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WWW Resources on the Marshall Islands

Non-traditional settlement patterns and typhoon hazard on contemporary Majuro Atoll, Republic of the Marshall Islands

Abstract

Low-lying islands and atolls are particularly prone to storm surges created by tropical depressions and typhoons. This paper presents a case study of traditional and contemporary settlement patterns of Majuro, the capital of the Republic of the Marshall Islands, and discusses its vulnerability to such storm surges. The paper shows that the application of traditional knowledge extends to the realm of urban planning and that, in fact, ignoring this traditional knowledge as expressed in pre-World War II settlement patterns, exposes urban development to increased flood hazards, a risk which may exact a price too high in life and property.

Keywords:

Town Planning--Environmental Considerations

Heritage--Settlement Patterns

Climatic Extremes--Impact on human habitation

Pacific Islands--Marshall Islands--Urbanization

Low-lying areas and islands are particularly prone to flooding due tostorm surges generated by tropical depressions and typhoons. Typhoon-related flooding and its impacts on the low-lying areas of Bangladesh, for example, are common occurrencs, with widespread devastation of property and human suffering (*cf.*Alexander 1993, p. 523ff.; Haque and Blair 1992). The magnitude of these disasters is regularly brought home by compelling media images.

However, the impact of coastal flooding due to typhoon surges is not restricted to large river delta areas. Most of the world's atolls, at least the fully formed ones, comprise of a ring of islets and sand cays supported by a reef platform, without any higher ground. Exposed on small and narrow islets with little elevation (often much less than 2m above high water), residents have no place to go to, if and when the storm surges wash across the land. Dramatised by Nordhoff and Hall in the fiction novel "*The Hurricane*" (Nordhoff & Hall 1936) typhoon inundations can result in entire islands being depopulated.

Small island states are particularly vulnerable to natural disasters and to global climate change induced sea-level rise (cf. Lewis 1990, Spennemann 1993, Spennemann *et al.* 1990). Traditionally, Pacific Island cultures had learned to accept the devastation of these events, but, by the same token had learnt to forecast the approach of potential typhoon centers (Erdland 1914) and to minimize loss of property and lives by adjusting the settlement and subsistence pattern (*cf.* Schneider 1957).

In the last decade it has been gradually accepted that traditional communities have an intimate relationship with their environment, which has been based on the cumulative experiences of past generations. There is a growing body of literature showing that traditional technology and knowledge, because of its more appropriate nature for both environmental and cultural conditions prevalent in the area, has a place in modern development contexts. It has been shown that in numerous cases traditional technology is eminently suitable to fulfil the needs while at the same time is more cost efficient than modern counterparts (*cf.* Spennemann 1989). Furthermore, in his groundbreaking study "Words of the Lagoon," R.E. Johannes has shown that the body of knowledge of fish biology by the Palauan traditional fishermen rivals that of modern science (Johannes 1981). A similar study of the traditional fishing in the Torres Strait Islands has shown much of the same results (Johannes and MacFarlane 1991). In the last decade, traditional tenure systems both of terrestrial (Crocombe 1988; Dahl 1985; Pulea 1988; Pulea and Associates 1985, Utanga 1988) and marine resources (Dahl 1988) have been recognised by regional organizations as fostering environmental conservation and thus prolonging thelife of resources.

In the Marshall Islands context, a number of studies have been conducted in the last few years. Alessio showed the economic potential of traditionally constructed outrigger canoes over imported fiberglass boats (Alessio 1991) and has gone on to show that such technology is still capable of building ocean-going canoes (such as the canoe sent to the Pacific Arts festival, Rarotonga 1992), while Spennemann showed the potential of using traditionally procured arrowroot starch as a substitute for imported corn starches (Spennemann 1992c; in press).

Such studies showed the relevance of traditional skills for modern society and often documented that the renewed or continued use of these technologies may in fact be economically beneficial. The remainder of this paper will present a case study of traditional and contemporary settlement patterns and will show that the application of traditional knowledge extends to the realm of urban planning and that, in fact, ignoring this traditional knowledge may be detrimental to the physical well being of a population.

Unpleasant at best, devastating at their worst, tropical, circular high-speed low-pressure wind systems ("typhoons", "cyclones", "hurricanes") are a fact of life in many parts of the world. Living on a series low-lying and narrow island exposes residents to a substantially increased risk of destruction and personal peril: when a typhoon comes, there is no higher ground to go to. Whilst the occurrence of a typhoon cannot be prevented, its impact can be mitigated or compounded by the choice of settlement location. The aim of this paper will be to argue that traditional, pre-World War II settlement patterns on the atolls making up the Republic of the Marshall Islands (RMI) provided for a maximum of protection given the prevalent environmental conditions. It will also be argued that the present location of the two population centres, Ebeye on Kwajalein Atoll, and Delap-Uliga-Djarrit (henceforth D-

U-D) on Majuro Atoll, defeats traditional wisdom and unnecessarily exposes the residents to typhoon risk.

