EVALUATION OF SEA LEVEL RISE FOR FEMA FLOOD INSURANCE STUDIES: MAGNITUDE AND TIME-FRAMES OF RELEVANCE.

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Abstract: At present, evaluation of sea level rise is not a required component of Federal Emergency Management Agency (FEMA) National Flood Insurance Program (NFIP) Flood Insurance studies (FIS). Present day rates of sea-level rise are not insignificant, and the potential exists for these rates to accelerate. This study investigates whether current and anticipated rates of sea level rise are relevant to the NFIP considering current product life-cycles. Observed rates of sea-level rise and anticipated increases in water levels at four sites were compared to the statistically determined 1% annual chance stillwater elevation. The effect of sea level rise on mapped base flood elevations was evaluated using the Coastal Hazard Analysis Program. Results show that although increases in water elevations due to sea-level rise are not significant compared to the 1% annual chance stillwater, changes in base flood elevation zone breaks can occur over time-frames relevant to NFIP products.

INTRODUCTION

Increased levels of atmospheric greenhouse gasses in the atmosphere have resulted a global warming of surface temperatures, which, in turn, has initiated accelerated rates of sea level rise through thermal expansion due to warming of oceans and melting of the

continental glaciers in the 20th century (Church *et al.* 2001). More recent observations demonstrate that the rate of sea level rise (SLR) may be increasing (Cazenave and Nerem 2004), and a significant level of SLR within the next century is conceivable (Titus et al. 1991) and expected (IPCC SPM 2007). Eustatic increases in the elevation of the sea surface would result in accelerated rates of coastal erosion as beach profiles readjust to the increased water levels. In addition, SLR would result in greater exposure of coastal structures and properties to the risk of damage and destruction during large storm events (Titus et al. 1991).

Over the last century, SLR has been determined mostly from tide gauge records and more recently satellite altimetry. The National Atmospheric and Oceanic Administration (NOAA) determined sea-level rise trends for 117 water level stations comprising the U.S. national water level observation network (NWLON) (NOAA 2001) for the period 1854 to 1999 (most stations in the network had shorter records). The majority of the stations showed a trend of sea-level rise, however, further analysis of 60 stations with the longest records did not indicate any statistically significant trend of accelerated sea-level rise in the last 50 years (NOAA 2001).

A large amount of uncertainty exists regarding the magnitude of SLR expected to occur in the next century due to climate change. Early estimates by the U.S. Environmental Protection Agency (EPA) had high estimates in the 2.5 to 3 m range (EPA 1983), later reduced to 0.45 m, with a small chance of 1.2 m rise by 2100 (Titus and Narayanan 1995). Contemporary estimates have decreased further, with several predicting sea-levels to increase by approximately 0.3 m by 2100 (Church and White 2006), and a recent Intergovernmental Panel on Climate Change (IPCC) report has mid-range estimates of 0.2-0.43 m, with a full range estimate of 0.18-0.59 m by 2100 (IPCC 2007). Application of relationships between global SLR to global mean sea-surface temperatures using IPCC scenarios has given higher ranges of expected SLR by 2100, from 0.5-1.4 m as compared to 1990 levels (Rahmstorf 2007), almost double the IPCC prediction.

Under the authority of the National Flood Insurance Act of 1968 and the Flood Disaster Protection Act of 1973, The Federal Emergency Management Agency (FEMA) administers the National Flood Insurance Program (NFIP) for communities within the United States and territories. The NFIP provides insurance and disaster relief to communities who agree and adhere to the program guidelines. Risk to coastal inundation and wave impacts are quantitatively evaluated and mapped by the NFIP through Flood Insurance Studies (FIS) and these risks are presented to the public and insurers as flood zones on Flood Insurance Rate Maps (FIRMs).

