

Erosion and migration of an artificial sand and gravel island,
Niakuk III, Beaufort Sea, Alaska

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Open File Report 82-608

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INTRODUCTION

Artificial islands and causeways of sand, gravel and mud have been a proven and, apparently, economical structure used by industry in the exploration and development of petroleum resources in the shallow seas of the Arctic. The changes these islands undergo while aging will affect their usefulness as structures and will affect their impact on the natural physical and biological environment. Concern has been expressed regarding this impact on faunal habitat, circulation, ice motion patterns, and sediment transport pathways. In this report we address the changes that have occurred at one of these islands in about 4 m of water north of Prudhoe Bay, Alaska (Fig. 1) in an effort to provide insight needed to assess natural versus manmade changes.

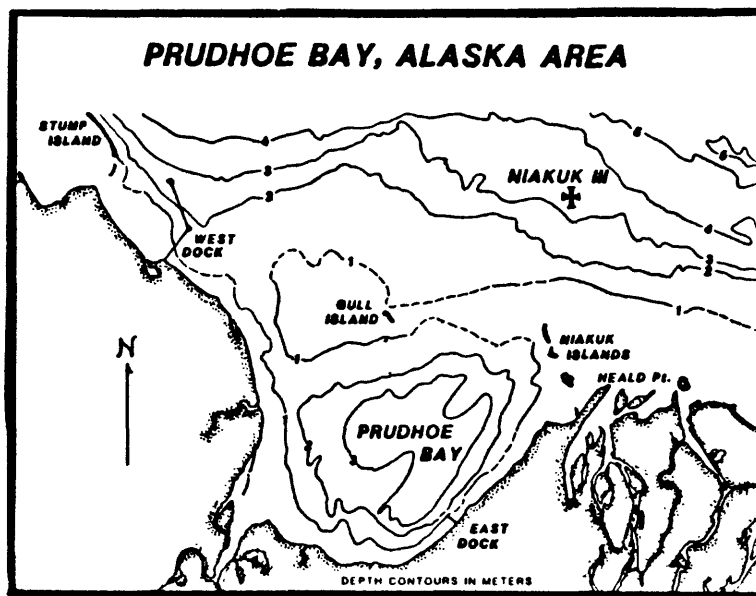


Figure 1. Location map showing the regional bathymetry and location of Niakuk III artificial gravel island.

Natural islands off the northern coast of Alaska are known to be migrating and changing in shape at a rapid rate. The rates of these changes amount to several meters per year (Barnes et al., 1977; Reimnitz et al., 1979; Hopkins and Hartz, 1978; Short, 1979). The offshore islands in this segment of the Beaufort Sea coast are composed primarily of sandy gravels (Hopkins and Hartz, 1978). Niakuk III, an artificial island, is also built of sandy gravels, materials which were mined from a buried river channel on shore. Thus, without erosional protection, this artificial island was expected to change in a manner similar to the natural islands.

A rectangular island was built during the winter of 1978-1979. As built, the island measured 95 m by 120 m at the top with base dimensions 150 m by 170 m and used about 100,000 m³ of fill material. The island extended about 2 m above sea level in water depths of about 4 m.