The Marshall Islands

The Marshall Islands, comprising 29 atolls and 5 islands, are located in the north-west equatorial Pacific. With the exception of the two north-western atolls, Enewetak and Ujelang, the Marshall Islands are arranged in two island chains running roughly NNW to SSE: the western Ralik Chain and the eastern Ratak Chain. Majuro Atoll, with its close neighbor, Arno Atoll, is located on the northern margin of the southern group of atolls of the Ratak Chain. Not counting the five full islands, Jemo, Jabwat, Kili, Lib and Mejit, the atolls of the Marshall Islands range from very small, with less than 3.5km ^{2}, such as Nadikdik (Knox) Atoll, to very large: with 2173km ^{2} lagoonal area, Kwajalein Atoll has the distinction of being the atoll with the world's largest lagoon (U.S. Army Corps of Engineers 1989; Spennemann 1992a).

Majuro Atoll

Majuro Atoll, situated at 7deg.03'-7deg.13' and 171deg.02-171deg.23'E, measuring about 45 by 11kms in dimensions, is oriented ENE-WSW and covers a total lagoon area of 295km^2 with a total land area of only 9.17km^2. The atoll can be split into a north-western, windward side and a south-eastern, leeward one. The north-western part is characterised by large, extended reef flats with very few islands, save for the distinct Enyagin Group, which located at the very north-western tip of the atoll and which consists of two reasonably large islands (Jelte and Rongrong). Towards the east, the islands on the northern side become more numerous and are relatively closely spaced. Located there are the three most populated islands: Djarrit, Uliga and Delap (henceforth D-U-D). The southern side of the atoll consisted, until 1905, of a single continuous island reaching from Rairok to Laura. The typhoons of 1905 and 1918 disrupted this continuous island, especially in its eastern part. In the south-west the island is still intact, largely only 200 to 300m wide, with the largest land mass, Laura (Majuro Island) at its western end (see figure 1). Of the over 60 islands of the atoll, 3 islands belong to the large category (>0.5km^2), 10 to the medium category, and 51 to the small category (<0.1km^2) . (U.S. Army Corps of Engineers 1989; Spennemann 1992a).

Traditional settlement patterns

The available land mass on Majuro Atoll, as on all other atolls of the Marshall Islands, is very limited. The width of the islands and islets making up the atolls is limited by the width of the supporting reef platform and determined by current conditions. On any given atoll, the majority of islands is less than 200m wide and 500m long. Settlement space, that is land suitable for human habitation is even more limited. Stretches of the ocean shore of the atoll are so exposed to wind driven salt spray, generated in the breaker zone of the reef, that they are all but uninhabitable. Today they are preferred locations for cemeteries.

The choice of the *prime* settlement locations is basically governed by environmental considerations (such as wind, wave action, protection from storms etc.), which have changed only little -- if at all -- since the beginning of human habitation in the

Marshall Islands some 2500 years ago. Traditionally human habitation was restricted to the strip of land along the lagoonal shore of the large leeward islands protected from storm surges and typhoon effects. Drinkable ground water, a prerequisite for ongoing human habitation, but also for the success of vegetation, is restricted to rainfall-recharged ground water lenses suspended within the permeable coral reef platform and floating upon the heavier salt water. The volume of these lenses is determined by the width of the island and are, as a rule, the thickest in an island's centre. Wind and ocean swell conditions vary on an atoll, with those islands on the windward side being smaller and comprised of coarser soil, ranging from coarse sand to rubble. Given frequent inundation during storm events, their freshwater lenses are shallow and not supportive of salt sensitive plants, which in turn diminished their agricultural value.

Human habitation on atolls occurs predominately on the large, leeward islands, which possess fine-grained soil, a durable thick ground water lens which supports an abundance of plants, decomposition products of which, in turn, provide fertile soils conducive to plant growth. For people these large, leeward islands were sheltered from storm events, had a secure drinking water supply, secure food resources and, usually, sheltered sand beaches utilised for landing canoes. Small islands on the windward side possesses none of these characteristics and were thus avoided except to serve as temporary fishing camps and the like. In fact, the large islands were so important compared to the remaining islands on the atolls, that the names of these islands were used eponymously with the name of the entire atoll. The only exception for this is Maloelap Atoll, where due to different current conditions there are three large islands

On Majuro Atoll the prime settlement areas are the large islands in the west, namely Majuro Island (`Laura") and Rongrong. The eastern islands are unsuitable for long-term habitation and, at the time of European contact In the early 1800s, were also very sparsely settled. This situation continued unchanged until the onset of World War II. Archaeological data indicate that the western part of Majuro was settled as early as the middle of the first millennium B.C. (Riley 1987; Spennemann 1992a). A scatter of radiocarbon dates tends to suggest that human habitation, at least on the major island, Majuro ("Laura") has been continuous to the present (see Spennemann 1992a).