Coastal hazards are evaluated for FIRMs by assessing the return periods of inundation and the magnitude and extent of wave impacts using the Wave Height Analysis for Flood Studies model (WHAFIS), which simulates 1-dimensional overland wave propagation and attenuation (FEMA 2007a). WHAFIS output provides the base flood elevation (BFE) and locations where the zone breaks (gutters) are mapped. BFEs are represented

as an area (zone) on the FIRM rather than at a discreet location. Because of this, zone break locations are provided by WHAFIS at the half-foot value of whole-foot intervals (i.e. 4.5, 5.5, etc.). The zone is then assigned the rounded whole-foot elevation. For example, a zone bounded by a 4.5 and 5.5 ft flood elevations would be assigned a BFE of 5 ft.

In addition to wave and inundation hazards, primary frontal dunes are evaluated for erosion or failure using simplified criteria (FEMA 2007b). Risks mapped on the FIRM are based on the 1% annual (100-year) chance event (the base flood), although inundation hazards up to the 0.2% annual (500-year) chance event are determined. The risk in a specific area is identified to the map user by the combination of flood zone type and base flood elevation. The flood zone type reflects the location of an area within the extent of the base flood (AE), a ponding area or sheetflow area (AO), or within the coastal high hazard zone and subject to waves greater than 3 ft (~0.91 m, VE). The base flood elevation provides the user the elevation of the 1% annual chance event at that location, and a regulatory elevation to which the first floor of structures must be elevated for eligibility of coverage in the NFIP. FIRMs were originally expected to have a life-span of 5 years; however, updates typically are less frequent and periods of 15-20 years and longer before hazards are re-assessed are not uncommon due to study costs and funding levels. At the present time, study contractors are not required to consider the effects of sea-level rise during a FIS (FEMA 2007b).

Impacts of SLR to the NFIP have previously been evaluated (FEMA 1991). This investigation evaluated the programmatic effects of SLR on the NFIP and determined that significant impacts to the program were not likely by 2100, given the present rate of SLR. This investigation employed simplified relationships and did not consider increases in the coastal high hazard zone due to profile steepening, increased risk of failure of primary frontal dunes due to coastal erosion, and further inland propagation of wave action.

This paper evaluates whether current and anticipated rates of SLR are relevant to the NFIP in consideration of life-cycle of an effective FIRM. The evaluation considers the effect of both the increased water elevation on inundation and increased wave hazards by conducting CHAMP simulations on sea-level rise scenarios. Recently completed projects located on the East and Gulf coasts of the United States, in addition to the Caribbean Sea and Pacific Ocean are used as case examples. Rates of SLR over the last century, and potential rates of SLR over the next century are compared to the 1% annual chance stillwater elevation at these sites. This analysis was conducted with emphasis on the relative significance within typical timeframes of NFIP hazard assessment products. NFIP effective transect data are re-evaluated for potential changes based on observed and potential SLR at various time intervals to determine the magnitude and period at which local rates of SLR induces changes to the zone locations and base flood elevations, including implementation of predicted coastal retreat due to SLR in the time-frames of interest.

STUDY LOCATIONS

To evaluate the potential effect of SLR on the determination of base flood elevations and extent of the coastal high hazard zone, four locations were examined: 1) Suffolk County New York, located on the northeast Atlantic Coast, 2) Jackson County Mississippi, on the Gulf Coast, 3) Puerto Rico, located in the Caribbean Sea, and 4) the Hawaiian Islands in the Pacific Ocean (Figure 1).

RATES OF SEA-LEVEL RISE COMPARED TO STILLWATER ELEVATIONS

To place the rates of SLR in perspective with coastal hazards typically represented on a FIRM, the established trend of SLR for each study location was compared to 1% annual chance stillwater elevations (SWEL). Long-term sea-level trends were retrieved from NOAA (2001) and extrapolated to intervals over which a NFIP study is typically updated. For areas having more than one long-term water level station in the NOAA NWLON network, a regional average was calculated. Effective SWEL were retrieved from effective FIS reports (FEMA 1987, 1997, 1998, 1999, 2000, 2002, 2004 and 2005) and preliminary study data (Hawaii and Mississippi SWEL).

