likely take 2-3 days for the first survey (to establish marks/pegs for future profiling based on the locations of the profiles undertaken during the feasibility study), and 1-2 days for following surveys. A further day will be required to input the data into spread sheets for analysis – base-point of profile (GPS position and profile number), distance along transect, level, description, etc.

An independent consultant will be engaged to analyse the monitoring data, while maintenance issues will be conveyed to government representatives following construction.

References

Mead, S. T., J. Borrero, D. Greer and D. Phillips, 2014. Woja Causeway Project: Coastal Processes and Feasibility Study. Prepared for Global Climate Change Alliance: Pacific Small Island States (GCCA:PSIS), February 2014.

Appendix 1 – Engineering Drawings

Appendix 2 – Geotextile Specifications