Modern settlement patterns

Following their take-over at the beginning of World War I, the Japanese, administering the Marshall Islands as part of the League of Nations' Mandated Territory of the North Pacific Islands established a small administration on Majuro with a trade store owner as the resident officer. The effects of a devastating typhoon in 1918 on copra production, the economic base of Majuro Atoll, suspended further development of the atoll. Trading, and hence administrative interests, awakened again in the late 1930s, when the coconut plantations had recovered and began to produce. Centralized planning on Majuro began by 1940, when a sea-plane base was built on the eastern, leeward part of the island, chiefly the island of Djarrit. The choice of location was governed by both the protected nature of the lagoonal waters leeward of the windward islands (suitable for large ships), and the fact that the western part of the lagoon was studded with patch reefs making seaplane activities hazardous. The main population centre of Majuro was still located on the western end of the atoll, away from the Japanese base, which made base security easier. By late 1942 the base was abandoned in favor of a base on Mile Atoll some 140 kmsoutheast of Majuro.

Development of Majuro Atoll 1944 - 1950

Immediately after their landing on 31 January 1944, the US troops began the construction of a forward military naval and air base on the eastern part of Majuro Atoll. The criteria for the choice of location were the same as those of the Japanese: base security and lagoonal conditions favourable for large ships and sea planes. Until the end of the war, the base on Majuro was further developed and expanded to neighbouring islet (Uliga, Delap). The sparse Marshallese population on the new base islands was forcibly moved to Laura, at the western end of the atoll (Richard 1957).

Given the extent of war-induced destruction at Jaluit (the old capital of the Marshall Islands), the enormous amount of unexploded ordnance spread about, and given that at the same time a functioning US base had been erected relatively close-by, the US administration of the fledgling UN Trust Territory of the Pacific Islands decided to leave the administrative centre on Majuro Atoll and not to relocate to Jaluit.

The transition to peace-time administration facilitated rapid change. It implied job opportunities in the territorial administration as well as in private business, well-stocked trade stores and the like. The shift in the settlement focus on Majuro had begun. Rapid development of housing occurred on Delap, Uliga, but especially on Djarrit. No organized development took place on the islands other than the D-U-D area, with the exception of Rongrong, where a U.S. Coast Guard base was established in 1947 and abondoned by about 1954.

Development until today

By 1967, most development had taken place with most buildings erected on the lagoon side of the D-U-D, simply because the road ran there. In addition, this location is away from the destructive salt spray and the winds, which also made it favourable (U.S. Army Corps of Engineers 1969, p. 4). However, a land use map shows that while Uliga was quite densely developed, both Delap and Djarrit still had substantial portions of land then used for gardening (Hawaii Architects and Engineers 1968b, plate 17). During the Kennedy administration, several development plans were initiated (McHenry 1975). The Trust Territory Development programme activities in the Marshall Islands focused on Ebeye and Carlson Islands, Kwajalein Atoll (Hawaii Architects and Engineers Inc. 1968c) and Majuro Atoll (Hawaii Architects and Engineers Inc. 1967, 1968a, 1968b). In addition, plans for the development of Wotje as a district centre had been drawn up (Hawaii Architects and Engineers Inc. 1972).The Majuro development plan proposed a development centered on the D-U-D area.

Following the 1979 storm surge, which inundated large parts of the D-U-D area (see below) a development plan was drafted, which included precautions to prevent similar situations from developing in the future. By the mid-1960s the refurbishment of the 1944 military airstrip had on Delap Island had become a necessity. Since the advent of jet air services required the extension of the existing strip it was decided to relocate the airport to an area west of Rairok, and to utilize the area on Delap for industrial, commercial and residential development.

The period from 1981 to 1993 has seen an increased intensification of residential housing in the D-U-D area with the exception of the old Delap airstrip, where commercial buildings, as well as a hospital and the Capitol Building have been erected. In addition, the development of the new airport has created an artificial `boundary' on the atoll, whereby everything west of the airport is perceived as remote, while the area between the D-U-D area and the airport is seen as close and has seen an increased development of residential housing during the period from 1989 to 1993. Even though the land is less than 250m wide for most of the distance, there is a almost continuous line of houses both along the lagoon and the ocean side of the main road from the airport to the D-U-D area. In many instances a second row of houses has been developed between these house and the lagoon, as well as the ocean shore.

Development trends

In summing up, the period since the end of World War II has seen commercial and administrative developments focused on the D-U-D area of the atoll, with residential housing following suit. Whilst much of the land had been open space in 1945, either in the form of gardening land or in the form of runways, planned, and "unplanned" development has seen such spaces diminished. Only the very fringe of the ocean shore, often less than 5m from the high tide line, is left unutilized, (though on Djarrit a number of seawalls have been constructed, pushing out the habitable area onto the reef platform). Over time, not only the islands of Djarrit and Delap have seen increased residential development, but also the narrow stretch of land between the CBD and the airport. The increase in population, due to both births and inward migration, has led to incredibly high population densities by 1988 (table 1).

