SEA LEVEL RISE
AND
ITS IMPACT ON
THE CAYMAN ISLANDS

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A report on secondary research undertaken with both a national and international perspective into sea level changes in the Cayman Islands.

EXECUTIVE SUMMARY

The Cayman Islands are particularly vulnerable to the effects of global climate change on the surrounding sea surface. The islands do not appear to be subject to significant land movement, and sea surface levels around the islands are close to the global mean according to satellite telemetry, consequently forecast changes in mean global sea surface levels are likely to be realistic for the Cayman islands. The total mean global sea surface rise by 2100 estimated by the Intergovernmental Panel on Climate Change Fourth Assessment at between 0.18 and 0.59 metres is likely to be exceeded according to recent research, reaching at least 1 metre. The rate of sea surface rise, presently circa 3.1mm/year, may have increased at least threefold by 2100. These changes will result in beach erosion and the widespread destruction of mangroves, thus rendering the coastline even more vulnerable to flooding than at present.

Forecast changes in the intensity and longevity of hurricanes and tropical storms will exacerbate the effects of sea surface rise. Associated storm surges may increase in magnitude, increasing beach erosion and in particular the erosion of coral reefs. Given the observed effects of coral bleaching probably related to periods when sea temperatures are higher than the mean, reefs may be particularly affected. The combination of rises in the sea surface and increases in the intensity and longevity of storms can only result in serious coastal erosion and flooding. Tsunamis will undoubtedly occur some time in the future, and higher sea surface levels will increase their impact, but their size and frequency cannot be forecast.

Adaptation to these changes will be assisted by improvements in knowledge. There is an urgent need for more detailed information on the progress of relative sea level change. This should be provided by both ground and satellite measurement of sea levels and land movement. There is also an urgent need to determine whether or not the frequency of hurricanes and tropical storms is increasing and on what timescales. A detailed and systematic survey of the health of all coral reef areas around the islands is needed to identify trends and locate reefs that are at risk. The response of mangroves in the Cayman Islands to rates of relative sea level rise and likely future rates needs determination. With improved knowledge of the threats to the coastline, adaptation can be planned. A sustainable approach to coastal defence is probably the most effective in the long run, with planting of trees and shrubs that will trap sediment and disrupt waves. Revised planning laws for coastal development may be needed, and both water supply and sewage arrangements may need to be examined. Some changes in the pattern of tourist activity will be required.

Notwithstanding the many problems which climate change will bring to the Cayman Islands, there are opportunities. The response of the islands may provide an exemplar for similar but more vulnerable or less developed small islands elsewhere in the world. The future may be gloomy, but there is much that can be done.

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1. Introduction

With their low lying topography and location in an area frequently affected by hurricanes and potentially subject to tsunamis, the Cayman Islands are more likely to be seriously affected by sea level rise due to global warming than many areas of the world. This account provides a perspective on the threats posed by sea level rise. Beginning with a short section putting the setting of the islands in context, this report examines the geological record of sea level change in the islands and considers the prospects for future changes, before considering the incidence of hurricanes and tsunamis, the impact of which will be affected by sea level rise. The effects of such changes and flooding events on the main features of the Cayman coastline are outlined and the likely effects on tourism are discussed. A short concluding statement identifies the main effects of sea level change and flooding on the islands and observes that the forecast changes require an increased awareness of the importance of these changes from both the local community and more widely if the islands are to prosper in the future.

2. Setting

.1 Location. The Cayman Islands lie in the central part of the Caribbean Basin (Figure 1), between 19° 15' and 19° 45' North and between 79° 44' and 81° 27' West. The islands (Figure 2) consist of Grand Cayman, Little Cayman and Cayman Brac, and are 150 miles south of Cuba and 180 miles northwest of Jamaica.

Figure 1. Central America and the Caribbean.

Figure 2. The Cayman islands.

.2 Topography. The islands occupy an area of 260 square km. Grand Cayman (Figure 3) and Little Cayman (Figure 4) lie mostly close to sea level, Grand Cayman reaching a maximum altitude of 20m and Little Cayman 16m. On Cayman Brac (Figure 5) the island is marked by a sharp ridge, which reaches 43m at its north-eastern end. A particularly conspicuous feature of the Cayman Islands is the Central Swamp and North Sound on Grand Cayman. Over 50% of Grand Cayman is occupied by swamp.

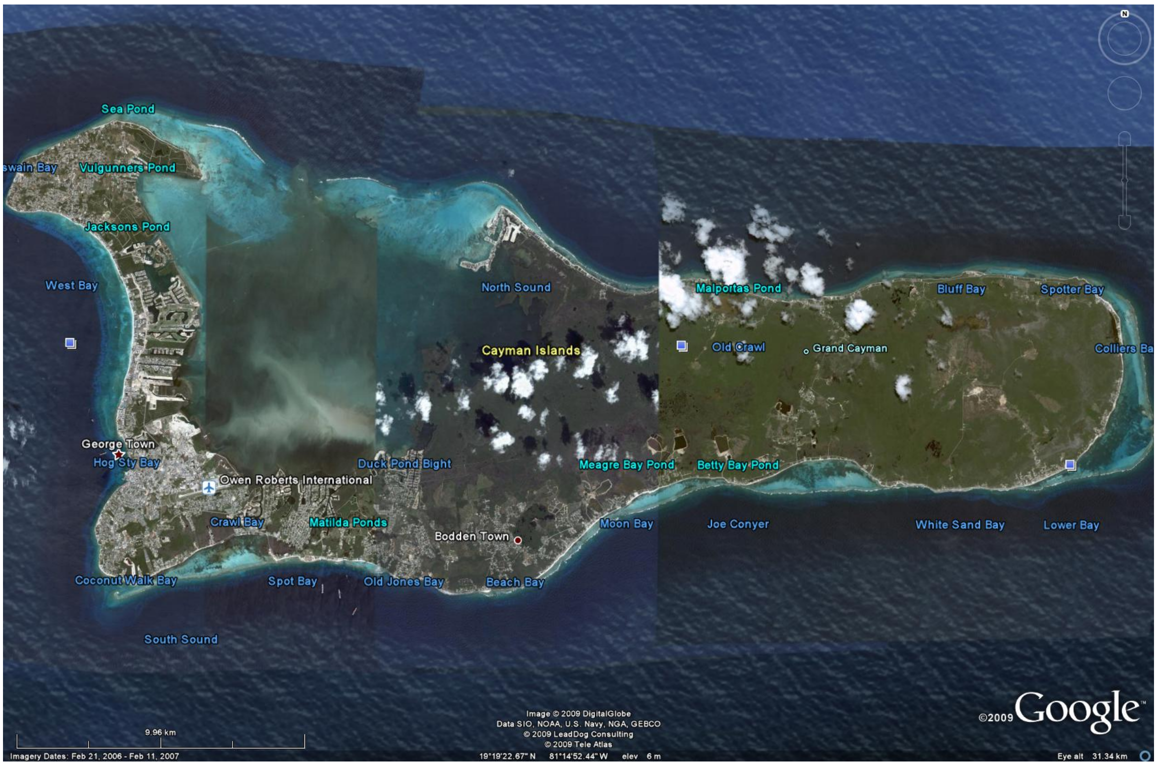

Figure 3. Grand Cayman (Google Earth). Note the Central Swamp, North Sound and Little Sound to the left (west) and the fringing coral reef.

Figure 4. Little Cayman (Google Earth). North is at the top of the picture. Note the fringing coral reef.

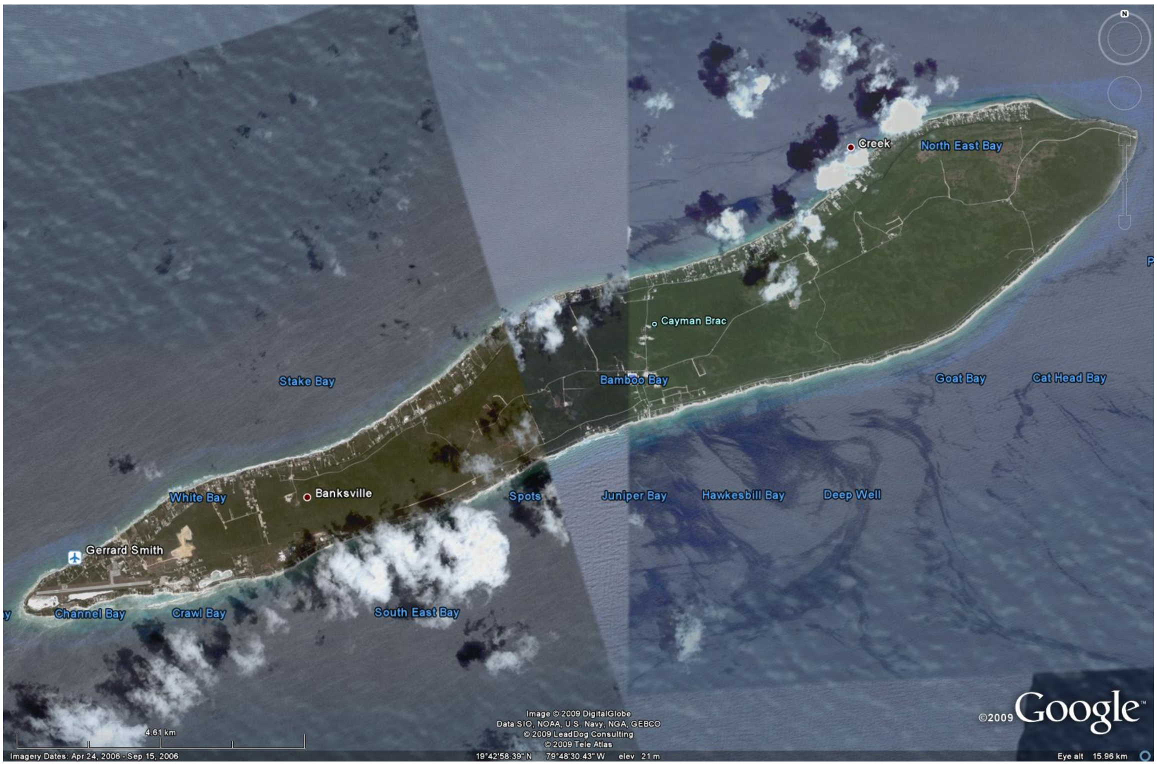

Figure 5. Cayman Brac (Google Earth). North is at the top of the picture. The high ground, culminating in The Bluff, is at the north-east end of the island.

.3 Bathymetry. Offshore, the sea floor (Figure 6) reaches depths in excess of 2000m to the north and west, and to the south slopes steeply to the Cayman Trench (the Bartlett Trough), which reaches a maximum depth of over 7000 metres. Depths to the east are much shallower.

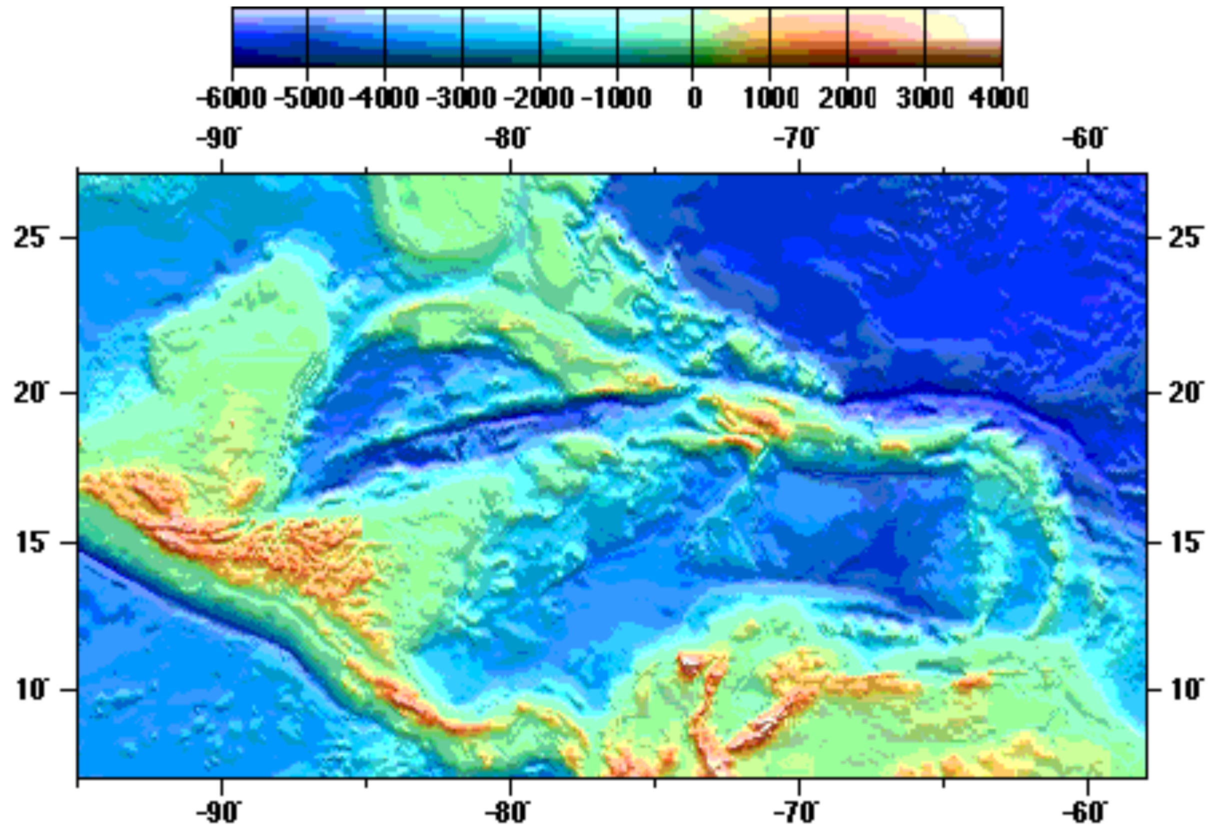

Figure 6. Caribbean bathymetry. Note the Cayman Trench in the centre of the image.

.4 Geology. The Cayman Islands are the summits of the Cayman Ridge, running east-north-east to west-south-west from southern Cuba towards Belize, and on the southern margin of the North American tectonic plate (Figure 7). The islands have a granodiorite base, overlain by basalt, which is in turn covered by limestones and dolostones (e.g. Matley, 1926). The nearshore environment is marked by extensive fringing coral reefs. The Cayman Trough offshore to the south marks the northern boundary of the Caribbean plate, and is a seismogenic zone of some 100-250km width and 2000km length. The displacement along the Cayman Trough is a strike-slip deformation, with the Caribbean plate moving eastwards relative to the North American plate.

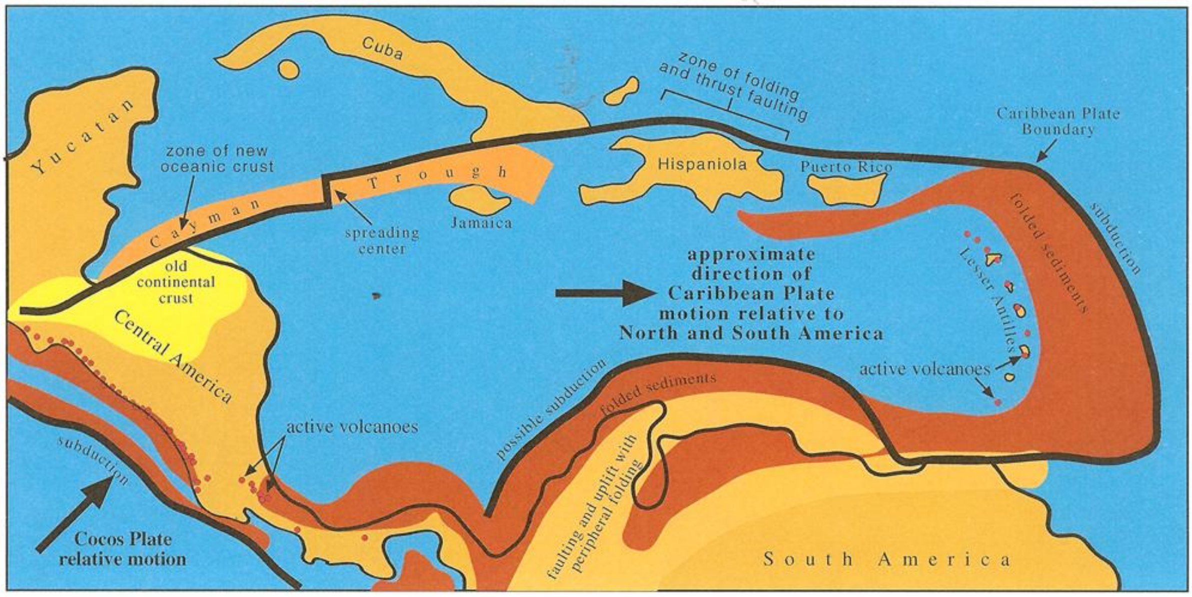

Figure 7. Tectonic plate boundaries in the Caribbean.