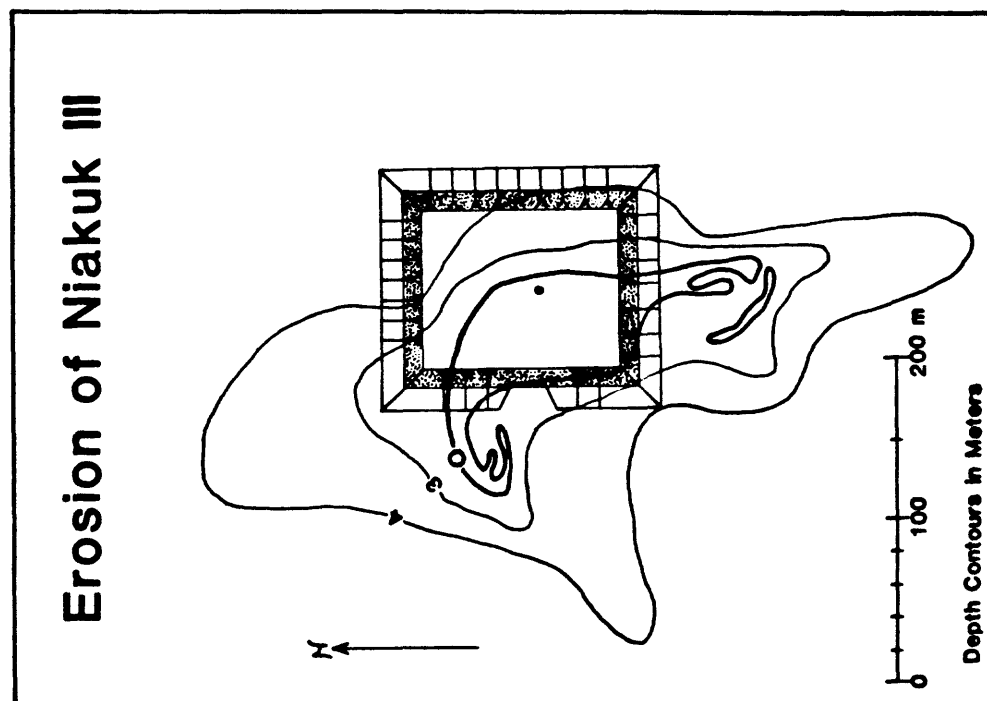


Figure 2a. Niakuk III as originally built superimposed on its shape as determined from the 1980 survey data.

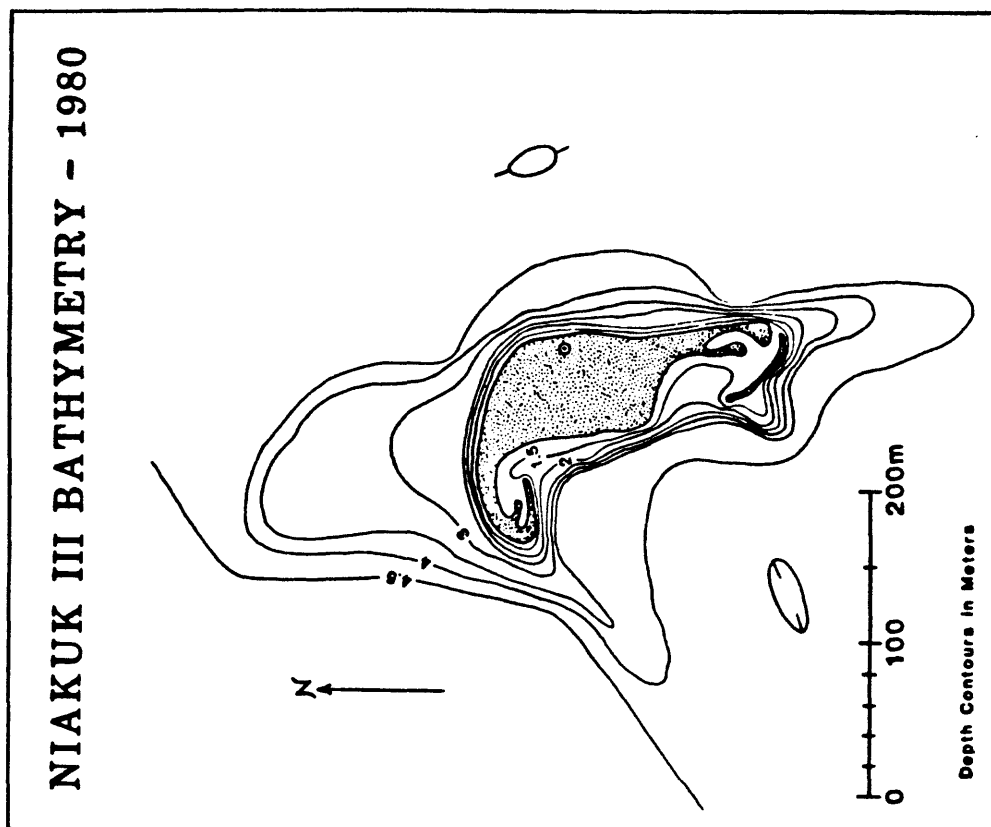


Figure 2b. Detailed bathymetry in the vicinity of Niakuk III from survey in July 1980.