Rates of SLR were determined for each location at a 10-, 15-, and 30-yr interval, as well as the elapsed time from the last updated of SWEL in the coastal hazard analysis. The 10-15 year time frame is representative of the typical frequency that coastal hazard analyses are updated under the NFIP, with the 30-yr time frame representing the near-upper limit of the maintenance cycle. The time-frame from the last update of SWEL for each location was retrieved from the effective FEMA FIS texts.
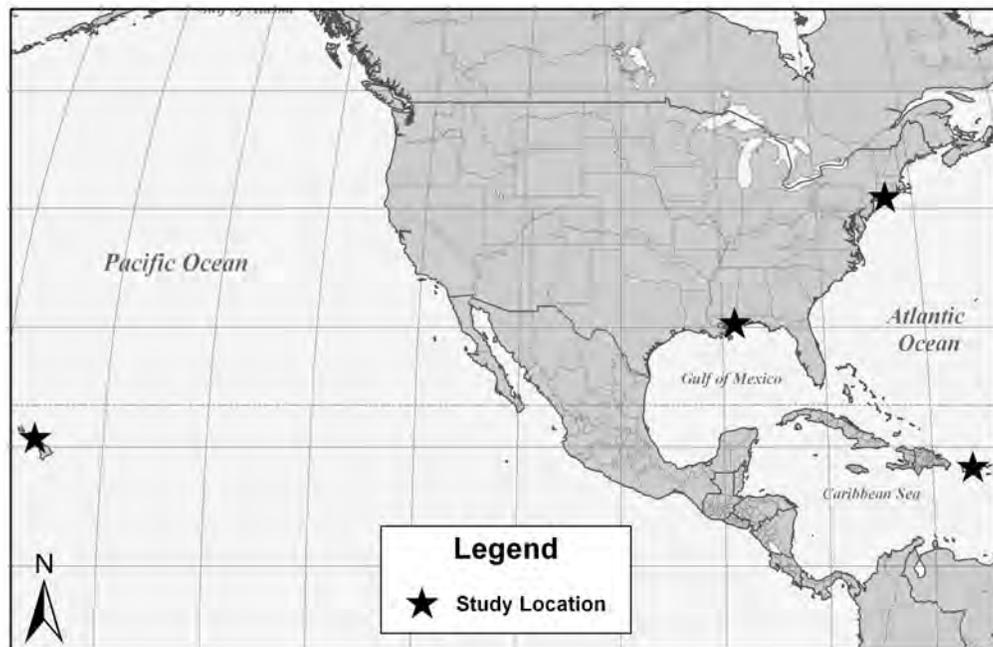

Fig. 1. Study locations

Comparison of the magnitude of SLR expected for the four study areas over the length of an effective FIRM indicates that SLR as observed during the last century is not significant compared to water levels expected from a 100-yr surge event. Values of SLR over 10-, 15-, 30-yr, and from the last updated of SWEL in the coastal hazard risk analysis are summarized in Table 1. The rate of SLR for the four locations varied from a minimum of 1.34 mm/yr (Puerto Rico) to a maximum of 2.93 mm/yr (Jackson County, MS), which yields an increase in SWEL of 0.04 and 0.09 m, respectively. These values are insignificant, and typically round to zero. Table 2 puts the expected values of SLR into perspective with the magnitude of 1% annual chance SWEL. Again, values are small and not significant when compared to the base flood SWEL. Suffolk County, NY (2.55 mm/yr), and Jackson County, MS (2.93 mm/yr) have moderate rates of SLR, but SLR over the course of 30 years (upper limit of FIRM update) only represents 2.5% of the SWEL on which the maps are based. Rates at these sites are similar to those predicted by the IPCC (2007) over the next century. Of the four sites investigated, Hawaii has the lowest storm surge SWEL of 0.3 m (neglecting tsunami hazards). Despite the minimal value of SWEL at this location, SLR over the 30-yr period would only represent 1.9% of the SWEL, which is statistically insignificant. Thus, at first glance, it does not appear that present-day rates of SLR at these sites are high enough to produce changes on a FIRM.

