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An Estimate of the U.S. Population Living in 100-Year Coastal Flood Hazard Areas

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ABSTRACT

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The Federal Emergency Management Agency (FEMA) recently completed a coastal demographics study of the United States and U.S. territories. As part of this study, FEMA estimated the United States population subject to the 1% annual chance (100 y) coastal flood hazard as mapped by FEMA. This determination followed a three-step process: (1) create a national digital flood hazard database by compiling the best available coastal-proximate, digital flood-hazard-area data using FEMA data sets; (2) develop a systematic method to separate coastal and riverine flood hazard areas and incorporate this boundary into the digital flood hazard database; and (3) combine the year 2000 census data with the digital flood hazard database using a geographic information system. This enabled estimates of the U.S. population subject to the 1% annual chance coastal flood. The analysis was conducted at the census block-group level, with census block-group populations (permanent residents) assumed to be uniformly distributed across each block group. The results demonstrate that approximately 3.0% of the U.S. population lives in areas subject to the 1% annual chance coastal flood hazard. It must be emphasized, however, that these numbers are based on the 1% annual chance (100 y) coastal flood. Historical coastal floods less frequent than the 1% chance annual flood have occurred in the U.S. on numerous occasions. If less-frequent coastal flood events were considered in this study, such as the 0.2% annual chance (500 y) coastal flood or, if seasonal (vacations) population were considered, then a much greater percentage of the U.S. population would be determined as subject to coastal flooding.

ADDITIONAL INDEX WORDS: *Coastal population, FEMA, Flood Insurance Rate Maps, FIRMs, National Flood Insurance Program, NFIP.*

INTRODUCTION

How many people live in coastal areas? With the growing concern about global warming and its potential effects on coastal ecosystems and infrastructure, information and data that can address and answer this question are undeniably important. Unfortunately, published data and information on coastal population are limited and usually represent the upper bounds of a wide range of possible coastal-population statistics (Crowell *et al.*, 2007). Moreover, these limited primary sources are often indiscriminately and inappropriately cited in various academic papers, technical reports, the popular press, and other media. Because of the paucity of coastal demographic information, in particular the population subject to coastal flooding, we have developed methods to approximate areas in the United States that are subject to the 1% annual chance (100 y) coastal flood and to estimate the population living therein. The Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies were used as the primary bases for this analysis.

Background

A number of estimates of the U.S. coastal population have been published in a variety of sources over the past several years:

- Culliton *et al.* (1990) estimate that “almost one-half [45 percent] of our population now lives in coastal areas.” The authors identify 451 counties as coastal counties (which include counties bordering the Great Lakes); however, it is not clear what criteria were used to make this determination. Further, it appears that the criteria used to determine coastal counties may be inconsistent, as the publication states that “for this report, coastal counties are those identified by either the Federal Coastal Zone Management Program…, or by individual state coastal management programs.”
- Culliton (1998) and Crossett *et al.* (2004) estimate that there are 673 coastal counties and that 53% of the U.S.

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population lives in these counties. A "coastal county" is defined in these publications as (1) a county with at least 15% of its total land area located within the nation's coastal watershed or (2) a county with a portion of its land that accounts for at least 15% of a coastal cataloging unit. The National Oceanic and Atmospheric Administration (NOAA) defines a coastal cataloging unit as "a drainage basin that falls entirely within or straddles an Estuarine Drainage Area or Coastal Drainage Area. Typically, most EDAs or CDAs are composed of several complete cataloging units (drainage basins)" (U.S. Census Bureau, 2009a). Note that Culliton (1998) and Crossett *et al.* (2004) use the same definition of "coastal county" and list the same counties identified as "coastal." (Hereinafter, "Culliton" refers to both Culliton [1998] and Crossett *et al.* [2004].)

- Hinrichsen (1998, 1999) estimates that 55%–60% of the U.S. population lives in 772 counties adjacent to the Atlantic and Pacific oceans, the Gulf of Mexico, and the Great Lakes. It is unclear what criteria were used to identify these 772 counties.
- The United States Census Bureau (using the 2000 census) notes that 48.9% of the U.S. population lives within 50 mi of the coastline. The Census Bureau clarifies these figures by noting that "for this calculation, the coastline was any land that borders the ocean and any of its saltwater tributaries, including bays and tidal rivers, and the Great Lakes" (U.S. Census Bureau, 2009b).
- The National Ocean Economics Program (NOEP) maintains a webpage (NOEP, 2008) where one can select several different interactive parameters to determine coastal populations. These parameters include the use of areas defined by zip codes, in which the boundaries are located "immediately adjacent to an ocean, Great Lake, or included river or bay," and by coastal zone counties, where such counties are defined using several different criteria (such as watershed based, contiguity with the ocean and/or Great Lakes, and other criteria).

Recognizing that the majority of peer-reviewed published data on coastal demographics were limited and usually represent the upper bounds of a wide range of possible coastal-population statistics, Crowell *et al.* (2007) presented an alternative method to determine coastal population based on whether a county bordered the coast (or associated sheltered water bodies) or contained velocity zones (V Zones) as defined by FEMA. As explained below, V Zones are a type of flood hazard area subject to coastal flooding and high-velocity waters, or are determined based on the presence of primary frontal dunes. The Federal Emergency Management Agency refers to these areas as "Coastal High Hazard Areas." Thus, if a county did not border the coast but contained a V Zone—no matter how small—that county was also considered a coastal county. Given these criteria, and using 2000 Census Bureau data, the authors note that there are 364 coastal counties containing 37% of the total U.S. population when the Great Lakes are included, or 281 coastal counties containing 30% of the U.S. population when the Great Lakes are excluded (these figures are based on permanent residents and include Alaska and Hawaii but exclude the U.S. territories). Crowell *et al.* (2007) also applied this methodology to smaller census block groups in order to get a more-refined estimate using the "bordering the coast"/V Zone criteria. Census block groups usually contain between 600 and 3000 persons (U.S. Census Bureau, 2009c). The results indicated that there are 9,790,000 people living in coastal census block groups (including the Great Lakes) defined using these criteria, or 3% of the total U.S. population. These results did not include the U.S. territories in order to provide a more-direct comparison to Culliton (1998). Figure 1 displays a map of the United States showing "coastal counties," reflecting the Crowell *et al.* (2007) criteria (dark gray counties) as well as the Culliton (1998) criteria (light and dark gray counties).