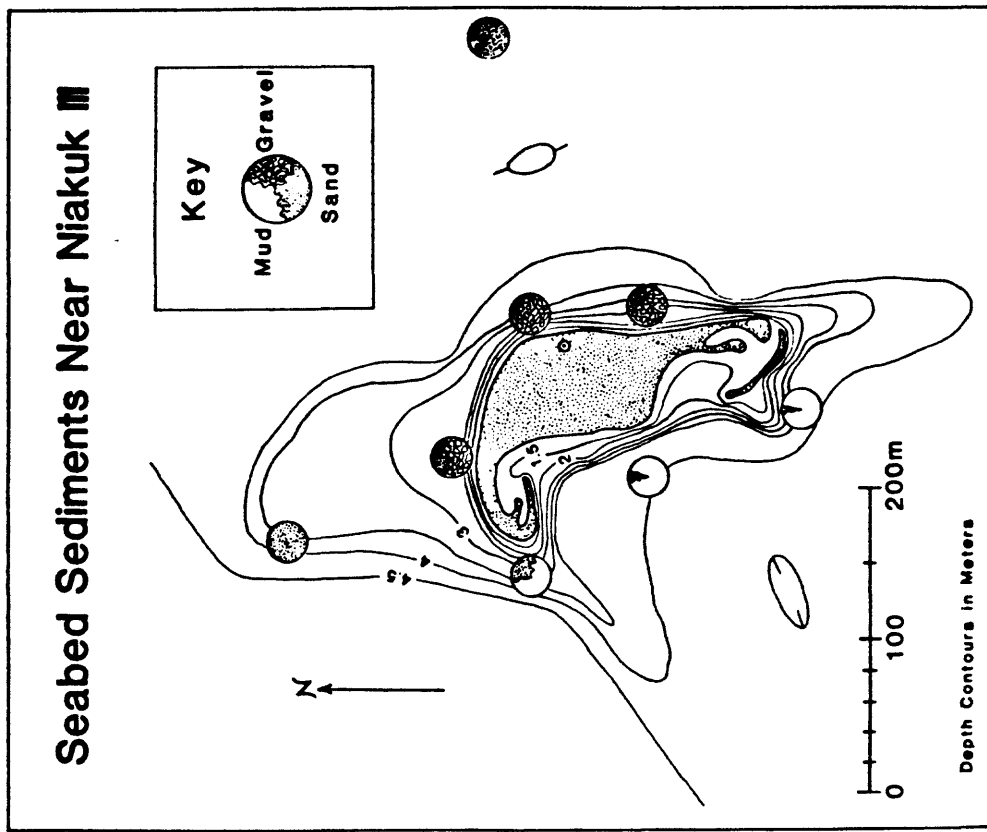


Figure 4. Location and sediment texture of 1980 samples in the immediate vicinity of Niakuk III.