Table 1. SLR compared to 1% annual chance SWEL over various temporal periods

| Location | SLR, mm/yr | SLR over typical NFIP study timeframes, m | | | | Typical 1% SWEL, m |
		Last update	10 yr	15 yr	30 yr	
Suffolk County, NY	2.55	0.069	0.026	0.038	0.077	3.05
Jackson County, MS	2.93*	0.059	0.029	0.044	0.088	5.18
Commonwealth of Puerto Rico	1.34	0.011	0.013	0.020	0.040	2.13
Hawaiian Islands	1.92**	0.034	0.019	0.029	0.058	0.30

*Dauphin Island, AL (closest NWLON station)
**Range of 1.1 to 3.36 mm due to differential isostatic adjustment of individual islands.

Table 2. SLR compared to 1% annual chance SWEL

| Location | SLR, as percentage of 1% annual chance SWEL | |
	30-yr period	Timespan of last SWEL update
Suffolk County, NY	2.5%	2.3%
Jackson County, MS	2.8%	0.5%
Commonwealth of Puerto Rico	1.3%	1.1%
Hawaiian Islands	1.9%	6.3%

SLR AND POTENTIAL CHANGES TO FLOOD ZONE LOCATIONS

Although the relative magnitude of SLR not significant compared to base flood SWEL, we conducted some "what-if" scenarios to evaluate the effect of the slight changes in the stillwater elevation on BFEs and zone breaks. To evaluate potential changes to flood zones, two test sites were chosen in Suffolk County, NY: a transect expected to suffer

dune erosion but no dune failure during the base flood (Transect A) and a second expected to have dune failure during the base flood (Transect B). Coastal wave and flooding hazards were determined using CHAMP to produce a baseline condition for both transects. Next, the SWEL was increased by the expected rates of SLR in a 30-year period, at 2.55 mm/yr (NOAA 2001), and hazards were re-evaluated through the CHAMP model. Values were rounded to two significant digits, which is typical for Flood Insurance Studies.

Results of the test at the two sites showed that SLR was relevant at the 30-yr time scale. Results at Transect B showed small differences in base flood zone locations, with zone breaks being shifted inland for the 30-year SLR case by 6.2-12.1 m (20-40 ft), with large differences landward of the dune line with a maximum 76.2 m (250 ft) shift and culminating in a 1 foot increase in BFE towards the end of the transect. In general for the SLR test case, areas of wave regeneration tended to occur earlier and were slightly higher. For Transect A, the changes were greater. Results seaward of the dune were similar, whereas the location of the zone breaks were observed to shift by 76.2 m (250 ft) inland. The two test cases converged at approximately 2.7 km (1.7 mi) inland. An example of changes in zone break locations at Transect A is presented in Figure 2.

Overall, increases of the BFEs were not greater than 1 ft. Differences between the two transects are most likely related to the localized topography and obstructions at the sites. As previously discussed, BFEs are determined by WHAFIS at only the half-foot elevations. The observed 1 ft increase and movement of zone breaks can be attributed to rounding of the output, rather than solely the inclusion of the expected SLR.

SLR AND ANTICIPATED EROSION

In conjunction with SLR, the anticipated retreat of the shoreline in response to rising water levels should also be considered. It is theorized that as sea level rises, the nearshore beach profile must adjust horizontally and vertically in order to remain in equilibrium with sediment supply and forcing conditions (Bruun 1962). Therefore, as sea-level rises, sediments from the upper beach profile must be eroded and deposited offshore to maintain this equilibrium. This process ultimately results in recession of the shoreline as the sea level rises. This concept, known as the "Bruun Rule" provides a simple method of estimating potential coastal retreat based on equilibrium profile theory and site characteristics (Bruun 1962). The simplified version of the Bruun Rule (Hands 1983) is shown below:

$$x = \frac{zX}{Z} \tag{1}$$

Where x is the amount of shoreline retreat, z is the change in sea level, Z is the depth of closure, and X is the distance to closure from the shoreline. Despite criticism (Pilkey et al 1993, Cooper and Pilkey 2004), numerous studies have found that the relationship provides a reasonable method of estimating coastal retreat, i.e. Rosen (1978), Hands (1983), Morang and Parson (2002), and Jones and Hayne (2002).

