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Measuring Tsunami Exposure and Pedestrian Evacuation Potential for the City of Alameda, California, Evacuation Playbook Phases

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MEASURING TSUNAMI EXPOSURE AND PEDESTRIAN EVACUATION POTENTIAL FOR THE CITY OF ALAMEDA, CALIFORNIA, EVACUATION PLAYBOOK PHASES

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ABSTRACT

MEASURING TSUNAMI EXPOSURE AND PEDESTRIAN EVACUATION POTENTIAL FOR THE CITY OF ALAMEDA, CALIFORNIA, EVACUATION PLAYBOOK PHASES

by Jeff Peters

A maximum tsunami inundation zone modeled by the California Geological Survey (CGS) is currently the basis for all tsunami evacuations in California, although CGS is developing Evacuation Playbooks of specific event-based evacuation phases. This report estimates population exposure for the Alameda, CA, Evacuation Playbook Phases since past U.S. Geological scientific reports estimated a large difference in numbers of Alameda residents in the maximum inundation zone when compared to an event-based inundation zone. A pedestrian evacuation analysis using an anisotropic, path distance model was also conducted to understand the time it would take for populations to reach high ground by foot. Initial results suggest that the two islands of the City of Alameda require different emergency planning when it comes to the four tsunami evacuation phases. Results suggest Alameda Island face challenges evacuating recreational marinas and Robert W. Crown Memorial State Beach for phases 1 and 2, whereas Bay Farm Island might be challenged with evacuating for phases 3 and the Maximum Phase. Considering the limited safe high ground suitable to pedestrian evacuation, vehicle evacuation analyses for Bay Farm Island may be warranted. City of Alameda emergency managers may consider different evacuation phases for each island depending on the tsunami event.

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Introduction

Recent tsunamis around the world (for example, 2004 Indian Ocean, 2009 Samoa, 2010 Chile, 2010 Sumatra, 2011 Japan, and 2015 Chile) have caused loss of life and extensive property damage, raising attention about tsunami planning elsewhere. Historic accounts and geologic records indicate the California coast has experienced comparable large tsunamis and is expected to experience more. California coastal communities are susceptible to tsunamis generated by both near and distant earthquake sources (Wilson & Miller, 2014). Examples of distant source earthquakes that have generated tsunamis on California's shores include the 2011 magnitude 9.0 Tohoku earthquake in Japan, the 2010 magnitude 8.8 Chilean earthquake, and the 1964 magnitude 9.2 Aleutian-Alaska Subduction Zone earthquake. Faults near California's coast could also generate tsunamis expected to arrive much sooner than distant sourced tsunamis. Noteworthy nearby faults capable of generating a local tsunami in California are the Point Reyes Thrust Fault, the Rodgers Creek-Hayward Fault, and the San Gregorio Fault (Wilson & Miller, 2015).

In order to minimize impact from future tsunamis, emergency managers need to understand the extent of potential flooding that may occur in their community. The California Geological Survey (CGS) has modeled tsunamis extensively based on historical records and examination of geologic deposits along California coastlines. Maximum tsunami inundation zones derived from composites of potential tsunami sources around the Pacific Ocean basin have been mapped for all California jurisdictions with coastal land. These zones are currently the basis for all recommended tsunami-related evacuations in California. CGS also models tsunami inundation for individual events referred to as scenarios that reflect actual historical events or hypothetical but plausible events based on earthquake forecasting. The maximum inundation zone represents the worst-case event which is often favored in hazard planning due to the infrequency and unpredictability of individual events. Scenario models are used in hazard research to understand what may happen if a specific event were to occur.

Once the extent of tsunami inundation is estimated, research on populations within expected inundation zones is conducted to help local emergency managers understand how many and what types of residents could be impacted during a tsunami event. A U.S. Geological Survey (USGS) tsunami exposure report for California suggests that the island community of Alameda has more residents and employees in tsunami-hazard zones than any other community. The report estimated 39,515 City of Alameda residents are located in the maximum tsunami inundation zone (Wood et al., 2013a). However, a subsequent USGS tsunami report estimated only 3,332 Alameda residents reside in the scenario tsunami zone (based on the 1964 Aleutian-Alaska earthquake and tsunami), suggesting that evacuations will not be necessary for over 36,000 residents (Wood, Ratliff, Peters & Shoaf, 2013b). This difference sheds light on the issue of whether to evacuate all residents within maximum tsunami zones or to use smaller zones that better reflect actual threat from a specific event.

The City of Alameda has worked with CGS and the California Office of Emergency Services (CalOES) to develop a playbook of four evacuation zones based on tsunami scenarios of varying inundation, referred to as “Evacuation Playbook Phases” (Wilson & Miller, 2015). This method is new for identifying evacuation areas based on forecasted tsunami severity. City of Alameda emergency managers expressed interest in exposure and evacuation analyses for each phase, with details on total population, businesses and employees affected, and pedestrian evacuation travel time estimates. This report will help Alameda emergency planners identify population variations in each Evacuation Playbook Phase and potential increases of exposed populations relative to other phases.

Research Questions

How many and what types of people live and work within the Alameda Tsunami Evacuation Playbook Phases? How long should it take Alameda evacuees to travel on foot to high ground or safety outside each of the Alameda Evacuation Playbook Phases? Analyses to answer these questions include measuring population exposure and pedestrian evacuation for the four Evacuation Playbook Phases in order to understand the variations in the population and time needed to reach high ground depending on tsunami inundation. Population exposure estimates and evacuation time maps help emergency managers target populations in areas of their city that could have challenges reaching safety. Understanding the variations in these estimates for each phase help emergency managers understand the evacuation implications of deciding when to evacuate to a certain phase versus the others.

Study Region

The City of Alameda (population 73,063) comprises two islands located in the San Francisco Bay (U.S. Census Bureau, 2014). The largest, Alameda Island, extends east to west approximately 12.8 km (8 mi) long and approximately 3.2 km (2 mi) wide

(Figure 1). Originally a peninsula, Alameda Island was created when a canal dredged in 1902 opened access to onshore shipping facilities and separated nearly 8.9 square km (2,200 acres) from the City of Oakland. This island is where about 80% of Alameda residents, the majority of commerce, and City Hall are located. The furthest northwestern 2.5 square km (624 acres) of the island is the decommissioned Alameda Naval Air Station (NAS), consisting largely of paved runways this now vacant site is used for special events (Figure 1). Alameda Island’s south shore includes notable features such as the 4 km (2.5 mi) long Robert W. Crown Memorial State Beach, the docks surrounding the USS Hornet Aircraft Carrier Museum and 2 small recreational marinas (Figure 1). Along Alameda Island’s north shore there are several recreation boating marinas, a ferry terminal dock, and the 0.26 square km (64 acres) Coast Guard Island positioned between the two cities (Figure 1).

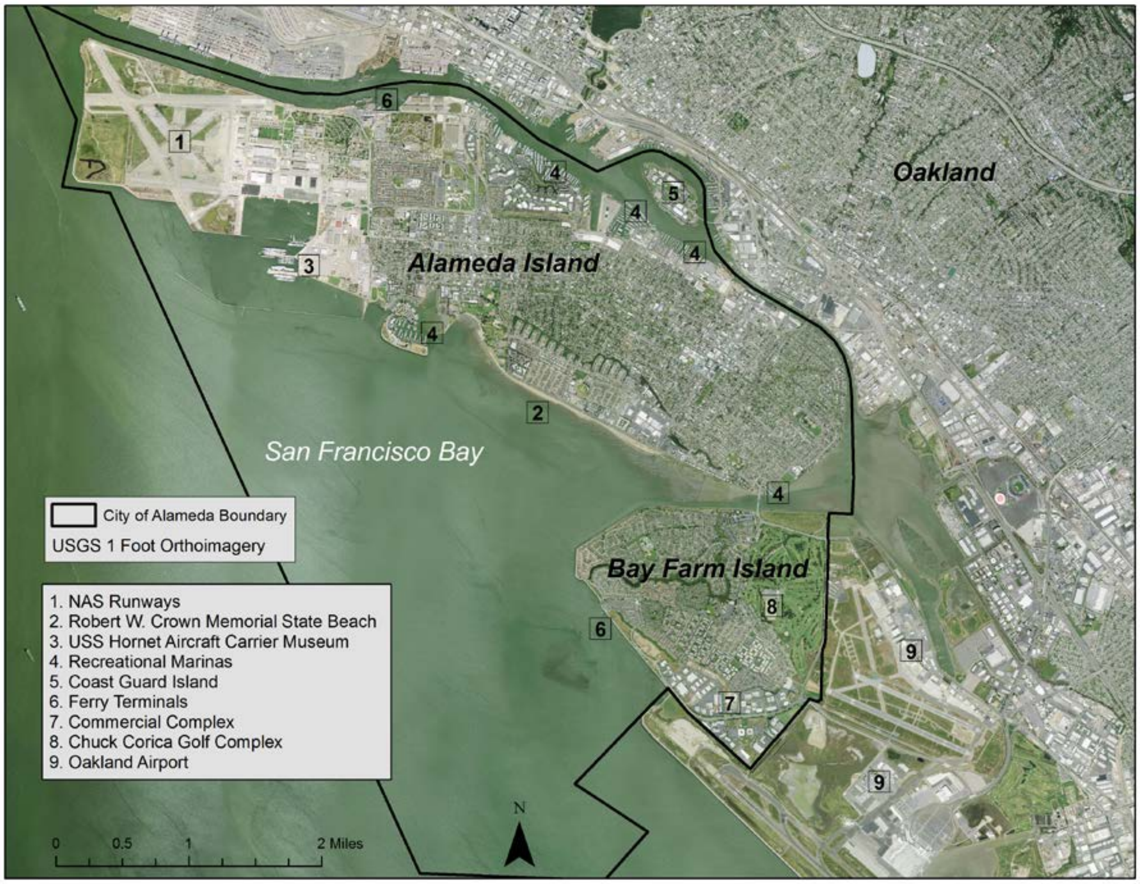

Figure 1. Study region map of various islands and noteworthy locations in and around the City of Alameda boundary.

Bay Farm Island is actually a peninsula, located less than 1 quarter mi off of the southernmost tip of Alameda Island (Figure 1). It was originally farms and orchards but became primarily single-family residences and high occupancy apartment complexes after an infill project increased the peninsula's size. There is a large commercial complex located in the southernmost portion of the City of Alameda's boundary, a ferry terminal on the southwestern shore, and Chuck Corica Golf Complex at the City's westernmost edge (Figure 1). Separating the City of Alameda's portion of Bay Farm Island peninsula from Oakland on the mainland is Oakland International Airport (Figure 1).

To aid in assessing population exposure and the surfaces evacuees will travel across, land cover types based on 2011 National Land Cover Dataset (NLCD) were tabulated within the study region's tsunami-prone areas (Homer, 2015). While analyzing land cover types in all Evacuation Playbook Phases, focus was directed to determining developed land areas. Population exposure is assumed to increase as area and developed land percentage increases within the Evacuation Playbook Phases (Wood et. al, 2013a). Therefore, the following three NLCD land cover classes were used to assess Alameda exposure to tsunami hazards:

- High-intensity developed pixels, which contain more than 80% impervious surfaces, contain little or no vegetation, and typically represent heavily built-up urban centers, large buildings, and abundant paved surfaces (such as runways and interstate highways);
- Medium-intensity developed pixels, which contain 50-79% impervious surfaces, are a mix of constructed and vegetated surfaces, and typically represent single-family housing units and associated outbuildings; and
- Low-intensity developed pixels, which contain 21-49% impervious surfaces are similar to medium-intensity developed pixels with the addition of roads and associated trees (Multi-Resolution Land Characteristics Consortium, 2011).

A fourth developed land category ("developed, open space") is not used to assess variations in community exposure to tsunami hazards because it identifies areas that have few impervious surfaces and are primarily covered in vegetation, such as lawn grass found on large lots, golf courses, cemeteries, beaches, and parks. For the purposes of this report, all other land cover classes have been consolidated into "other."

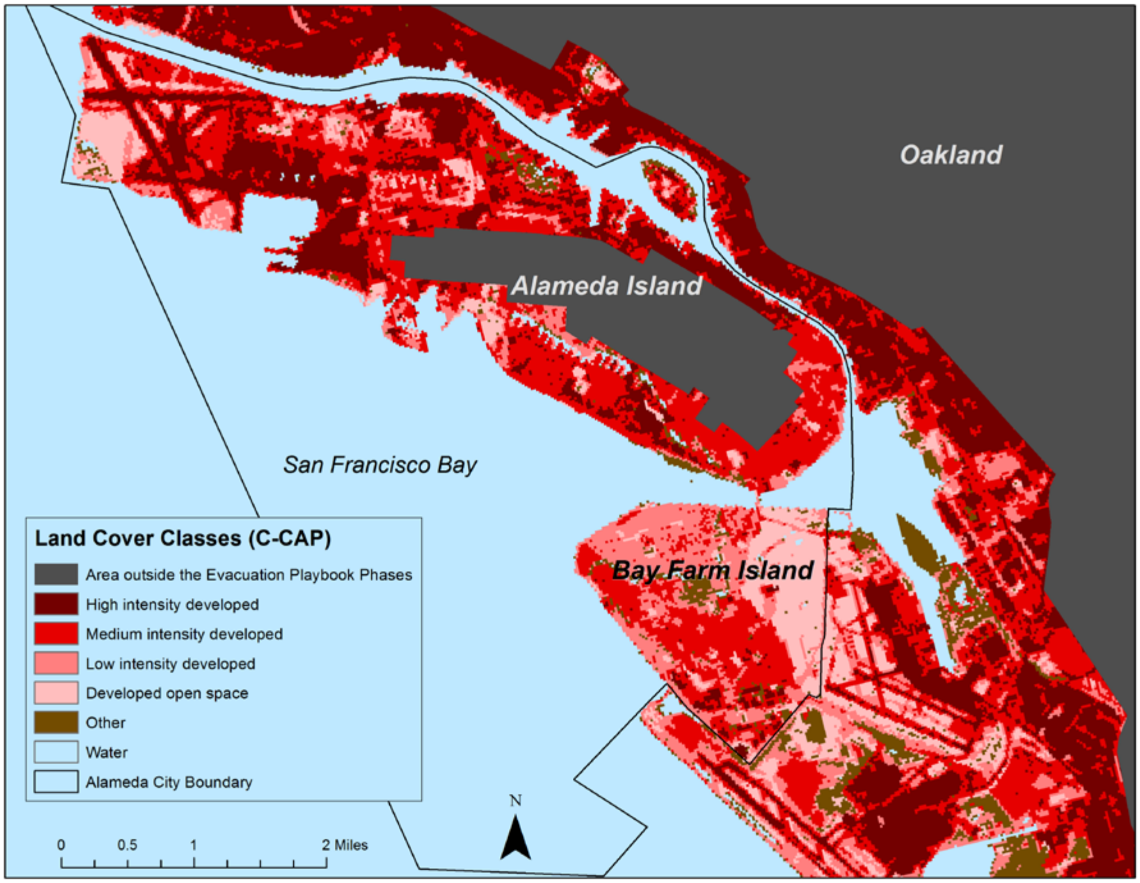

Figure 2. Alameda land cover types based on NLCD classification.