.5 Tides and currents. The islands lie in a microtidal area as defined by the National Oceanographic and Atmospheric Administration (NOAA). The tidal regime is mixed semidiurnal and of low amplitude: the maximum tide range at George Town harbour is 0.73m (Tide-forecast, 2009). The islands lie within the zone of the Caribbean current, which is marked by a series of eddies, passing mainly to the south of the islands and on a westerly path (Carton, 1999). The eddies may result in a variation of sea surface elevation by up to 0.2m. The current enters the Caribbean through passages between the islands of the Lesser Antilles. It passes north of the Yucatan Peninsula, into the Gulf of Mexico, and finally exits the Caribbean through the Florida Strait into the Atlantic as the Gulf Stream.

.6 Wind and wave climate. The islands are impacted by waves generated by moderately strong unidirectional trade winds blowing from the North-East at speeds of 5-7 metres/second, generating waves of circa 1metre in height (Brunt and Davies, 1994). Eastward facing coasts have higher levels of wave energy. During the winter, occasional "northwesters" may briefly reach the islands and alter the wave pattern.

3. Situational Analysis Summary

The Cayman Islands are today at an important juncture in their development history. The population has been growing at 4.73% per year. As an indication the islands population grew 428% between 1970 and 2006. If this trend continues the projected population will be 134,000 by 2026.[1] As well, the construction industry is booming with new condominiums, homes and apartments being built and rumours of new hotels flourishing. In light of the projected population growth and construction boom, now may be the time to consider some of the effects that climate change may have on these islands.

The Cayman Islands, being low lying islands with an average height above sea level of seven feet are vulnerable to rising sea levels caused by global warming. Without resolute counteraction, climate change will overstretch many societies' adaptive capacities within the coming decades.[2] As has been stated by the World Bank, the Intergovernmental Panel on Climate Change[3] and NASA's Goddard Institute of Space Studies[4] sea levels are rising due to manmade Green House Gas (GHG) emissions'. During hurricane Ivan in September 2007 over 70⁺% of Grand Cayman flooded to depths varying from a few inches to 10'⁺ feet.

Many of the islands homes, resort hotels and condominium developments are built on the coastline and are extremely vulnerable to adverse weather and the resulting storm surge. Storm surge and wave damage will be compounded by sea level rise in years to come, making it imperative that the issue be addressed today. The two oil companies represented in the Cayman Islands, Exxon and Chevron have their oil storage installations on the Western coast of the islands, making them vulnerable to storm surge / wave action from the west, the fact that these installations are situated among residential areas makes the danger greater. Grand Cayman's only airport, Owen Roberts International is also on the coastal flood plain, bordering as it does on the edge of the North Sound. This vital part of the countries infrastructure was flooded in hurricane Ivan. During the same incident the islands communications infrastructure was rendered unusable, due either to loss of electrical power or wind damage to masts and antennas. Caribbean Utilities, Grand Cayman's only supplier of electricity is situated on the shores of the North Sound and within the coastal flood plain. During a severe storm or hurricane the generators are shut down as there is a strong possibility that segments of the transmission and distribution grid will be destroyed and that the plant itself will be flooded. Much of Grand Cayman's potable water infrastructure was destroyed in hurricane Ivan as the mains supply follows, to a large degree, the coastal roads making it vulnerable to damage from wave action and storm surge.

Sea level rise (SLR) due to climate change is a serious global threat: The scientific evidence is now overwhelming. Continued growth of greenhouse gas emissions and associated global warming could well promote SLR of 1m-3m in this century, and unexpectedly rapid breakup of the Greenland and West Antarctic Ice Sheets (WAIS)[5] might produce a 5m SLR. [6] NASA's James Hansen and his collaborators argue that based on the paleoclimate records is that sea level rise is likely to be five metres this century under a business as usual (BAU) trajectory.[7]. In December 2006, data presented to the American Geophysical Union Conference suggested that the Arctic might be free of all summer ice as early as 2030 and likely by 2040. This will have the effect of setting up a "positive feedback loop" with dramatic consequences for the entire Arctic region. The question in relation to Greenland is whether or not the ice cap can survive the forcing contributed by the albedo effect of open ocean for the duration of Arctic summers.

Dr. James Hansen states that there has been and still is a reticence within the scientific community to state one's personal views on controversial subjects, of which rising sea levels is certainly a controversial one. He further states *"as a physicist, I find it almost inconceivable that [under a] Business as Usual (BAU [scenario]) climate change would not yield a sea level change of the order of meters on the century timescale".* This in comparison to the Intergovernmental Panel on Climate Change (IPCC) whose midrange projection for sea level rise this century is 8–17 inches and full range is 7–23 inches.[8] The IPCC report goes on to note that they are unable to evaluate possible dynamical responses of the ice sheets, and thus do not include any possible 'rapid dynamical changes in ice flow. [9] Other scientists have noted that if one uses the observed changes of the past century that we end up with a projection for the next century of over one metre.[4]
Rising sea levels have three causes, the first being the expansion of the planet's oceans caused by the rising temperature [3] , and the second being the melting of ice caps and glaciers globally and the third is the change in terrestrial storage. The IPCC "Climate Change 2007 Report[8] Fourth Assessment Report states that 'Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea

level'.[3] In a high level meeting with a senior advisor the British Government the author was informed that the UK is expected to have monsoon type rains in years to come, necessating the replacement of storm drainage systems in many metropolitan areas.[10] This therefore is another consideration for the Cayman Inlands, that due to the rising average global air temperature, the atmosphere will be able to hold more moisture leading to heavier rainfall and inevitably greater terrestrial flooding,[11] [10] flooding that is already problematic and will be exacerbated by increased sea level.

The World Bank states that to date there is no evidence that the international community has seriously considered the implications for sea level rise for populations in high risk areas. [6] The OECD has published a report in conjunction with Risk Management Solutions[12] (RMS) and the University of Southampton looking at the effect on the worlds major sea ports, however little has been published with reference to the effect on vulnerable populations. Nor has there been any evidence of the Cayman Islands considering the implications of these phenomena. During Hurricane Ivan, seventy percent of Grand Cayman flooded as shown on the map prepared by the Cayman Islands Lands & Survey Department [See Appendix].

Given the magnitude of the problem facing the Cayman Islands, and indeed all Small Islands Developing States (SIDS), not to mention many of the worlds major sea ports[13] [14] including those in Florida, from which the Cayman Islands get their supplies, we should start to address the issue today. At the present time the Cayman Islands Government (CIG) are discussing the construction of new cruise ship and cargo docking facilities and therefore consideration has to be given, not only to future sea level but beyond this to the effect of hurricane storm surge on top of the increased average sea level. The Owen Roberts International airport was out of operation in the immediate aftermath of hurricane Ivan due to flooding and now a new terminal is being constructed.

Rising sea level will impinge on many aspects of life in the Cayman Islands; it will affect construction of infrastructure such as roads, aircraft runways, port infrastructure, on fresh water lenses, on agriculture, on sewage and refuse disposal and on disaster management. The risk to the population will be heightened and the availability of insurance and mortgages may become problematic. At present, there are areas of the Island of Grand Bahama Island in the Bahamas where the residents cannot obtain insurance on their homes because of past flooding. [12] In the risk management industry the Cayman Islands are in the most severe category of risk due to their geographic location. [12] Planning regulations will have to be adapted to make allowances for all of the above scenarios as will all utility planning by Cable & Wireless, Caribbean Utilities Company Ltd., the Water Authority and Cayman Water Company. Hurricane shelters will have to be increased, both in numbers to shelter the growing population and in elevation to protect against higher storm surge.

Many countries have implemented sea defences, such as the Thames Barrier or the North Sea defences on the coast of the Netherlands. The Netherlands is coming to grips with rising sea level by examining the feasibility of constructing offshore barrier islands for coastal protection,.[15] which may also be used for siting wind turbines. They are also giving consideration to declaring certain areas as no-build areas so that they may be utilised as flood plains. However, the viability of sea defences for an entire island may well be cost prohibitive. In the short term the answer may lie in enhanced regulations and policy by the Government of the Cayman Islands to ensure that all future buildings and infrastructure are constructed at sufficient elevation above sea level to minimise potential damage by storm surge. All critical utilities would have to be protected against potential damage and their transmission infrastructure would have to hardened or elevated.

4. Sea level change

.1 The geological record. At the last glacial maximum, global sea levels lay at least 120m below present (e.g. Fairbridge, 1961). The subsequent rise, bringing the sea surface up to present levels, has been the subject of many studies world-wide and has been largely responsible for the development of organisations specifically concerned with sea surface level change, for example the International Union for Quaternary Research (INQUA) Shorelines Commission and successive International Geological Correlation (IGCP) programmes. Initially, it was thought that the sea surface changes were simultaneous and of the same order across the globe, but by the 1970s it was recognised that although the major changes associated with ice sheet decay had occurred at about the same time, different regions saw significantly different, often metre-scale, changes. Most early research took place in Europe and North America, but by the 1970s and especially as research on coral reefs developed, studies of sea surface change began to increase in the Caribbean.

Figure 8. Erosion of the Bluff on Cayman Brac, Cayman Islands

Lighty et al. (1982) derived a curve of sea level change for the last 10,000 years based upon radiocarbon dating of the coral *Acropora palmata* (all years here are expressed in radiocarbon terms unless otherwise stated) from sites across the Caribbean. Digerfelt and Hendry (1987) produced a curve for the last 8000 years from Jamaica, but based upon mangrove and swamp peat, comparing this with curves from nearby areas.

Figure 9. Erosion of coastal bluff on Cayman Brac, Cayman Islands

Later, Fairbanks (1989) produced a curve for the last 17,000 years from *Acropora palmata* reefs in Barbados. Blanchon and Shaw (1995) subsequently produced a curve for the last 20,000 years also based upon *Acropora palmata* reefs in the eastern Caribbean at sites ranging from Florida to Guyana. More recently, Toscano and Macintyre (2003, 2005) produced a curve for the last 10,000 years based upon *Acropora palmata* for sites across the Caribbean from Florida to Panama, comparing coral and peat dates (Figure 8), and comparisons with the Barnados graph of Fairbanks (1989) are made in Figure 9. Apart from the early study of Lighty et al. (1982), which cautiously recognised the probable depth range of *Acropora palmata,* all these studies recognise that sea surface levels attained present within the last 2000 years. However, caution should be expressed over a detailed interpretation of these curves because of tectonic and isostatic uplift at several localities (although the amount is uncertain), as illustrated by varying views on the amount of uplift. The paper of Toscano and Macintyre (ibid.) has attracted criticism on this basis (Gischler, 2006) and also on the basis of the methodology employed (Blanchon, 2005). Responses by Toscano and Macintyre (2005) and Toscano (2006) recognise some of the uncertainties identified. In so far as tectonic effects are concerned, Digerfelt and Hendry (1987) maintain that there has been little tectonic disturbance of the Caribbean plate during the Holocene (the last 10,000 years), but other areas studied by Toscano and Macintyre (ibid.) exhibit evidence of movement. The study of Fairbanks (1989) makes corrections for probable tectonic movement in his data from Barbados, and indeed it is observed here that the corrections made are very much assumptions. Given the uncertainties about land movement at different sites, it is usual for measurements of sea level against the land in specific studies to be referred to as *relative sea levels*, whereas more generally if changes in the sea surface (without reference to the land) are discussed the term *sea surface levels* is normally used.

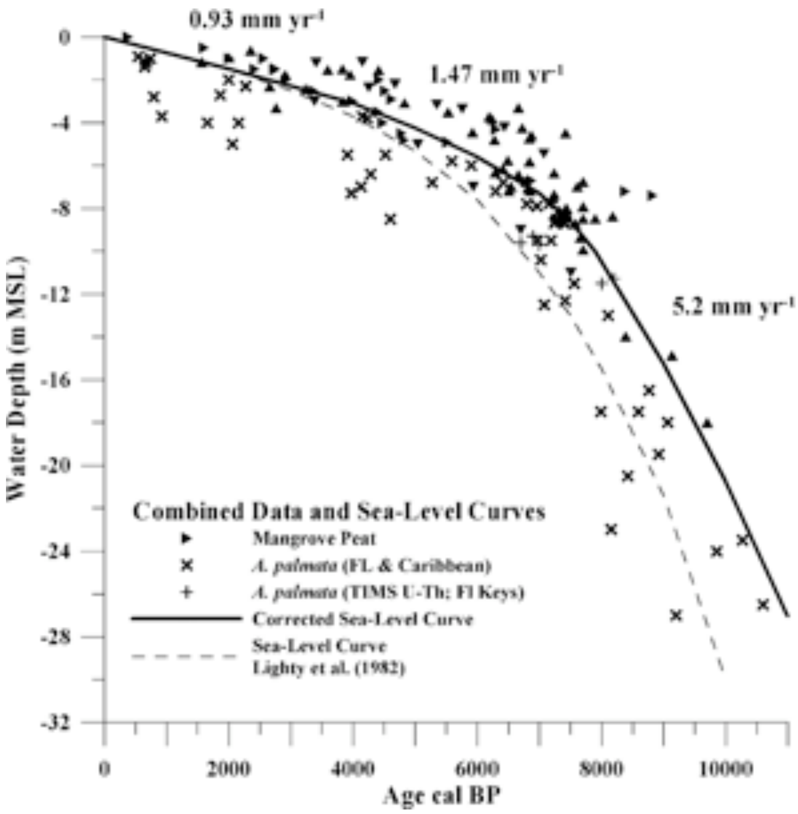

Figure 10. Relative sea level graph (solid line) for the Caribbean area from Toscano and Macintyre (2003), showing data on which it is based, rates of rise, and the curve of Lighty et al (1982). The rate of 5.2mm/yr refers to the period 10,600 – 7,700 BP; that of 1.47mm/yr to 7,700 – 2,000 BP and that of 0.93mm/yr to 2,000 – 400 BP.

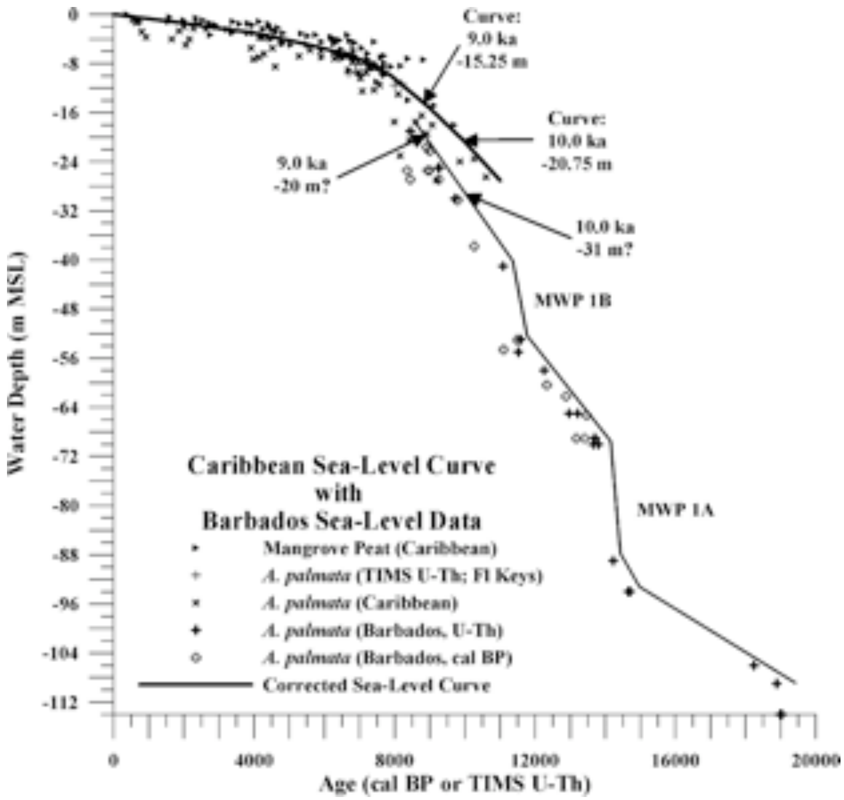

Figure 11. Relative sea level graph of Toscano and Macintyre for the Caribbean for circa 12000 BP to present compared with that of Fairbanks (1989) for circa 18000 – 7000 BP for Barbados. After Toscano and Macintyre (ibid.). Note the discrepancy between the two graphs around 11,000 – 8,000 cal BP.