The combined impact of sea-level rise and coastal retreat on a NFIP coastal hazard assessment was evaluated by determining the potential magnitude of erosion via the Bruun Rule. Coastal retreat was implemented in the modeling profile by applying a landward translation of the offshore portion by the distance indicated by the Bruun Rule. The onshore portion of the cross-section was truncated accordingly, while the pre-existing slope of the berm was retained. This test was applied to Transect B (dune removal case) and results were compared to the 30-year SLR test case discussed above.

Representative values for depth and distance to closure for the south shore of Long Island in the vicinity of Westhampton are -7.1 m (NAVD 88) and 595 m offshore, as determined from a 7-yr time-series of beach profiles (Batten 2003). The rate of SLR , was calculated by taking a regional average of water level gauges (NOAA 2001) was 2.55 mm/yr. Predicted amounts of coastal retreat for these parameters at 10-, 15-, and 30-year intervals are 2.2 m (7 ft), 3.2 (11 ft), and 6.5 m (21 ft), respectively.

Results indicated that changes in zone break locations and BFEs were limited to areas seaward of the dune. Here, the gutter locations zone breaks were pushed inland and generally far enough to increase mapped BFEs by 0.3-0.6 m (1-2 ft). Since SLR was included, differences can be attributed to the translated profile and resulting increases in wave height elevations rather than rounding. Zone breaks and base flood elevations were reconciled with the test case lacking erosion as soon as the profile progressed landward of the dune line. Larger changes would be expected in locations with narrower beaches, where retreat of the shoreline would result in erosion and or failure of the dune.

DISCUSSION

Results of the WHAFIS evaluations for SLR and erosion did not produce significant changes to mapped hazards. Although the magnitude of SLR is not significant in comparison to the SWEL, the inclusion of SLR resulted in rounding of the BFE to the next foot. However, in consideration of the uncertainty of the model inputs, i.e. return period flooding elevations, the magnitudes of SLR presented here are again insignificant.

Despite this, the rates of SLR considered here are derived from a statistical analysis of long-term water levels records, at locations where rates are near the observed average value determined from NOAA NWLON stations. Base flood elevations increases of 0.3 m (1 ft) at the edge of a floodplain would result in expansion of that flood plain to the next highest topographic contour. In steeper areas, the changes are not significant, although in lower lying areas this could extend a floodplain by several hundred feet. In the larger picture, the increase represents increased risk.