Assessing land cover distributions within the Evacuation Playbook Phases indicates little diversity in how tsunami-prone areas are used. The bulk of developed land in tsunami-prone areas on both islands is classified as medium intensity developed, which likely represents residential housing and associated outbuildings (such as garages and sheds) (Figure 2). The high-intensity developed land on Alameda Island likely represents dense single-family housing and commercial facilities, as well as large runways on the Alameda NAS; where high-intensity developed land within tsunami-prone areas on Bay Farm Island are all commercial business centers (Figure 2).

California Tsunami Evacuation Playbook

Wilson and Miller (2014) describes how current evacuation plans for tsunami events might overestimate the number of people who need to evacuate. Their solution is defining phases of evacuation by modeling tsunami inundation for potential earthquake source scenarios. Inundation zones typically follow elevation contours that may be difficult for an evacuee to identify on the ground. For clarity when implementing an evacuation, tsunami modelers and local planners collaborate to relate inundation extent information to an appropriate and recognizable physical landscape feature (e.g., streets or landmarks). This process creates understandable and communicable evacuation phases.

The decision as to which phase to evacuate is ultimately up to the local emergency mangers but the Evacuation Playbook includes a three-step process to help with this decision. Step 1 is obtain information about the earthquake and tsunami from the National Tsunami Warning Center in Alaska, the regional National Oceanic and Atmospheric Administration (NOAA) Weather Forecast office, and/or Alameda County emergency managers. Information gathered will include earthquake epicenter, magnitude, tsunami alert level (rated least to most severe as "watch," "advisory," or "warning"), and FASTER calculation results. The regional NOAA Weather Forecast Office will conduct the FASTER calculation for each community during a tsunami event and include a phase recommendation to help local emergency managers decide which phase to evacuate (Wilson & Miller, 2015). Five tsunami input parameters are used in the FASTER calculation:

- *FA*, Forecasted Amplitude (wave height)
- *S*, storm Surge or existing ocean conditions
- *T*, maximum Tidal height (first 5 hr of tsunami)
- *E*, forecast Error potential (30%; analysis of 2010-11 events)
- *R*, site amplified Run-up potential (from existing modeling, unique to each location; applied if inundation expected).

The resulting FASTER value relates to the expected tsunami run-up or the elevation the tsunami flood is forecasted to reach. The example given in the playbook is a 1.3 m FASTER value could lead to NOAA recommending a Phase 2 evacuation. However, uncertain ocean fluctuations like tide, currents and storms that effect tsunami run-up make it difficult to recommend an Evacuation Playbook Phase ahead of time, so each specific tsunami event will need a new FASTER calculation conducted.

Step 2 is to compare information from step 1 to the Tsunami Response Decision Tree (found on page 5 of the Alameda Tsunami Evacuation Playbook) and select the branch that best fits the forecasted tsunami information. A series of playbook tables relate evacuation phases to FASTER run-up values, anticipated NOAA tsunami alert levels, earthquake sources, and expected tsunami wave arrival times to assist emergency managers in deciding which phase to choose. Step 3 is to refer to the Evacuation Playbook pages corresponding with the Decision Tree flow for applicable instructions on which phase to evacuate and how to do so effectively.

Figure 3 displays the resulting Evacuation Playbook Phases for Alameda (Wilson & Miller, 2015) and the neighboring City of Oakland (R. Wilson, personal communication, January 29, 2015). Evacuation Playbook Phase 1 relates to a run-up of less than 1 m and is an advisory alert level that calls for evacuation of beaches, pier, and harbor docks that are indicated by circle ones in Figure 3. Except for the ferry terminal on Bay Farm's south shore, only Alameda Island is affected in a Phase 1 evacuation. The table indicating scenario earthquake source does not show source with expected run-up below 1 m so no specific earthquakes are affiliated with Phase 1 (Wilson & Miller, 2015).

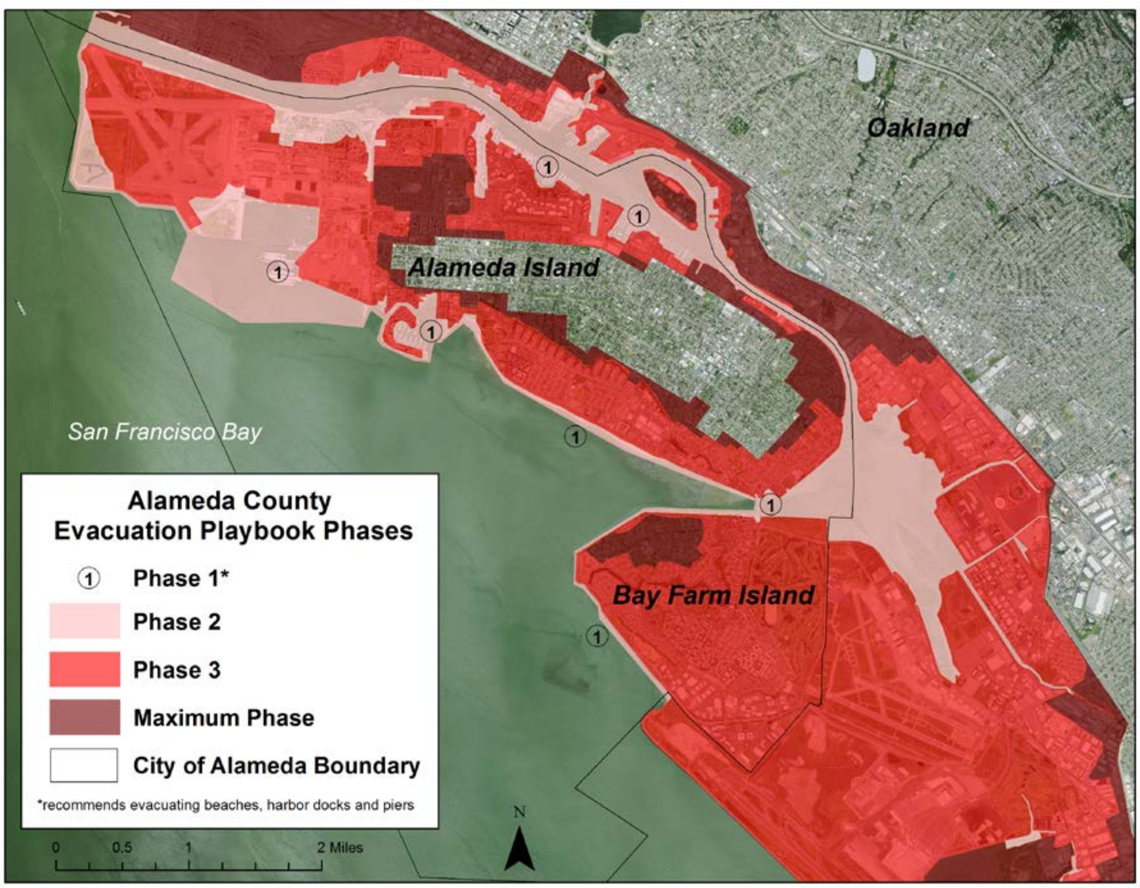

Figure 3. Evacuation Playbook Phases for the Cities of Alameda and Oakland.

Evacuation Playbook Phase 2 could be recommended for a tsunami run-up value of 1.0-1.5 m and depending on the source can be an advisory or warning level. Phase 2 only affects Alameda Island, as no Bay Farm Island shoreline is expected to be flooded, and relates to tsunamis that are expected to inundate the least amount of land area. However it is important to remember if a Phase 2 evacuation is called, areas for Phase 1 are included. Associations are made in playbook tables that link run-up values (1.0 m and above) to scenario earthquake sources, local and distant, and expected tsunami wave arrival times. Potential earthquake sources modelled as tsunami scenarios affiliated with Phase 2 include local sources: M_w7.3 Point Reyes Thrust Fault, M_w6.6 Rodgers Creek-Hayward Fault and M_w7.1 San Gregorio Fault, all of which have wave arrival estimates within 10-15 min of shaking; or distant sources: M_w8.8 Kuril Islands III, M_w8.8 Kuril Islands IV and a M_w8.6 Marianas Trench, which have wave arrival estimates within 9-11 hr of shaking (Wilson & Miller, 2015).

Alameda Evacuation Playbook Phase 3 is always a warning level (compared to the less severe Phase 1 and 2 advisory level) relates to run-up values of 1.5-2.5 m and affects both Alameda and Bay Farm Islands. Phases 1 and 2 are located within Phase 3 and will evacuate when Phase 3 is called. Modelled scenarios of potential earthquake sources affiliated with Phase 3 include only distant sources: M_w8.9 Central Aleutians II, M_w8.8 Kuril Islands II, M_w8.8 Japan II, M_w9.5 Chile 1960 and M_w9.4 Chile North, which could generate tsunami waves estimated to arrive in Alameda within 5-13 hr of initial ground shaking (Wilson & Miller, 2015).

The Alameda Evacuation Playbook Maximum Phase is always warning level, relates to tsunami run-up values greater than 2.5 m and affects both islands with the largest evacuation area. The Maximum Phase on Bay Farm Island is affiliated with tsunamis that could flood the entire island and require complete evacuation of all residents and employees. The Maximum Phase also includes all areas inside Phases 1, 2 and 3. Modelled scenarios of potential earthquake sources affiliated with the Maximum Phase include only distant sources: M_w9.2 Alaska 1964, M_w8.9 Central Aleutians I and M_w9.2 Central Aleutians III, which are estimated to arrive within 5 hr of shaking (Wilson & Miller, 2015).

Literature Review

Population Exposure

The following section summarizes several reports that analyze population exposure to natural hazards with attention devoted mostly to exposure analysis methods. Wood and others authored three statewide tsunami exposure reports for Hawaii and California (Wood et al., 2007; Wood et al., 2013a; Wood et al. 2013b). Tsunami hazard zones were acquired from state emergency managers (for Hawaii and California) in the form of Geographic Information System (GIS) polygon or polyline data files. Land cover data were downloaded from National Land Cover Data (NLCD) or Coastal Change Analysis Program (C-CAP) from their respective websites. 2010 U.S. Census Bureau block scale data were downloaded for demographics (including race, housing, and age). Proprietary data from Infogroup USA on businesses were also used to count and categorize business sectors and estimate employees located within hazard areas. Spatial overlays of the tsunami zones with the land cover and population data resulted in tabulation of land cover types and census numbers within tsunami hazard zones (Wood et al., 2007; Wood et al, 2013a; Wood et al. 2013b).

Modeling of hurricanes in relation to sea level rise in Florida created multiple hazards zones not unlike the Tsunami Evacuation Playbook Phases. Frazier, Wood, Yarnal and Bauer (2010) measured population exposure to sea-level rise (SLR) effects on hurricane flood exposure in Sarasota County, Florida. The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model provided by the U.S. National Hurricane Center (NHC), and NOAA was used as the hurricane zone and then expanded this to mimic a 30 cm, 60 cm, 90 cm, and 120 cm SLR to create four hazard zones. Population exposure was estimated by overlaying census and business data with the SLR zones. Results estimated a correlation between increased flooded land (due to SLR) with increased population and employee exposure. Frazier et al. then met with local stakeholders, who agreed with research plausibility, to assess initial findings and began discussing potential changes in land use planning to address future impact scenarios.

Tsunami exposure research in Portugal outlines methods for estimating exposure by time of day. Freire, Aubrecht and Wegscheider (2013) researched how population exposure to tsunamis would vary between night and day in the Lisbon Metropolitan Area (LMA), Portugal. They used dasymetric mapping techniques, combining areal interpretation with census and land cover data, to increase spatiotemporal accuracy when analyzing variations in population exposure. Census data describe nighttime population distributions, while workplace information and mobility statistics were used to represent daytime locations. Results showed that the exposed population increased during the daytime due to more businesses being located in predicted inundated areas than in residential zones, and evacuation estimates revealed that daytime evacuation could be a problem.

Pedestrian Evacuation

Wood and Schmidtlein (2012) discuss two methods for modeling pedestrian evacuation that have gained popularity in recent research—agent-based models and least-cost-distance (LCD) models. Agent-based techniques model evacuees as individuals with rules defining their travel behavior and are typically used to simulate evacuation for a specific hazard event. LCD uses geographic information systems (GIS) software to calculate travel times to safety from any location in the study region hazard zone with consideration of the surface and slope an evacuee must travel across. Wood and Schmidtlein improved the LCD approach by incorporating anisotropic algorithms that recognize elevation or slope directionality. Time map results are helpful for understanding the overall evacuation times for the entire study region, which is useful when a community is threatened with many varying tsunami sources (Wood & Schmidtlein, 2012).