As can be seen from the Culliton (1998), Hinrichsen (1998, 1999), U.S. Census Bureau (2009b), and NOEP (2008) coastal-population estimates (along with the population estimates presented in Crowell *et al.* [2007]), various combinations of defining criteria can be used to tabulate coastal populations, and altering any one of them could significantly impact the population tallies. These criteria can be categorized as:

- Geopolitical or spatial buffers (if used): *e.g.,* geopolitical units such as census block groups, counties, *etc.*, or buffers such as 50-mile, 100-mile, *etc.*
- Geophysical indicators: *e.g.,* the presence of coastal watershed, boundary line for the 1% annual chance coastal flood (see below), shoreline, *etc.*
- Inland boundaries: *i.e.,* how far inland into bays, inlets, deltas, *etc.*, one can go before an area is no longer considered "coastal." The inland boundaries can be set by geophysical indicators, geopolitical boundaries, or other criteria.
- Geographic regions: *i.e.,* inclusion or exclusion of the Great Lakes, the Pacific, Atlantic, and Gulf coasts, or other geographic regions or territories.

Given this categorization, Crowell *et al.* (2007) estimated coastal population based on the following criteria: (1) a geopolitical buffer defined by census block groups or counties; (2) geophysical indicators defined by the presence of the shoreline and/or V Zones; (3) inland boundaries defined by the inland location where census block-group boundaries stop following the physical coastline and join together across an open-water area; and (4) geographic regions including or excluding the Atlantic, Pacific, Gulf, and Great Lakes coasts.

Crowell *et al.* (2007) used the V Zone as a geophysical indicator because it represents the landward limit of coastal high-hazard areas. In addition, a geo-coded digital representation of the V Zone boundary was readily available. However, V Zones only account for the subset of coastal flood hazard areas that are impacted by significant wave action or high-velocity waters. In order to obtain a more-complete estimate of population with a 1% annual chance of experiencing coastal flooding, one must also consider coastal A Zones.[1] These are areas subject to coastal flooding but which are *not* impacted by

[1] Coastal A Zones sometimes refer to the area located landward from the V Zone to a line defined by the 1.5 ft. wave. In this paper, "coastal A Zone" refers to any A Zone determined using storm surge analyses, regardless of wave height.

Figure 1. Map showing coastal counties as defined by Culliton (1998) using watershed-based criteria (light and dark gray) and Crowell *et al.* (2007) using coastal contiguity or V Zone criteria (dark gray).

the significant wave action/high-velocity waters associated with V Zones. At this point, it is useful to provide some background on FEMA flood zones.

FEMA Flood Zones

The Federal Emergency Management Agency administers the National Flood Insurance Program (NFIP). Key engineering components of this program are Flood Insurance Studies and FIRMs. Flood Insurance Studies are prepared in order to determine the elevation of the 1% annual chance flood, which is a flood height that has a 1% chance of being equaled or exceeded during any given year (the 1% annual chance flood is sometimes referred to as a "100 y flood"). The water surface elevations of the 1% annual chance flood are termed Base Flood Elevations (BFEs) and are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29), the North American Vertical Datum of 1988 (NAVD88), or a local datum where NGVD29 and NAVD88 are not available. (One of FEMA's goals over the next few years is to eventually convert all flood maps from NGVD29 to NAVD88.) Areas subject to 1% annual chance floodwaters are termed Special Flood Hazard Areas (SFHAs). The boundaries and lateral extent of the SFHAs and other flood zones are established when the BFEs are overlain on topographic data. This information is then used to produce FIRMs, which depict the extent of SFHAs (and other flood hazard boundaries) and associated BFEs. Over the past several years, as part of a map modernization effort, FEMA has been producing updated FIRMs using digital methods. These georeferenced, modernized, and more-accurate FIRMs are called Digital FIRMs, or DFIRMs (Crowell, Hirsch, and Hayes, 2007).

Most riverine SFHAs are categorized as A Zones or AE Zones and are determined using numerical models designed for riverine flood analyses. These include hydrologic models such as the Hydrologic Engineering Center–Hydrologic Modeling System (HEC-HMS) and the United States Geological Survey National Flood Frequency program, and hydraulic models such as the Hydrologic Engineering Center–River Analysis System (HEC-RAS) and the Federal Highway Administration Water Surface PROfile (WSPRO). In coastal areas, A or AE Zones are