In the Cayman islands, there is both morphological and stratigraphical evidence for relative sea level change. Offshore, prominent terraces at depths of circa 8m and circa 20m are believed to indicate former relative sea levels, reached perhaps during pauses in the sea surface rise during and/or following melting of global ice masses, perhaps accompanied by land movement. Onshore, terraces have been identified marking higher relative sea levels of unknown date (Emery, 1981; Woodroffe et al., 1983; Brunt and Davies, 1994). The most detailed evidence, however, has been obtained from mangrove peats and molluscs at sites around the North Sound and Little Sound, where recent studies have provided an insight into relative sea level change in the last *circa* 2500 years. Based upon mangrove swamp stratigraphy primarily at Barkers Peninsula, North Sound, Woodroffe (1981) determined that rising relative sea levels had reached 1.85m below present at 2100 BP, before rising to present levels, with the mangroves retreating before the rising relative sea level, evidenced by the inundation of patch reefs (Woodroffe et al., 1980). More recently, Macinnon and Jones (2001) investigated a wider area around and across North Sound. They concluded that the sea first entered the sound across a sill at its entrance no later than 2200 BP. However, their relative sea level elevations were circa 3m below those of Woodroffe (ibid), and they concluded that the difference was due to the material dated, suggesting that the true curve probably lies between the trend of Woodroffe (ibid.) and their trend. Macinnon and Jones (ibid.) estimated that over the 2200 year period, relative sea levels rose into North Sound at a rate of 1.60m per 1000 years. Neither study found variations in the rate of relative sea rise. It seems likely that the conclusions on relative sea level change reached for Grand Cayman apply to Little Cayman and Cayman Brac, since Jones and Hunter (1990) have shown that there is probably no difference in tectonic movement between the islands.

Thus, relative sea levels on Grand Cayman, and by implication on Little Cayman and Cayman Brac, have been rising without variation according to these studies since circa 2200 BP.

.2 Recent sea level change. In the absence of detailed published documentary or instrumental evidence on the Cayman Islands, the approach taken here is to consider available information on sea surface changes, both regionally and globally, then examine how this may relate to the local area. The Third Assessment Report of the Intergovernmental Panel on Climate Change produced in 2001, following Flemming et al. (1988), remarked that over the last 6000 years, the increase in ocean volume may have added 2.5 to 3.5 metres to global average sea level, but observed that significant variations in the sea surface level would have resulted in the rise being different in different areas. The report suggested that fluctuations in the rise would have been minor, and would have not exceeded 0.5m. For the 20th century the report estimated a global mean rise of 1.8±0.1mm/year, but could not exclude that a figure as low as 1.0mm/year might have obtained. However, the report suggested that there might have been an acceleration in the rate of rise towards the end of the century. The Fourth Assessment Report, produced in 2007, confirmed the likelihood of an acceleration (see Table 1).

Table 1 Observed rate of mean global sea level rise and estimated contribution from different sources, IPCC Fourth Assessment Report, 2007.

Source of sea level rise	Rate, mm/yr, 1961-2003	Rate, mm/yr, 1993-2003
Thermal expansion	0.42±0.12	1.6±0.5
Glaciers and ice caps	0.50±0.18	0.77±0.22
Greenland ice sheet	0.05±0.12	0.21±0.07
Antarctic ice sheet	0.14±0.41	0.21±0.35
Sum of individual climate contributions to sea level rise	1.1±0.5	2.8±0.7
Observed rate of global mean sea surface rise	**1.8±0.5**	**3.1±0.7**

The Third Assessment Report estimate of a mean global total rise of between 0.20m and 0.86m between 1990 and 2100 was narrowed down in the Fourth Assessment to between 0.18m and 0.59m (Table 2).

Table 2 Projected mean global total sea level rise at the end of the 21st century, IPCC Fourth Assessment Report, 2007

Modelled Scenario	Range, metres
B1	0.18-0.38
A1T	0.20-0.45
B2	0.20-0.43
A1B	0.21-0.48
A2	0.23-0.51
A1F1	0.25-0.59
Range of all scenarios	**0.18-0.59**

It should be noted that the figures in Tables 1 and 2 are mean global figures, and will vary between locations across the globe. However, in these estimates, it is possible (but not certain) that the Cayman islands would exhibit changes close to the mean, for two reasons. Firstly, because there is no evidence of recent changes in the gravitational field affecting the sea surface in the area. Secondly because there is no evidence for land movement if Digerfeldt and Hendry (1989) are correct. Thus at the present time, *relative sea levels* in the Cayman Islands are close to *sea surface levels*. It is of interest to note that global sea surface level maps (e.g. from TOPEX/POSEIDON, JPL and NASA) place the sea surface around the Cayman islands close to the global mean sea surface level. Figure 10 illustrates the altitude, which will not change greatly over the year except during storms.

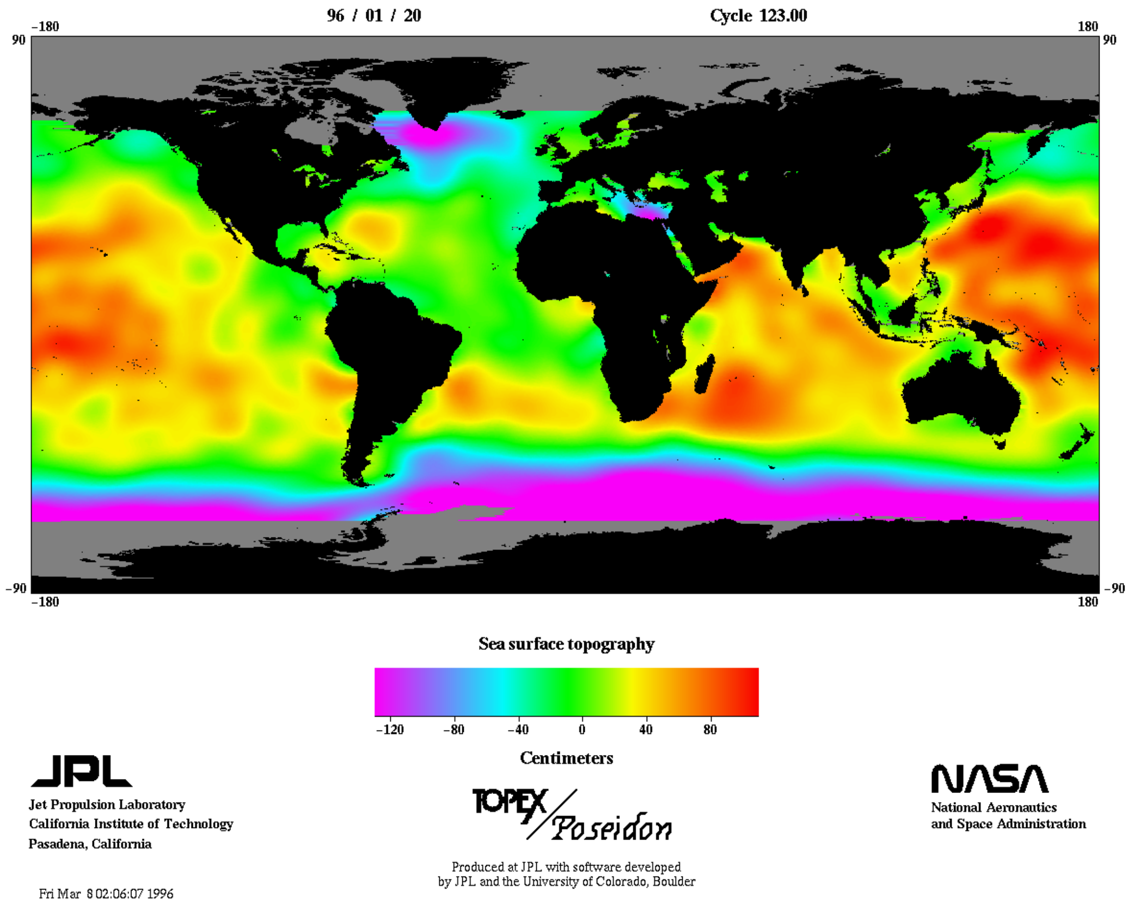

Figure 12. Sea surface topography, 20th January 1996.

Since the publication of the Fourth Assessment Report new interpretations of the data on which it was based and new observations have been made, resulting in a considerable amount of debate surrounding both the rate and amount of sea surface rise. Most of the views expressed support a greater rate and amount of sea level rise in the future than the report indicates. Much of the argument centres around the rate of retreat of the Greenland and Antarctic ice sheets. It is well known that were the Greenland ice sheet to melt, global mean sea levels would rise by about 7 metres, while disintegration of the West Antarctic ice sheet could raise global mean sea levels by 5 metres. However, IPCC were unable to predict how the ice sheets would change in the future because the rate of flow of the ice was uncertain.

More is now known about the flow of the ice sheets. Remarkable detail is now publicly available on the topography beneath the ice and the pattern of individual ice streams. It was becoming evident as the IPCC report was being produced that rates of flow of ice streams into the seas surrounding both Greenland and Antarctica were increasing due to the increase in meltwater at the base of the ice and the decay of buttressing ice shelves. Although some areas of the ice sheets (mainly the centre of the Greenland ice sheet and the East Antarctic ice sheet) were thickening with increased precipitation, the speed of flow of the ice was beginning to result in negative "mass balance" of the ice sheets (i.e. greater loss of volume than gain) (e.g. Thomas et al., 2004). The situation is exacerbated by the fact that recent research shows that the Antarctic is warming, with the trend first observed in the Antarctic Peninsula and later in West Antarctica now apparent over part of East Antarctica (Steig et al., 2009). Most scientists are agreed that these ice sheets are loosing volume and hence are contributing more to global sea level rise than IPCC had estimated. Indeed, questions have been raised about the stability of the ice sheets (e.g. HM Treasury, 2006; Hansen, 2007a).

Hansen (2007b) estimates that a rise in sea surface levels of up to 2 metres, partly due to the decay of the ice sheets, may occur by 2100. This estimate is almost four times the maximum IPCC estimate. Rahmsdorf (2007) observed that the rate of sea level rise is roughly proportionate to the magnitude of warming above the temperatures of the pre-industrial age, estimating a rise of between 0.5 and 1.4 metres above 1990 levels by 2100. This view was contested by Holgate et al. (2007) and Schmith et al. (2007), but was supported by the US Geological Survey report in 2008 to the US Congress on Abrupt Climate Change, which envisaged a rise in mean global sea level of at least 1.5m by 2100 (Clark and Weaver, 2008). These and other reports indicate that the IPCC estimate of the total rise is probably too conservative, and that a rise in global mean sea levels of at least 1 metre is likely by 2100. Although some are sceptical of these estimates, the weight of scientific opinion is supportive. In the event that a rise of 1 metre is achieved by 2100, the rate of rise would increase to three times the present observed rate. A rise to 1.5m would involve a rise increasing to five times the present observed rate. Rates of rise are extremely important, and have often been ignored in press reporting of estimates of mean global sea level rise.