The USGS developed a GIS tool called the Pedestrian Evacuation Analyst Tool (PEAT) that incorporates methods from Wood and Schmidtlein into an ArcMap extension, improving both usability and organization of input data and results (Jones, Ng & Wood, 2014). PEAT processes elevation, land cover and hazard zone data using least cost distance geoprocessing tools to model pedestrian travel across the landscape. It was designed to create travel time maps for use in communication efforts with emergency managers and residents to recognize areas where travel times may exceed expected tsunami wave arrival.

PEAT has gained popularity in evacuation research as several reports using the tool have been published in recent years. Wood, Schmidtlein and Peters (2013) compared modern and historical evacuations for the 1964 Good Friday Alaskan earthquake and tsunami in Seward, AK. Using modern and historical imagery to classify land cover changes determined that improvements to Seward waterfront areas in response to severe damages in 1964 may have increased evacuation times for landslide related tsunamis. Wood and Peters (2014) compared evacuations in five Alaska towns that were inundated by the 1964 Good Friday tsunami. Results show the three towns susceptible to landslide generated tsunamis may have less than adequate time to evacuate docks and waterfront areas compared to expected wave arrival times.

Methodology

Population Exposure

An inventory of population exposure relative to the four Evacuation Playbook Phases was conducted and includes estimates of numbers and percentages on resident demographics, and employees and business sectors. Following methods described in Wood et al. (2007, 2013a, 2013b), Frazier et al. (2010), and Freire et al. (2013), this analysis used geospatial data (for example, census blocks or business address points) to determine how many and what type of people are inside the four Evacuation Playbook Phases. Many census block boundaries intersect Evacuation Playbook Phase boundaries, so in order to tabulate demographics by phase, the census data spatial accuracy needed modification. Data acquired for the exposure analysis are:

- Evacuation Playbook Phases shapefile for Alameda (Wilson et al., 2015) and Oakland (R. Wilson, personal communication, January 29, 2015)
- Census block shapefile (U.S. Census Bureau, 2014b)
- Population demographic data (U.S. Census Bureau, 2014a)
- Alameda tax parcel shapefile (Alameda County, CA, 2014)
- Alameda tax parcel use code table (Alameda County Data Sharing Initiative, 2014)
- Infogroup Employer Database (Infogroup, 2011).

Census data were distributed to residential parcel centroids using a spatial join and a ratio of point density per block within ArcMap 10.2. This method is not meant to associate an exact location of residents to parcels, but rather a topology to evenly apply census population within spatial boundaries using tools available. Graphs and maps illustrate trends in population exposure within the four phases on both islands.

Pedestrian Evacuation

Pedestrian travel times to safety at high ground outside each Alameda Evacuation Playbook Phase were modeled with the USGS Pedestrian Evacuation Analysis Tool (PEAT). PEAT Version 20141023 was downloaded from the USGS website and installed using instructions in the PEAT manual. Spatial data acquired for PEAT inputs are:

- 1 meter, multi-pass LiDAR (A. Foxgrover, USGS Pacific Coastal Marine Science Center, personal communication, January 26, 2015)
- Alameda tax parcel shapefile (Alameda County, CA, 2014)
- Alameda tax parcel use code table (Alameda County Data Sharing Initiative, 2014)
- Wetlands shapefile (United States Fish and Wildlife Service, 2014)
- National Hydrography Dataset water body shapefiles (U.S. Geological Survey, 2015)
- Streets shapefile (Alameda County, CA, 2014)
- Evacuation Playbook Phases shapefile for Alameda (Wilson et al., 2015) and Oakland (R. Wilson, personal communication, January 29, 2015).

Land cover shapefiles were digitized from observations of the most recent Google Earth imagery and Google Maps street view. Shapefiles representing barriers to pedestrian travel are also necessary for PEAT, including water bodies, buildings and fences. A buildings footprint shapefile supplied by the City of Alameda (E. Smith, personal communication, November 6, 2014) was updated to reflect recent developments, both residential and commercial, and the demolition of homes on the Alameda NAS. Fences were digitized using imagery and Google Maps street view, but because finding every fence is outside the scope of this project, priority was given to very large fenced areas (for example, golf courses or airports). The estimated amounts of developed land covers for both islands suggest pedestrian evacuation will be limited to paved surfaces since they will likely be hindered by many fences dividing residential yards. Therefore, parcel polygons coded as residential were used as barriers to pedestrian travel understanding that evacuees would be confined to roads and unable to move freely through yards. However, resulting time maps will show residential house footprints for cartographic clarity—displaying fenced yards makes maps unreadable. The processed population exposure data, including census derived demographics and Infogroup Employer Database numbers, were used to tabulate travel times for residents and employees by island and evacuation phase.

The PEAT travel speed parameter was set to Average Walk, equaling 1.22 m per second (4 ft per second). A moderate speed was chosen to reflect evacuee differences that may vary their individual travel speeds, a consideration that cannot be accounted for in the software. Travel times are calculated as if a person was traveling toward high ground from any given location within the study region and begins moving immediately; therefore the reaction time related to a real event is not considered. Slowing of travel speed due to fatigue is also not considered.

Results from PEAT are displayed in travel time maps and charts with travel times for various populations for each evacuation phase and island. These graphics are not meant to estimate evacuation times for individuals in precise locations, but for evaluating the evacuation times across Alameda and Bay Farm Islands.

Population Exposure

Emergency managers and planners benefit from quantifying land cover types, population size, demographics, and businesses and employees found within community tsunami-prone areas. Exposure can be measured simply by determining population proximity to hazard (Miti, 1999; Wisner, Blaikie, Cannon & Davis, 2004). This information helps managers understand who could be affected if a tsunami occurs and in turn helps planners target populations for further educational outreach and evacuation strategies.

Residents

Evacuation Playbook Phase 1 recommends evacuating beaches, harbor docks, and piers, and unlike the other three phases is not defined with spatial polygon data (Figure 2). Phase 1 is confined to Alameda Island since there are no beaches, harbor docks, or piers around Bay Farm Island except for 1 ferry terminal dock for which data were unavailable. While it is possible to live aboard boats docked around Alameda Island, the census does not report dock residences. Therefore, manual tabulation was conducted using the most recent Google Earth imagery, which approximated 3,240 (Table 1) small boat docks present in 8 marinas, and private dock facilities (meaning not those intended for larger military, shipping, or coast guard vessels) were found on Alameda Island shorelines. The City of Alameda Planning and Building Department (2014) states that 10% of a marina's docks may be permitted as live aboard, equating to 337 docks (including 41 house boats). Private docks (Table 1) might also support live aboard residences. In a personal communication with Alameda Marina Harbor Master, B. de Lappe (2014), he described receiving many live aboard permit requests each day, which he attributes to high rent costs characteristic of the Bay Area. Many marinas allow temporary overnight stays on vessels that have overnight permits but do not keep accurate counts.

Table 1.

Alameda Island boat dock and live aboard estimates, by marina.

Marina	Liveaboard Permits*	Dock count
Aeolian Marina	8	85
Alameda Marina	53	530
Ballena Isle Marina	50	500
Barnhill Marina	41	61
Fortman Marina	49	497
Grand Avenue Marina	37	367
Marina Village	95	953
Mariner Square	4	38
Private Docks	n/a	209
Total	337	3240

*potential liveaboard permits, unverified

The four Evacuation Playbook Phases contain approximately 43,385 residents, nearly 59 percent of the total City of Alameda population. Approximately 204 residents live within Phase 2 on Alameda Island, but no residents live inside Phase 2 on Bay Farm Island (Figure 4 A). Phase 3 adds approximately 18,332 Alameda Island residents (18,536 total) and contains 11,511 Bay Farm Island residents, totaling 30,047 residents in Phase 3 (Figure 4 A). Phase 3 contains 31% of Alameda Island residents and 85% for Bay Farm Island residents, or 41% of the City's total population (Figure 4 B). If evacuation needs reach the Maximum Phase, approximately 2,089 additional Bay Farm Island residents (13,600 total), meaning 100% of the island's population will need to reach safety. The Maximum Phase on Alameda Island includes an additional 11,248 residents (29,785 total), equaling 50% of that island's population (Figure 4).

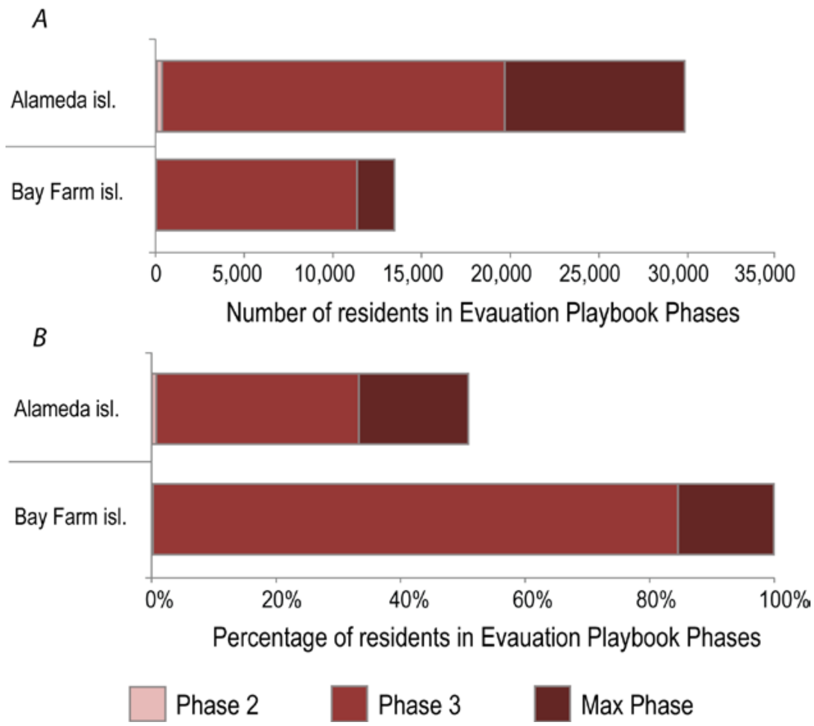

Figure 4. Cumulative number (A) and percentage (B) of residents by Evacuation Playbook Phase and island.

Demographic factors, such as age, ethnicity, and tenancy, can amplify an individual's sensitivity to hazards (Wood 2013a, 2013b). Therefore, in addition to general population tallies, resident counts in tsunami-prone areas were tabulated according to ethnicity (Hispanic or Latino), race (American Indian and Alaska Native, Asian, Black or African American, Native Hawaiian and other Pacific Islander, and White—either individually or in combination with one or more other races), age (individuals less than 5 and more than 65 years in age), gender with particular family structures (female-headed households with children under 18 years of age and no spouse present), and tenancy (renter-occupied households). Block-level demographic data for residential populations in all Alameda Evacuation Playbook Phases are based on the 2010 U.S. Census Bureau.

Demographic sensitivity categories are not based on former studies of residents in California tsunami-inundation zones, but instead on past social-science research pertaining to all disaster types (earthquakes, tornadoes, and hurricanes). It is not implied that all individuals of any certain group will behave identically. The extent to these demographic sensitivities will vary by local physical and social contexts, level of preparedness before a tsunami, and ability to respond during a tsunami.

Figure 5 shows resident composition by race and ethnicity in each Evacuation Playbook Phase, relative to race percentages for the City of Alameda. The percentage of individuals who identify as White is higher on Alameda Island in Phase 2, 66% when compared to 56% across the entire city (Figure 5). Alameda Island residents who reported White as their race in Phase 3 and those within the Maximum Phase are within 1% of the city's 56%, but are lower on Bay Farm Island, 50% in Phase 3, and 54% in the Maximum Phase (Figure 5). Percentages of residents who reported their race as Asian vary more than any other race across the three evacuation phases and two islands. On Alameda Island, percentages of residents who identify as Asians are lower than in the city (36%) in all phases (14% in Phase 2, 32% in Phase 3, and 33% in the Maximum Phase), whereas on Bay Farm Island they are higher (48% in both Phase 3 and the Maximum Phase) (Figure 5). Percentages of residents who identify as Hispanic on Bay Farm Island are slightly lower in all evacuation phases (7%) compared to the city (11%), whereas on Alameda Island they only deviate from the city's by about 1% in all phases except Phase 2 (15%). Percentages of residents who reported their race as African American are higher in all phases on Alameda Island (18% in Phases 2, 12% in Phase 3, and 11% in the Maximum Phase) compared to 8% for the entire city, but slightly lower on Bay Farm Island (4% in both Phase 3 and the Maximum Phase). Percentages of residents who report their race as "Some other race," are slightly lower than the city (5%) on Bay Farm Island (2% in all phases) but the same on Alameda Island (Figure 5). Percentages for residents who identify as both American Indians or Alaskan Natives and Native Hawaiians or other Pacific Islanders are very low and closely match city percentages.