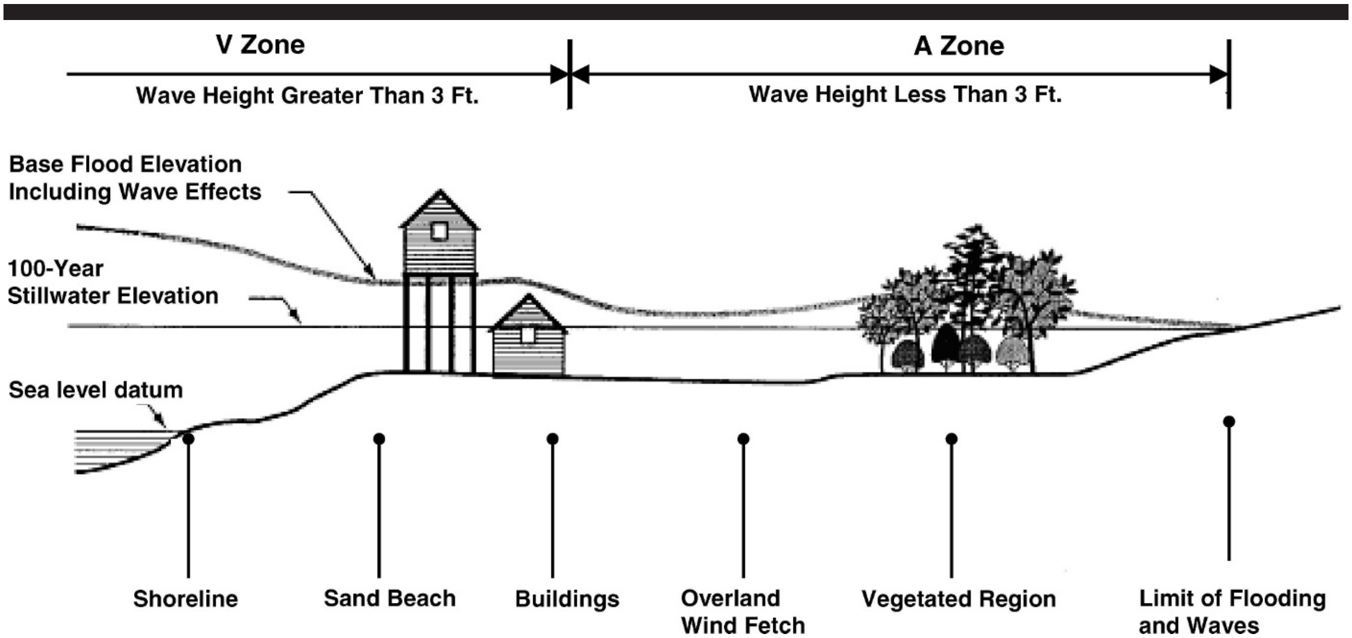

Figure 2. Schematic showing the relationship between wave effects, flood zone delineations, and base flood elevations (modified from FEMA, 2003).

determined using coastal storm surge analyses and may include the effects of wave heights less than 3 ft. These analyses may use tsunami, hurricane, or coastal storm surge models such as the FEMA Standard Storm Surge Model (Surge), the Advanced Circulation (ADCIRC) Model, or the Danish Hydraulic Institute Mike 21 hydrodynamic models; or they may use tide gauge analyses from long-term NOAA or United States Army Corps of Engineers tide gauge records.

Another type of SFHA, found exclusively in coastal areas, is called the V Zone or VE Zone.[2] A V Zone is determined using the same coastal storm surge analyses used in determining coastal A Zones, with the exception that the landward boundary of the V Zone is generally determined by the inland limit of significant wave action, high-velocity waters, or the landward toe of the primary frontal dune. As such, the landward extent of the V Zone boundary usually lies seaward of the landward extent of the coastal A Zone. Current general practice for mapping the landward extent of V Zones is to locate and map the most landward of the following (Bellomo, Pajak, and Sparks, 1999; Crowell, Hirsch, and Hayes, 2007):

- The limit of where a 3 ft. wave height could occur
- The location where the eroded ground profile (or noneroded ground profile, if applicable) is 3 ft. below the computed wave runup elevation
- The inland limit of the primary frontal dune, as defined in NFIP regulations
- The wave overtopping splash zone (generally the area landward of the crest of an overtopped barrier).

[2] The terms "AE Zones" and "VE Zones" refer to flood zones in which base flood elevations have been computed (as opposed to A or V Zones, in which base flood elevations have not been computed). Hereinafter, for the sake of simplicity, these zones will be referred to as "A Zones" and "V Zones."

Typically, V Zones are more hazardous than A Zones. Consequently, NFIP floodplain management and construction requirements are more stringent, and flood insurance rates are usually much higher in V Zones. Figure 2 is a schematic that shows the relationship between the 3 ft. wave, V Zone delineations, and BFEs.

The landward extent of coastal A Zone flooding may extend a significant distance inland at river and stream confluences where a transition occurs and riverine flooding begins to dominate. Unfortunately, current FEMA regulations do not distinguish between coastal and riverine A Zones; consequently, the coastal A Zone/riverine A Zone boundary is not differentiated and therefore not delineated on FIRMs. As such, in order to determine population impacted by 1% annual chance coastal flooding, irrespective of wave height or high-velocity waters, methods had to be developed to estimate locations in A Zones where coastal flooding dominates riverine flooding; that is, the location of the coastal A Zone/riverine A Zone boundary line. Figure 3 is a cartoon showing the relationship between riverine A Zones, coastal A Zones, and V Zones.

METHODS

The determination of population located in coastal flood zones followed a three-step procedure. The first step was to create a national database by compiling the best available coastal-proximate, digital flood hazard data showing the location and extent of coastal and riverine SFHAs. The second step was to develop a systematic method to separate the coastal and riverine A Zones and incorporate this new boundary line into the digital flood hazard database. The third step was to use a geographic information system (GIS) to combine 2000 census data (for permanent residents) with the national digital flood

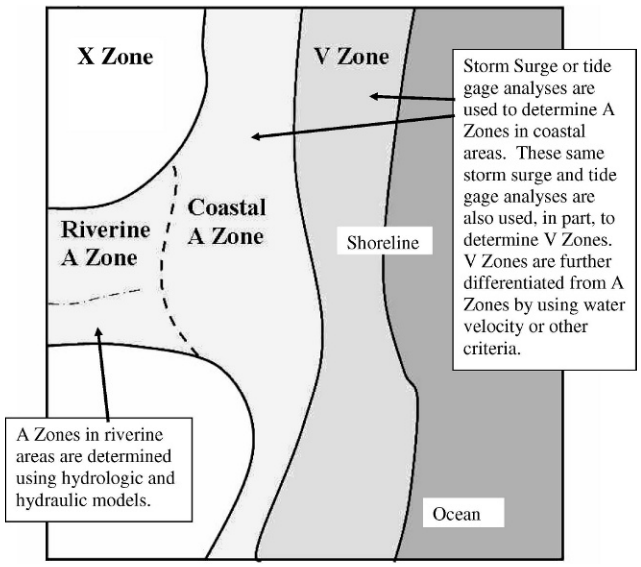

Figure 3. Cartoon showing the relationship between A Zones in riverine areas, A Zones in coastal areas, V Zones, and X Zones. The A Zones and V Zones are based on the 1% annual chance (100 y) flood and are known as Special Flood Hazard Areas (SFHAs). In riverine areas, A Zones are determined using hydrologic models such as HEC-HMS and hydraulic models such as HEC-RAS and WSPRO. In coastal areas, A Zones are determined using storm surge analyses. This includes hydrodynamic models such as FEMA Surge, ADCIRC, and Mike 21; and gauge analyses. The same models/analyses used to determine V Zones as are also used to determine A Zones in coastal areas, although V Zones are further differentiated from coastal A Zones based on wave, velocity, or primary frontal-dune criteria. Shaded X Zones generally represent areas of 500 y floods, whereas unshaded X Zones are areas determined to be outside the 500 y floodplain. These X Zones are not considered SFHAs. The dashed line separating the coastal A Zone from the riverine A Zone was specifically created for this analysis of coastal population and is not delineated on FIRMs.

hazard database and the boundaries for the V Zone and coastal A Zone/riverine A Zone. These steps enabled estimates of the U.S. population subject to the 1% annual chance coastal flood. Two different approaches to determine coastal population were used in this step, as explained below.