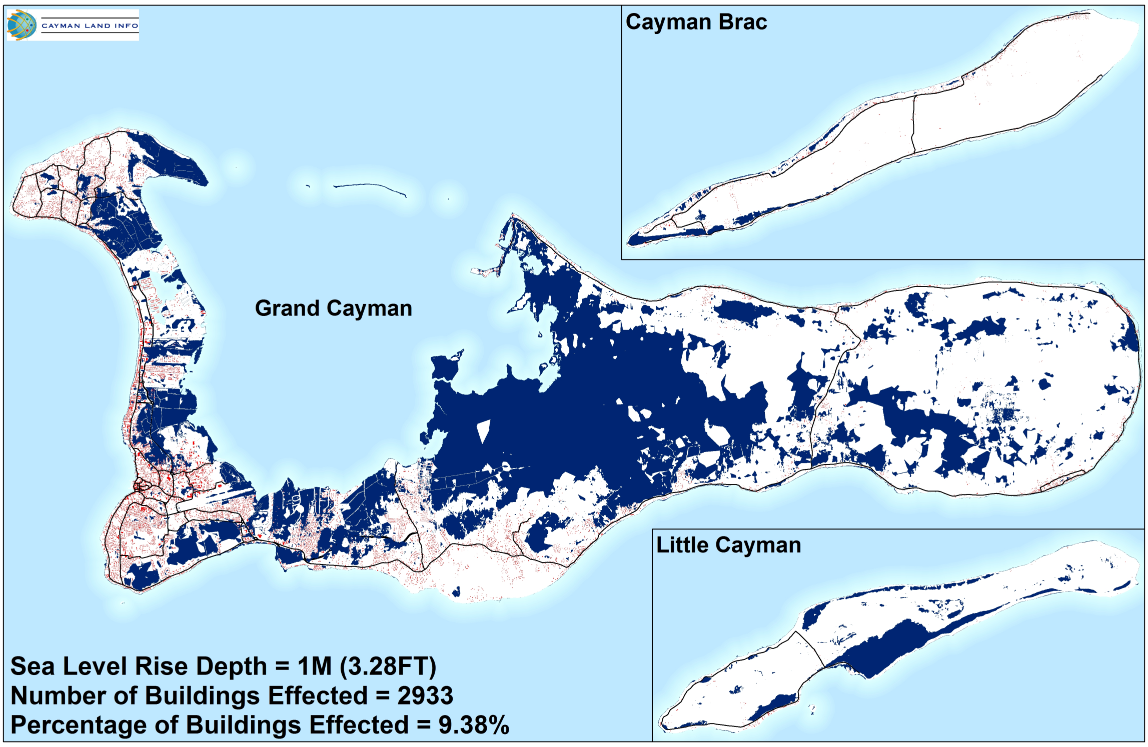

Figure 13. Overlay of 1 Metre sea level rise on the Cayman Islands

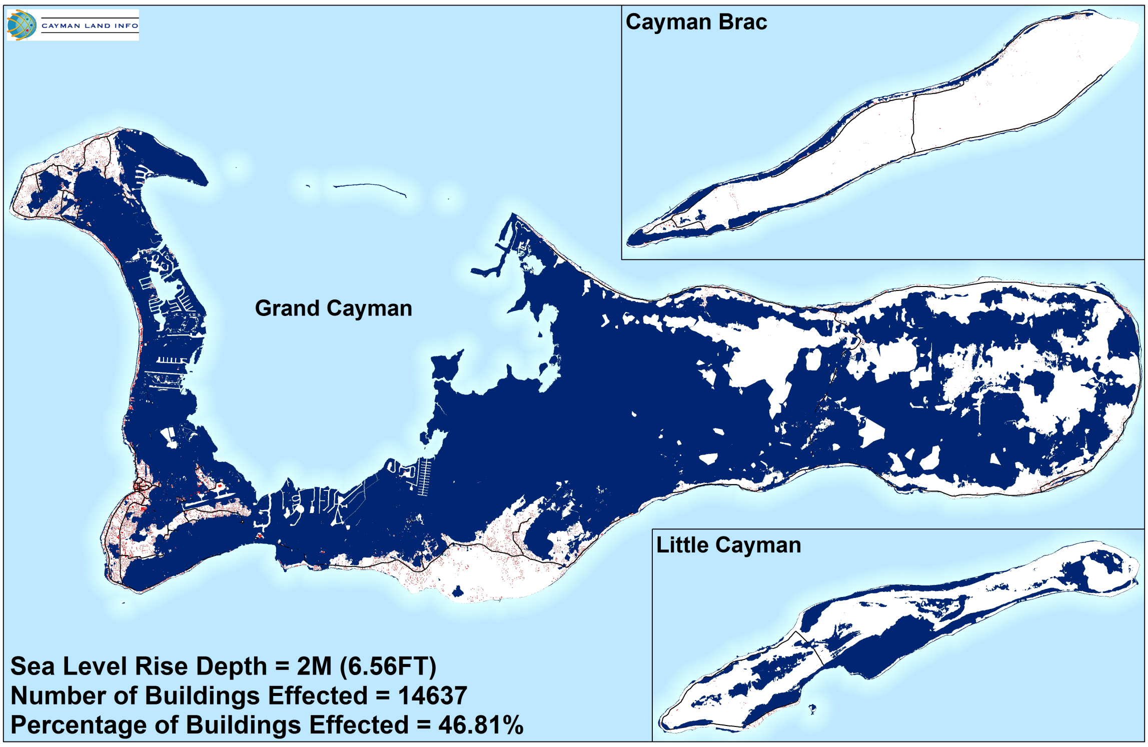

Figure 14. Overlay of 2 Metres sea level rise on the Cayman Islands

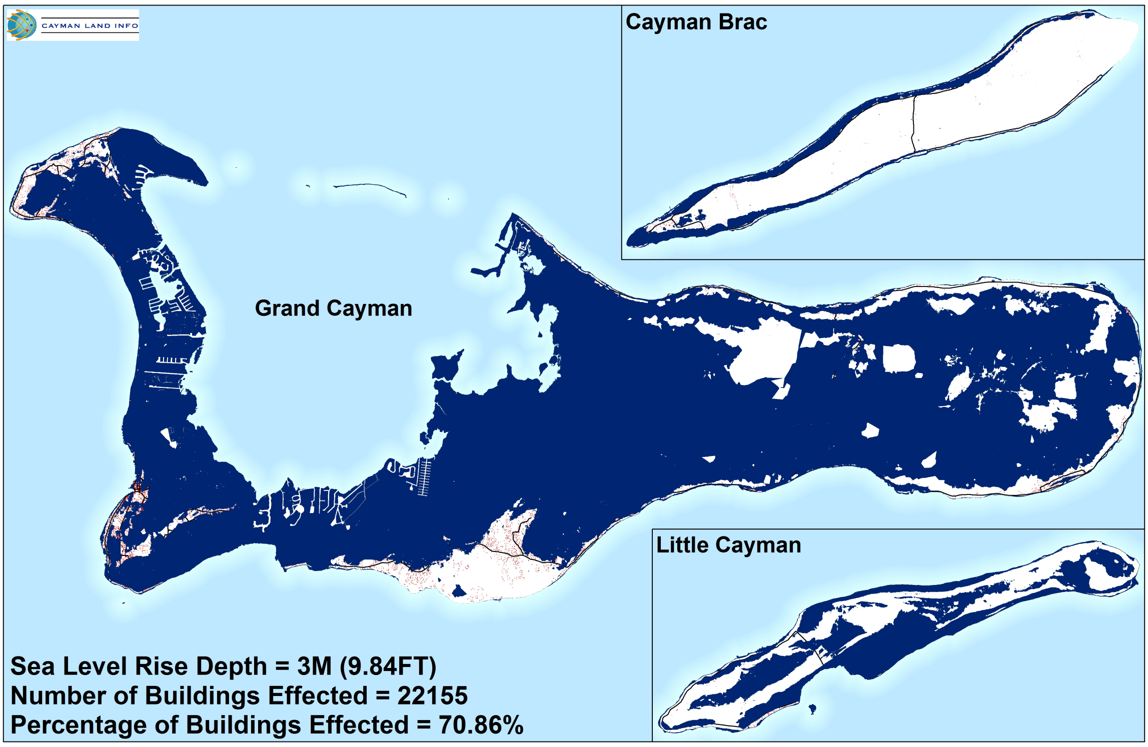

Figure 15. Overlay of 3 Metres sea level rise on the Cayman Islands

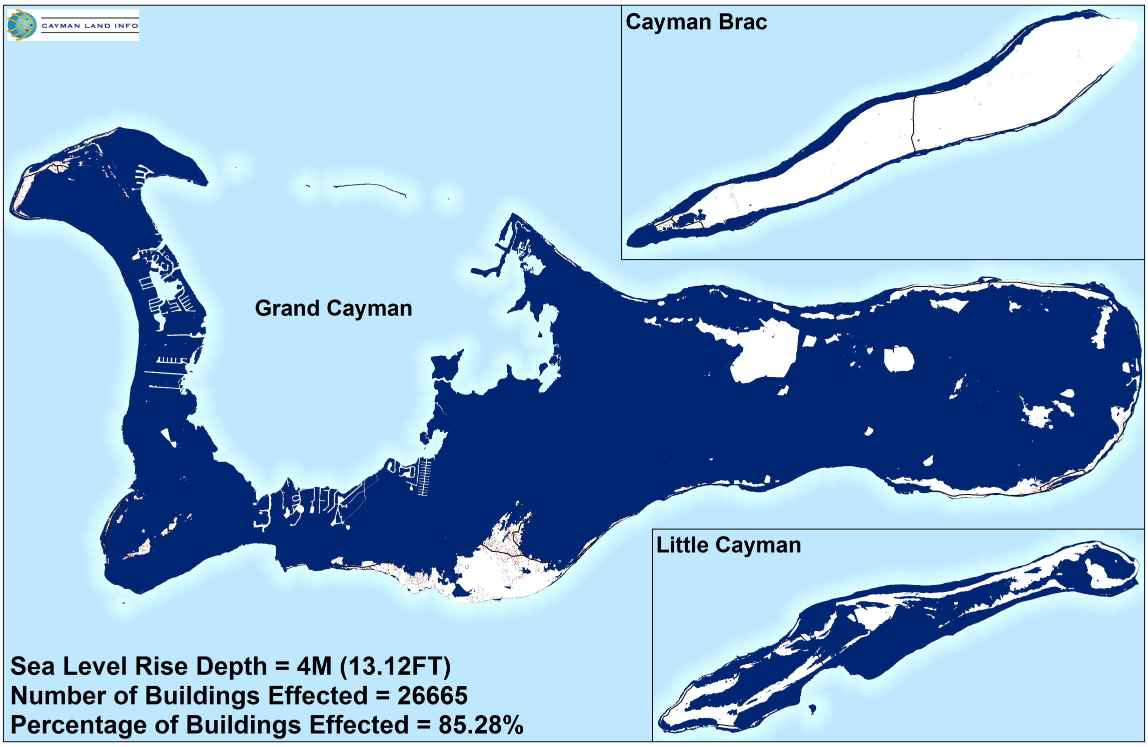

Figure 16. Overlay of 4 Metres sea level rise on the Cayman Islands

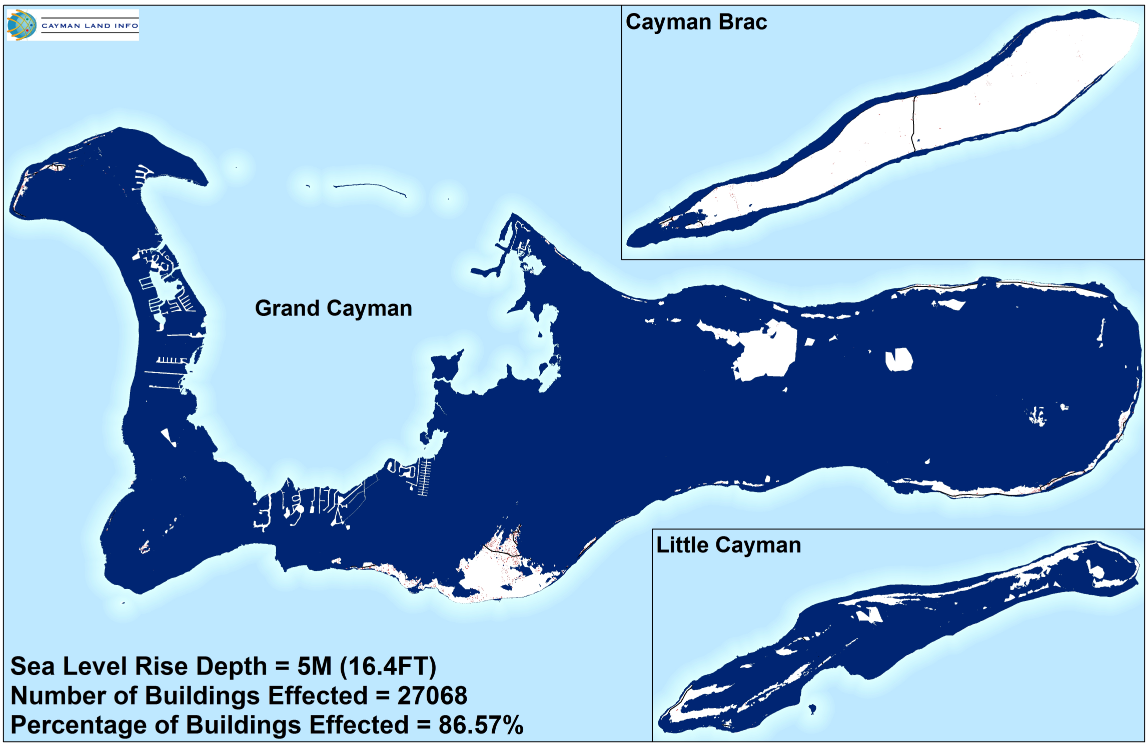

Figure 17. Overlay of 5 Metres sea level rise on the Cayman Islands

Buildings Affected Per Sea Level Rise Scenario

	0.82FT 0.25M	1.64FT 0.50M	2.46FT 0.75M	3.28FT 1M	6.56FT 2M	9.84FT 3M	13.12FT 4M	16.40FT 5M	+16.40FT +5M
APARTMENT\ CONDO	2	25	147	545	2179	3246	3744	3773	4036
COMMERCIAL	0	11	61	181	775	1114	1300	1312	1381
EDUCATION\ RELIGION	0	3	7	28	121	257	362	366	416
HORTICULTURAL	0	0	1	4	13	21	26	26	28
INDUSTRIAL	0	1	2	23	117	148	164	165	174
PUBLIC	0	2	4	11	75	153	228	239	305
RESIDENTIAL	17	69	335	1315	6779	10268	12473	12683	15009
TOURISM\ LEISURE	1	13	32	57	260	424	532	538	618
UNCLASSIFIED	13	60	228	765	4269	6446	7743	7872	9194
UTILITY	0	0	0	4	49	78	93	94	104
TOTAL	33	184	817	2933	14637	22155	26665	27068	31265

**unclassified buildings are non addressable and generally consist of sheds or outbuildings*

Figure 18. Buildings affected by sea level rise at various levels of sea level rise

5. Extreme events

.1 Hurricanes. Hurricanes are an ever present feature of the climate of the Caribbean. Table 3 illustrates the periodicity of these events. The hurricane season is June to

November, with the peak season mid-August to October. The statistical peak occurs on 10th September.

Table 3 Recorded Tropical Storms and Hurricanes by month since 1851 (Source: NOAA)

Month	Total	Mean
January - April	5	0.03
May	19	0.1
June	80	0.5
July	102	0.7
August	347	2.2
September	466	3.0
October	281	1.8
November	61	0.4
December	11	0.07
Total	**1,372**	**8.8**

Table 4 lists the most intense Atlantic hurricanes, and shows the minimum pressure recorded. The pressure value provides a measure of the likely rise in the sea surface beneath the storm and therefore the likely rise (see below).

Table 4 The most intense Atlantic Hurricanes

Rank	Hurricane	Season	Minimum Pressure
1	Wilma	2005	882mb
2	Gilbert	1988	888mb
3	"Labour Day"	1935	892mb
4	Rita	2005	895mb
5	Allen	1980	899mb
6	Katrina	2005	902mb
7	Camille	1969	905mb
	Mitch	1998	905mb
9	Ivan	2004	910mb
10	Janet	1955	914mb

(http://www.hurricanecity.com/Rank.htm)

There is some debate about the changing frequency and intensity of hurricanes. Given that the development of a hurricane is dependent upon the temperature of the sea surface layers and given that sea water temperatures appear to be increasing (e.g. Goreau et al., 1997; Domingues et al., 2008), it might be thought that with global warming the number and intensity of hurricanes will be increasing. Some studies indeed suggest that the frequency of hurricanes is increasing, based on increases over the period 1975 – 2004. However, when larger timescales are considered, an increase in frequency is less clear (Nyberg et al., 2007). It seems that there are oscillations in the frequency of hurricanes (Elsner et al., 1999), and it is now thought that hurricane activity is related to the El Niño/La Niña oscillation (ENSO) (e.g. Tartaglione et al., 2003; Donnelly et al., 2007). El Niño events in the Pacific, occurring every 4 – 7 years (e.g. Tingstad and Smith, 2007), are thought to suppress hurricane activity in the Atlantic. In an El Niño, high altitude winds create wind shear, focussing the storm's latent heat over a wider area and decreasing the centripetal force at the centre of a tropical storm, making it less likely to develop into a hurricane. La Niña events, occurring on a similar timescale, are thought to involve less wind shear and consequently to result in conditions more favourable for Atlantic hurricanes. There seems to be more agreement on hurricane intensity. Emmanuel (2005) and Emmanuel et al. (2007) maintain that hurricane intensity is increasing, as well as hurricane longevity.

The storm surges associated with hurricanes may cause considerable damage and flooding. Storm surges precede the arrival of hurricanes, then continue during them and their effects may involve larger areas. Storm surge height is related to the depression in pressure in the hurricane, so that the lower the pressure the higher the surge. Since pressures in hurricanes are getting lower as intensity increases, storm surges are getting higher, and on top of this as winds become stronger storm-driven waves become larger, so it seems likely that because intensity is increasing, storm surges will increase. The surge associated with Hurricane Ivan in 2004 reached 2.4m in Grand Cayman, including in George Town (Cayman Islands Government, 2004).