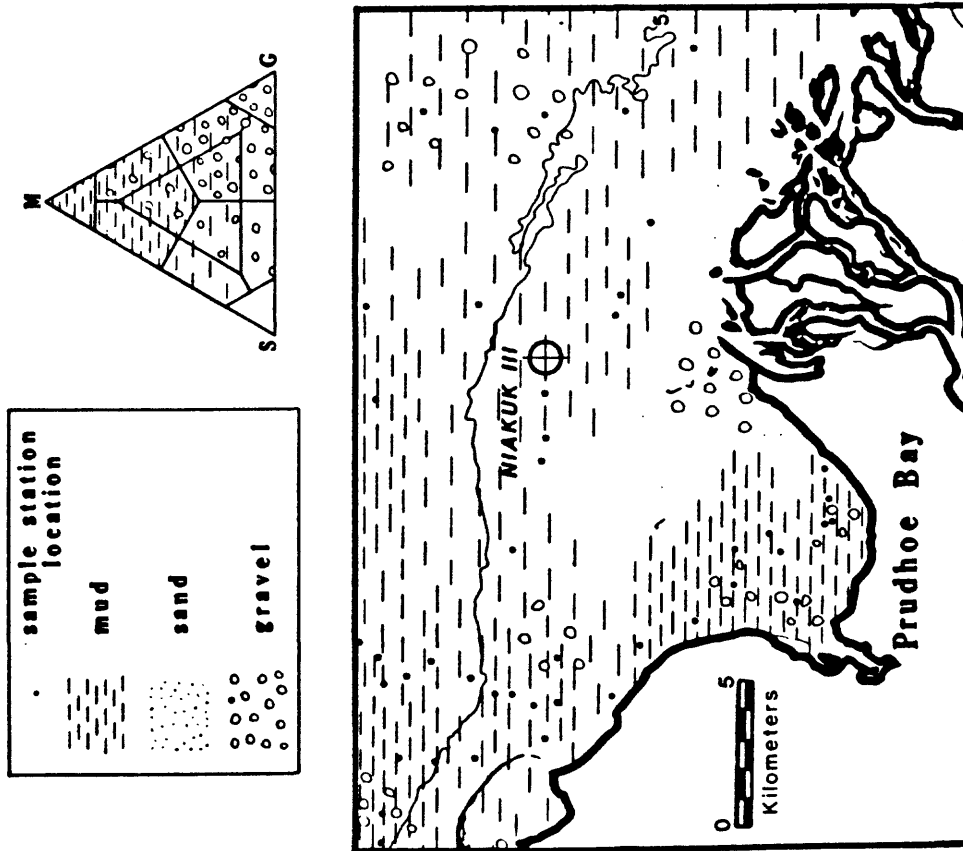


Figure 3. Sediment texture of the sea floor in the vicinity of Niakuk III (after Barnes, et al., 1980).

METHODS

In July 1980 seafloor bathymetry in the vicinity of the island was measured with a 200 kHz fathometer on which depths could be read with a precision of 10 to 15 cm. The observed depths were corrected for tidal difference to the National Ocean Survey's tide gauge at the West Dock about 11 km to the west. The bathymetry was contoured from 12 tracklines run in a star-shaped pattern around the island. Navigation on tracklines utilized a precision range-range system, and fixes along the trackline are believed to be accurate to within 5 m. The wellhead, extending 1.5 m above the island surface, was used as a visual reference point for year-to-year photography. Bottom samples were obtained using a 10-liter Van Veen grab. Sediment analysis followed standard sedimentologic procedures. For a more complete discussion of field techniques refer to Kempema et al. (1981).

OBSERVATIONS

Morphology

Niakuk III is located on the broad, shallow northwest flank of the Sagavanirktok River delta-front platform in about 4 m of water. The island was built during the winter of 1978-79. The presumed initial shape of the island when open water first allowed wave and current reworking first occurred in the spring (July) of 1979 is the above-described rectangle. One year later during July 1980, the morphology of the island had changed significantly both subaerially and subaqueously. The northeastern segment of the island was displaced, eroding the shoreline about 80 m. Recurved subaerial spits were developed to the west and south extending 70 to 80 m beyond the original shores of the island. Only the southwest corner of the island appeared in 1980 as it did when built the previous year (Fig. 2a).

Sediment that was originally part of the island has been redistributed to the west and to the south, covering an area about double the original base area of the island. The steep slopes on the northeast flank of the island drop to approximately pre-island depths within about 40 m of the island. On the north side of the island a platform-like tongue extends about 100 m to the north at 3 to 4 m depth while to the west and south the subaqueous extensions of the spit slope smoothly to the surrounding sea floor (Fig. 2b).

Sediments

Prior to construction the sediments of the sea floor in the vicinity of the island were slightly muddy sands (Barnes et al., 1980). No gravels were sampled within several km (Fig. 3). The island was built primarily of gravel, but 5 to 10 percent of the fill was less than 0.25 mm in diameter or finer than medium sand (Northern Technical Services, 1981).

The emplacement of the island and subsequent wave and current modification affected the sediment regime in the immediate vicinity. Sampling in 1980 (1 1/2 years since construction) showed that lag gravels were present to the northeast where the island was eroded (Fig. 4). To the southwest and west fine-grained sediments have been deposited. Samples do not extend far enough to the west to determine the limit of these fines. However, it is apparent that gravels are not being carried beyond the spits of the island.