Under the NFIP Community Rating System (CRS), participating communities can lower rates implementing programs to mitigate flood hazards. A popular approach under the CRS is to adopt a 0.2 m (1 ft freeboard) over mapped hazards. Given the changes observed in this analysis, wider use of this practice could function as an approach for accounting for SLR for sites with similar rates as those in this study.
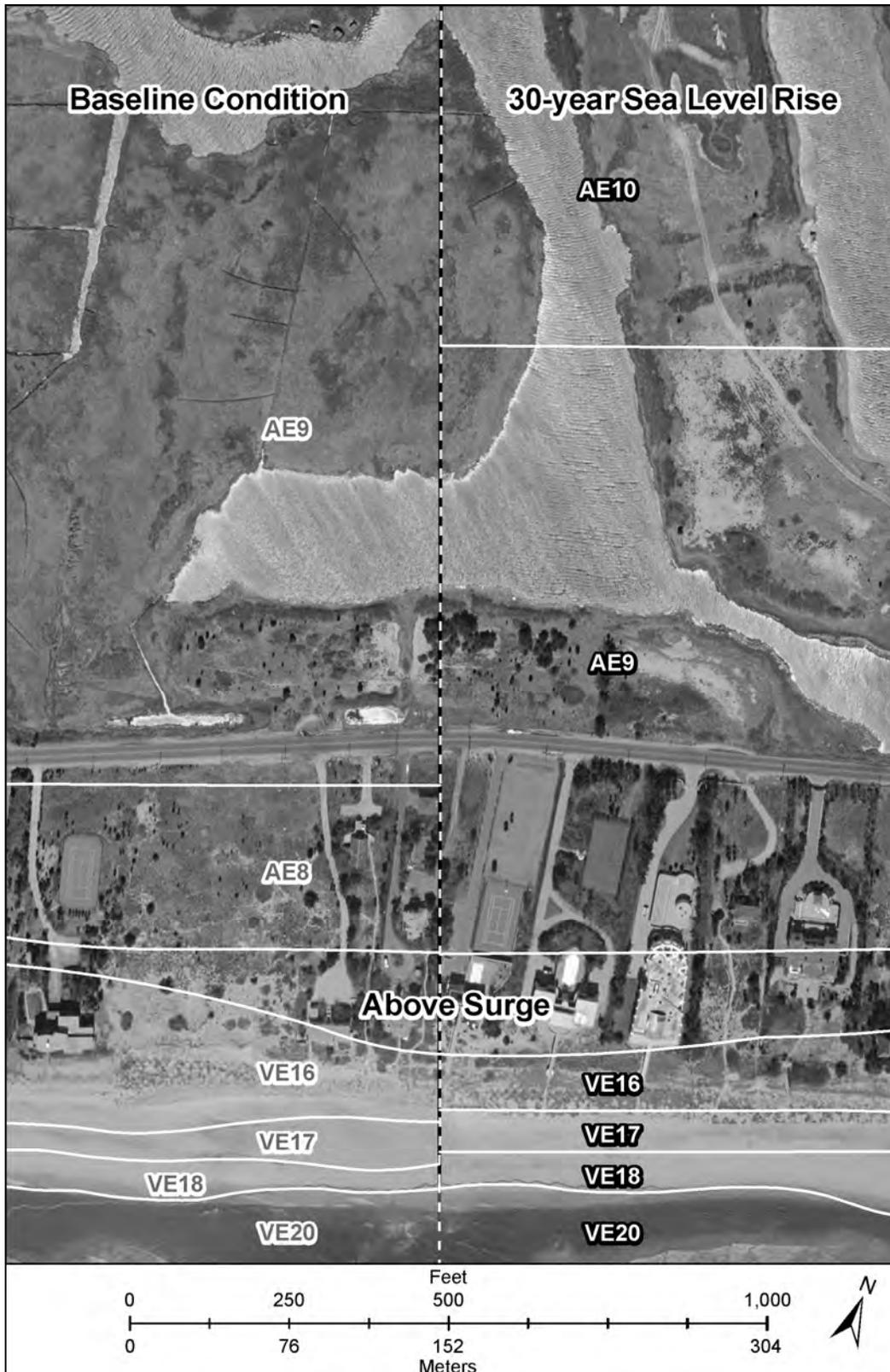
Fig. 2. Mapped coastal hazard zones for baseline and sea-level rise over a 30-year period (no SLR-induced erosion applied) at Transect A.

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CONCLUSION

The relative magnitude of SLR is minor compared to 1% annual chance stillwater elevations on which FEMA bases coastal hazard assessments for the National Flood Insurance Program. Increases of SWEL due to SLR over the typical timeframes of NFIP products were not significant at the study locations. Test cases showed that the addition of anticipated rates of SLR can increase BFEs by 0.3 m (1 ft) and shift zone breaks landward within a 30-year period. The foot increase was attributed to rounding of the results by the model due to inclusion of SLR. Inclusion of anticipated erosion with SLR did not result in significant changes to mapped hazards for a location with a moderately wide beach (approx. 23 m/75 ft). Although increases in BFEs were minimal, it is recommended that communities consider a 0.3 m (1-ft) freeboard over effective FIRMs to account for additional risk due to SLR over the product timeframe.

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