Step 1: Digital Base Data Compilation

Three digital data sources were used to compile the base coastal data set used for this analysis: (1) National Flood Hazard Layer (NFHL) data, (2) Q3 data, and (3) National Elevation Data terrain data combined with estimates of 1% annual chance still-water elevations. The still-water elevation is defined by FEMA as the surface of the water resulting from astronomical tides, storm surge, and freshwater inputs but excluding wave setup contributions (FEMA, 2007).

The NFHL is a national database currently being compiled by FEMA that comprises available DFIRM data. Given its DFIRM underpinnings, NFHL data represent the best available digital spatial data set showing the location and extent of SFHAs and associated floodwater surface elevations. The NFHL represents the most recent flood studies and does not include images or data files scanned from older paper FIRMs. Currently, approximately 35% of coastal counties in the United States are represented in the NFHL, either partially or completely, depending on data availability.

Whereas DFIRMs are designed from start to finish as a digital product and are represented in the NFHL, FEMA's Q3 database was developed during the 1990s by digitizing existing hard-copy FIRMs that were prepared using older, manual techniques. As such, the Q3 database is considered less accurate than the NFHL database. The Q3 database contains vectorized flood zone and political boundaries, but it does not include BFEs.

Figure 4 shows current NFHL and Q3 coverage for coastal and Great Lakes counties. Whereas the majority of the Atlantic, Gulf, and Pacific coastal counties are represented by NFHL and/or Q3 data, many of the Great Lakes and most of the Alaskan coastal counties are not represented by either of these data sets. As such, other national data sets were evaluated that could provide a means for approximating the coastal A Zone boundary where there was no NFHL and Q3 coverage. The evaluation of publicly available national-terrain data sets indicate that 1/3 Arc Second (equivalent to 10 m resolution) Digital Elevation Models (DEMs) from the United States Geological Survey were the most cost effective and viable terrain data that could be readily used for this effort.

Step 2: Riverine and Coastal A Zone Separation

Two features common to riverine A Zones are not present in coastal A Zones, and these proved useful in differentiating between the two. The first is that riverine BFEs are generally depicted on FIRMs as wavy lines plotted perpendicular to the course of the riverine flooding, with BFEs increasing in an upstream direction. Coastal BFEs, on the other hand, usually run roughly parallel to the shoreline and are indicated by smooth lines, with BFEs generally decreasing in an inland direction. As such, for any given A Zone, if the BFEs are depicted as wavy lines, that means riverine hydraulics dominate coastal hydraulics during a 1% annual chance flood event, and that riverine models were used to determine and delineate the A Zone. If the BFE lines are smooth, that means that coastal hydraulics dominate riverine hydraulics during a 1% annual chance flood event, and that coastal models were used to determine and delineate the A Zone. Thus, where NFHL data and associated BFE locations were available, riverine and coastal A Zones were separated where the first downstream riverine BFEs were observed.

The second feature often plotted on FIRMs and associated with riverine A Zones is the floodway. The floodway is a portion of a river channel and adjacent floodplain that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height. The FEMA Q3 database does not include BFEs but does provide spatial locations of floodway boundaries. Where Q3 data were available and NFHL data were not available, riverine and coastal A Zones were generally separated at the downstream limit of floodways.

In areas where neither NFHL nor Q3 data were available, such as along the Great Lakes and Alaskan coastlines, coastal