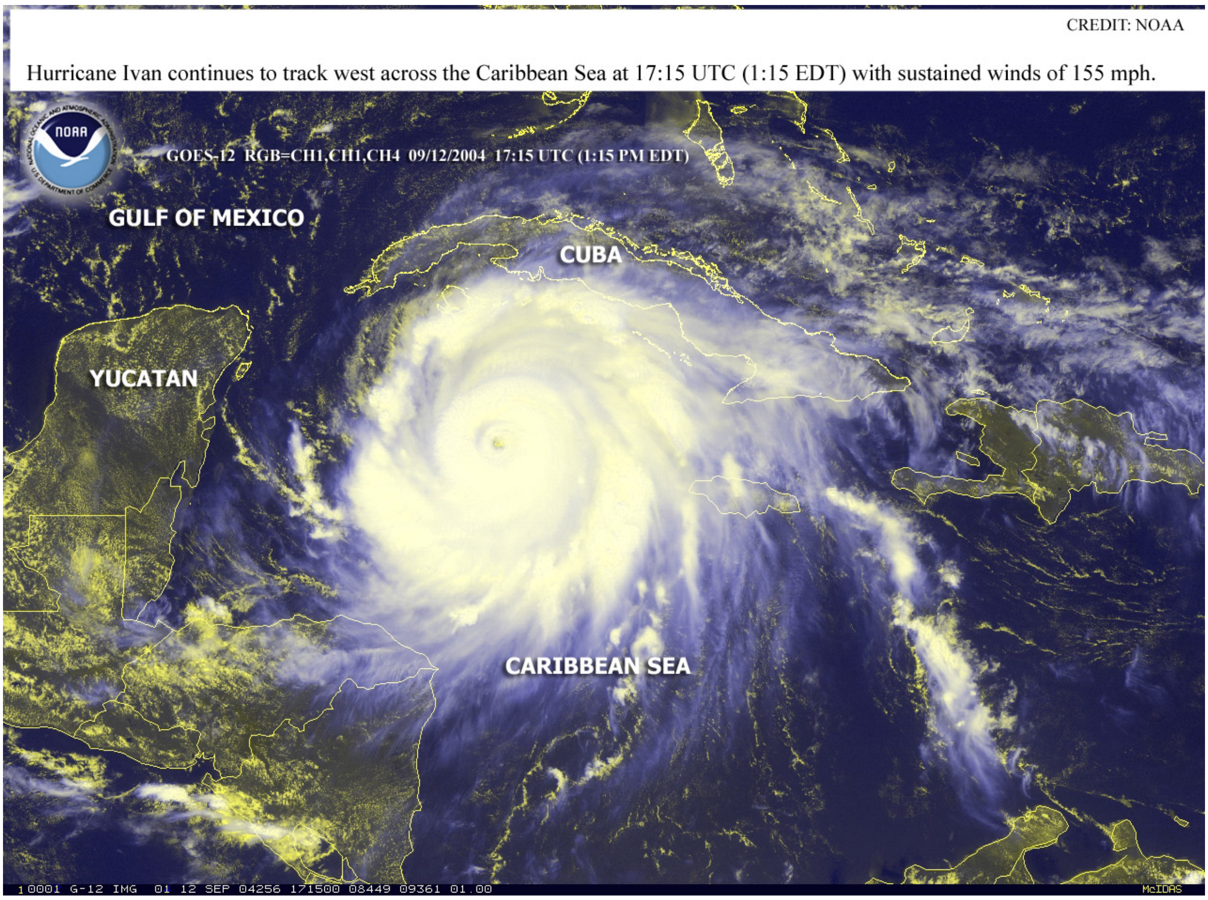

Figure 19. Hurricane Ivan at its maximum intensity, passing the Cayman islands, September 2004

Hurricane categories and associated storm surge amplitudes are shown in Table 5.

Table 5 Saffir – Simpson Hurricane Scale (US National Hurricane Center)

Category	Wind Speed (mph)	Storm Surge (metres)
1	74-95	1.2-1.5
2	96-110	1.8-2.4
3	111-130	2.7-3.7
4	131-155	4-5.5
5	>155	>5.5

The Cayman islands have recorded the highest number of hurricanes for any comparable area of the Caribbean, with a hurricane having brushed or hit the islands on average every 2.23 years, and a direct hit every 9.13 years (NOAA, 2007). Six major hurricanes have had a significant impact on the islands since 1980. Given the now well documented rise in relative sea level, and the likelihood that such a rise will increase in the future, the impact of hurricanes can only increase in the long term. In view of the topography of the islands that increase may well be extremely serious.

.2 Tsunamis. As the Indian Ocean tsunami of December 2004 showed, tsunamis can cause considerable loss of life and destruction to infrastructure. No coastline in the world is immune, but some are more prone to tsunami impact than others. Tsunamis have been known about and researched in the Pacific for many years, but it is only recently that coastal populations in other areas of the world have become aware. The origins of tsunamis are many and are summarised in many publications (e.g. Murty, 1977; Smith, 2005). For the Cayman islands the question must be whether the threat is real and should it be taken seriously.

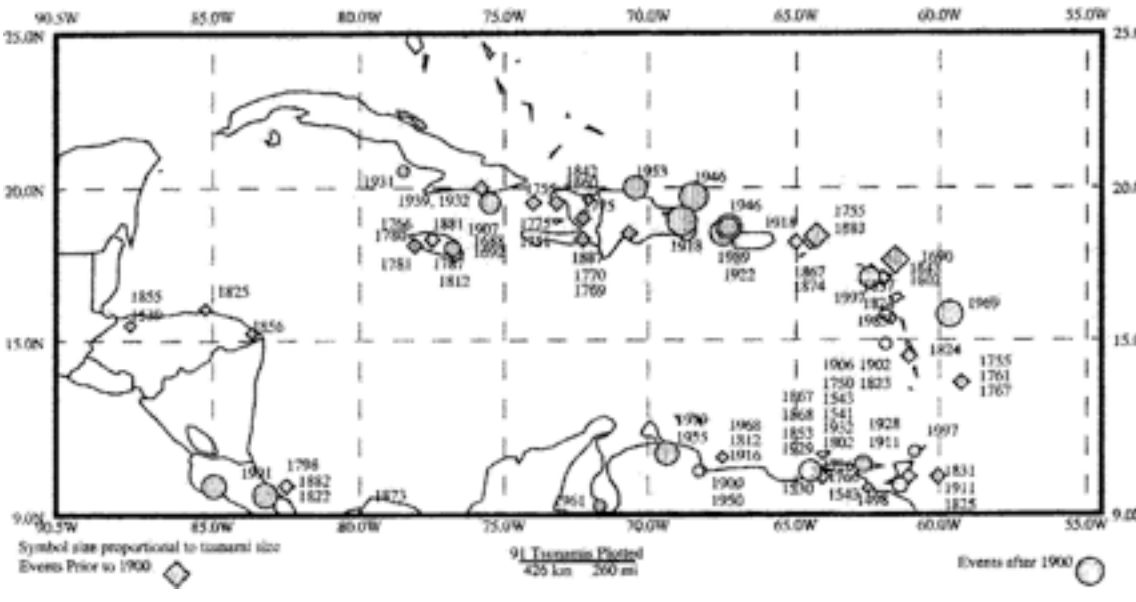

Figure 20. Tsunamis in the Caribbean since the sixteenth century, taken from Lander et al. (2002). Events prior to 1900 are shown with a diamond; events post 1900 with a circle.

Across the Caribbean as a whole, tsunamis do not have a high profile in the literature on disasters. The United Nations Environment Programme Regional Report (2008) does not even mention tsunamis in its short section on natural disasters. Nevertheless tsunamis do occur and although their threat is sometimes exaggerated in the press it is nonetheless real.

Much has been written about the threat of a great tsunami originating from the collapse of the volcano Cumbre Vieja in the Canary Islands (e.g. Trombley, 2008). However such events are unpredictable, occur on a geological timescale, and it would be unrealistic to even attempt to anticipate them. Even if collapse of the volcano concerned occurred today, the speed could be so slow that only a very small tsunami might occur. It is considered more realistic to examine the likelihood of smaller, more frequently occurring events.

Tsunamis have occurred widely in the Caribbean in the past (Figure 12). Tsunami catalogues (e.g. Lander et al., 2002; O'Loughlin et al., 2003) list over 40 possible tsunamis since the late fifteenth century, although they observe that several are uncertain and the actual number is probably closer to 30. Some have probably been caused by submarine slope failure (Swab et al., 1991); fault movement along plate boundaries (Voigt, 2004); or volcanic activity (Paras-Carayannis, 2004). Most tsunamis were generated along the Caribbean/North American plate boundary in between Cuba and the Lesser Antilles, and most resulting deaths have occurred in this area (Table 6). It has been observed that more tsunamis have been recorded for the Caribbean than for the Atlantic coast of North America.

Table 6 Caribbean Tsunami fatalities since 1842 (after Lander et al., 2002)

Year	**Location**	**Number of fatalities**
1842	Haiti	300+
1853	Venezuela	600+
1867	Virgin Islands	23
1882	Panama	75+
1906	Jamaica	500
1918	Puerto Rico	140
1946	Dominican Republic, Haiti	1790
1946	Dominican Republic	75
Total		**3428+**

Some tsunamis were generated outside the Caribbean area, notably the 1755 Lisbon tsunami and a later one in 1761. Waves from the Lisbon tsunami caused run-ups of up to 7 metres in the eastern Caribbean (Lander et al., 2002). Whilst many of the tsunamis recorded were localised, some (including the Lisbon tsunami) were felt widely in the Caribbean.

It would be surprising if tsunamis had not visited the Cayman islands in the past. Coastlines to the west, in central America, notably Honduras, and to the east, in Jamaica and Cuba, experienced tsunamis in the eighteenth and nineteenth centuries. Most of the tsunamis recorded in the Caribbean were probably generated along fault lines, such as along the plate boundary north and east of Jamaica, the Dominican Republic and Puerto Rico, or by submarine slope failure, such as may have happened north of Puerto Rico, and these tsunamis may travel long distances. For example, the Indian Ocean tsunami of 2004, which was a fault-generated event, travelled around the world, and the Lisbon tsunami of 1755, also fault-generated, crossed the Atlantic (Lander et al., 2002). The Alaska tsunami of 1946, generated by slope failure off the Aleutian islands, crossed the Pacific and reached the Antarctic Peninsula, where icebergs were disrupted (Myles, 1985). Tsunami run-ups (the maximum altitude reached by the tsunami above the ambient water level) can exceed 20m including in tsunamis generated by volcanic events, such as may occur in the eastern Caribbean. The possibility that the Cayman islands may one day be affected cannot be excluded, and given the low-lying nature of the islands a tsunami could have a far-reaching effect. Frequent seismic shocks in the islands (including the recent earthquake of February 7th, 2007) demonstrate that the general area is seismically active. The recent proposal to establish a tsunami warning system for the Caribbean (United States Department of State, 2008) must therefore be welcomed, especially since rising sea levels would exacerbate the impact of tsunamis in the future.

6. The impact of sea level rise and extreme events on the coasts of the Cayman islands

The low-lying coasts of the Cayman islands are vulnerable to both sea level rise and extreme flooding events. The extensive fringing coral reefs are subject to erosion during storm surges associated with hurricanes, and as these storms become more intense, their increasing power will erode reefs. In increasingly intense storms, waves will reach greater amplitudes and thus wave bases will be lower, reaching lower levels on the reef. Disruption to reefs may increase the exposure of mangroves to erosion. Erosion of beaches and redistribution of sediment may affect reefs.

Mangroves are of considerable importance in protecting the shoreline from erosion, but will be increasingly affected by rising sea levels and increases in the impact of extreme flooding events (Woodroffe and Grindrod, 1991; Parkinson et al., 1994). Woodroffe (1990) has maintained that mangrove peat formation may not keep pace with a rise in excess of 2mm/year, so that the present mean global rise of 3.1mm/year may result in the erosion of mangroves. Ellison and Stoddart (1991) pointed to the vulnerability of mangroves on low islands, maintaining that mangroves could not survive rises greater than 0.9mm/year. Much depends upon the accumulation of mangrove peat and in the availability of minerogenic sediment, so that it is difficult to generalise. However, the retreat of mangroves observed by Woodroffe (ibid.) on Grand Cayman gives cause for concern in that locality, and the likely increase in the rate of relative sea level rise by the end of the century gives extreme cause for concern.

Hurricanes are responsible for much beach erosion. Waves in hurricanes comb sediment out to sea, and thus remove it from the beach. Hence, more intense hurricanes with increased wave power are likely to increase rates of beach erosion. However, hurricanes may also result in localised sediment accumulation and the ridges of broken corals produced may trap sediment. Much depends upon the coastal morphology. Tsunamis generally result in widespread deposition. Tsunamis waves, being long period waves, will bring sediment onshore (often from great depths) and will often distribute that sediment as far as the flood reaches (e.g. Smith et al., 2004; Soulsby et al., 2007). This however depends upon the availability of sediment. However, Roberts (1971) did not identify any consistent sand horizons (such as might be indicative of tsunami activity) in cores in North Sound or Little Sound, while in addition, the stratigraphical transects undertaken by Woodroffe (1981) and Mackinnon and Jones (2001) in North Sound and Little Sound do not disclose sand horizons in the mangrove peat even though their cores extend over a period in excess of 2000 years, when at least one or two tsunamis may probably have reached the North Sound area, implying that sediment availability offshore is limited in that area.

Caribbean Environment Program (CEP) Technical Report 3 (1989) drew attention to the implications of climate change for the coasts of the wider Caribbean region, emphasising the threats to coral reefs and mangroves, which are a major feature of the Cayman islands' coastline.

7. The impact of rising sea levels and extreme events on tourism in the Cayman islands

Tourist numbers in the Cayman Islands have been increasing and tourism now accounts for a high proportion of the islands' GDP (World Travel and Tourism Council, 2008). Thus any impact of climate change will be of concern to the tourist industry.

Arguably, the most direct effect of rising relative sea levels on tourism will be the erosion and retreat of beaches and the effect on beach properties. Cambers (2007) estimated that a shoreline would retreat by 100 times the total rise in relative sea level, so that with a rise of 1 metre a shoreline will retreat by 100 metres. This generalised amount does not take into account variations in the underlying lithology, but is a useful measure. On top of this, hurricane activity will exacerbate coastal retreat, especially if the projected rise in sea level brings more easily eroded areas within reach of the storm surges associated with hurricanes. Beach erosion will compromise hotel development, threaten communications and reduce the attractiveness of the beach environment.

Changes in beaches may affect wildlife and thus be of concern to the tourism industry of the Cayman Islands. In this regard, it has been claimed that turtle nesting may be affected where the beach is narrow (Fish et al, 2005). The destruction of areas of coral reef by greater storm surges associated with more intense hurricanes will affect wildlife habitats.

Changes in patterns of sedimentation consequent upon rising relative sea levels may also affect tourism if coral reefs are affected. Brunt and Davies (1994) observed that around the Cayman Islands, reefs are interrupted where sediment is extensive. In the event of beach erosion and retreat, the redistribution of sediment might affect reef growth.

In some areas of the Caribbean, perception of the likelihood of hurricanes has caused cancellation of holidays. In the event that hurricane intensity and frequency increases, education of the travelling public about the timing of the hurricane season may be called for. At present, the more popular travel companies overseas do not always inform their clients in any detail about the possibility of hurricanes, even though the industry is well aware of the problem, as the TravelMole account of 18th July, 2007 shows. Increases in hurricane intensity may affect cruise traffic (TravelMole, 2nd September 2008), in terms of both routing and the availability of docking facilities, as the effects of Hurricane Ivan showed (Cayman Islands Government, 2004).

Adaptation is important, as is shown in the increasing appreciation of the Cayman Islands' government to tropical storm risk, outlined by Tompkins (2005). Travel company websites frequently express concern about the effects of sea level rise on tourist destinations. In December 2007, concern was expressed about several destinations, including Cancun (TravelMole, 4th December 2007). Again, in January 2009, concern was again expressed following the US Geological Survey report to the US Congress (TravelMole, 5th January 2009).

8. Adaptation

There is little doubt that the observed rise in relative sea levels globally, the increase in hurricane intensity and longevity, and the prospect of tsunamis place the Cayman Islands at great risk in the near future. This prospect requires adaptation, and actions undertaken thus far demonstrate that the island community is aware of the need for this. Hurricanes can cause enormous loss of life and damage to infrastructure (Pielke et al., 2003; Cayman

Islands Government Report, 2006), as inhabitants of the Cayman Islands know well. Tompkins (2005) has described the approach of the Cayman Islands Government to hurricane preparedness, in which the importance of greater institutional integration is emphasised and improved planning legislation introduced. The annual National Hurricane Plan, produced since 1989, has been formalised into government planning processes and Tompkins observes that the ability of the government to respond to hurricanes is now greatly improved. Bueno et al. (2008) have quantified the costs of not responding to climate change, and in the case of the Cayman Islands, they estimate that this will rise to 8.8% of GDP in 2025, and to 53.4% in 2100 based upon the Intergovernmental Panel on Climate Change 2007 report. Given that sea levels will probably rise by a greater amount than IPCC estimated, the figures provided by Bueno et al. (ibid.) must be regarded as at least very conservative.