Majuro's population appears to have been increasing steadily up to a maximum of 1600 or 1800 people, if the late 19th and early 20th century estimates are to be believed. (Spennemann 1992b). A dramatic change took place after the Pacific War. The population increased nationwide at a rate of only 3.7 % per annum, while that of Majuro increased at a rate of 16.5%, clearly reflecting the increased importance of post-War Majuro as an administrative and commercial centre (Spennemann 1992b). The population increased from 837 in 1947 to 3415 in 1958 (Nucker 1958) and 19695 in 1988 (OPS 1989). The uneven distribution of the population meant that in 1988 population density ranged from 46 persons/km^2 on Enumanet to 17325 persons/km^2 on Djarrit. Various scenarios of future increase of the population have been presented (OPS 1989). Based on conservative projections, the population of Majuro Atoll is predicted to increase to 26,000 people by the year 1995, 31,500 people by the year 2000 and over 47,000 people by the year 2010. As was shown above, the population in 1988 was mainly concentrated in the D-U-D area. It is predicted that this area will see the majority of the population increase (Spennemann 1992a). The population on Majuro has far exceeded the horticultural carrying capacity of the atoll and the population has, by choice *and* necessity to rely on food imports from other islands and overseas.

Prehistoric settlement patterns defied

The modern settlement pattern described above, with the high concentration of people in the eastern part of the atoll, exposed to swell and storms, and often living very close to the ocean shore, defies the traditional settlement pattern and hence traditional wisdom. The focus of the atoll has shifted from the west to the east. The question arises whether this change in settlement patterns should be of any concern to modern urban planners, or whether the modern pattern merely reflects the technological advantage of being able to support a population in an otherwise adverse environment.

As I will show in the remainder of the paper, there is room for very serious concern that the defiance of traditional wisdom may in the future lead to major cost in life and property. The key factor in the equation are the typhoons.

Environmentalconstraints

The passing of the tropical storm "Zelda" in late November 1991 and of typhoon "Axel" in early January 1992 has once more shown that the islands of the atolls of the RMI are very vulnerable to typhoon impact. The overall damage incurred comprised wind damage to structures; direct inundation of the low-lying areas including structures erected thereon; wind damage to food trees; and especially damage to food and utility trees (flowers, bark) caused by wind-driven salt spray. The detailed extent of the damage incurred is beyond the scope of this paper. It is sufficient to say that on Majuro Atoll most of the southern and eastern reef platform and the islands thereon were affected by storm-driven waves *and* wind damage, while destruction in the western section of the atoll was confined to wind damage alone. In the south-east, inundation of low-lying areas occurred in a number of locations, temporarily merging ocean and lagoon and making the road impassable. In addition, areas not impacted by flooding saw the destruction of fruit trees by wind breakage of fronds, leaves and small branches. Some trees, chiefly among them breadfruit trees, but even some coconut palms, experienced such high levels of salt spray, generated at the breaker zone and driven inland by the high velocity winds that they showed a (temporary) shut-down reaction, with trees shedding their leaves within a week after the typhoon.

The above is a summary of the damages incurred by a *low-impact* typhoon. The potential damages wrought by a strong typhoon passing directly over atolls in the Marshall Islands are several magnitudes worse. Depending on the strength of the storm, whole islands can be depopulated and, in the extreme, even washed away in their entirety. Historic references speak of human tragedy of vast proportions (cf. Spennemann and Marschner 1994 for summary). The most complete data exist for the effects of the 1905 and 1918 typhoons, both of which affected Majuro Atoll (for detailed study on the history effects of these typhoons see Spennemann, in prep.)

The typhoon of 1905

On June 30th, 1905 a strong typhoon passed over the southern Marshall Islands, severely affecting Nadikdik (Knox), Mile, Arno, Majuro and Jaluit Atolls. Other atolls, namely Aur, Maloelap and Ujelang were affected to a lesser degree (Jeschke 1905, 1906, Erdland 1905; 1914; Erdland in Linckens 1912, p. 22-24, Rife 1905; 1906; Schwabe 1905a; 1905b).

Over 227 Marshallese lost their lives on that day on the affected atolls of the Marshall Islands, most of them on Nadikdik and Mile (Treue 1940, p. 198). Many more were injured. Following the destruction of all food stocks and fruit on the trees approximately 90 other people died in the following months due to starvation. The lagoon of Mile, and to a lesser extent of Jaluit, was reported to be completely full of floating debris: trees, bushes, houses, broken canoes, wooden utensils and corpses. The concentration of drift material in the waters of the Marshalls during July and August 1905 was so high that it constituted a serious shipping hazard, making the-limited-relief operations not any easier. The flooding by salt water caused die back of many fruit trees as well as the contamination of the freshwater lens.