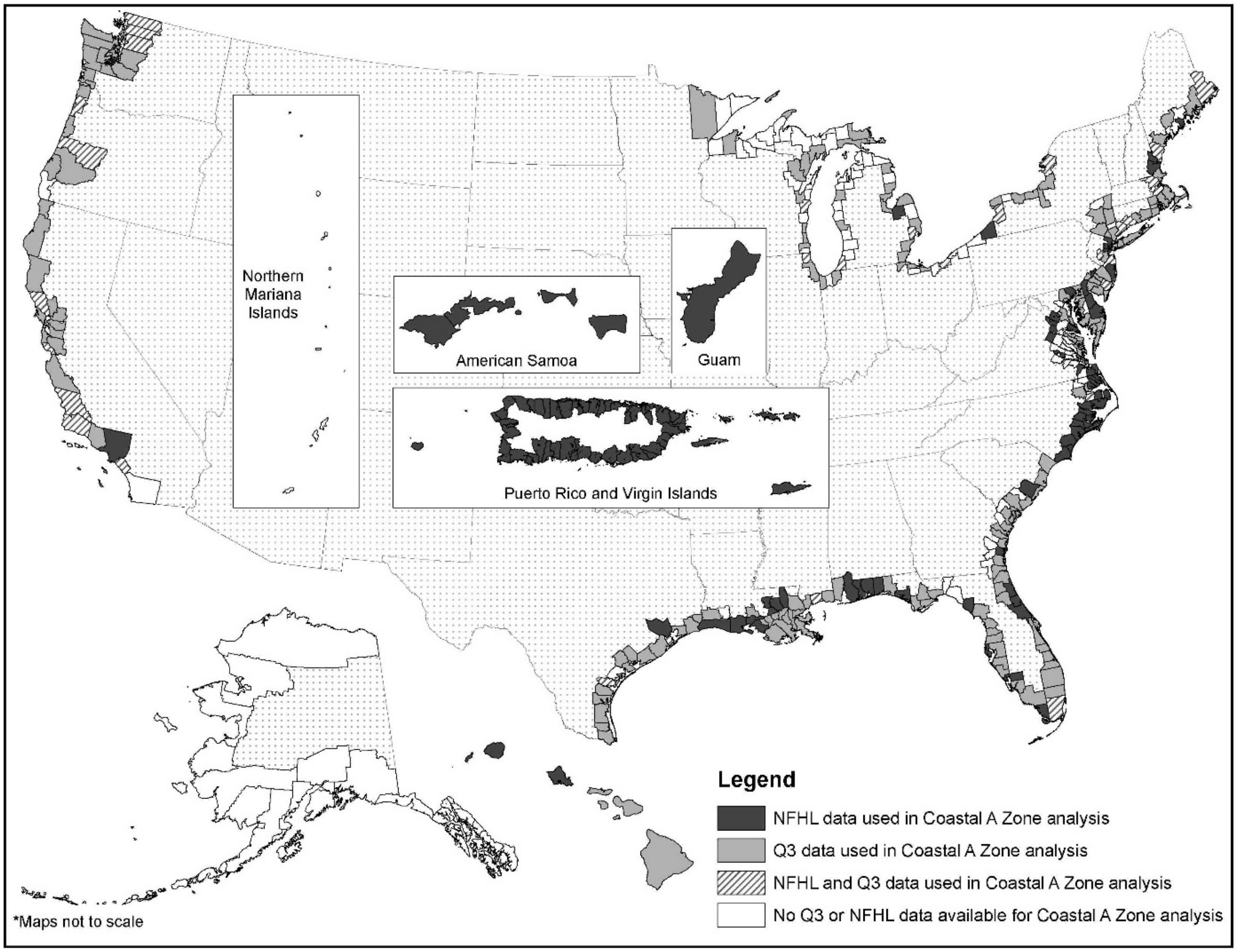

Figure 4. Map of the United States and U.S. territories showing distribution of digital data sets used in the coastal-population analysis.

A Zone boundaries were approximated by associating a 1% annual chance still-water elevation to the DEM. Still-water elevations were obtained by referencing published FEMA flood insurance study reports and selecting a representative 1% annual chance still-water elevation for each coastal county without NFHL or Q3 data. A polygon coastal A Zone area was then approximated by identifying grid cells from the DEM below the representative still-water elevation.

Step 3: Estimating Coastal Population

Two different approaches for estimating coastal population were developed. The first and more important approach considered a geophysical indicator, the 1% annual chance flood, irrespective of geopolitical boundaries. Once coastal A Zones were separated from riverine A Zones, the SFHAs seaward of this separation line were classified as *coastal flood hazard areas*, consisting of coastal A Zones and V Zones (Figures 5 and 6 show coastal flood hazard areas delineated for New Jersey and North Carolina). Next, GIS unions were performed to spatially combine the coastal flood hazard areas with census block groups. Tabular data from the GIS unions provided estimates of the portion of each census block group located within the coastal flood hazard areas. Census block-group populations were assumed to be uniformly distributed across each block group, and the population within a coastal flood zone was estimated in a spreadsheet calculation by multiplying the block-group population density by the square-mile area of the coastal flood zone. Consequently, the resulting population estimates were primarily based on geophysical criteria; census block groups were only used as a method for determining population distribution and were not used as a geopolitical buffer.

The second approach for estimating coastal population considered census block-group geopolitical boundaries combined with geophysical indicators defined by coastal shorelines and/or coastal flood hazard areas. With this definition, if a census block group was contiguous with the coastline, it was

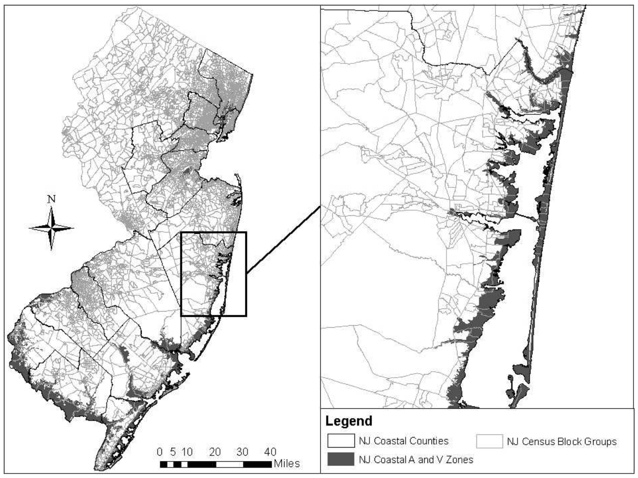

Figure 5. Map of New Jersey showing coastal flood hazard areas (*i.e.,* coastal A Zones and V Zones).

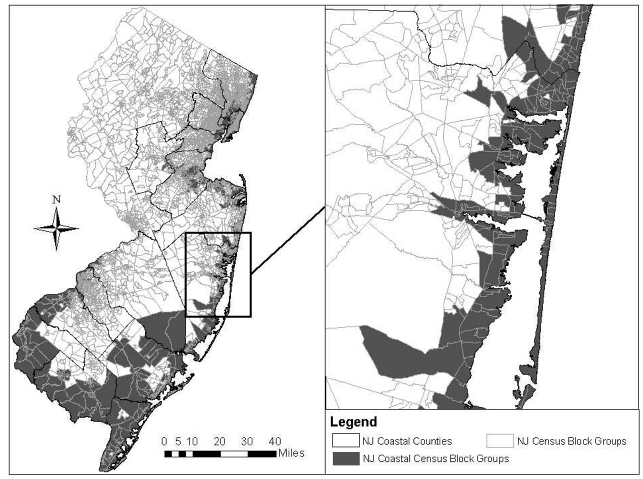

Figure 7. Map showing New Jersey "coastal" census block groups, defined as census block groups adjacent to a coastline or containing V Zones and/or coastal A Zones. Note that there are several locations, most notably in southern New Jersey, where "islands" of noncoastal census block groups are surrounded on all sides by coastal census block groups. These "islands" are caused by the variation in size and geometry of census block groups relative to the intersection of the coastal A Zone and V Zone boundaries.

considered a coastal area. If the census block group was not contiguous with the coastline but contained a V Zone or coastal A Zone, no matter how small, that census block group was also considered a coastal area (Figure 7). In this approach, inland boundaries of coastal shorelines were delineated where census block-group boundaries join across NOAA-defined water boundaries (Figure 8). Coastal shorelines defined as such generally include coastlines associated with bays, inlets, deltas, mangrove islands, and backsides of barriers.

RESULTS

Table 1 shows a summary of the U.S. population, by state, that lives in areas subject to coastal flooding as defined by the 1% annual chance coastal flood hazard (including the primary frontal dune). The data show that for the United States and its territories (with a total permanent resident population of about 285,620,000, according to the 2000 U.S. census), approximately 8,651,000 people (3.0%) live in areas subject to the 1% annual chance (100 y) coastal flood hazard. Note that this estimate also includes the population living in V Zone areas that are not subject to the 1% annual chance flood but are nonetheless mapped as V Zones because of the primary frontal dune. These primary frontal-dune areas, while situated above the 1% annual chance flood elevation, are shore-parallel, narrow reaches and are included in the population estimates because of their coastal-proximate location. According to FEMA estimates, fewer than 70,000 people reside in primary frontal-dune areas (FEMA, 2008).

