Spatial Analysis of Industries, Employment, and Commute Flows in Areas of Concentrated Damage from the HayWired Earthquake Scenario

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Chapter V5 of
The HayWired Earthquake Scenario—Societal Consequences
Edited by Shane T. Detweiler and Anne M. Wein

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Chapter V5

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Abstract

After a large earthquake, heavily damaged areas face challenging recoveries and businesses and employees can be more impacted by their work and home surroundings than direct damages to the buildings they occupy. This spatial analysis explores how California's San Francisco Bay region industries, jobs, and residence-workplace relations could be disrupted by concentrations of damages to homes and business establishments in census tracts (as a representation of neighborhoods). In the HayWired earthquake scenario mainshock, building damages are caused by shaking, liquefaction, landslides, and fire following earthquake. These estimated building damages are used to define areas of concentrated damage where 20 percent or more of building square footage in census tracts would be extensively or completely damaged. Analyses show: (1) building occupancy square footage contained in areas of concentrated damage; (2) industry employment in areas of concentrated damage; and (3) relations between employees' homes and (or) workplaces in areas of concentrated damage.

Results vary across geographical subareas and industry sectors. Areas of concentrated damage are largely determined by presence and vulnerability of industrial/warehouse, retail/commercial, and multifamily or group-living buildings. The central Alameda County subarea is a focal point for concentrated damage that contains a large share of the region's industrial/warehouse employment and residents working in these jobs. The concentration of vulnerable buildings could engender neighborhood effects that spread disruption to buildings that are otherwise still usable. For example, population displacement from usable single-family/duplex buildings could be caused by neighborhood disruption of household services (such as schools). Neighborhood effects may be further spread through commute patterns if employees' performance is adversely affected by the physical and psychological toll of living in concentrated-damage areas. Some of these employees would work in less-impacted areas of Alameda and Contra Costa Counties, in San Francisco office jobs, and in Santa Clara County goods-producing jobs. On the other hand, employees with jobs in concentrated-damage areas could lose jobs and income, further affecting the communities where they live throughout the San Francisco Bay region. Overall, around 442,000 employees live and (or) work in areas of concentrated damage from earthquake hazards, which is about 10 percent of the nine-county San Francisco Bay region employment. These numbers increase to 595,000 employees and 14 percent of employment if damages from fire following earthquake hazards are included. Some of these employees would lose income for various periods of time, lose jobs, change workplaces, and (or) be displaced from their residences.[6]

Leveraging recent disaster literature and regional studies, analyses of concentrated-damage areas and the home-workplace relation raises a number of considerations for emergency managers, businesses, communities, cities, and regional entities to mitigate, prepare, respond, and recover from a large earthquake in the San Francisco Bay region. The spatial perspective of building damages reinforces the merits of systematic building retrofits to protect a neighborhood and planning for a quick recovery that is consistent with its community characteristics and its balance of residential and business functions. Potential cordons around heavily concentrated damage incites preparations for cordon implementation and the management of tensions between public safety and business resumption, and location or redundancy of critical assets outside potential cordons. The home-workplace

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[6]Broad consequences of employment losses are addressed in the HayWired macroeconomic chapters by Kroll and others (this volume) and Sue Wing and others (in prep.; planned to be published as part of this volume).

relation prompts businesses to plan for stranded employees after a large earthquake; for incapacitated, less productive, or displaced employees during response and recovery; for transportation and communication barriers between the workplaces and homes; and for relocation of business premises. Across sectors, effects of concentrated building damage and home-workplace relations prompts consideration of organizational adaptation and where support and resources may need to be focused. For example, construction and goods-movement industries, an important source for middle income jobs, are disproportionately impacted, yet instrumental for recovery. Job and commute disruptions from a large earthquake on the Hayward Fault could affect the current industrial land uses by accelerating the exit of declining manufacturing and construction industries (in Alameda and Contra Costa Counties, respectively). This could exacerbate the already precarious position of specialized industrial clusters in older manufacturing districts, especially in the central Alameda County subarea, and move manufacturing to more affordable places, which would create ripple effects to suppliers, customers, research and development, and headquarter operations. Accelerating the gradual conversion of industrial to higher uses of mixed land uses and priority development areas (PDAs), would additionally dislocate jobs. After a large earthquake, spatial economic demand shifts of businesses and residences may boost and stress less-damaged areas while recovery lags in the concentrated-damage areas and resource allocations would be a regional issue for the San Francisco Bay region and beyond. The findings also have broad implications for economic development policy in the region, suggesting value in focusing forward-looking resilience policies on geographies where key middle-wage industrial activities are concentrated in the region, so that they have more capacity to plan for and recover from a large earthquake.

Introduction

The HayWired scenario examines a hypothetical earthquake (mainshock) with a moment magnitude (M_w) of 7.0 occurring on April 18, 2018, at 4:18 p.m. on the Hayward Fault in the east bay part of California's San Francisco Bay region (Detweiler and Wein, 2017). An estimate of building damages and costs caused by mainshock shaking, liquefaction, landslides, and fire are documented in Seligson and others (2018) and Scawthorn (2018). However, the specific geography of the damage to the region's places of work and its residential communities, as well as the relation between them, will affect the function of the region's economy following the mainshock. This chapter provides a spatial analysis of how the San Francisco Bay region's industries, jobs, and employee residences could be disrupted by concentrations of building damages (defined as more than 20 percent extensive and complete damage to building square footage in a census tract). Using relations between homes and workplaces, the analysis shows how damaged neighborhood effects could spread through job/income losses and (or) difficult living conditions. The analysis uses the same maps of concentrated damages developed by Johnson and others (Concentrated Damage, in prep.; planned to be published as part of this volume) to complement a focus on potential residential population displacement with a perspective on potential disruption to industry sectors and jobs and also to connect the two analyses through the relation between employee workplaces and (or) their homes in heavily damaged neighborhoods in the San Francisco Bay region.