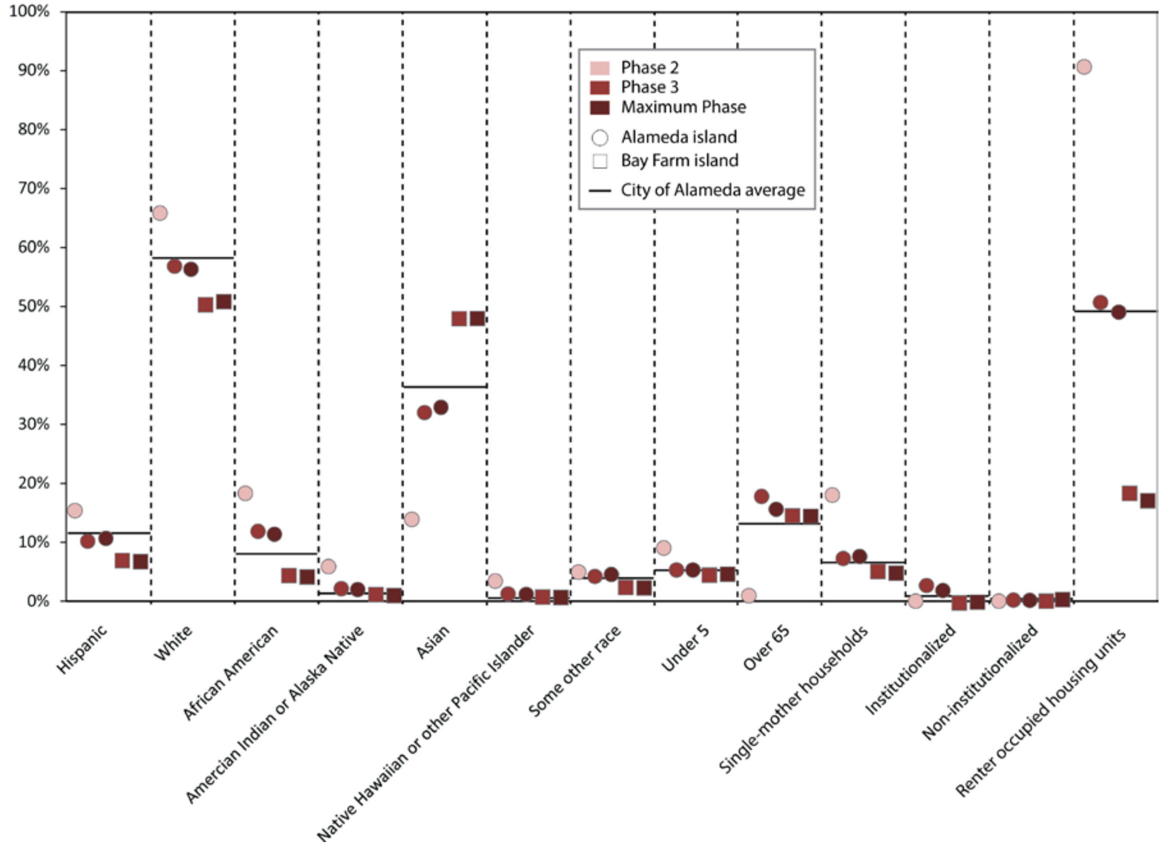

Figure 5. Demographic percentages for all residents within Evacuation Playbook Phases, by island.

People under 5 and over 65 years of age are considered to be more vulnerable than other age groups, particularly to tsunamis because of potential mobility and health issues (Morrow, 1999; Balaban, 2006; McGuire, Ford & Okoro, 2007; Ngo, 2003). Individuals younger than 5 years in age are considered to have heightened vulnerability because they often require guidance and assistance to evacuate due to immaturity and size. They are also prone to developing post-traumatic stress disorders, depressions, anxieties, and behavioral disorders as a result of their inability to comprehend and process disaster effects (Balaban, 2006). Individuals less than 5 years in age represent 6% (2,596) of all residents in all the Evacuation Playbook Phases, which is 1% more than the city average (Figure 5). While percentages for each phase on both islands closely match the city average, over half of the city's total population under age 5 (4,182) resides within all three phases.

Individuals older than 65 years are considered also to have heightened vulnerability due to potential mobility and health issues, reluctance to evacuate, the need for special medical equipment at shelters (McGuire et al., 2007), and the lack of social and economic resources to recover (Morrow, 1999; Ngo, 2003). Specific to tsunamis, older individuals are considered more sensitive than other demographic groups because of possible health and mobility issues related to the short evacuation time before tsunami inundation from local tsunami threats. In addition, if a tsunami were to occur during winter months, open-air emergency shelters may not adequately protect older individuals from low air temperatures and high precipitation (characteristic of northern California's Mediterranean climate), thereby creating additional health complications. Individuals older than 65 years represent 15% (6,611 residents) of all residents in all the Evacuation Playbook Phases (Figure 5). As was the case for individuals under 5 years in age, the percentages of at-risk individuals over 65 years in age in all the phases on all islands closely match the city's average (Figure 5). However, Phase 3 on Alameda Island contains almost half (3,196) of the city's total individuals over 65. Targeted education, evacuation training, and relief plans may be needed in phases with large older populations.

Female heads of households with children under the age of 18 having no spouse present (colloquially, single-mother headed households) may also be more vulnerable to extreme events. This definition is not meant to say that all households with unmarried mothers are without added assistance (for example, they may have a live-in life partner or family member to help during evacuation) but the census data does not address these demographic subtleties. Seven percent of households in all of the Evacuation Playbook Phases are considered single-mother households (Figure 5), which may be more likely to have limited mobility during an evacuation from a sudden-onset hazard and fewer financial resources to draw on to prepare for natural hazards or recover from a disaster (Enarson & Morrow, 1998; Laska & Morrow, 2007). Phase 2 on Alameda Island is the only phase that contains a higher percentage than city average, 18%, which represents 13 out of the 71 single-mother households (Figure 5).

Renters are also considered more vulnerable to and less prepared for extreme events (Morrow, 1999; Burby, Steinberg & Basolo, 2003). This heightened vulnerability may be due to (1) higher turnover rates limiting exposure to outreach efforts, (2) preparedness campaigns might pay less attention to renters, (3) renters typically have lower incomes and fewer resources to recover, and (4) renters may be less motivated to invest in mitigation measures for rented property (Burby et al., 2003). After a disaster renters have little control over the speed with which rental housing is repaired or replaced (Laska and Morrow, 2007). Forty percent of households in all Evacuation Playbook Phases are renter-occupied. Alameda Island has a higher percentage of renter occupied homes in Phase 2 (91%) than the city average (49%), but Phase 3 and the Maximum Phase percentages are the same as the city's (Figure 5). Whereas on Bay Farm Island

Phase 3 and the Maximum Phase contain 19% and 18% renter occupied homes, respectively, considerably lower than the city average (Figure 5).

Group quarter residents will also require special attention before and during a tsunami. This classification includes either institutionalized (for example, adult correctional, juvenile, and nursing facilities) or noninstitutionalized (for example, college/university student housing and military quarters). One percent of residents in all Evacuation Playbook Phases are living in institutionalized group quarters, which is comparable to the city average. Phase 3 and the Maximum Phase on Alameda Island contain 3% and 2%, respectively, of institutionalized group quarters residents (Figure 5). While these percentages only slightly deviate from the city average, they represent 565 residents in Phase 3 and an additional 64 residents (629 total) in the Maximum Phase who reside in 1 of 9 live-in care facilities on Alameda Island. Bay Farm Island estimates show no residents living in institutionalized group quarters but there is 1 live-in care facility within the Maximum Phase whose residents must not be accounted for in the most recent census data.

Residents living in noninstitutionalized group quarters within all Evacuation Playbook Phases, on either island, are less than 1%, which is consistent with the city average (Figure 5). Noninstitutionalized group quarter residents are affiliated with either the decommissioned Naval Air Station on Alameda Island or with Coast Guard Island. Several requests have been made to obtain accurate residential populations at these locations, but to date remain unavailable.

Employees

Employees can present challenges during an evacuation because they may be unaware of tsunami hazards or proper evacuation strategies, especially if they do not live in tsunami-prone areas. They also may rely on business owners for information if they lack social connections to the community. An estimated 13,708 employees at 1,036 businesses representing 67% and 44% of employees and businesses in the City of Alameda, respectfully, are within all the Evacuation Playbook Phases on either island. These estimates were calculated by overlaying the Evacuation Playbook Phases and the 2011 Infogroup Employer Database (Infogroup, 2011). Time and resource limitations made field-verification of each business location unrealistic for this project; therefore, employee and business counts are approximations. Observations of Google Maps and 1 m 2010 National Agriculture Imagery Program imagery (Cal-Atlas Geospatial Clearinghouse, 2013) helped verify and correct business locations in the Evacuation Playbook Phases.

Approximately 350 employees work within Phase 2 on Alameda Island but no employees were work in Phase 2 on Bay Farm Island (Figure 6 A). Calling a Phase 3 evacuation on Alameda Island adds approximately 6,943 employees (7,293 total), which equates to 47% of the total work force on Alameda Island (Figure 6). On Bay Farm Island there are 4,752 employees estimated to work in Phase 3 which equates to 99% of the island's total work force (Figure 6). The Maximum Phase on Alameda Island is estimated to contain an additional 1,634 (8,927 total) which equals 57% of that island's workers (Figure 6). If evacuation needs reach the Maximum Phase, an additional estimated 29 Bay Farm Island employees (4,781 total) could be affected, meaning 100% of Bay Farm Island's work force will need to reach safety (Figure 6).

Figure 6. Cumulative number (A) and percentage (B) of employees by Evacuation Playbook Phase and island.

Businesses Sectors

North American Industry Classification System (NAICS) codes (U.S. Census Bureau, 2014; see appendix A of Wood, 2007, for codes) were used to identify the primary business sectors and categorize the businesses in the Infogroup USA data. This categorization helps recognize locations that could draw more people into the Evacuation Playbook Phases or facilities that house potentially vulnerable populations. The business sectors include community support, critical facilities, dependent-care facilities and pubic venues.

Community Support. Community support businesses attract people throughout the day because they provide essential necessities. Facilities affiliated with these daily necessities found within the Alameda Evacuation Playbook Phases are:

- *Banks and credit unions*
- *Civil and social organizations*
- *Government offices*, such as courts and international affairs offices
- *Libraries*
- *Markets*
- *Religious organizations*
- *Retail*, such as clothing stores and car dealers
- *General services*, such as auto repair shops and beauty salons
- *Shipping*, such as freight trucking and freight transportation arrangement.

Phase 2 on Alameda Island contains 22 community support businesses, whereas none are found within Phase 2 on Bay Farm Island. Phase 3 on Alameda Island adds the most community support businesses, 209 (231 total, 62% of which are retail), whereas Phase 3 on Bay Farm Island contains 63 community support businesses (Figure 7). Calling a Maximum Phase evacuation on Alameda Island adds 50 community support businesses (281 total) but no additional community support businesses were found on Bay Farm Island in this phase (Figure 7). Most community support businesses in all the Evacuation Playbook Phases on either island are affiliated with the retail and general services industries. The 6 religious organizations in Phase 3 on Bay Farm Island present outreach and education opportunities for Alameda emergency managers to work with religious leaders in disseminating tsunami-hazard education materials or potentially coordinating tsunami education workshops (Figure 7). However, there are no religious organizations within any Evacuation Playbook Phase on Alameda Island.

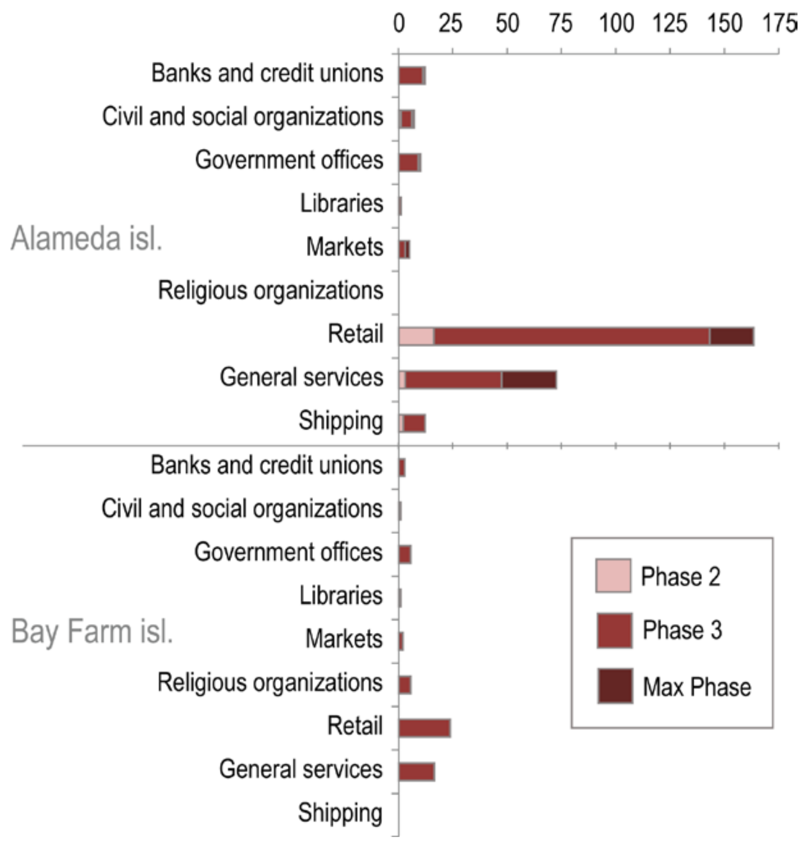

Figure 7. Cumulative numbers of community support businesses by Evacuation Playbook Phase and island.

Critical Facilities. Certain facilities are important for short-term emergency response and long-term community recovery following a tsunami. For the purposes of this study, critical facilities are those considered important for short-term response operations. This list is not meant to be a complete inventory of all facilities that will be important immediately after a tsunami occurs, but estimates of certain facilities for further discussions with the City of Alameda. Critical facilities found within the Alameda Evacuation Playbook Phases are:

- *Fire Stations*
- *National security facilities,* including military recruiting offices, Military bases
- *Electrical facilities*
- *Airline companies.*

Neither island has critical facilities located in Phase 2 (Figure 8). However, Phase 3 contains the most critical facilities on both islands, 1 fire station, 4 national security related facilities and 1 electric company on Alameda Island and 1 airline company on Bay Farm Island (Figure 8). The Maximum Phase on Alameda Island contains 2 additional National security facilities (6 total) but no additional critical facilities were found on Bay Farm Island. Providing locations of critical facilities is prohibited by the Infogroup Employer Database terms of use, so maps of critical facilities in relation to the Alameda Evacuation Playbook Phases are unavailable (Figure 8).