On Mile heavy seas washed across the islets, the storm surge effect being compounded by a high tide. According to eye-witnesses waves were as high as the tops of the coconut trees. Jeschke (1905) assumes a wave-height of 12 to 15m., but even if we take exaggeration into account and allow for the crest of the waves to consist of wind-driven foam, a wave height of some 5-7m can be estimated. On Mile Atoll three small islands on the southern coast were completely washed away, and some other narrow islands in the southern part of the atoll were breached in many places. Neighbouring Nadikdik Atoll was completely washed over, with several inhabited islands being reduced to the bare reef platform. All people on Nadikdik Atoll (70 people) were killed save for two boys who survived a 24-hour drift voyage on a breadfruit tree to the southern coast of Mile (Jeschke 1905).

Similar to the inhabitants of Mile, the people of Arno Atoll mentioned that the seas reached to the tops of coconut palms. Waves breached some islands and washed away three quarters of the narrow south-eastern strip of land. The people on Arno living on the exposed southern islands had sufficient warning to flee across the lagoon to the larger western islands and seek shelter there, resulting in a few casualties and only eight fatalities. On Majuro the waves breached the narrow continuous strip of land in two places on the south-eastern coast resulting in a loss of land of a total of 4.5kms length.

The typhoon of 1918

The typhoon of 1918 was devastating for Majuro Atoll. A storm surge washed across the entire southern part of the atoll flooding an area over 20 miles in length. The wave impact was not sufficient to reduce the entire island to the bare reef platform, but powerful enough to breach the narrow island in many locations in the south-eastern corner of the atoll. The islands devastated or ravaged by this typhoon range from the western end of Delap to Woja. Until 1905 there had been a narrow, but continuous land connection between Delap and Majuro Island (Laura). The typhoon of 1905 breached this in two places, and the 1918 event smashed it in numerous other locations between Delap and Ajeltake. The most serious breaches were along the south-eastern corner, between Delap and Rairok, leaving only little bits of land behind, such as the tiny islets of Utwe or Enirak, now all rejoined by a causeway. In the south-western areas the wave power was insufficient to breach the island, but strong enough to bombard it with coral boulders torn loose from the reef's edge. Trees, small vegetation and houses were washed into the lagoon.

On the other islands of Majuro damage seems to have been mainly restricted to wind damage to houses and trees and salt spray damage to vegetation. All churches and thatch stores were destroyed as were most of the thatch houses. Fruit trees were uprooted, coconut palms felled, taro plants broken and *Pandanus* trees defoliated.

There seems to have been little forewarning of the impending disaster and according to Japanese casualty figures, all told over 200 people drowned on that day on Majuro Atoll alone (Spoehr 1949). The census for 1912 provides a reliable figure of 1089 people for Majuro Atoll (Merz 1912) In the years following the typhoon, the population decreased substantially and sank as low as 526 people on 1920 (Hawaii Architects and Engineers 1968), caused by both the direct effect of the typhoon, and the after effects in the form of food shortages and inadequate health and housing. It appears that the population of Majuro Atoll did not recover to pre-typhoon strength until close to WWII in 1941 (Spennemann 1992b).

Exceptional High Tides

It does not need a direct overpass of a typhoon of 1905 or 1918 strength to create havoc and to incur substantial loss in property. Stable high pressure systems north-east of Wake Island or east of the Marshall Islands can create higher-than-normal sea levels which will cause flooding of low-lying areas if they coincide with a spring tide, or with higher wave action. Such high pressure systems are common and have affected the atolls of the Marshall Islands on numerous occasions (the 1979, 1989, 1990 and 1991 floods on Majuro Atoll for example).

In late November 1979 a subtropical high pressure system ("Alice") had formed some 2000 miles east of the Marshall Islands, creating higher than normal sea-level at its perimeter, as well as creating a storm surge, sent out as a swell with a wave amplitude of over 6m. The first set of waves inundated parts of the D-U-D area in the morning of 26 November 1979 (Ginoza 1979a). Since the weather forecast came too late, there was no warning and a great number of personal belongings were destroyed. During the night of 27 to 28 November a second inundation occurred (Ginoza 1979b), and a third inundation took place on 4 December when a third storm hit Majuro, this time accompanied by gale-force winds and a 20 foot surf (Hovertsen 1979). Before the second storm surge hit the atoll, some 4000 residents of the already devastated D-U-D area had been warned well ahead and had relocated themselves to Laura (Wagner 1979). On the morning of 28 November some 80% of the affected area was still covered by seawater (Ginoza 1979b). This high tide and flooding was made worse where the waters pushed by the strong winds had been channeled and funneled into the embayments of the former inlets now barred by causeways, and had washed over the causeways and adjacent reclaimed areas (*cf*. McCoy 1981).