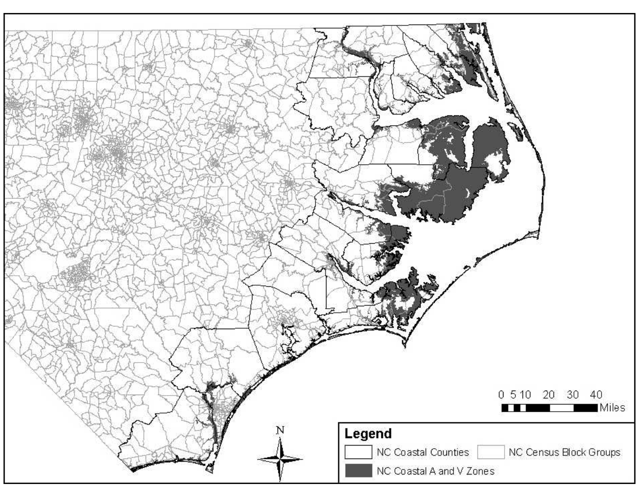

Figure 6. Map of North Carolina showing coastal flood hazard areas (*i.e.,* coastal A Zones and V Zones).

Excluding the U.S. territories, the Atlantic coast has the greatest density of population living in areas subject to the 1% annual chance flood, with 433 persons/sq mi, followed by the Great Lakes (372 persons/sq mi), Gulf (145 persons/sq mi), and Pacific (23 persons/sq mi) coasts.

Table 2 shows a summary of the U.S. population, by state, that lives in census block groups that directly border the coast or contain 1% annual chance coastal flood hazard areas (coastal A Zones or V Zones). The data show that for the United States and its territories, approximately 24,662,000 people, or 8.6% of the U.S. population, live in coastal census block groups.

DISCUSSION

As noted above, most published coastal-population estimates are determined using geopolitical areas or spatial buffers in conjunction with certain geophysical indicators bounded by defined inland boundaries (and further refined by the inclusion or exclusion of certain geographic regions). Our first approach estimated coastal population by relying exclusively on a single

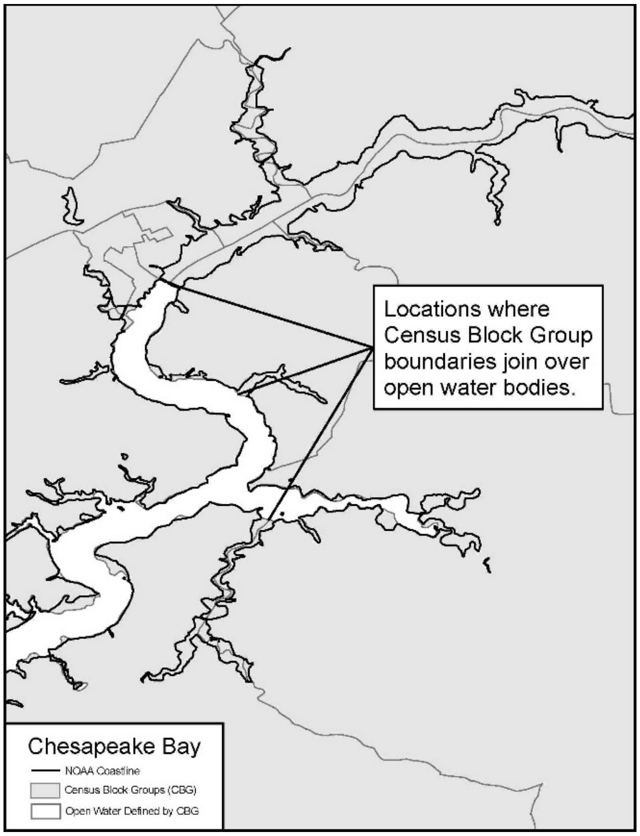

Figure 8. Example showing correlation between census block groups and the NOAA coastline. At this location (a tributary to the Chesapeake Bay), the coastline formed by census block groups generally follows the physical coastline as defined by NOAA; however, at various upstream locations the block-group boundaries join together across the NOAA-defined water bodies. Since the NOAA coastline generally corresponds to census block-group units, it provides a consistent spatial delineation for analyzing census demographic data.

Table 1. *Population tallies and area in square miles for locations subject to 1% annual chance (100 y) coastal flooding. Population tallies are rounded to the nearest thousand and areas subject to coastal flooding rounded to nearest whole number. Totals may include rounding errors.*

Coast	State	Population	Area Subject to Coastal Flooding (sq mi)
Atlantic	Connecticut	119,000	88
	Delaware	46,000	270
	District of Columbia	5000	5
	Florida	2,844,000	2995
	Georgia	172,000	1521
	Maine	33,000	199
	Maryland	148,000	992
	Massachusetts	174,000	207
	New Hampshire	11,000	17
	New Jersey	496,000	668
	New York	494,000	254
	North Carolina	152,000	2415
	Pennsylvania	18,000	24
	Rhode Island	55,000	52
	South Carolina	272,000	1789
	Virginia	283,000	806
	Total	5,322,000	12,302
Atlantic territories	Puerto Rico	112,000	72
	Virgin Islands	16,000	10
	Total	128,000	82
Gulf	Alabama	44,000	296
	Florida	1,101,000	4325
	Louisiana	1,095,000	10,231
	Mississippi	121,000	349
	Texas	197,000	2463
	Total	2,558,000	17,664
Pacific	Alaska	31,000	16,937
	California	217,000	301
	Hawaii	60,000	31
	Oregon	18,000	91
	Washington	78,000	323
	Total	404,000	17,682
Pacific territories	American Samoa	6000	3
	Guam	5000	7
	Northern Mariana Islands	4000	63
	Total	15,000	73
Great Lakes	Illinois	29,000	13
	Indiana	6000	6
	Michigan	80,000	294
	Minnesota	3000	7
	New York	58,000	105
	Ohio	29,000	108
	Pennsylvania	2000	2
	Wisconsin	17,000	67
	Total	224,000	602
United States	Total	8,651,000	48,406

geophysical indicator, that is, whether or not the population lives within a coastal flood hazard area as defined above. Geopolitical or spatial buffers were not used in this method, although census block groups were used to determine spatial distribution of population. Further, inland boundaries were set by the inland extent of the coastal flood-hazard-area boundary. In short, this approach simply results in a population estimate based on whether the population is subject to FEMA's definition of 100-year coastal flooding, as based on the 1% annual chance flood.