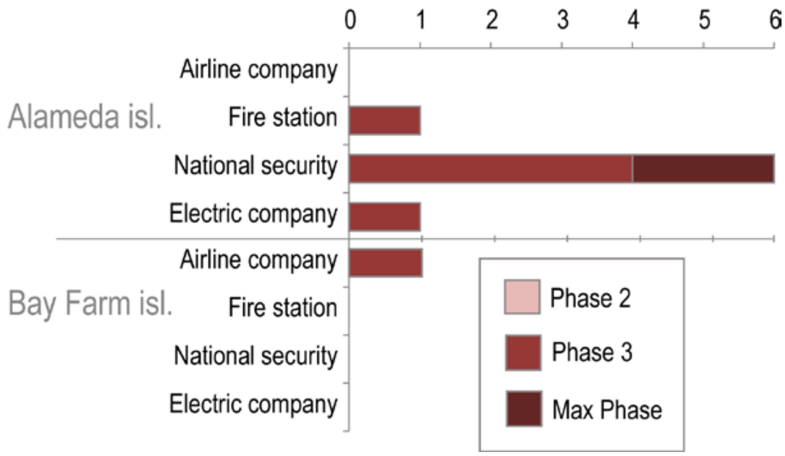

Figure 8. Cumulative numbers of critical facilities by Evacuation Playbook Phase and island.

Dependent Populations. For the purposes of this study, dependent populations are defined here as individuals who reside at facilities where they would depend on assistance to evacuate and recover. Facilities with dependent populations found within the Alameda Evacuation Playbook Phases are:

- *Adult-assistance services*, such as assisted living facilities for the elderly, continuing care retirement communities, and skilled nursing care facilities
- *Child services*, such as child day care services and child and youth services
- *Medical and health services*, such as family planning centers, offices of dentists, offices of physicians, and psychiatric and substance abuse hospitals
- *Medical centers*
- *Schools*.

Two child services facilities and 1 medical and health service facility were found in Phase 2 on Alameda Island, but on Bay Farm Island no dependent-care facilities were found in Phase 2 (Figure 9). Phase 3 contains the highest number of additional dependent-care facilities (116) (119 total). These dependent care facilities include 7 adult-assistance facilities, 1 additional child services facility (3 total), 79 additional medical and health facilities (80 total) and 6 schools found on Alameda Island; and on Bay Farm Island 1 adult-assistance facility, 5 child services facilities, 14 medical and health services and 3 schools found in Phase 3 (Figure 9). The Maximum Phase on Alameda Island contains 1 additional adult-assistance service facility (8 total), 3 additional child services facilities (6 total), 45 additional medical and health services facilities (125 total), and 4 additional schools (10 total). On Bay Farm Island the Maximum Phase contains 1 additional child service facility (6 total) and 1 additional school (4 total) (Figure 9). The only medical center in the City of Alameda, Alameda Hospital, is located within the Maximum Phase on Alameda Island.

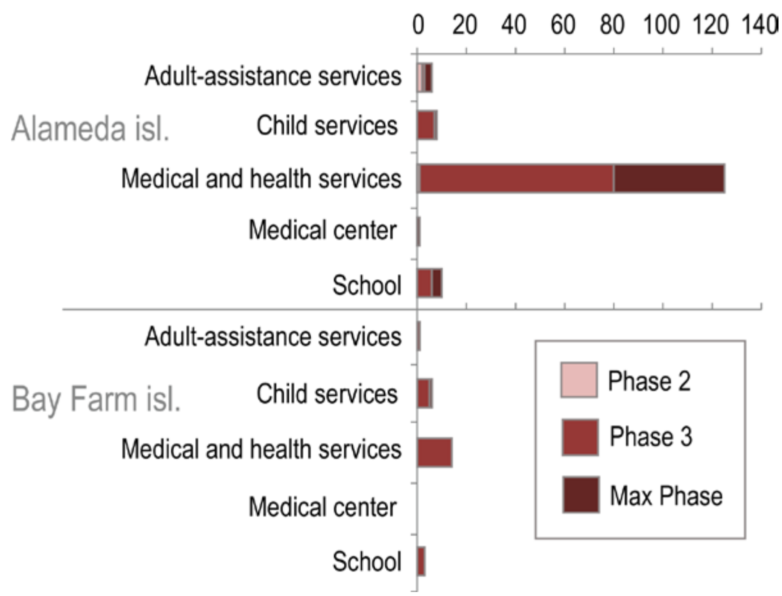

Figure 9. Cumulative numbers of dependent-care facilities by Evacuation Playbook Phase and island.

Public Venues. Identifying public venues provides some insight on where numbers of people, both local residents and people who live outside Alameda, may gather during the day. People who do not reside in tsunami-prone areas may have evacuation issues if a tsunami occurs due to potential lack of awareness and understanding of tsunami evacuation practices. Although I cannot determine how many people visit these sites at a given time, knowing where public venues are provides emergency managers with some insight on concentrations of community vulnerability. The following public venue facilities are estimated to be in the Alameda Evacuation Playbook Phases:

- *Colleges*, including colleges, universities, professional schools, and junior colleges
- *Entertainment*, including bowling centers, fitness and recreational sports centers, golf courses and country clubs, marinas, museums, nature parks, and theaters
- *Overnight accommodations*, including hotels and motels, bed and breakfasts, and room/board houses.

Numbers of public venues in Phase 2 are low with only 4 entertainment businesses on Alameda Island and no public venues on Bay Farm Island (Figure 10). Phase 3 contains the highest number of additional public venues (30) (34 total). These public venues include 18 (22 total) entertainment businesses and 4 overnight accommodation businesses on Alameda Island, and on Bay Farm Island 6 entertainment businesses and 2 overnight accommodation businesses (Figure 10). The Maximum Phase on Alameda Island contains 3 colleges and 5 additional entertainment businesses (27 total). There are no additional public venues in the Maximum Phase on Bay Farm Island (Figure 10).

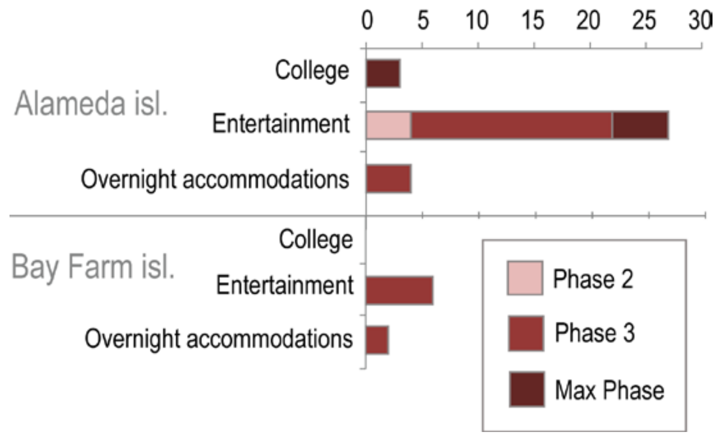

Figure 10. Cumulative numbers of public venues by Evacuation Playbook Phase and island.

The largest public venue is the Robert W. Crown Memorial State Beach the only beach in the City of Alameda and needs to be evacuated for any phase. According to ongoing visitor attendance research conducted by the East Bay Regional Park District, average yearly attendance between 2004 and 2013 was approximately 484,223 people (D. Cuoco, personal communication, November 20, 2014). Dividing yearly average by 365 presents potential daily beach attendance, equaling about 1,327 people. However, this does not consider visitor traffic fluctuations during summer months, on weekends, or holidays and special events.

Dwight, Brinks, Sharavana Kumar and Semenza (2007) studied annual beach-attendance variability at 75 southern California beaches. Their work suggests as much as 53% of all visits occur during summer months (June, July and August), and 48% of all visits occur on weekends. After applying Dwight et al. (2007) month and day-of-week weights the day with fewest beach visitors was determined to be a Tuesday in February, and conversely the highest visitorship would be a Saturday in July, with 288 and 6,514 visitors respectively. Calculations also resulted in an average 1,311 estimated daily visitors throughout the year. While it may seem unreasonable to apply beach visitor methods developed for southern California to a beach in the San Francisco Bay, this is the only research on its kind. Further limitations include beach visitors may have been double counted and whether or not counts include the large waterfront park area that connects to the State Beach remains unclear. Alameda emergency managers are aware of these limitations and approved this analysis in order to give context for month and day-of-week beach visitor fluctuations.

Pedestrian Evacuation

After characterizing the tsunami exposure for the City of Alameda's population and work force, an evacuation analysis was needed to estimate the potential amount time these populations may need to travel to high ground outside of each Evacuation Playbook Phase. There are essentially two modes of transportation a person could use to evacuate, by foot or by vehicle. The City of Alameda requested an analysis for both modes of transport but modeling vehicle evacuation can be quite challenging and does not fit within the scope of this project. All travel time estimates presented below assume a travel speed of 1.22 m per second (4 ft per second).

Marinas

In order to assess pedestrian travel times to safety for populations that may be in Evacuation Playbook Phases at marinas, the maximum travel time calculated on docks furthest from high ground for each marina was extracted. This estimate will not give a precise travel time for a specific live aboard resident in a given marina but will help recognize extreme travel times affiliated with a given marina. Since no Evacuation Phase boundary shapefiles were produced for Phase 1, Evacuation Playbook descriptions for expected inundation elevations for each Phases 1 and 2 were compared. Phase 1 is affiliated with inundation of land with elevation less than 1.0 m (3.3 ft), whereas Phase 2 is affiliated with inundation of land with elevations between 1.0 m (3.3 ft) and 1.5 m (5.0 ft). Therefore, using maximum travel time estimates for marinas at Phase 2 in Table 2 should be fairly representative of expected travel times for Phase 1 as well.

Table 2 shows for Phase 2, marinas are expected to experience an average maximum travel time of 4 min, the highest of which is 6 min for Grand Avenue Marina. For a Phase 3 marina evacuation, the average estimated maximum travel time is 13 min, the lowest being Alameda Marina with 5 min and the highest being Marina Village and Ballena Isle Marina with 18 min. The Maximum Evacuation Playbook Phase represents the farthest distance someone evacuating from a dock would have to travel. The average maximum travel time at marinas for the Maximum Phase is about 18 min, the lowest is Alameda Marina (7 min), and the highest is Mariner Square (30 min) (Table 2).

Table 2.

Approximate maximum estimated pedestrian travel times, by marina and Evacuation Playbook Phase.

	Maximum Travel Times (min.)		
Marina	**Phase 2**	**Phase 3**	**Max Phase**
Aeolian Marina	4	12	12
Alameda Marina	4	5	7
Ballena Isle Marina	4	**18**	18
Barnhill Marina	3	12	28
Fortman Marina	3	13	13
Grand Avenue Marina	**6**	12	13
Marina Village	4	**18**	25
Mariner Square	4	14	**30**
Average time	4	13	18.25

Phase 2

Within Evacuation Playbook Phase 2, no homes or businesses are located where the highest estimated travel times occur (about 17 min and above), for example, the jetty protecting the aircraft carrier docks (Figure 11). Eleven min travel of time is expected to evacuate from the end of the Alameda Ferry dock (Figure 11). All the 204 residents and 350 employees estimated within Phase 2 on Alameda Island are likely to need 1-14 min to travel high ground or safety (Figures 11 and 12).

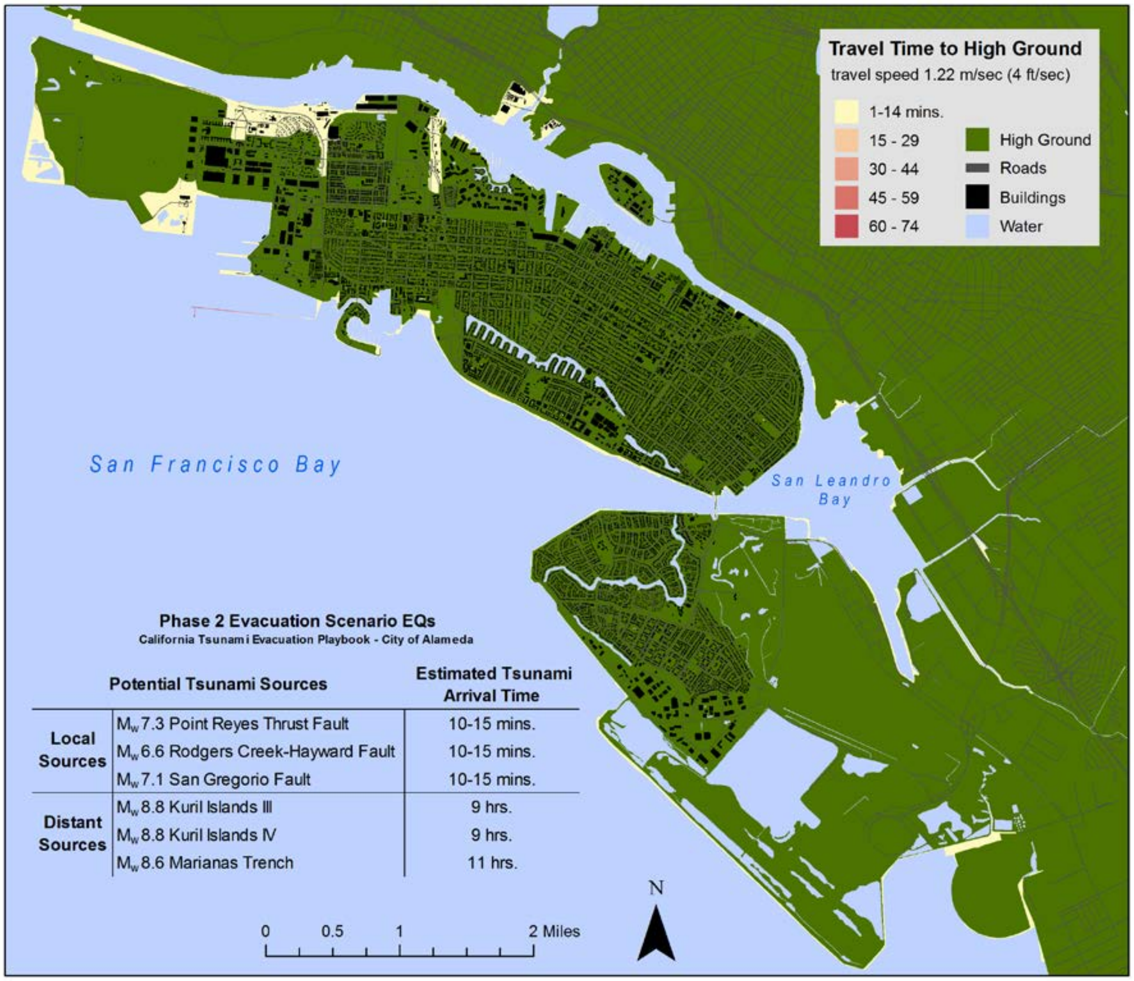

Figure 11. Evacuation Playbook Phase 2 pedestrian travel times to reach high ground and affiliated potential tsunami source earthquakes.