Figure 5. View of the NE corner (left) of Niakuk III taken in September of 1979 (view to the southeast). Note essentially square shape and location of well head.

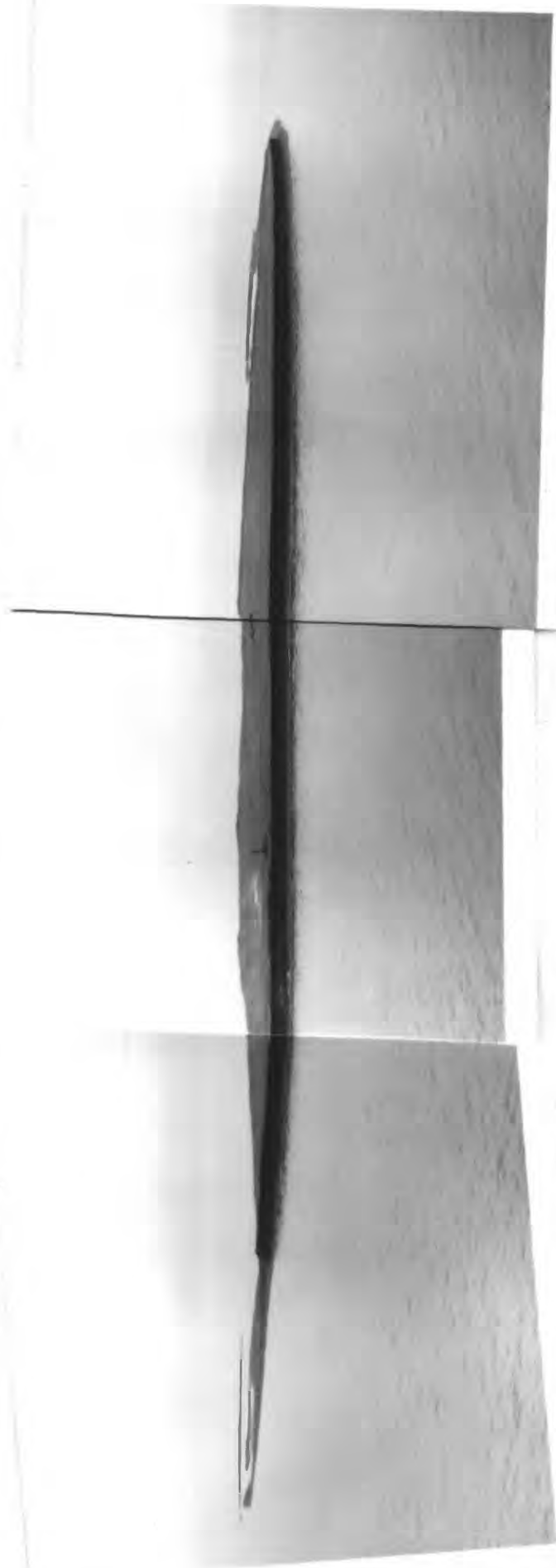


Figure 6. Photograph of the NE corner of NiakukIII taken in July, 1980. View is from the east. Note spit to south (left) and the location of the wellhead near the bluff.

The sample taken at the toe of the northwestern spit is a sandy mud. The two samples to the north and east at greater than 75 m from the island are similar to the regional sediments (Fig. 3), slightly muddy sand, indicating little or no gravel or mud deposition in this direction.

Other Observations

Visual observations taken in 1979, 1980, and 1981 also indicate the alteration of the island morphology. Photographs taken in the summer of 1979, the summer after construction of the island, show that the northeast corner had become rounded (Fig. 5). By 1980, the year of the detailed survey, the northeast quadrant had retreated further and the spits had been extended. The wellhead was about 15 m from the northeast-facing shore (Fig. 6). When we visited the island in summer of 1981, the wellhead was about 5 m offshore. Furthermore, the island appeared diminished in size, partly due to the removal of $21,600\text{m}^3$ of gravel at the end of the summer of 1980 for the construction of other islands (Northern Technical Services, 1981).