More broadly, government institutions in the Caribbean remain responsive to environmental hazards. Conferences and workshops are regularly held on the subject across the Caribbean. For example, the Cayman Islands Government Department of the Environment, the UK Tyndall Centre for Climate Change Research and the Caribbean Community Climate Change Centre (CCCCC) organised a workshop on "Preparing and adapting to climate change in the Caribbean" in 2005 (Tyndall Centre, 2005). Several organisations have been established to undertake research on climate change in the Caribbean. Thus, the Mainstreaming Adaptation to Climate Change (MACC) project (Caribbean Community (CARICOM) Secretariat, 2009) aims to mainstream climate change adaptation strategies into the sustainable development agendas of small island and low-lying states. The Caribbean Planning for Adaptation to Climate Change (CPACC) project (CARICOM Secretariat, 2009) seeks to build capacity for the Caribbean region to adapt to climate change impacts, particularly sea level rise through in particular the establishment of a sea level/climate monitoring network and the establishment of databases and information systems (UNESCO, 2003).

The Caribbean Community Climate Change Centre (CCCCC) (Heads of Government of the Caribbean Community, 2004; CARICOM Secretariat, 2009) was established in Belize in 2004 with a mandate to coordinate the regional response under the management of the Caricom Council for Trade and Economic Development (COTED) (Second UK/Caribbean Business Forum, 2007). CCCCC has links with scientists and organisations overseas involved with the study of climate change, including the Hadley Centre, the Tyndall Centre and the UK Climate Impacts Programme. Projects involving climate modelling, studies of the impact of rising sea levels, and the effects of hurricanes on coral reefs are being undertaken. CCCCC began a UK Department for International development (DFID)-funded project on enhancing the capacity for adaptation to climate change in the Caribbean Overseas Territories, in 2007, and the project is scheduled to run until 2010 (DFID Research and Development Report, 2007). Sea level rise is a major component of the project. Studies such as those of the Tyndall Centre (e.g. Gill et al., 2004) are examining the impact of environmental and economic impacts. The Adaptation to Climate Change in the Caribbean (ACCC) Project was designed to sustain activities under CPACC and address issues of adaptation and capacity building not undertaken by CPACC. It was succeeded by CPACC. The United Nations Environment Programme in collaboration with the Caribbean Community and Common Market CARICOM has produced several documents on the Caribbean environment, and notably on the challenge of adaptation. The matter of adapting to climate change was an issue at the 53rd Commonwealth Parliamentary Conference in India in 2007.

The many organisations, reports and meetings listed above demonstrate an awareness of the problem posed by global environmental change, but most were organised, produced or took place before the Intergovernmental Panel on Climate Change Fourth Assessment Report in the autumn of 2007. In that report, the challenges of adaptation were addressed in Chapter 16. Several key areas were identified as being underrepresented in contemporary research on the impacts of climate change on small islands. Of particular relevance to the Cayman Islands these included the role of ecosystems, such as mangroves, coral reefs and beaches in providing natural defences against sea level rise and storms; the development of appropriate methods and tools for identifying critical thresholds for biogeographical systems; and the strengthening of local capacity in areas of environmental assessment and management. These and other issues have been made more urgent in the light of the recent information on the likely acceleration in global sea surface rise. Adaptation strategies will need to be revised as the impacts of increased sea surface rise are assessed.

The review of the literature on relative sea level rise and extreme flooding events undertaken here has identified a number of actions which need to be taken if the effects of climate change in this field are to be mitigated. These are as follows:

.1 Estimating the pattern and rate of relative sea level rise. Relative sea level change at the coast is a consequence of both sea surface change offshore and land uplift onshore. In so far as **sea surface change** is concerned, global sea levels do not rise at the same rate and by the same amount everywhere. As the rising sea surface encounters coasts of varying bathymetry around the world the rise will vary. As great ice shelves disintegrate, their gravitational attraction is reduced and the sea surface level drops in their vicinity but rises elsewhere. Even over timescales of decades the sea surface rise will vary. In this context, the several graphs of sea surface rise in the Caribbean are only generalisations, and conceal fluctuations by the nature of the methodology employed. The changes in the future may decelerate at times, but may also accelerate. Where **land movement** is concerned only the most general information is available. For the Cayman Islands it is imperative that accurate measures, from both tide gauges and satellite telemetry, are obtained to track the rising sea surface and the changing land level. Knowledge of the rate of rise is important if the actual amount of coastal change is to be forecast.

.2 Determining changes in the activity of hurricanes and tropical storms. Further information on the relationship of hurricanes and tropical storms to ENSO is needed and more accurate forecasts of track, intensity and longevity are needed. In particular, however, the issue of frequency needs to be urgently addressed. The literature demonstrates differing views on this, with the balance being that frequency is not increasing overall, but is fluctuating, but given the Cayman Islands' record of hurricanes, this needs to be urgently determined.

.3 Determining the impact of relative sea level changes and hurricane activity on coral reefs. Coral reefs are the first line of defence along the Cayman Islands coastline. Any deterioration in the reefs will render the land behind more vulnerable to erosion (e.g. Watkinson, 2003). Coral bleaching is of concern, since it leads to break up of reefs. The bleaching event of 2005 was particularly serious (e.g. NOAA). Hurricane activity may lead to the irretrievable decline in reefs (e.g. Gardner et al., 2003; 2005). Hence, detailed monitoring of reefs spatially must be undertaken if future changes in the coastline are to be detected. The response of reefs to the changing rate of relative sea level rise needs to be closely monitored. If rises of as much as 15mm/year occur, can reefs respond? It seems unlikely, but there may be feedbacks, for example in the reduction of reef exposure to storm surges as the sea surface level rises.

.4 Determining the impact of relative sea level changes and hurricane activity on mangroves. It is understood that in some areas of the islands, mangroves are protected by ridges of coral eroded during storms. However, forecast rates of relative sea level rise and of more intense hurricane activity would seem to be inimical to the survival of many mangrove areas. Since mangroves protect the coast in some areas, this will be of concern.

.5 Protecting the coast from the impacts of relative sea level changes and extreme floods. Conventional protective measures are unlikely to be realistic, but a particularly useful measure would be the further establishment of woodland in coastal areas. In areas where tsunamis are more prevalent than in the Caribbean, planting palms is very effective. Palms will survive the greatest tsunami known, and if the forest is sufficiently dense, will act as traps for sediment. Their response to storm surges has not been studied as far as the writer is aware, but they may well prove a useful defence. Mangroves are also valuable in protecting the coast, but may not survive forecast rates of sea level rise.

.6 Developing further effective planning measures. Taking a cue from studies in tsunami-prone areas, planning measures such as when building larger structures like hotels and apartment buildings a skeletal ground floor plan and spaces between large sea front properties may be of value in the event of storm surges. Studies in Greece have identified these and other measures (e.g. Papathoma et al., 2003) as being effective in flooding events. Drinking water supplies are met by desalination plants and rainwater catchments, so saline penetration of the groundwater reservoir is not an issue. However, as relative sea levels rise and hurricane activity intensifies the location of storage areas for drinking water may have to be reviewed as may the sites for sewage disposal, including septic tanks and deep well injection sites.

.7 Responding to the challenges faced by the tourism industry. The impact of sea level rise and increased hurricane intensity and longevity on tourism in the Cayman Islands will be largely negative, and present a challenge to the tourism industry, an observation echoed by the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. To offset this negative effect, attraction of increased cruise traffic may be one approach, but ultimately as income from tourism reduces, alternative sources of income and employment will have to be sought.

The Cayman islands are a strong contender for a global sea surface monitoring location. There is probably no other location in the Caribbean area where the land could be sufficiently stable such that records of relative sea level are close to the mean for the globe. Isostatic effects are unlikely to be significant, given that the sea bed slopes so steeply on three sides. Tectonic effects are small, according to available evidence. The sea surface altitude is close to the global mean and is unlikely to change in the foreseeable future. Hence the islands could serve as a laboratory for future studies of the progress of global warming. Perhaps an outrageous suggestion, especially since this report is only based on secondary research, but probably one worth examining.

9. Conclusion

The marine environment of the Cayman Islands is one of low tidal range but noticeable wave and current activity. Sea levels around the islands have been rising for several thousand years and the coastline has been retreating, most notably in mangrove areas, but until recent decades coastal retreat in the islands has probably not been a major concern.

This secondary research study recognises that in recent years, global warming has begun to change the picture. Although the effect of tectonic activity is unknown, it seems reasonable to assume that the rate of rise in sea levels around the islands is currently about 3mm/year and will probably increase in the future as the Greenland and Antarctic ice sheets deliver increased volume to the oceans and seas of the world. Since the islands are subject to hurricane activity, and since this may become more intense as sea surfaces become warmer, the combination of a rising sea level with storm surges that could exceed 6m in the strongest hurricanes, poses a considerable threat to the islands. In addition, tsunamis are not unknown in the general area, and with the increased rise in relative sea level are of concern, although not as immediate as hurricane activity. Given the low elevation of the islands, the likely effects of sea level rise on the population and infrastructure must be of concern.

In view of the threat posed by rising sea levels, more intense hurricanes, and possible tsunami impact, it is evident that responses are needed. The developing policies and actions of the Cayman Islands Government demonstrate an awareness of this, and indeed, the Cayman Islands are probably better placed than many small island communities to respond to climate change. As such, it is conceivable that the Cayman Islands may take a lead in the response of the small island community world wide. However, the need for response has been heightened by the recently identified probability that the sea surface may rise by a greater amount than forecast by the Intergovernmental Panel on Climate Change Fourth Assessment Report. It is argued that there is a more urgent need for effective adaptation than may be currently appreciated.

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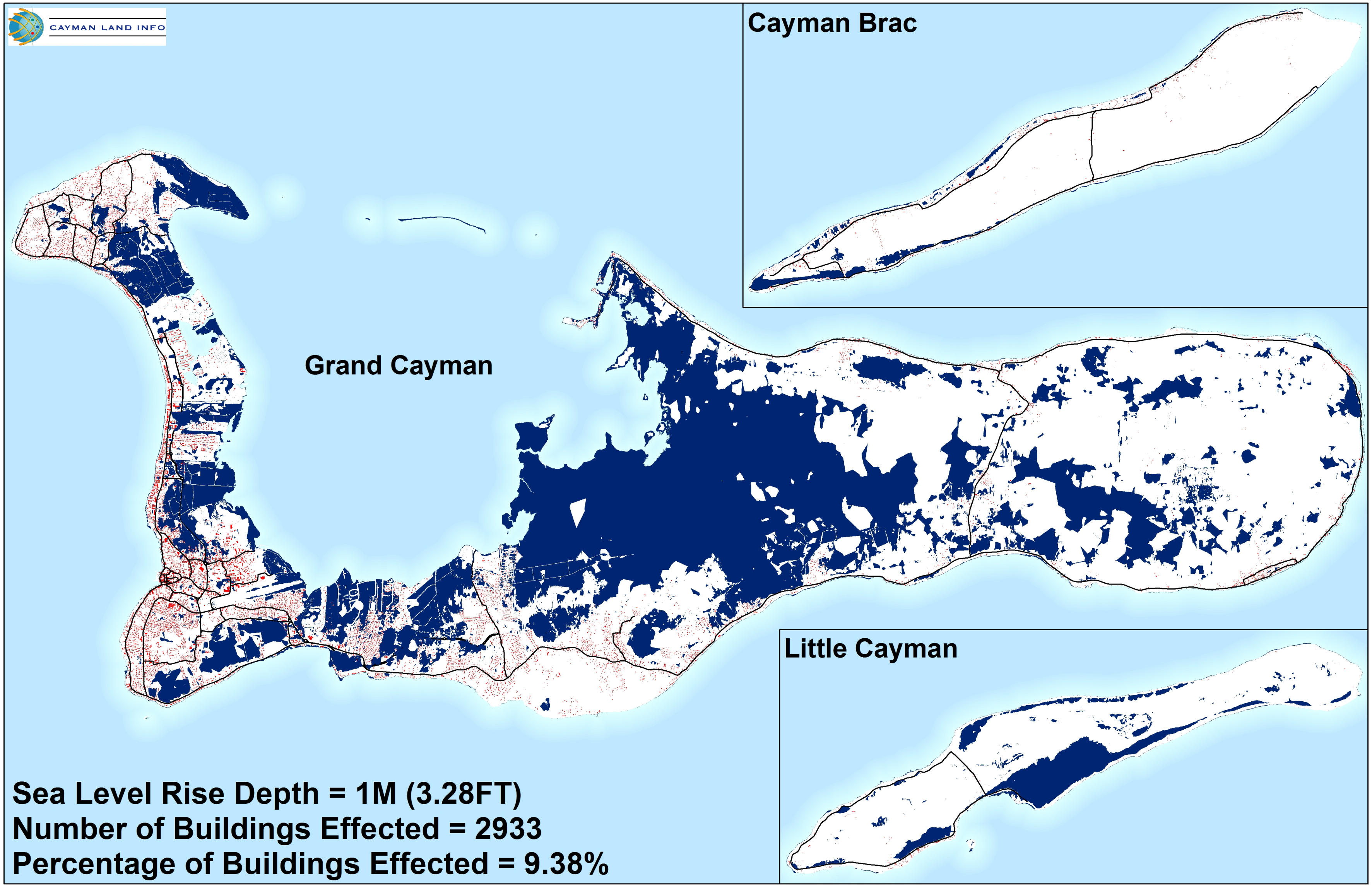
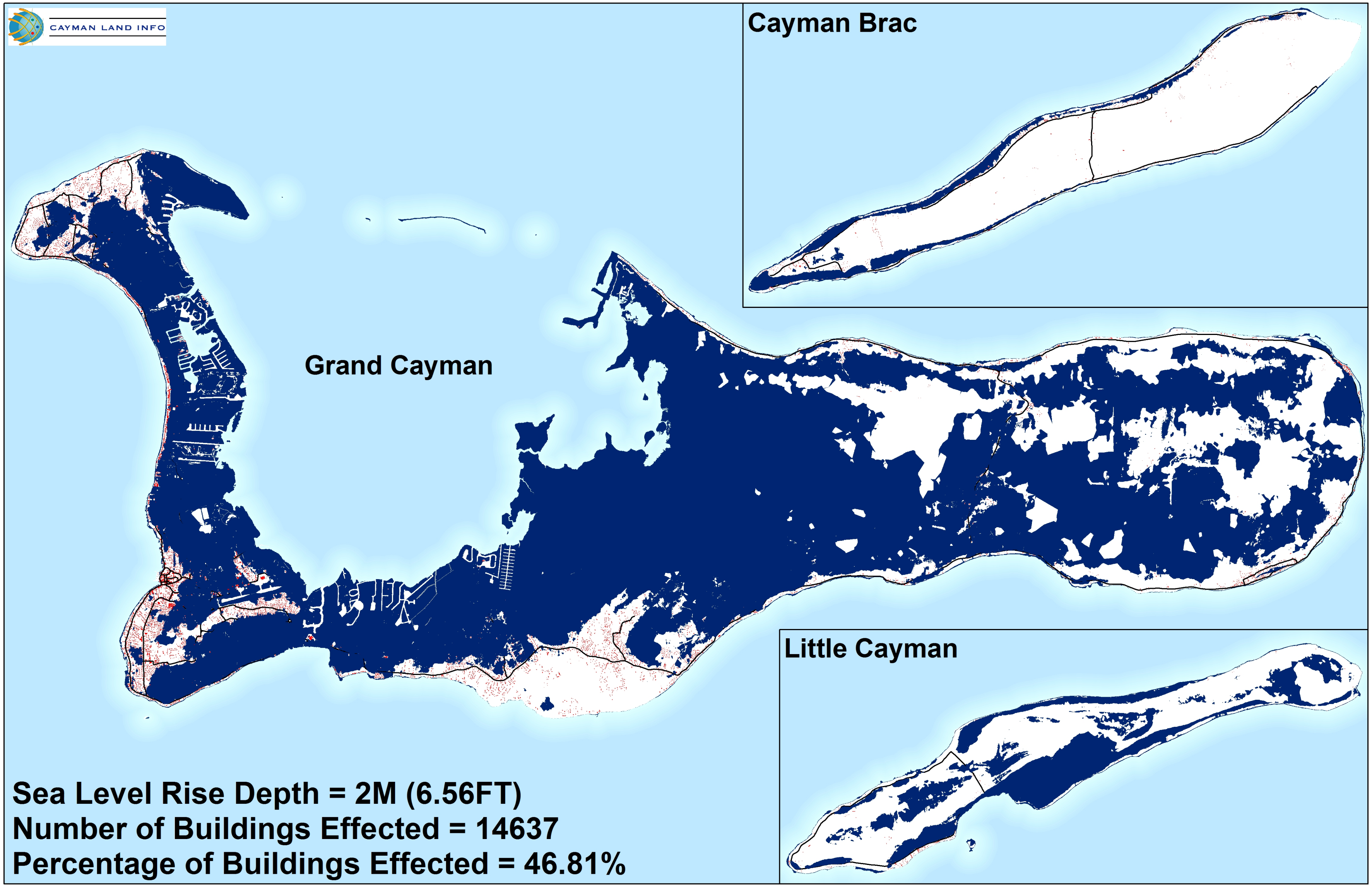
11. Acronyms used in this report