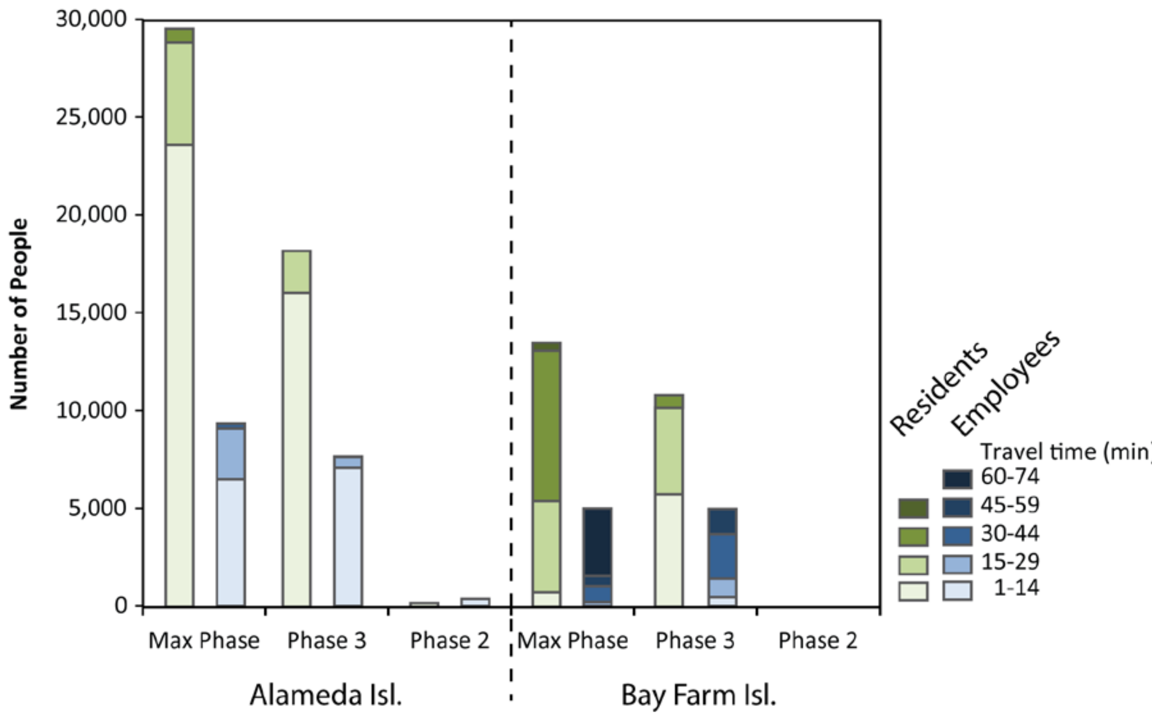

Figure 12. Cumulative resident and employee numbers and travel times (min) to safety, by Evacuation Playbook Phase and island.

Phase 3

The highest estimated travel times found on Alameda Island within Evacuation Playbook Phase 3 are neither in areas where people live nor work (Figure 13). In areas where people are more likely to be, travel times to safety (30-44 min) include an estimated 10 employees on Alameda NAS. Approximately 2,146 residents and 539 employees were found in areas where they may need 15-29 min to reach safety at high ground (Figure 12). The highest number of residents (16,187) and employees (6,744) are estimated to live and work where the lowest travel times (1-14 min) are found in Phase 3 on Alameda Island (Figure 12).

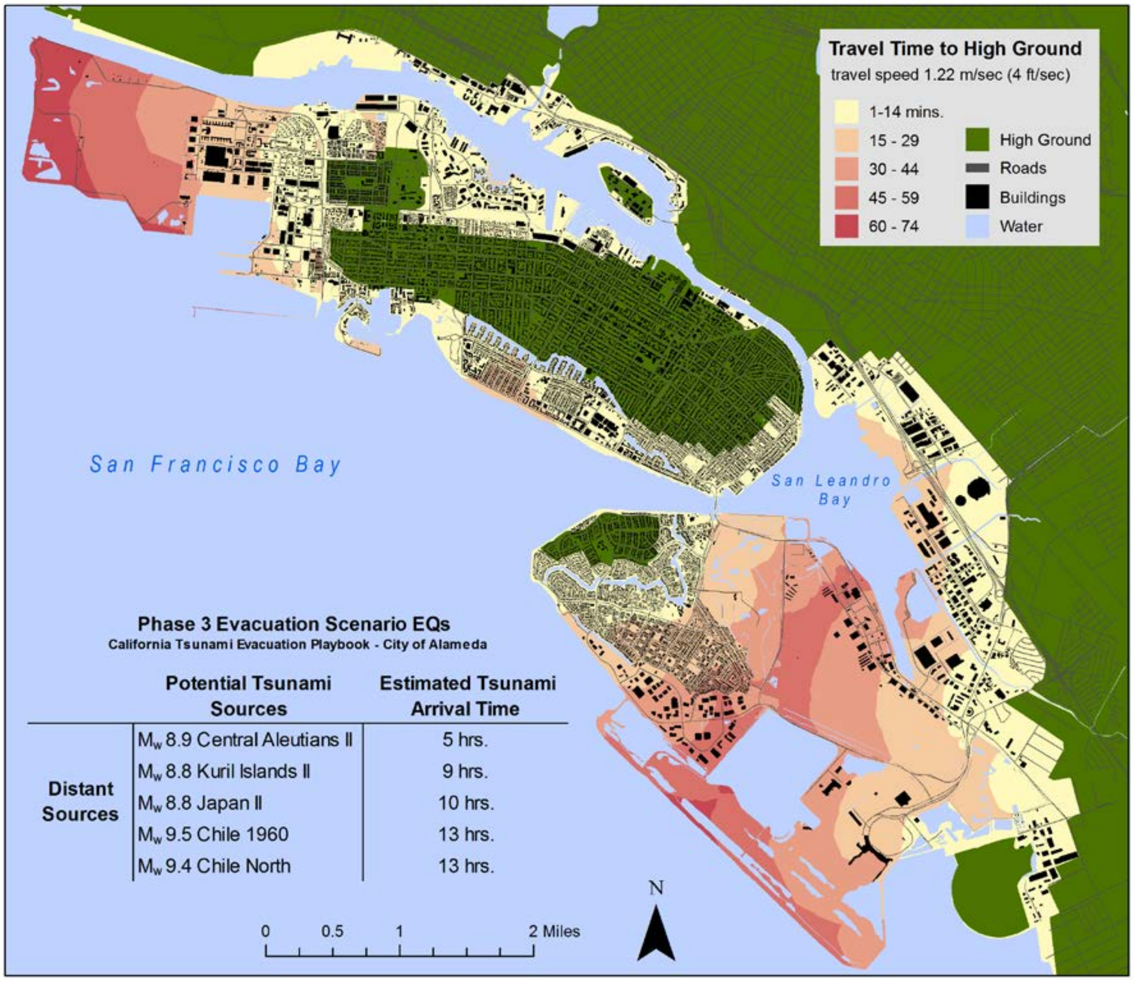

Figure 13. Evacuation Playbook Phase 3 pedestrian travel times to reach high ground and affiliated potential tsunami source earthquakes.

Similar to Alameda Island, the highest travel times to safety found in Phase 3 on Bay Farm Island were along the southern runway of Oakland Airport where people do not live or work (Figure 13). An estimated 1,234 employees work but no residents live where travel times to high ground of 45-59 min were found on Bay Farm Island (Figure 12). Areas on Bay Farm Island where travel times to safety were estimated at 30-44 min are where 2,168 employees work and 1,265 residents live (Figure 12). Places where evacuees will likely need 15-29 min to travel to high ground are in areas where 4,428 residents and 905 employees work and live (Figure 12). The highest number of residents (5,818) and lowest number of employees (445) were estimated to live and work where the lowest estimated travel times (1-14 min) were found on Bay Farm Island (Figure 12).

Most facilities in Phase 3 on Alameda Island relate to community support and dependent-care, the majority of which are estimated to need about 1-14 min to travel to safety (Figure 14). However, 7 of these dependent-care facilities are affiliated with adult-assistance services and likely have residents who could require assistance evacuating and might need medical equipment and medication (Wood et al. 2013a). The estimated 34 total businesses and facilities located where travel times to safety are expected to be 15-29 min are related to retail. The 3 facilities located where 30-44 min may be needed to reach high ground relate to community support (Figure 14).

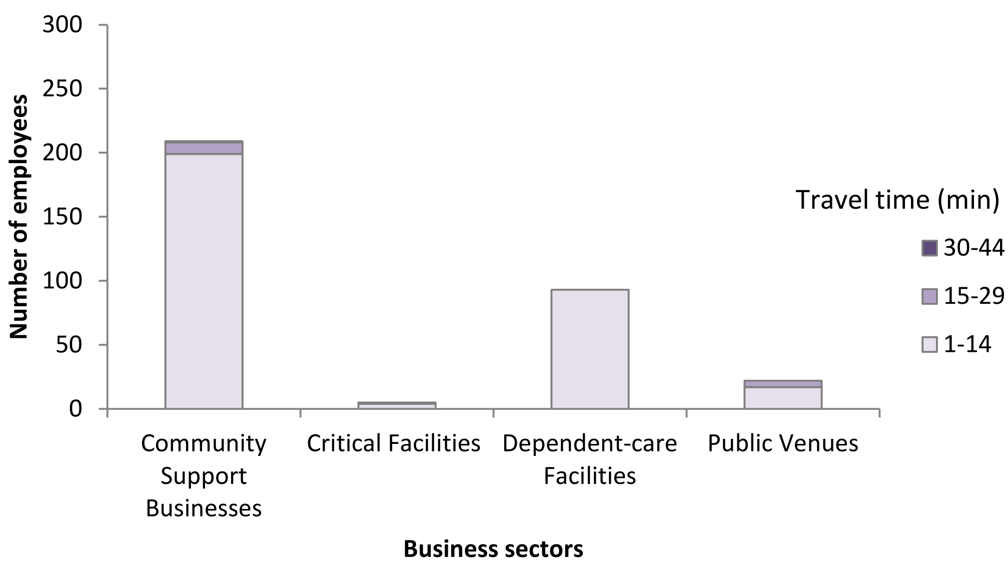

Figure 14. Estimated travel times to safety for Evacuation Playbook Phase 3 on Alameda Island by business sector.

Similar to Alameda Island, most of the businesses in Phase 3 on Bay Farm Island are community support and dependent-care, none of which are adult-assistance facilities (Figure 15). The majority of these businesses are located in areas where the travel times are estimated to be either 15-29 min or 30-44 min (Figure 15). Areas estimated to need the highest travel times (45-59 min) for Phase 3 on Bay Farm Island coincide with 5 community support businesses, 2 dependent-care facilities, and 1 public venue are located (Figure 15). The 1 critical facility (related to an airline service) on Bay Farm Island is located where travel times are estimated between 30 and 44 min (Figure 15).

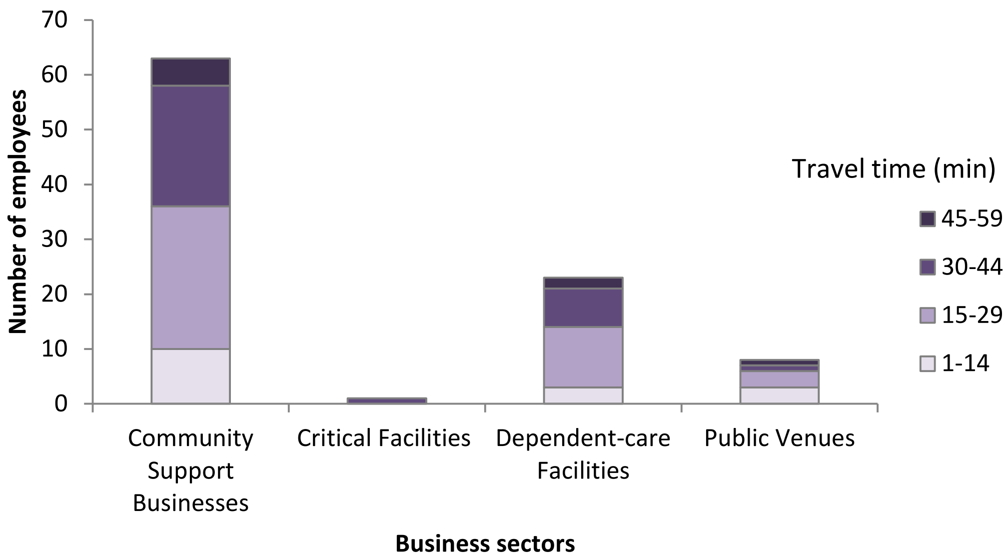

Figure 15. Estimated travel times to safety for Evacuation Playbook Phase 3 on Bay Farm Island, by business sector.