The entire flooding event went by without loss of life, although several people were injured. The effects of the inundations were destruction of housing and personal belongings, the inundation of septic tanks and subsequent spread of raw sewerage. Majuro was declared a disaster area, with quarantine measures enforced to prevent the spread of diseases. Some 5000 people were relocated into tent cities on Rairok Islet, a narrow strip of land in the southwestern section of the atoll. The total damage to housing and belongings was estimated to be $26 million during the first set of waves, and another $4 million as a result of the second set of inundations.

Frequency of typhoon events

In the Marshall Islands there is a common belief that the southern atolls do not experience serious typhoons, and that Majuro Atoll is relatively "safe." The previous examples of the 1905 and 1918 typhoons or the 1979 flooding are seen by many in the RMI as "freak" exceptions, rather than as the standard level of threat. The question arises whether this is indeed so.

In a review of 40 years of typhoon data, Birdwell and Daniels (1991) showed that probability of a tropical storm center occurring per year in the 5x5 degree areas in which the Marshall Islands are located is 28.75%, while the probbility of a typhoon/hurricane is 10%. But there is evidence that these typhoons are clustered.

The waters of the south-eastern equatorial Pacific undergo a quasicyclic phenomenon with a moving time interval of 3 to 5 years. During these effects, which have been termed the El Niño/Southern Oscillation (ENSO), global atmospheric disturbances develop. A rise in the atmospheric temperature and the sea-surface temperature will generate climatic conditions favourable to more frequent and also more severe storms (Holland *et al.* 1988). As the sea surface temperature stands in direct correlation with the minimum sustainable pressure and hence intensity of tropical typhoons (Emanuel 1987), an increase in sea surface temperature, either during ENSO events or as a result of Greenhouse-gas induced Global warming, is likely to: a) facilitate the occurrence of typhoons in areas hitherto not affected; b) shift the area of typhoon generation further eastward into the central Pacific; c) increase the frequency of storms and typhoons; and d) increase the severity of typhoons in areas already affected by typhoons (Wendland 1977).

An analysis of the historic record of typhoons in the Marshall Islands hasidentified a significant association between the occurrence of ENSO and the occurrence of typhoons in the Marshall Islands (Spennemann and Marschner 1994, in press). Whilst typhoons normally occur further to the west, the warming of the ocean waters around the Marshall Islands, as part of the ENSO phenomenon, spawns typhoons further to the east. The results of the statistical analysis suggest that typhoons are 2.6 times more likely to occur during ENSO years, with a 71% chance of a typhoon or severe tropical storm striking during an ENSO year, and only a 26% chance of one happening during a non-ENSO year. The observed association between ENSO and the historic occurrence of typhoons (Spennemann and Marschner 1994, in press) fits well within the expectation of the assumption of typhoon genesis and sea-surface temperature developments during ENSO phenomena. Further, the observed ratio of 2.6 times higher likelihood of typhoons during ENSO years fits well the frequency postulated by Wendland (1977).

Discussion

The association implied by both theoretical modeling and the analysis of historic data has a number of implications. Typhoons are not freak events, but regularly re-occurring disasters, which need to be considered in planning decisions. With an average elevation of 1.8m above high water the atolls of the Marshall Islands are so low lying that any major storm event will cause some levels of inundation. Any sizable typhoon will cause the inundation of substantial parts of an atoll, with the eastern (windward) parts of the atolls being more vulnerable.

Historic records quoted earlier, show that some typhoons were so violent that entire islands were washed away, leading to casualties of up to 80% of an atoll's population. In 1979 a mere inundation of the CBD of the capital on Majuro Atoll left 5,000 homeless. Should a typhoon like the one in 1918 reoccur on Majuro Atoll, casualties are likely to be in the thousands, with many thousands left homeless.

The Marshall government may do well to consider shifting the development focus to the comparatively safer islands, following traditional wisdom.

This paper does not argue for a wholesale relocation of the current population in the D-U-D area to Laura. This is rather impractical given the current infrastrcuture and private investment in the D-U-D area. In addition, the Marshallese have a strong link with their land, and permanent resettlement after natural or anthropogenic disasters is fraught with problems. While the relocation of people from the atolls directly or indirectly affected by nuclear testing, such as Enewetak, Bikini and Rongelap to relocation islands/atolls, such as Ujelang, Kili and Mejatto (Kwajalein) has resulted in a fair number of people moving on to the Urban centres Majuro and Kwajalein Atolls or overseas (Honolulu, Oklahoma, Costa Mesa), with little if any intent of ever returning to the home atolls, many have not given up that claim (Kiste 1976; pers.obs.)

The conclusions of this study are solely that the modern settlement location of the D-U-D area defies traditional wisdom and that future urban planning should seek to establish a second focus in the `safe' areas, with nall new major infrastruture to be located there.