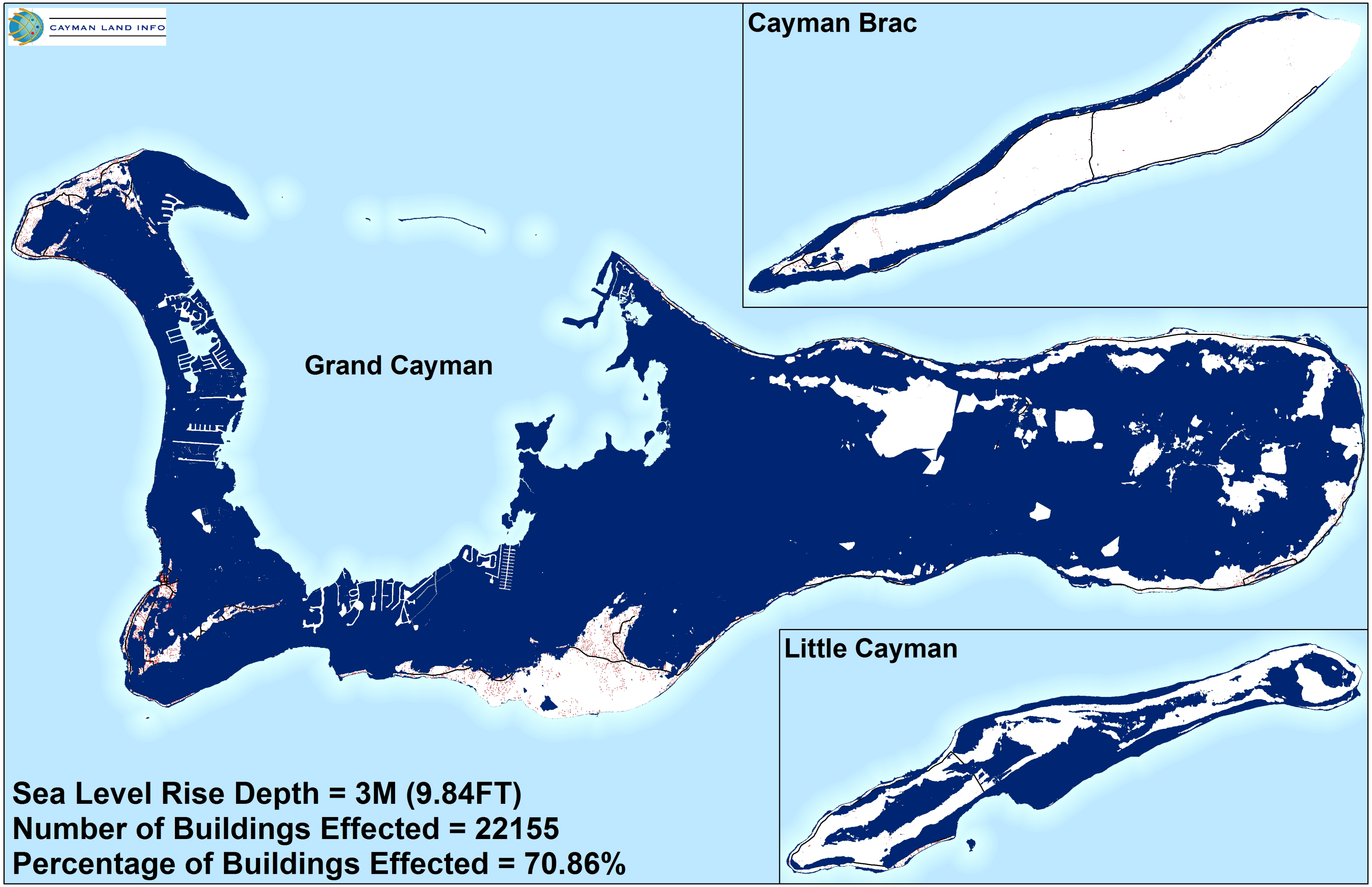
ACCC Adaptation to Climate Change in the Caribbean project
BP before present (i.e. before 1950)
CCCCC Caribbean Community Climate Change Centre
CARICOM Caribbean Community
CEP Caribbean Environment Programme
COTED Centre for Trade and Economic Development
CPACC Caribbean Planning for Adaptation to Climate Change project
DFID Department for International Development
ENSO El Niño-Southern Oscillation
GDP Gross Domestic Product
IGCP International geological Correlation Project
INQUA International Union for Quaternary Research
IPCC Intergovernmental Panel for Climate Change
MACC Mainstream Adaptation to Climate Change project
NOAA National Atmospheric and Oceanographic Administration
UNESCO United Nations Educational, Scientific and Cultural Organisation

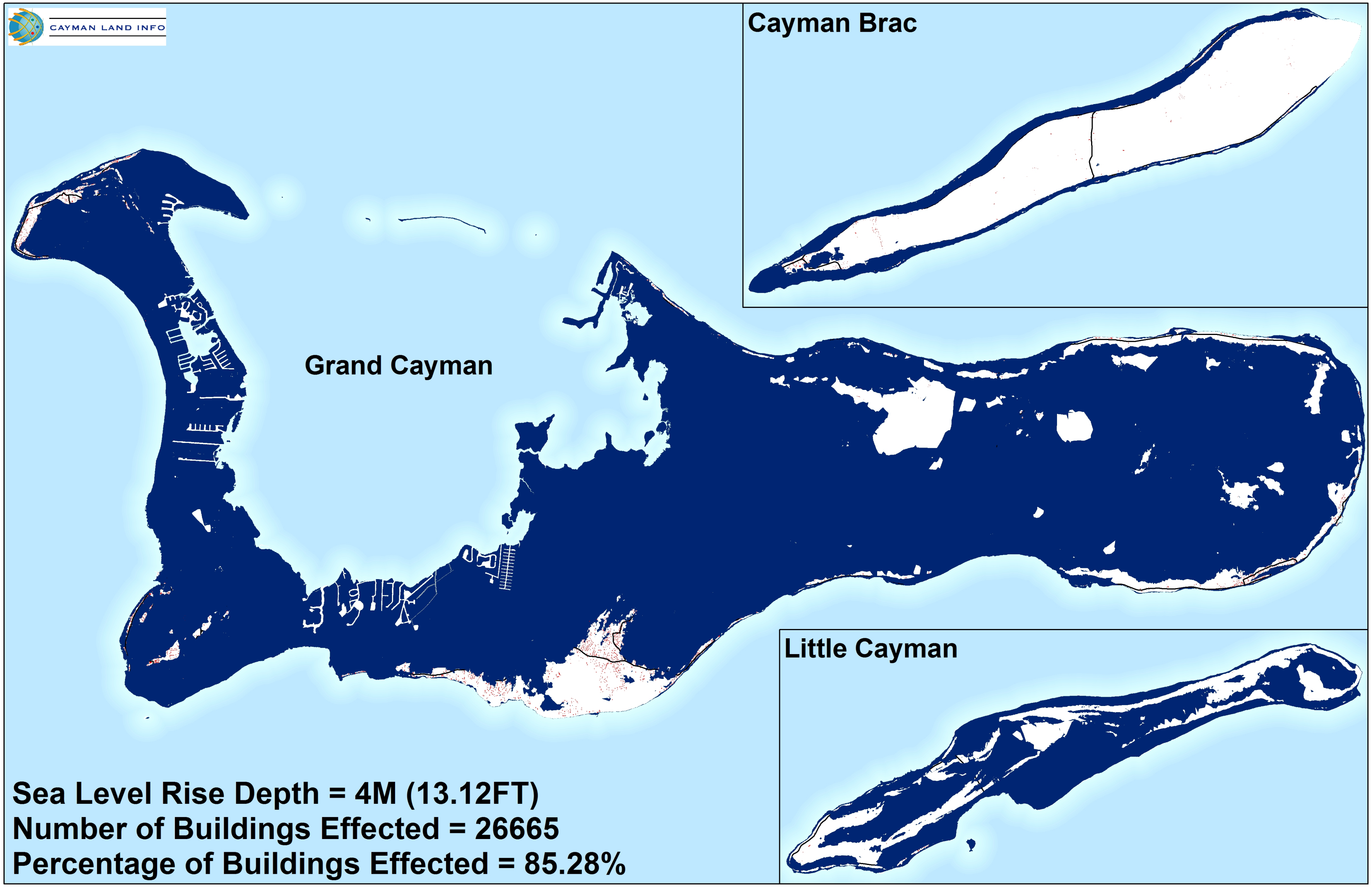
12. Appendix

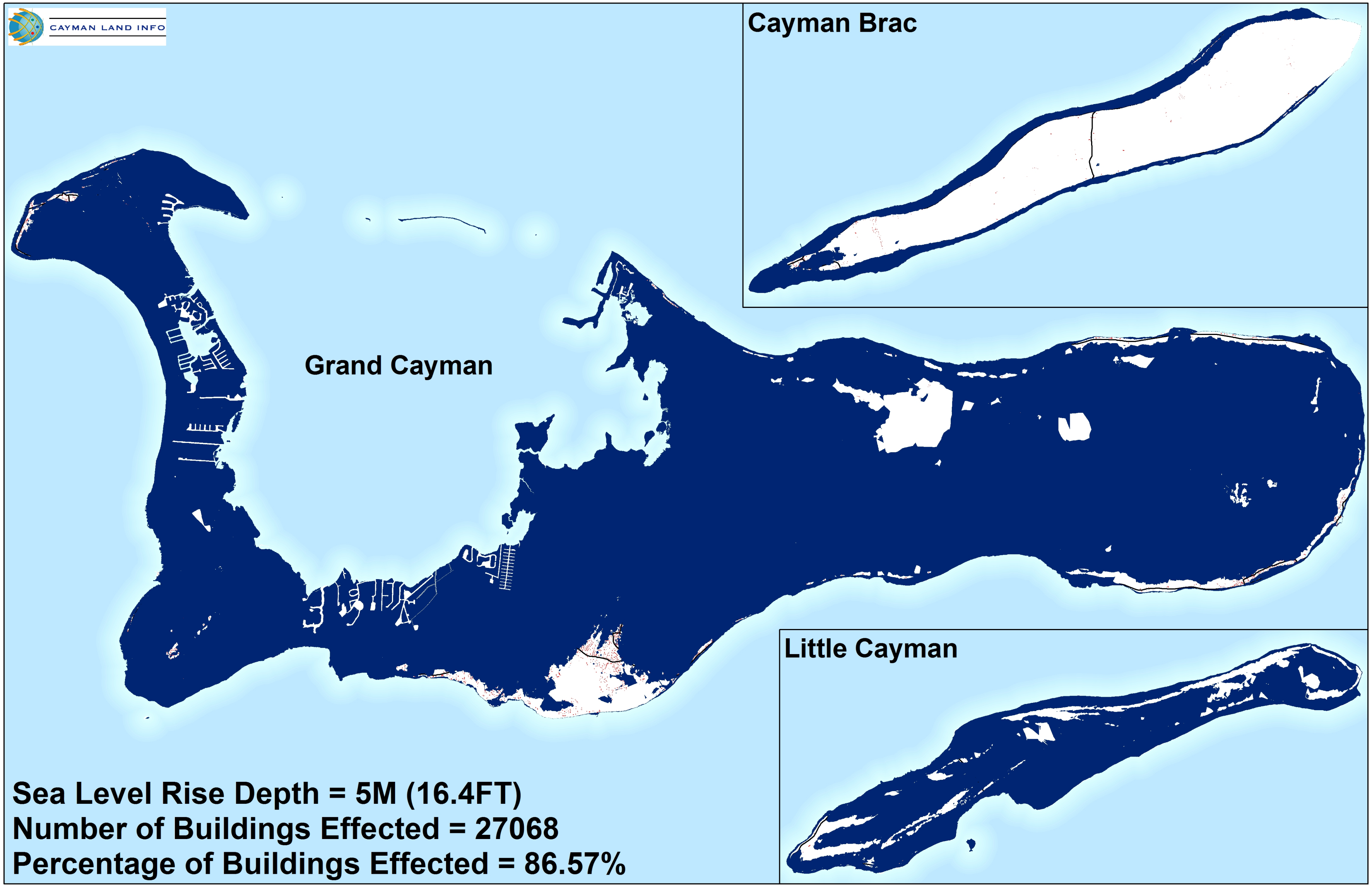
All map data below provided by the Lands and Survey Department of the Cayman Islands Government under Crown Copyright.

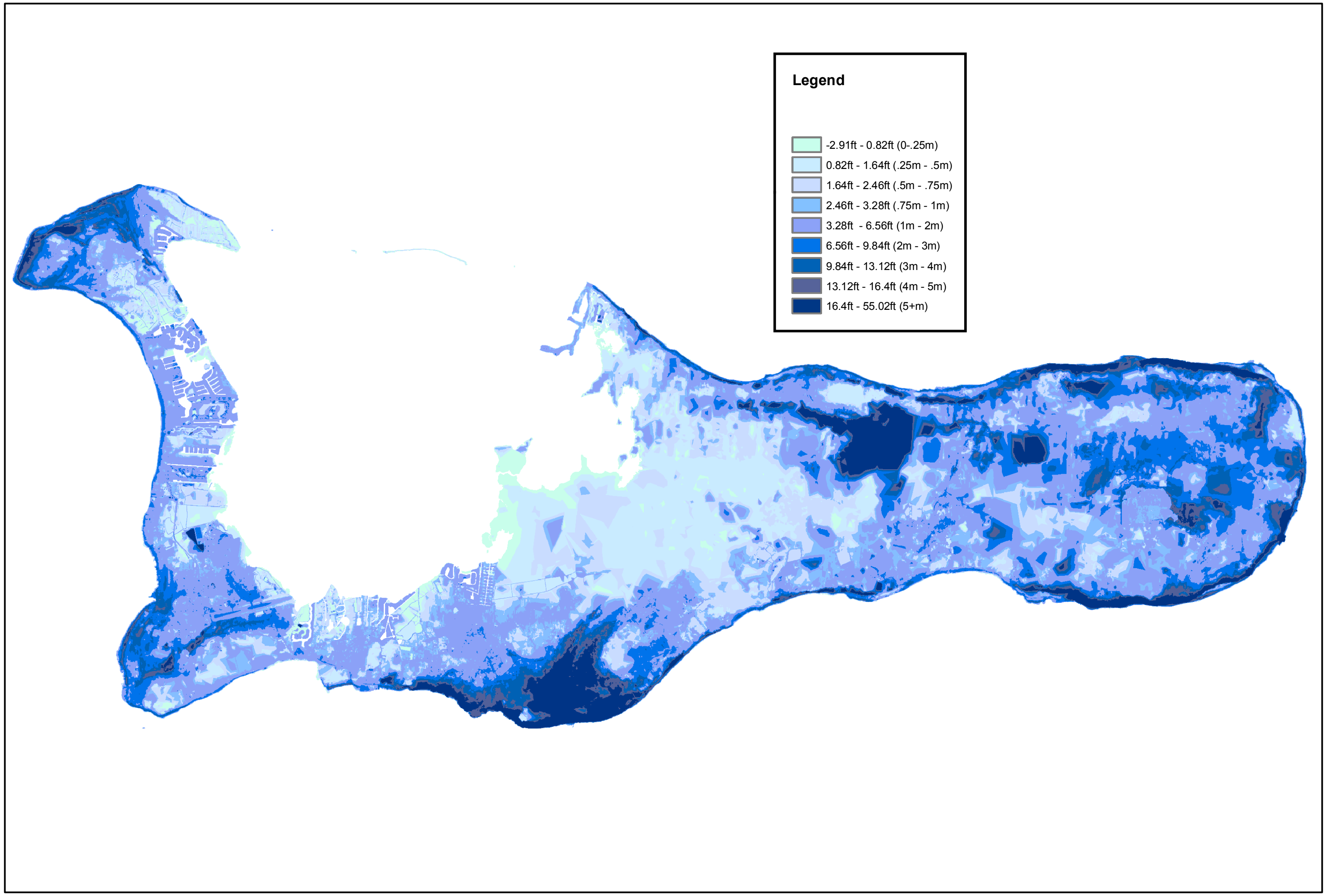

CAYMAN LAND INFO
Cayman Brac
Grand Cayman
Little Cayman
Sea Level Rise Depth = 1M (3.28FT)
Number of Buildings Effected = 2933
Percentage of Buildings Effected = 9.38%