Maximum Phase

Similar to other Evacuation Playbook Phases on Alameda Island, the highest estimated travel times are found in areas where no one resides or works (for example, the Alameda NAS runway outer edges) (Figure 16). Areas within the Maximum Phase where 30-44 min of travel times to safety were found include approximately 726 residents and 241 employees (Figure 12). Places where people will likely need about 15-29 min to reach high ground are in areas where about 5,267 residents live and 2,470 employees work (Figure 12). The areas where the lowest travel times to safety were estimated (1-14 min) within the Maximum Phase on Alameda Island are also where the highest numbers of residents live and employees work, 23,792 and 6,216, respectively (Figure 12).

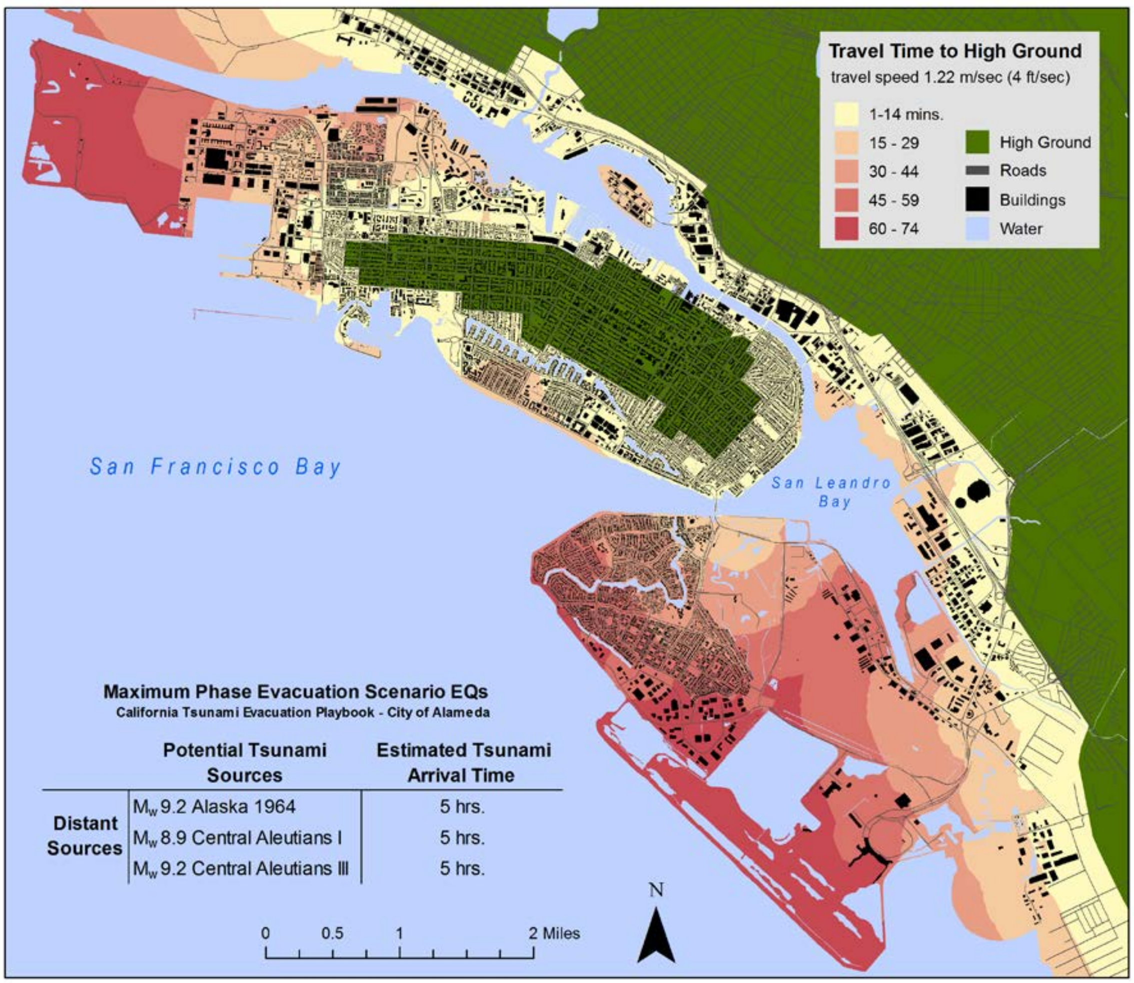

Figure 16. Evacuation Playbook Maximum Phase pedestrian travel times to reach high ground and affiliated potential tsunami source earthquakes.

As was the case with Phase 3, the majority of businesses in the Maximum Phase on Alameda Island relate to community support (likely retail) and dependent-care (Figure 16). In the Maximum Phase 219 estimated community support businesses are located where approximately 1-14 min of evacuation time is needed and 56 are located where it could take evacuees 15-29 min to travel to safety (Figure 17). An estimated 138 dependent-care facilities are in areas where expected travel time to safety is approximately 1-14 min and 12 are where travel times are estimated at 15-29 min (that includes 1 additional adult-assistance facility) (Figure 17). There is 1 critical facility, a fire station, located in an area where 30-44 min of evacuation time is estimated (Figure 17).

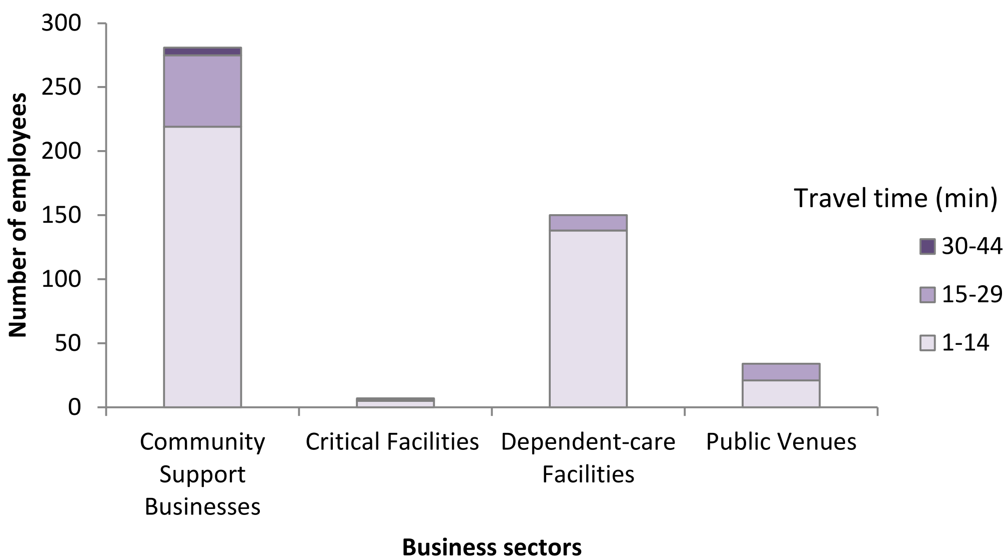

Figure 17. Estimated travel times to safety for Evacuation Playbook Maximum Phase on Alameda Island by business sector.

The Maximum Phase on Bay Farm Island is different than the other phases on either island in that areas with highest estimated travel times to safety (60-74 min) contain the majority of employees (3,311) but no residents (Figure 12). Locations where evacuees will likely need 45-59 min to reach high ground are in areas where 410 residents and 503 employees live and work (Figure 12). Areas of Bay Farm Island where travel time estimates to safety were between 30 and 44 min are where the majority of residents live (7,755) but far fewer employees work (754) (Figure 12). Areas where travel times estimated at 15-29 min are where 4,702 residents live and 213 employees work (Figure 12). Approximately 732 Bay Farm Island residents live but no employees work in areas where the lowest travel times were estimated (1-14 min) (Figure 12).

Only 2 facilities are added when transitioning from Phase 3 to the Maximum Phase on Bay Farm Island, therefore, travel time estimates at all other business and facility locations increase. The additional facilities are affiliated with an elementary school and are located in an area where travel time to safety is estimated at 30-44 min. Travel time to safety for the 1 critical facility (an airline related business) on Bay Farm Island increases to 60-74 min for the Maximum Phase (Figure 18).

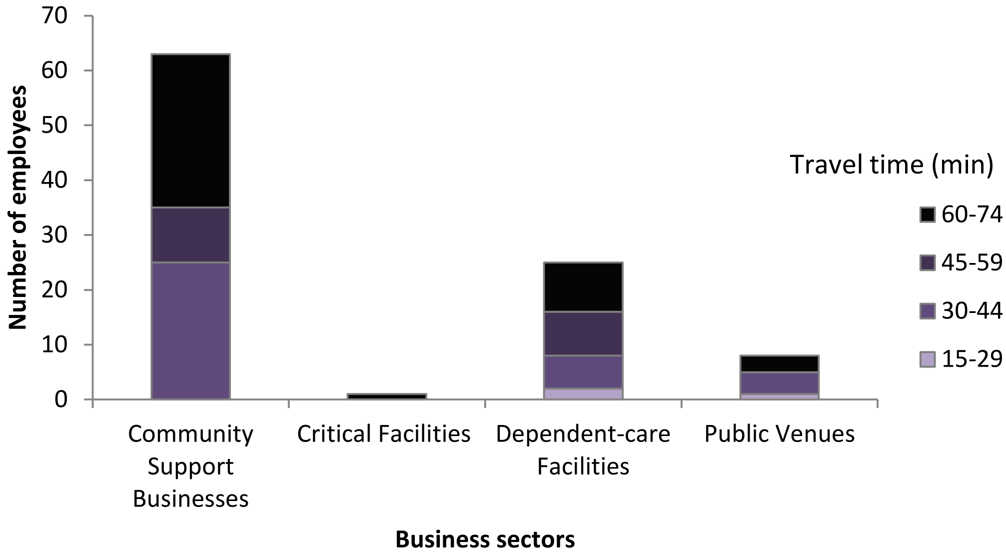

Figure 18. Estimated travel times to safety for Evacuation Playbook Phase 3 on Bay Farm Island by business sector.

Discussion

Based on evaluating the exposure and evacuation analyses, it is apparent that the two main islands that make up the City of Alameda have different situations regarding the Evacuation Playbook Phases. The discussion below is sectioned by island with subsections by evacuation phase. As mentioned before, Phase 1 and Phase 2 only affect Alameda Island and therefore are not included in the Bay Farm Island discussion. While the results and discussion are presented separately for each island, the City of Alameda emergency managers will have to decide whether to divide their resources to address the differences or not.

Alameda Island

Marinas and Beach. Evacuation of beaches, harbor docks and piers for Phase 1 offers several challenges. A Phase 1 evacuation is the most likely to occur; therefore emergency planning for Phase 1 may be considered highest priority. The sheer number of boats (potentially over 3,000) docked around Alameda Island will likely cause waterfronts to be busy during a tsunami event, as boat owners may rush to secure their vessels or to evacuate the area. Short reaction times and efficient evacuation off docks will be especially critical if a local source tsunami occurs. Estimated maximum travel times at marinas (between 3 and 6 min, Table 2) allow only a few min of preparation when compared to expected wave arrival times from modeled local earthquake sources (between 10 and 15 min). Furthermore, if a nearby earthquake occurs, people at docks may not want to practice drop, cover and hold-on (commonly advised during earthquakes) because the earthquake could indicate a potential tsunami arriving within a short time after the shaking, and remaining idle on docks could result in loss of life (Wood, Schmidtlein, & Peters, 2014; Wood & Peters, 2014). Emergency training for marina staff may be justified in order to minimize loss of life. Playbook authors at CGS are aware of evacuation challenges at harbors and are currently developing evacuation playbooks specifically for maritime communities that can be implemented separate from or in combination with the Evacuation Playbook Phases (Wilson & Miller, 2014).

Like the marinas, the 2.5 mi long public beach and park (Robert W. Crown Memorial State Beach) on Alameda Island may be busy during a tsunami, especially if it occurs on a weekend during the summer. Estimates show large numbers of people visit the beach regularly but there are no lifeguards on duty any time of year (East Bay Regional Park District, 2014). Evacuation of these areas could be challenging without adequately trained emergency staff, especially on peak visiting days, such as holidays or weekends during the summer. Beaches also typically have visitors from other cities who are likely unfamiliar with tsunami evacuation practices. Additional signage and information guiding beach visitors to evacuation routes and safe zones may be warranted.

Phase 2. Phase 2 contains relatively low numbers and percentages of residents on Alameda Island only. In most cases, proportions of ethnic groups are slightly higher than the city average in Phase 2. However, Phase 2 includes a high percentage of renters (91%) and single-mother-headed households (18%), who are populations that can face challenges when evacuating. Renters are likely to have minimal instruction on evacuations, possibly due to high turnover or because outreach efforts may target homeowners. Single-mothers can be challenged when evacuating because they will may have to guide their children to safety without assistance. Targeting these populations with tsunami outreach and evacuation education is reasonable.