DISCUSSION

The predominant factor affecting Niakuk III island has been erosion and redeposition of sediment from the northeast quadrant of the island. After being built, the island was exposed to one open-water season (summer 1979) prior to our early summer survey in 1980. Figures 2 and 6 suggest about a third of the island's volume had been displaced from its original emplacement site during this season. Given that the original volume of the island was about $100,000\text{ m}^3$, then at least $30,000\text{ m}^3$ would have been reworked, transported, and redeposited during the open-water season in 1979. This is a very high rate compared to natural coastal sediment transport to be expected for one year for arctic sand and gravel beaches (Nummedahl, 1979). This high rate is believed to be related to the fall storm discussed below or the lack of a substantial permafrost core.

The development of spits on the western and southern corners and the lack of erosion in the southwestern quadrant of the island are responses to currents driven by the regional and local wind regimes. Supplemental to the dominant regional northeasterlies, a diurnal northeasterly summer sea breeze is developed (Kozo and Brown, 1979). These northeasterlies are believed responsible for currents which caused erosion of the northeastern quadrant and the development of spits. The generally weaker and less prevalent westerlies and southerlies explain the lack of erosion in the southwestern quadrant but these winds may be responsible for currents which formed the recurved spits. A similar gravel spit developed off the western tip of the West Dock, primarily during a late September northeasterly storm in 1979 (Barnes and Ross, 1980).

The unnaturally steep slopes of the artificial island may act to increase the rate of sediment transport and reworking. Wave energy would not be partially dissipated as it is at some distance on the gradually sloping seabed of natural islands. Rather, the full force of the waves could be brought right to the island coast, providing increased wave energy to modify the shape of the island and transport sediments.

Another factor that may be related to the rapid erosion of the island is a lack of a well developed permafrost core. The lack of such permafrost would increase the rate of erosion, especially during storms. During storms permafrost on other islands are exposed and would inhibit coastal erosion by acting as a cement, bonding sand and gravel together and making the islands less susceptible to erosion. Storms are suggested, as normally we observe that permafrost is well below the level of normal wave reworking.

Sediments released during the construction of the island and during the subsequent reworking of the northeastern quadrant are believed responsible for the fine-grained sediments noted on the sea floor to the southwest of the island (Fig. 3). The lack of gravels in the lee of the island or on the toe of the spits suggests that neither current nor ice have transported significant quantities of gravel far from the island. Thus, except for 20 per cent of the island removed for construction purposes, the mass of gravel originally emplaced at Niakuk III has been morphologically altered but transported only short distances.

The long-term changes to Niakuk III can only be approximated with the existing observations of an extremely dynamic system. The island will continue to migrate to the southwest as the materials from the original island are used as a sediment source for the elongation of spits. Migration will result in retreat of the northeastern shore of at least 5 m per year based on the retreat of other offshore islands (Reimnitz et al., 1977). The resulting southwesterly migration of the island will probably leave a pavement of lag gravel on the sea floor, remnant from the passage of the island mass.

The ultimate shape of the island is unknown. The island could take the form of one of the small islets common in the chain of sand and gravel islands along the Beaufort coast. These are crescent-shaped features oriented with the long axis northwest-southeast (Nummedahl, 1979). Another form could be a submerged northeast-trending ridge such as Dinkum Sands, (Reimnitz et al., 1980). Whatever the shape, the island will continue to migrate in a westerly direction.

CONCLUSIONS

1. Northeasterly wind-driven currents and waves significantly altered the original shape of an artificial gravel island in 3 open-water seasons - 1979, 1980, and 1981. The northeast quadrant was eroded back in excess of 80 m and spits were built to the west and south with the eroded material.

2. Coarse-grained materials are remaining within the island mass and as a lag where the island was constructed. The fine-grained sediment from island construction activity and subsequent reworking of island material by waves are blanketing the seabed to the southwest. The migration, lag gravels, and siltation have and will continue to affect an area of the seabed much larger than the original emplacement area of the island.

3. Rapid rates of erosion and modification can be expected on similarly built islands and causeways unless measures are taken to protect the northeast quadrant from erosion and longshore drift.

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