Relying just on the coastal flood hazard area to determine coastal population is insufficient, however, if the goal is to determine a "coastal population" *per se*, because some areas bordering on the ocean or Great Lakes coast, particularly those fronted by bluffs or cliffs, may not have any associated coastal flood hazard areas—and therefore no defined coastal population. Obviously, there are other coastal-related hazards or processes besides flooding (see below) that could be used to define "coastal areas." In addition, there may be other issues to consider, such as socioeconomic factors, which may be important in defining coastal areas. For example, neighborhoods adjacent to areas subjected to coastal flooding may also be affected because of job loss, disruption of services, or other reasons. This suggests using a geopolitical or spatial buffer to incorporate these second-order impacts. As such, our second approach estimated coastal population using two geophysical indicators (presence of coastal flood hazard areas and contiguity with the ocean and Great Lakes coasts), with a geopolitical buffer defined by census block groups. As stated above, in this approach, if a census block group was contiguous with the coastline, it was considered a coastal area. If the census block

Table 2. *Population tallies for and number of coastal census block groups (CBG) per state. Population tallies are rounded to the nearest thousand.*

Coast	State	No. Coastal CBG	Population
Atlantic	Connecticut	461	579,000
	Delaware	119	210,000
	District of Columbia	8	13,000
	Florida	2153	4,527,000
	Georgia	253	360,000
	Maine	296	314,000
	Maryland	727	1,042,000
	Massachusetts	726	849,000
	New Hampshire	53	75,000
	New Jersey	1168	1,394,000
	New York	1274	1,742,000
	North Carolina	340	518,000
	Pennsylvania	57	44,000
	Rhode Island	271	327,000
	South Carolina	421	625,000
	Virginia	854	1,330,000
	Total	9182	13,949,000
Atlantic territories	Puerto Rico	333	502,000
	Virgin Islands	85	45,000
	Total	418	547,000
Gulf	Alabama	99	170,000
	Florida	1478	2,261,000
	Louisiana	1407	1,794,000
	Mississippi	214	268,000
	Texas	440	528,000
	Total	3638	5,021,000
Pacific	Alaska	205	230,000
	California	890	1,281,000
	Hawaii	232	416,000
	Oregon	147	155,000
	Washington	546	704,000
	Total	2020	2,786,000
Pacific territories	American Samoa	63	35,000
	Guam	62	38,000
	Northern Mariana Islands	45	48,000
	Total	170	121,000
Great Lakes	Illinois	215	318,000
	Indiana	48	53,000
	Michigan	645	711,000
	Minnesota	37	34,000
	New York	387	564,000
	Ohio	235	266,000
	Pennsylvania	38	43,000
	Wisconsin	210	249,000
	Total	1815	2,238,000
United States	Total	17,243	24,662,000

group was not contiguous with the coastline but contained a V Zone or coastal A Zone, no matter how small, that census block group was also considered a coastal area.

Hurricane-Force Winds

Coastal flooding is just one of several natural hazards that can affect the coast, and it is the focus of this paper. What happens, however, when we consider the impact of hurricane winds as a defining criterion for determining coastal counties or census block groups and associated population demographics? One way to approach this is to use the geographic boundaries of "hurricane-prone regions" as defined by the American Society of Civil Engineers (ASCE). The ASCE definition of hurricane-prone regions is "areas vulnerable to hurricanes [in] (1) the U.S. Atlantic Ocean and Gulf of Mexico coasts where the basic wind speed is greater than 90 miles per hour," and (2) Hawaii, Puerto Rico, Guam, Virgin Islands, and American Samoa (ASCE, 2006). Note that basic wind speeds are based on 3-second gust speeds, whereas wind speeds used in the Saffir-Simpson Hurricane Wind Scale are based on sustained wind speeds averaged over a 1-minute period. As such, a basic wind speed of 90 mi/h is approximately equivalent to the minimum Category 1 hurricane wind speed (74 mi/h) on the Saffir-Simpson scale. Applying 2000 census data to the boundaries of the ASCE-defined hurricane prone regions indicates that 30.5% of the U.S. population lives in a county in which any part of that county lies within the 90 mi/h wind contour. If the statistics are recalculated using a finer-resolution census block-group geospatial unit, the results show that about 28.2% of the population lives in a coastal census block group as defined using the ASCE criterion.

Misuse of the Culliton and Census Bureau Data

Earlier in this paper we noted that a review of peer-reviewed coastal-oriented literature reveals that there are a variety of methods and defining criteria that can be used to define coastal areas. This can result in a wide variety of coastal-population estimates that range from less than 10% to greater than 50% of the total U.S. population. This wide disparity in estimates does not necessarily mean that some estimates are correct and others incorrect, but that some methods of determining coastal areas and associated populations may be more applicable to certain processes or situations than others. For example, the Culliton (1998) watershed-based population data may be appropriate to use in situations where coastal ecosystems or water quality is a major concern (particularly where jurisdictional geopolitical matters are considered). Alternatively, the 3.0% population figure determined in this paper is appropriate if the goal is to determine the population subject to the 1% annual chance coastal flood hazard as defined by FEMA. Further, the 8.6% population figure determined in this paper may be more appropriate if the goal is to determine the percent population living in or near areas subject to coastal flooding or perhaps erosion or some other nearshore process. Problems arise when researchers or authors indiscriminately use these population data to buttress arguments, exaggerate significance, or otherwise use the data for purposes contrary to sensible use. In short, it is important that the methods and defining criteria used to determine coastal populations properly correspond to the physical process or geopolitical issue being considered.