Numbers and percentages of employees within Phase 2 are higher than residents on Alameda Island. Outreach and education for evacuation practices in Phase 2 may need to target management at major employers in the area, as they are likely to be responsible for training their employees. The business sector with the most facilities in Phase 2 is community support most of which are retail or community support. Employees and patrons at community support facilities would be more likely to be impacted if a tsunami were to occur during typical business hours (from about 8 a.m. to 6 p.m.). In addition, patrons at these facilities may be unaware of tsunami threats specific to that location and therefore not fully aware of evacuation procedures or tsunami potential when they are out running errands. While only 3 dependent-care facilities are located in Phase 2, 2 of them are child services related to day care. Employees at these child care businesses should be trained in assisting very young people with evacuation. The 4 public venues within these areas are affiliated with marinas, further emphasizing the need to train marina management as they may be responsible for guiding evacuees to safety.

All residents and businesses (and their respective employees) in Phase 2 were estimated to need between 1 and 14 min to travel to safety. In the case of a tsunami generated by a local sourced earthquake, residents may need to react quickly and could have little time to prepare due to the expected wave arrival time of 1-15 min after shaking. Evacuees are encouraged to always use warning time wisely, even when it seems they have excessive time to reach safety. Similar to the marina populations, it may be reasonable for residents and employees in these areas to not drop, cover and hold-on if they feel an earthquake in order to ensure they reach high ground before the tsunami arrives.

Phase 3. The increase in total land area in Phase 3 on Alameda Island means evacuees need to travel much farther relative to Phase 2. Evacuation at Phase 3 will involve moving tens of thousands of residents into an area where thousands of residents already reside. This will require city wide cooperation by residents and emergency officials. If all Alameda Island residents are directed to the safe area on the island, opposed to off the island completely, the population density in that safe area will more than triple the normal density on that island (Table 3). This density estimate is for demonstration purposes only since it assumes that all residents are on the island at the time of evacuation and does not include employees. Given this evacuation scenario, the estimated population density in the safe area would be 7,334 residents per square km, which exceeds the density of the most populous nearby city, San Francisco's 6,711 residents per square km (U.S. Census Bureau, 2015).

Table 3.

Safe zone population density, by Evacuation Playbook Phase and island.

	Population Density in Safe Zone (# person per sq. km)			
	No Evacuation	**Phase 2**	**Phase 3**	**Maximum Phase**
Alameda Isl.	**2,403**	**3,125**	**7,334**	**11,187**
Bay Farm Isl.	**2,091**	**2,091**	**22,192**	**n/a**

The increase in numbers of residents (from 204 to 18,537) when choosing a Phase 3 over Phase 2 evacuation on Alameda Island is larger than in any phase on either island. Emergency managers should be aware that their resources will be far more impacted when evacuating to Phase 3 versus Phase 2. Percentages of resident demographics in Phase 3 on Alameda Island are closely comparable to city averages. The percentage of individuals 65 years or older is slightly higher compared to the city average or any other phase so efforts toward assisting elderly residents with evacuation may need emphasis during a Phase 3 evacuation on Alameda Island.

As with residents, the additional number of employees (6,943) when deciding to evacuate to Phase 3 versus Phase 2 on Alameda Island, is the largest increase relative to other phases on both islands. This implies the difference when evacuating to Phase 3 will likely have a great impact on the community's emergency management resources when it comes to helping people who work in these locations. Training about tsunami awareness and evacuation strategies for employees of businesses in Phase 3 on Alameda Island is warranted as they may live outside the city and may not be targeted through their home address. These employees may also be required to guide patrons who may also be unaware of tsunami risk and evacuation requirements if they do not live in tsunami-prone areas.

The majority of residents and employees in Phase 3 on Alameda Island are in areas where 1-14 min of travel time is needed to reach safety. Since Phase 3 is only affiliated with distant source earthquakes, estimates show more than adequate time to evacuate by foot. Even with adequate estimated evacuation time, populations within Phase 3 should still react quickly and evacuate efficiently because the high numbers of expected evacuees will require cooperation from everyone.

Maximum Phase. The additional area when going from a Phase 3 to a Maximum Phase evacuation on Alameda Island includes more additional residents (11,248) than employees (1,634). Directing emergency response efforts toward helping residents during a Maximum Phase evacuation may be reasonable, especially if the tsunami occurs at night. Percentages of resident demographics in this phase are normal when compared to the city average.

The Alameda Hospital is the only health care center in the city and is in Maximum Phase. People with existing health issues and injured people will be especially vulnerable and may rely on this facility in a tsunami event (Wood et al., 2013b). Training Alameda hospital staff for the potential of a Maximum Phase evacuation is warranted and they may need additional assistance to evacuate. The College of Alameda community college is also in the Maximum Phase, and had enrollment of about 10,774 students in the 2013-2014 school year according to California Community Colleges (2015) website. The college is a unique forum to capture the attention of a large group of people (the employees and student body) for tsunami awareness and evacuation training. One fire station is also in the Maximum Phase on Alameda Island so firefighters and other staff should be made aware that their location is expected to evacuate since their services are likely to be needed during a tsunami event.

Even if a Maximum Phase evacuation is called, the majority of the residents and employees are still found within areas where 1-14 min is expected to evacuate. A tsunami that would likely call for a Maximum Phase evacuation on Alameda Island is not expected to arrive for 5 hr, which should give all residents and employees enough reaction and preparation time to reach safety before flooding occurs. Even with estimated adequate evacuation time, populations in the Maximum Phase will need to cooperate with thousands of others in order evacuate effectively.

Bay Farm Island

Phase 3. A Phase 3 evacuation on Bay Farm Island leaves very little safe or high ground for evacuees to gather on that island (about 0.6 square km or 0.23 square mi). If all the Bay Farm Island residents who do not live on high ground outside of Phase 3 travel into that area, the population density could increase over 10 times the density Bay Farm residents are normally used to (Table 3). Evacuating to the safe area for Phase 3 on Bay Farm Island could also water lock evacuees, potentially making it difficult to rescue them until the flooding subsides. Exploring possible evacuation tactics for relieving this density increase and water locking of evacuees for Phase 3 on Bay Farm Island is justified.

A demographic anomaly compared to other races in Phase 3 is percentages of residents who reported their race as Asian on Bay Farm Island are higher than the city average. However, percentages of residents reporting themselves as Hispanic, White and African American are lower than the city average on Bay Farm. Emergency managers may consider further research on the languages spoken within this Asian community to better target communication of tsunami evacuation strategies.

While the total number of employees in Phase 3 on Bay Farm Island is lower than Alameda Island, almost every employee (99%) will be affected. Efforts to train employees on evacuation strategies at all businesses on Bay Farm Island may be defensible since they may live outside of the City of Alameda and may not be aware of the severe tsunami threat where they work.

Estimated travel times to safety for Phase 3 on Bay Farm are higher in areas where people work which typically relate to daytime evacuations. Modeling results suggest that all Bay Farm residents should be able to reach high ground in less than 29 min, but the majority of employees (3,402) may need up to 59 min to leave Phase 3. These estimates likely reflect evacuees traveling to safety on Bay Farm Island but PEAT does not track evacuation routes. Further research on routes evacuees might choose to travel may be considered as Bay Farm populations could be directed to evacuate farther off the island given the small safety area on the island.

Maximum Phase. A tsunami requiring a Maximum Phase evacuation is the least likely to occur but could present extreme challenges for Bay Farm Island. Complete inundation of all Bay Farm Island's land at the Maximum Phase will require all Bay Farm residents and employees to evacuate over the bridge to Alameda Island or over 5 mi (at the farthest) past the Maximum Evacuation Phase boundary in mainland Oakland. Crossing the one bridge onto Alameda Island may not be reasonable because the roads and safe areas may already be congested with that island's residents and employees. Also the population density will further increase (not including employees) to 13,745 per square km, more than doubling the living space standards of San Francisco (Table 3). Therefore, it may be plausible to evacuate the entire population of Bay Farm onto the mainland and into the City of Oakland boundary. Further research to better understand the impact on surrounding communities is warranted, potentially including exposure and evacuation analyses for areas of Alameda County that intersect the Alameda Evacuation Playbook Maximum Phase.

As with Phase 3, a demographic anomaly for the Maximum Phase is the percentage of residents who reported their race as Asian on Bay Farm Island are higher than the city average. A more in depth analysis of the Asian community on Bay Farm Island regarding languages could help communication of tsunami evacuation strategies. The only additional facilities affected when going from Phase 3 to Maximum Phase evacuation on Bay Farm Island are an elementary school and its affiliated child care services. School Employees and emergency managers should be aware of the distance required to travel to safety from this school, especially when directing evacuees to safety in Oakland, as children are less able to sustain long distances than adults.

Evacuation travel time estimates for the Maximum Phase on Bay Farm Island are the highest where people work compared to any phase on either island. Efforts to target tsunami educate for employees working at businesses in the large commercial complex at the southernmost corner of Bay Farm Island is warranted as they are the farthest from safety. While some of these employees may need 60-74 min to travel to high ground that is still adequate time given a tsunami affiliated with the Maximum Phase is estimated to take 5 hr to reach Alameda after initial earthquake shaking. While the minimum expected tsunami arrival times affiliated with the Maximum Phase are 5 hr, emergency managers might plan to evacuate Bay Farm Island residents and employees off the island given the small area of safety on the island. This plan could increase travel times in some areas of Bay Farm Island and decrease travel times in other areas, so further evacuation analysis is warranted.

Conclusion

Several differences in the population exposure and pedestrian evacuation potential between the two City of Alameda islands surfaced in this research. Emergency managers may consider treating these islands as separate populations with regards to the Evacuation Playbook Phases. Considerations below are based on findings of this report and future research will be suggested in a separate chapter. Considerations should not be treated as exclusive to one phase as areas concerning lower phase are included in higher phases.

Phase 1 considerations:

- Focus tsunami training and outreach on Alameda Island for marina populations, beach visitors and large waterfront events and public venues
- If evacuees feel an earthquake, they may need to react quickly and consider not practicing drop, cover and hold-on in order to travel off docks or beaches immediately due to short wave arrival time estimates for local sources.

Phases 1 and 2 considerations:

- Target populations who are considered to have added sensitivity (e.g. single-mothers and renters) for tsunami education
- Evacuees may need to react quickly and understand routes to safety due to short expected wave arrival times for local sources
- If evacuees feel an earthquake, they might consider not practicing drop, cover and hold-on in order to travel directly toward safety at high ground due to short wave arrival time estimates for local sources.

Phases 1, 2 and 3 considerations:

- Emergency managers, residents and employees should be aware of the large number of people expected to evacuate once Phase 3 is called and that city-wide cooperation will help minimize impacts
- Residents and employees should be encouraged to react quickly and evacuate as soon as possible even if expected wave arrival times exceed travel time estimates
- A potential need for outreach and preparedness materials in multiple languages

- Staff at adult-assistance services facilities on Alameda Island should be aware of evacuation strategies and may need training to assistance with evacuation.

Phase 1, 2, 3 and Maximum Phase considerations:

- Alameda emergency managers should communicate with Oakland and other surrounding jurisdictions because some Bay Farm Island populations will need to evacuate to these areas
- Communicate evacuation strategies to Alameda hospital and the fire station on Alameda Island since they provide emergency resources that may be unavailable
- Communicate clearly where Bay Farm Island Populations are to go to safety
- The 1 additional Elementary school on Bay Farm Island should be aware of the distances needed to travel to safety as children may be susceptible to fatigue.

Precautions to educate Alameda residents and employees on tsunami evacuation practices, routes and safe area locations will help minimize loss of life or injury during a future evacuation. Large public forums such as The College of Alameda or religious organizations provide outreach opportunities that can help disseminate information about tsunami awareness. Although some populations may have more challenges than others, modelled evacuation times indicate Alameda residents and employees should be able to reach safety before wave arrival for all of the Evacuation Playbook Phases, especially if they react quickly and understand the severity of the impending tsunami ahead of time.

Future Research

Due to time and resource limitations, several aspects of tsunami exposure and evacuation for the City of Alameda have been not been addressed in this report. Data for many events and locations in and around Alameda were requested from appropriate sources but remains unavailable. Special events held on the Alameda NAS runways can attract thousands of people, including a very large monthly outdoor antique fair. Compiling attendance data for large events in Alameda to better understand how many attendees could be affected in a tsunami evacuation may be warranted. The USS Hornet Aircraft Carrier museum, docked on the south shore of Alameda Island, could also attract many visitors that will likely need guidance during an evacuation. Patrons at the ferry terminals on both islands should also be analyzed to better understand the impact a tsunami could have on those people. It is possible that ferry riders do not live in Alameda and may be unaware of tsunami threat and evacuation practices.

Another suggestion for future research is to better understand the routes pedestrians might take to evacuate and where they may seek high ground. Currently PEAT analyses do not address these concepts but later versions are expected to have a feature for this research (J.M. Jones, USGS, personal communication, September 1, 2015). The travel time maps are useful for knowing which areas require a lot of time to reach safety, but do not offer information about where evacuees are seeking safety. For example, near the 3 bridges to Oakland on Alameda Island's north shore, it is not clear whether modeled travel times for Phase 3 are indicating people are traveling to safety on or off the island. Another good example is whether Bay Farm Island populations are evacuating to Alameda Island or staying on Bay Farm. Knowing what locations and routes for which the tool is modeling the shortest evacuation times could inform emergency manager's decisions as to where to send evacuees during an actual event.

The final suggestion to further understand the evacuation potential for the City of Alameda is to conduct vehicle evacuation modeling for Bay Farm Island. If evacuees are sent to high ground on Alameda Island, it could impact the ability for that island's population to reach safety in a timely manner. However, sending evacuees from Bay Farm Island to Oakland on foot could result in fatigue due to long distances. A simulation to understand whether Bay Farm Island populations could make it to high ground in Oakland using vehicles may be beneficial.

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