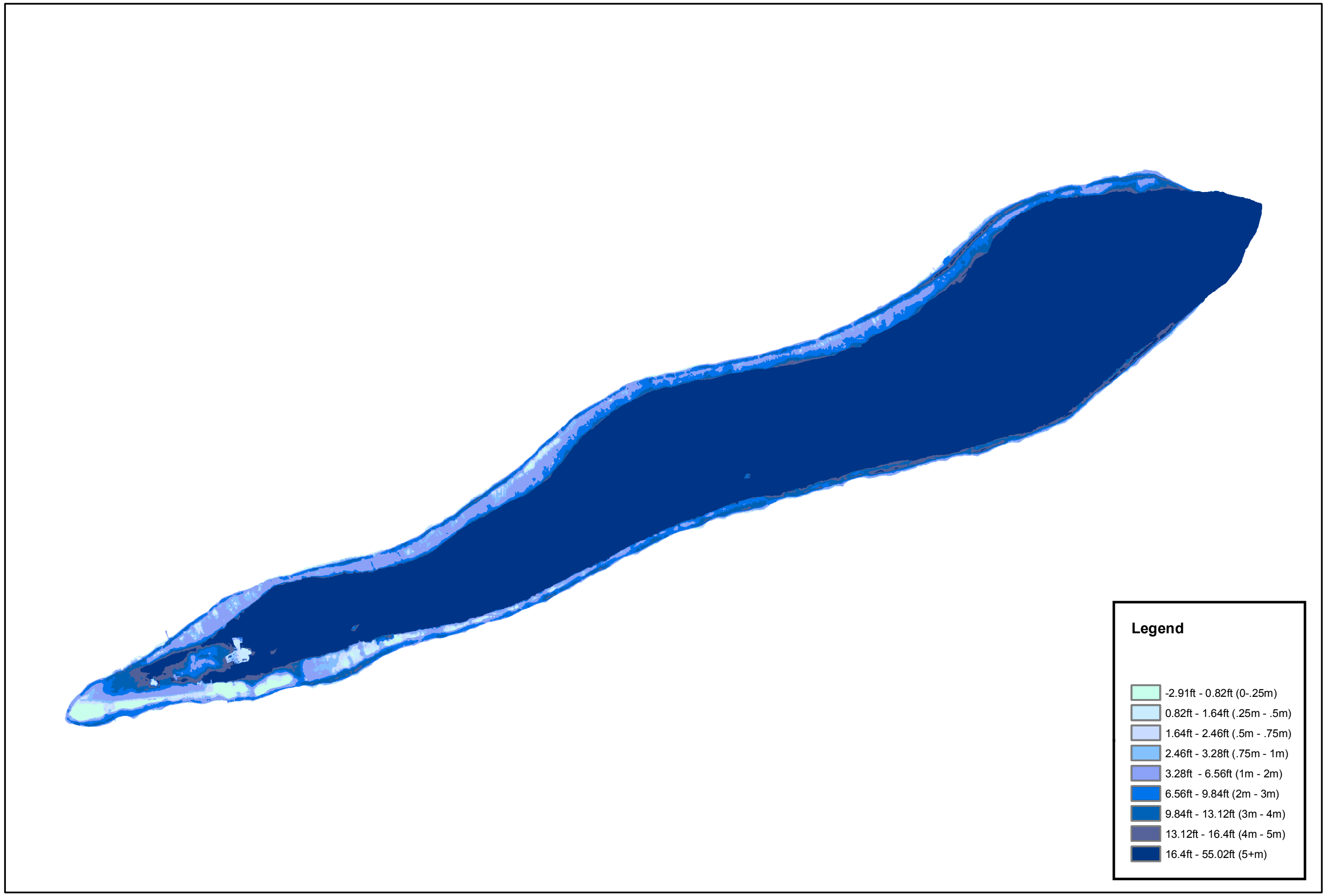

CAYMAN LAND INFO
Cayman Brac
Grand Cayman
Little Cayman
Sea Level Rise Depth = 2M (6.56FT)
Number of Buildings Effected = 14637
Percentage of Buildings Effected = 46.81%

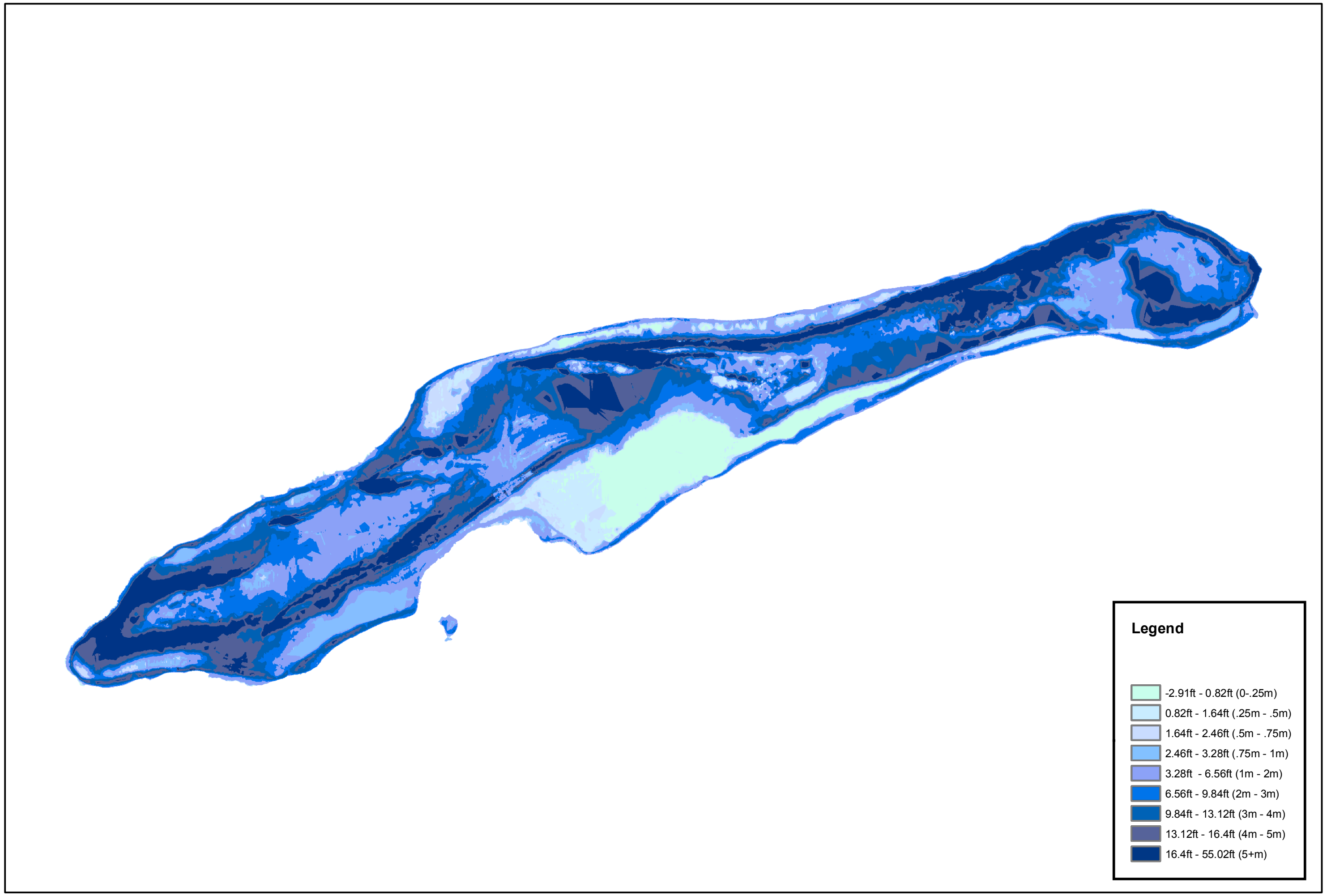

CAYMAN LAND INFO
Cayman Brac
Grand Cayman
Little Cayman
Sea Level Rise Depth = 3M (9.84FT)
Number of Buildings Effected = 22155
Percentage of Buildings Effected = 70.86%


CAYMAN LAND INFO
Cayman Brac
Grand Cayman
Little Cayman
Sea Level Rise Depth = 4M (13.12FT)
Number of Buildings Effected = 26665
Percentage of Buildings Effected = 85.28%


CAYMAN LAND INFO
Cayman Brac
Grand Cayman
Little Cayman
Sea Level Rise Depth = 5M (16.4FT)
Number of Buildings Effected = 27068
Percentage of Buildings Effected = 86.57%


Legend
-2.91ft - 0.82ft (0-.25m)
0.82ft - 1.64ft (.25m - .5m)
1.64ft - 2.46ft (.5m - .75m)
2.46ft - 3.28ft (.75m - 1m)
3.28ft - 6.56ft (1m - 2m)
6.56ft - 9.84ft (2m - 3m)
9.84ft - 13.12ft (3m - 4m)
13.12ft - 16.4ft (4m - 5m)
16.4ft - 55.02ft (5+m)

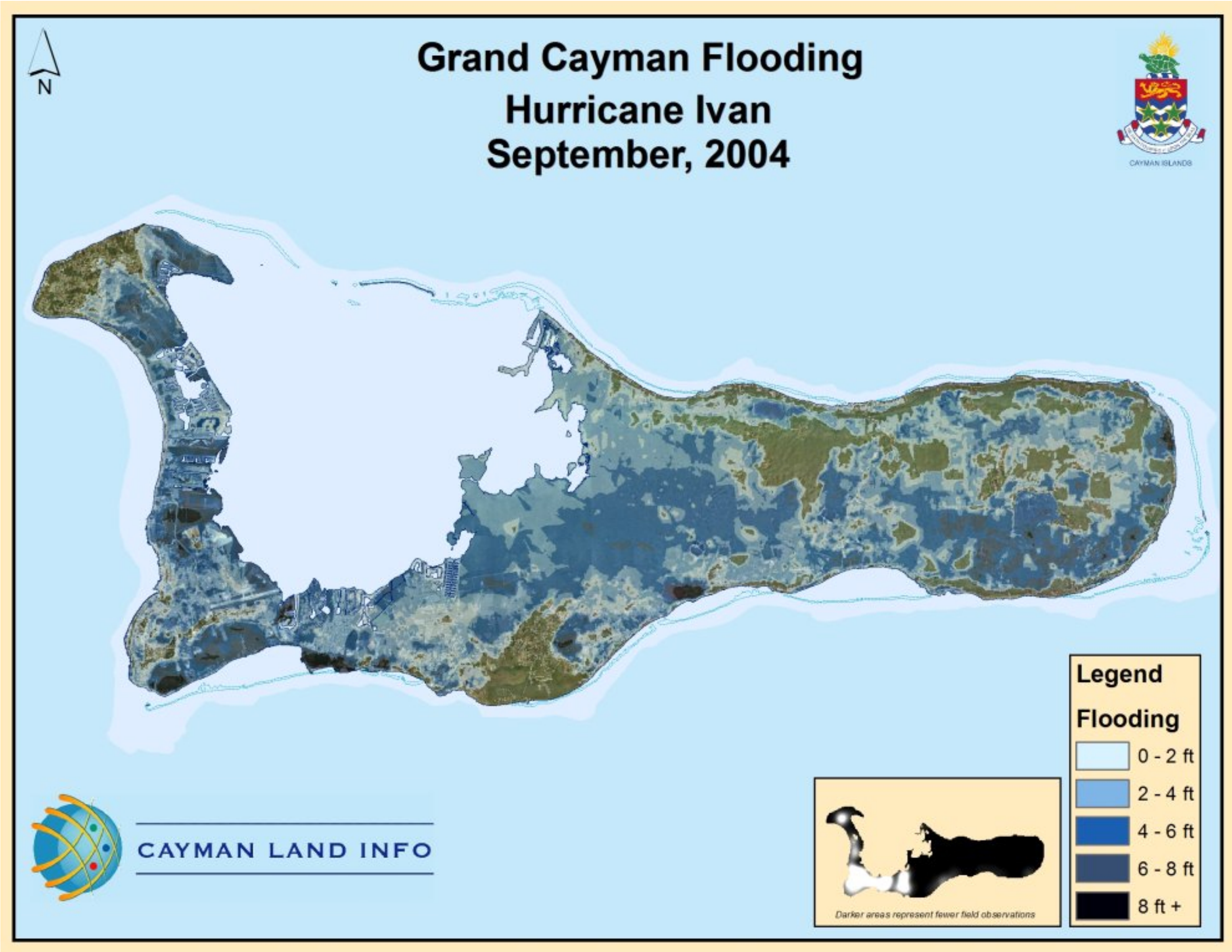

Legend
-2.91ft - 0.82ft (0-.25m)
0.82ft - 1.64ft (.25m - .5m)
1.64ft - 2.46ft (.5m - .75m)
2.46ft - 3.28ft (.75m - 1m)
3.28ft - 6.56ft (1m - 2m)
6.56ft - 9.84ft (2m - 3m)
9.84ft - 13.12ft (3m - 4m)
13.12ft - 16.4ft (4m - 5m)
16.4ft - 55.02ft (5+m)


Legend
-2.91ft - 0.82ft (0-.25m)
0.82ft - 1.64ft (.25m - .5m)
1.64ft - 2.46ft (.5m - .75m)
2.46ft - 3.28ft (.75m - 1m)
3.28ft - 6.56ft (1m - 2m)
6.56ft - 9.84ft (2m - 3m)
9.84ft - 13.12ft (3m - 4m)
13.12ft - 16.4ft (4m - 5m)
16.4ft - 55.02ft (5+m)

Buildings Affected Per Sea Level Rise Scenario

	0.82FT 0.25M	1.64FT 0.50M	2.46FT 0.75M	3.28FT 1M	6.56FT 2M	9.84FT 3M	13.12FT 4M	16.40FT 5M	+16.40FT +5M
APARTMENT\ CONDO	2	25	147	545	2179	3246	3744	3773	4036
COMMERCIAL	0	11	61	181	775	1114	1300	1312	1381
EDUCATION\ RELIGION	0	3	7	28	121	257	362	366	416
HORTICULTURAL	0	0	1	4	13	21	26	26	28
INDUSTRIAL	0	1	2	23	117	148	164	165	174
PUBLIC	0	2	4	11	75	153	228	239	305
RESIDENTIAL	17	69	335	1315	6779	10268	12473	12683	15009
TOURISM\ LEISURE	1	13	32	57	260	424	532	538	618
UNCLASSIFIED	13	60	228	765	4269	6446	7743	7872	9194
UTILITY	0	0	0	4	49	78	93	94	104
TOTAL	33	184	817	2933	14637	22155	26665	27068	31265

**unclassified buildings are non addressable and generally consist of sheds or outbuildings*


Grand Cayman Flooding
Hurricane Ivan
September, 2004
N
CAYMAN ISLANDS
CAYMAN LAND INFO
Darker areas represent fewer field observations
Legend
Flooding
0 - 2 ft
2 - 4 ft
4 - 6 ft
6 - 8 ft
8 ft +