The Culliton (1998) and U.S. Census Bureau (2009b) coastal-population statistics are by far the most common coastal demographics cited in academic papers, books, professional reports, and popular press articles dealing with various aspects of coastal population. The Culliton (1998) data set is based on county geopolitical units and coastal, watershed-based geophysical indicators. The inland boundaries are defined by the coastal watershed. The commonly cited statistics "673 coastal counties" and "53 percent of the population lives in coastal counties" in the Culliton report include Great Lakes counties and their population tallies. With this in mind, the Culliton data set includes population data from numerous landlocked counties, including Sussex County, New Jersey, a county located entirely in the highlands and piedmont of New Jersey (in fact, 20 of New Jersey's 21 counties are considered coastal); San Bernardino County, California, a county of 1.7 million people with a population center located 50 mi from the ocean, and which includes the San Bernardino Mountains and large expanses of the Mojave Desert; and Appomattox County, Virginia, whose closest border lies more than 100 mi from the Chesapeake Bay and approximately 140–150 mi from the open ocean coast. Further, 83 Great Lakes counties are included in this data set; in fact, 89% of Michigan's counties are considered coastal according to Culliton (Crowell *et al.* 2007; Culliton, 1998).

In contrast, the census data set (U.S. Census Bureau, 2009b) uses 50 mi geospatial buffers with boundaries defined by geophysical indicators such as ocean shorelines, saltwater tributaries (including bays and tidal rivers), and geographic regions that include the Great Lakes. According to the U.S. Census Bureau (2009b), "Excluded from this boundary were coastal rivers and lakes. (Therefore, the tidal Potomac and the Chesapeake Bay were included, for example, while the Hudson River and Lake Pontchartrain were not.)"

The U.S. Census Bureau (2009b) and Culliton (1998) data sets both have limitations on how they should be used or referenced in coastal studies—particularly studies focused on coastal hazards. For example, the census coastal-population data are not associated with any particular geophysical process or hazard (other than the coastline), and since the data include populations from Great Lakes areas and Pacific coast states, this rules out its use in sea level rise, hurricane impact, and tsunami impact studies unless there is further parsing of the data or a clarifying discussion. Similarly, the Culliton coastal watershed-based data set, while based on a geophysical process (water flowing from coastal watersheds into the ocean or Great Lakes), also has limitations on how the data should be used. Given the inclusion of the Great Lakes counties and the numerous counties located tens of miles away from the coast and/or elevated many meters above sea level, it is obvious that papers dealing with coastal hazards such as sea level rise, hurricanes, tsunamis, *etc.* should also refrain from referencing the Culliton (1998) data set unless there is further parsing of the data or a clarifying discussion. Clearly, the Culliton data are most appropriate for situations or research where coastal ecosystems or water quality is of major concern. Similar concerns apply to the Hinrichsen (1998, 1999) data set, which includes tallies of coastal counties and coastal population that are even greater than those provided by Culliton (Crowell *et al.*, 2007; Culliton, 1998).

Crowell *et al.* (2007), however, note that numerous publications improperly reference the Culliton (1998) and Hinrichsen (1998, 1999) population data sets. Examples are given (*e.g.,* Neumann *et al.*, 2000 and Cooper and Pilkey, 2004) where the authors cite the Culliton (1998) or Hinrichsen (1998, 1999) population numbers (inclusive of the Great Lakes population tallies) within the context of sea-level-rise impact. This is done even though, as explained above, these data sets are clearly inappropriate for this use. Improper references to the census coastal-population data sets are also common. For example, in a 2007 paper in the *Marine Technology Society Journal* titled "The NIST-NOAA Resilient Communities Cooperative Initiative and its Contribution to Coastal Community Resilience" (Gaynor and Simiu, 2007), the authors note that, within the context of tsunami risk reduction, "Fifty percent of the U.S. population lives on or near the coast" (p. 32). A recent example from the popular press (*Skeptical Inquirer*) also improperly cites similar population statistics. In an article titled "Storm World: Hurricanes, Warming, and Scientific Uncertainty" (Mooney, 2007), the author states, "It's a staggering statistic: Half of the U.S. population lives within fifty miles of the coast. And they are not anywhere close to being ready to withstand a major hurricane's impact" (p. 40).

SUMMARY AND CONCLUSIONS

The impetus for this coastal-population analysis originated because of the lack of adequate demographic data sets associated with coastal flooding. However, additional motivation was provided by the plethora of inappropriate citations that can be found in published media regarding the Culliton (1998) and the U.S. Census Bureau (2009b) coastal-population data sets. Oftentimes popular literature, mainstream news media, and most disturbingly, peer-reviewed, academic journal articles casually reference the 50% or 53% coastal-population demographics without a clear understanding of the statistic's origins and implications. This misrepresentation of the data could lead to ill-informed and costly public-policy decisions. In light of this, we have attempted to determine other coastal-population statistics that could more effectively address the flood hazards affecting our coastal communities. We propose two new methods for determining coastal population: one based strictly on population directly subjected to coastal flood hazards as defined by the 1% annual chance coastal flood; the other based on population living in coastal census block groups that border the coast or that contain areas (no matter how small) that are subject to coastal flooding as defined by the 1% annual chance coastal flood/primary frontal dune, as determined by FEMA. Our analyses of coastal-population distributions using these definitions yield the following results:

- About 8,651,000 people, or slightly more than 3.0% of the total U.S. population, live in 1% annual chance coastal flood hazard areas as defined by FEMA. This includes the Atlantic, Gulf, Pacific, and Great Lakes coasts and the U.S. territories. When the Great Lakes are excluded from the data set, then the population decreases to 8,427,000, or slightly less than 3.0% of the total U.S. population.
- About 24,662,000 people, or 8.6% of the total U.S. population, live in census block groups that border the open ocean coast or that contain 1% annual chance coastal flood hazard areas as defined by FEMA. When the Great Lakes are excluded from the data, then the population decreases to 22,424,000 or about 7.9% of the total U.S. population.

These population statistics are based on the best coastal flood hazard and demographic (2000 census) data currently available. The results, however, are not intended to be interpreted as an upper bound on population exposed to coastal flood hazards. In fact, there are numerous examples where coastal floods more rare than the 1% annual chance coastal flood have occurred and damaged homes, businesses, and other infrastructure. Consequently, if less-frequent coastal flood events were considered in this study, such as the 0.2% annual chance (500 y) flood, then larger swaths of land and associated population would be impacted.

Further, it is important to understand that the results presented are a snapshot in time. The population data sets are derived from 2000 census data, and the dates associated with the acquisition of flood hazard information vary considerably. Different results should be expected in the future as populations shift, flood hazards change, and flood hazard studies and maps are updated and become more accurate. Regardless, tracking these changes independently over time is valuable in that it enables a better understanding of the key exposure drivers (population shifts and changes in flood hazards), which ultimately allows people to make more-informed decisions about where to live, work, and play.

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