Public education to alleviate or reduce future typhoon impacts is needed. There are several traditional low-cost technologies available which can be utilized to alleviate some of the salt-spray and wind effects in future typhoon or tropical storms, among them the re-creation of salt spray barriers in form of traditionally utilized plants, preferably of such species which have other uses as well, such as *Pandanus*. The re-creation of a natural salt spray filter benefits the house owners as it cuts down on salt levels in the air, thereby prolonging the life of electrical appliances, especially the outside mounted air conditioners.

The physical development, coupled with the extra ordinary population increase on Majuro Atoll, caused by the location of the capital on the atoll, resulting internal migration and biological population growth, is coupled with a departure from the traditional settlement pattern. The focus of settlement shifted from the protected areas, *i.e.* the large leeward islands, to the exposed windward ones. Further, over time the settlement on the islands in the D-U-D area extended from the protected lagoonal shore on the ocean shore. This trend is continuing with further houses being erected ever closer to the shoreline. In the meantime settlement is rapidly extending on the islands between Delap and the airport which are very vulnerable to typhoon-generated wave action. In the process, the coastal vegetation, as little as there is left in many areas, is becoming increasingly sparse.

The traditional methods of land management have been abandoned and the land is increasingly modified to suit individual short-term needs. Eroding land is not stabilized to the degree feasible, nor is care given in the inland areas to preserve the fragile layer of topsoil, upon which plant growth relies. The long-term perspective which the Marshallese traditionally had, is being rapidly forgotten. In addition, a large number of people are "squatting" on Majuro Atoll, and on Ebeye (Kwajalein) without hereditary rights to the land and without proper lease agreements affording them rights or security of tenure. Understandably, therefore, there is little, if any, personal commitment to the land. This is well reflected in the houses, which often can be pulled down at a moment's notice and thus are of inferior structural quality well below the economically affordable level. Both previous causes lead to the fact that few, if any plants are being planted to improve the immediate environment. Plants of no immediate commercial value are not planted at all. These aspects certainly compound the effects of typhoons and there can be no doubt that both increase the impact a typhoon will have.

The issue at hand is easily clouded by the introduction of real or spurious socio-economic arguments, such as that much of the population of Majuro consists "not of subsistence agriculturalists, but of urbanites whose income is assured as the result of compensation from US bomb testing and therefore mostly have no wish or skill to feed themselves by toiling the soil" (Anonymous referee's comments). There can be no question that the population of the centres on Majuro and Kwajalein is utterly dependent on imported (overseas) foodstuffs and that sole reliance on subsistence horticulture is no longer a feasible alternative. But this cultural shift in the subsistence base also applies to those Marshallese living on the `safer' parts of Majuro, and to a degree also to those living on the non-urbanised atolls.

Likewise, the argument that housing in the area is inadequate detracts from the main consideration of this paper. Much has been written on disaster resistence of traditional settlements and how the architecture of traditional dwellings can be improved (cf. Diacon 1992, Minor 1984), resulting both in safer housing (*inter alia* Mishra & Prakash 1982; Mitchell 1985; Scobel 1982) and in improved user satifaction (cf. longitudinal study by Snarr & Brown 1978, 1979, 1980, 1982, 1984, 1994) unless temporary housing measures become permanent establishments (Kreimer 1979).

There can be no doubt that traditional housing in the Marshall Islands is virtually non-existent, with a few 'westernised' versions of vernacular architecture and traditional building materials occasionally present, (Spennemann in press) and that the majority of housing is based on western designs, often executed in standards unsuitable to withstand typhoons or even large-scale storms (cf. pers. obs.). The suitability of traditional Marshallese housing to withstand typhoons is untested and not an issue in the debate. The standard of housing will impact on the level of wind-generated devastation, regradless where on Majuro Atoll the houses are located.

The *sole* issue of concern is that the geographical location of the D-U-D area is at the exposed eastern margin of the atoll, that this area is extremely prone to storm surge-induced flooding-cum-wave impact and that traditional settlement atterns show that this location is unsitable for habitation.In addition, the islands on the leewardside offer more area and hence room for future settlement increases.

Conclusions

Traditional settlement patterns located the population centers on the safest island on an atoll, which, in the southern Marshall Islands is located on its western fringe. All atolls in the Marshalls (with the exception of the atolls affected by nucelar testing) have seen an increase in population. On all atolls other than Majuro and Kwajalein the traditional settlement location has remained the focus and the popualation of these areas has incresed. Only Majuro and Kwajalein have seen a shift in settlement focus. Today, Majuro's population concentration is on the exposed eastern islands. Environmentally, the present spatial concept of urban Majuro is clearly unsuitable, as it unnecessarily exposes the residents to storm surge hazards. In a modern planning framework there is no need to perpetuate a concept which was created by war-time expediency, driven by short term perspectives, with planned obsolescence. That the D-U-D area remained the focus of Majuro, and in fact the entire Marshall Islands, is an accident of history, rather than the result of careful planning.

As the past 75 years have shown, not all typhoons need to be as destructive as those of 1905 and 1918, but it may be too costly to underestimate the potential of a re-occurrence of a typhoon of such magnitude.

One of the potential impacts of Global Climate Change is the limited increase of the sea surface temperature which in turn is likely to increase typhoon frequency and intensity. The variations in typhoon occurrence as a result of the cyclic ocean warming caused by the El Niño/Southern Oscillation effect are ample proof of the impacts of limited temperature variations. Thus, a repeat of the 1918 disaster may take a long time to come--or it may just be round the corner. But it will come.

Natural disasters habe been vehicles for cultural and social change (cf. Barbina 1979), where temporary solutions have become permanent fixtures (Tonkinson 1979). However, there is no reason to wait for another disaster to occur to reconsider urban planning on Majuro.

The past has much advice to offer for present and future development. Many skills were developed over the more than 2000 years the Marshallese settled the atolls now named the Marshall Islands. This time period allowed the people to fine-tune their technologies and their techniques of managing and exploiting the natural environment within the technological constraints they experienced. In this case, previous experience, in the literal sense of the word, taught the Marshallese where to settle, which islands on an atoll to choose. Traditionally the windward islets were only used for temporary settlement or saw a very small scattered population residing there, while the larger islands on the leeward side of an atoll were inhabited. Placing the population concentration on these islands ensured protection from extreme climatic events such as typhoons and storm surges. The post-World War II settlements on Ebeye and the D-U-D area on Majuro Atoll have departed from that traditional wisdom, both are erected on the exposed windward side of the atolls, and both islands had to pay a price during typhoon Axel. Technological development may have moved ahead at a dramatic rate, yet people remain at the whim of nature's unharnessed ire: the typhoon experiences of the past are still valid today.

Let us hope the price to ignore the lessons of the past will not, one day, be too high to pay.

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Table 1 Distribution of population and population density (in persons per km^2) on Majuro Atoll in 1988 (data after OPS 1989)

District	Popu-la tion	Area (km2)	Population density
Jelte	24	0.233	102.96
Rongrong	245	0.355	690.47
Calalen	19	0.259	73.36
Biken	8	0.052	154.44
Enemonet	6	0.130	46.33
Denmeo	7	0.052	135.14
Bokrej	14	0.041	337.84
Drirej	16	0.130	123.55
Garra	9	0.034	267.30
Ejit	170	0.049	3,454.58
Enarau	3	0.016	193.05
Djarrit	6813	0.389	17,536.68
Uliga	2144	0.293	7,325.66
Dalap	5692	0.648	8,790.73
Rairok	2021	0.622	3,251.29
Ajeltake	556	)	
Woja	224	)	
Arrak	118	) 5.180	477.41
Laura	1575	)	

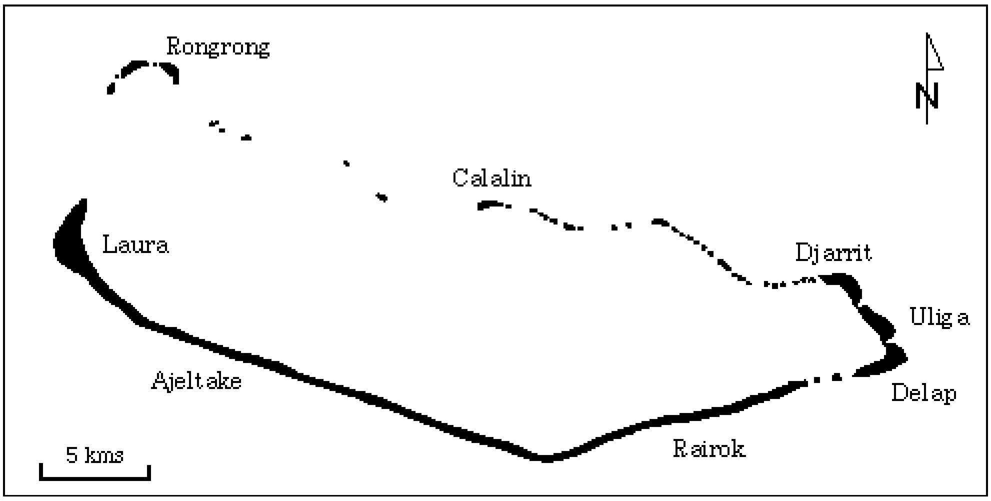

Figure 1. Map of Majuro Atoll showing the locations mentioned in the text.

Figure 2. Demographic development of the population of Majuro, 1912 and 1988. Data for 1912 based on estimates derived from historical sources; data for 1988 based on census returns.

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