This spatial analysis is informed by the disaster literature (summarized in the next section) in the following ways:

- macroeconomic analyses can hide uneven microeconomic-level or business impacts;
- neighborhood effects of concentrated damage can have larger impacts on businesses than direct damages alone;
- spatial economic demand shifts occur in response to concentrated damages, which may have broad implications for long-term survival of an industry where it is concentrated in a damaged area; and
- businesses can be affected by employee productivity losses and population displacement caused by concentrated damage in their residential neighborhoods such that business and residential recoveries are intertwined.

Our first analytical step is to define concentrated building damage that likely impacts its surrounding residential neighborhood or business districts. We use the same definition justified by Johnson and others (Concentrated Damage, in prep.; planned to be published as part of this volume), that is, 20 percent of the building square footage in a census tract is extensively or completely damaged as categorized by the Federal Emergency Management Agency's (FEMA) Hazus-MH 2.1 loss-estimation software (hereafter referred to as Hazus) in Federal Emergency Management Agency (2012). The 20-percent damage concentration threshold is not ironclad, but follows from observations of how much damage an area (beyond individual buildings) can sustain and still function and readily recover, with the implication that beyond this threshold, which functions as a tipping point of sorts, recovery challenges become increasingly greater (Johnson and others, Long-Term Recovery, in prep.; planned to be published as part of this volume). Two cases of building-damage concentrations are considered: (1) damage from only ground shaking, liquefaction, and landslide hazards (estimated by Seligson and others, 2018; hereafter referred to as "earthquake hazards") and (2) damage from fire following earthquake in addition to the three earthquake hazards (from Johnson and others, Concentrated Damage, in prep. [planned to be published as part of this volume]; hereafter referred to as "all hazards"). The examination of the earthquake hazards and all hazards cases illustrates the different distribution of impacts that fire could add in this spatial analysis, separates out the larger uncertainty of the fire analysis, and aligns with the other analyses in this volume that examine both cases (Johnson and others, Concentrated Damage, in prep. [planned to be published as part of this volume]; Wein,

Haveman, and others, this volume; Sue Wing and others, in prep. [planned to be published as part of this volume]).

We group concentrated-damage areas within seven geographic subareas (of census tracts and [or] cities) to capture the general spatial distribution of the HayWired mainshock damages and develop broad insights about business vulnerability and recovery needs based on lessons from prior studies and experience. We present spatial analyses of the two hazard cases and subareas from three perspectives:

1. Building occupancy damage inside and outside of concentrated-damage areas to illustrate potential neighborhood disruption to otherwise usable buildings;
2. Employment by industry groups in areas of concentrated building damage to estimate the number of jobs that are potentially affected; and
3. Relations between employees' homes and (or) their workplaces in concentrated-damage areas to illustrate potential employed resident issues (for example, displacement or difficult living situation) and (or) employee issues (for example, job relocation or loss).

In conclusion, we incorporate insights from the disaster literature and regional studies to discuss mitigating, preparing for, responding to, and recovering damaged neighborhoods and implications for businesses, emergency managers, communities, governments, and their corresponding policies and programs.

Disaster Literature on Spatial Aspects

Macroeconomic analyses are included in this volume, but they may obscure localized economic impacts (Dahlhamer and Tierney, 1998). One example of this is the 2010–present Canterbury earthquake sequence in New Zealand—the regional economy remained strong and was reasonably resilient (Parker and Steenkamp, 2012) despite damages that were 20 percent of the country's total Gross Domestic Product and despite the loss of the use of workplaces for 50,000 employees and hundreds of residences in the City of Christchurch's central business district (CBD).

Not all buildings in the Christchurch CBD were unsafe for occupancy, but 110 city blocks were initially cordoned in response to aftershock risks from damaged and weakened buildings (Kim and others, 2017). Most businesses were able to relocate, but the accommodation and hospitality sector was one of the hardest hit because two-thirds of the hotels were concentrated in the CBD; the retail sector was also impacted, but not the manufacturing sector that was located outside of the worst hit area (Parker and Steenkamp, 2012). However, after the 1995 Kobe, Japan, earthquake that more directly and disproportionately impacted productive industries and the port (Horwich, 2000), employment in manufacturing shifted to (lower paying) service jobs faster than the rates of de-industrialization (duPont and others, 2015).

Neighborhood effects have been documented before in the San Francisco Bay region, starting with the 1989 Loma Prieta earthquake. Kroll and others (1990) reported that single-location retail and some finance, insurance, real estate, and service businesses were not only affected by direct damages, but also surrounding damage. After the more recent 2014 South Napa earthquake, a single-location retail business was ordered to evacuate away from an unsafe adjacent building and was closed for more than a year before it could re-establish in an affordable space (observed by A. Wein during an Earthquake Engineering Research Institute [EERI] reconnaissance trip in 2016).

Neighborhood effects on businesses were first substantiated by Dahlhamer and Tierney (1998) when they found that shaking intensity was a stronger explanatory variable than direct physical damage for a business being worse off 18 months after the 1995 Northridge earthquake. Similarly, Chang and Falit-Baiamonte (2002) found that physical damage was a weak predictor of business loss and business recovery was determined by conditions and perceptions of the neighborhood, including street closures, lost parking spaces, and media portrayals that deterred foot traffic. Brick-and-mortar retail and commerce, and city/local government services, have been vulnerable to losing the local customer base, in particular (Brown and others, 2015; Chang and Falit-Baiamonte, 2002; Whitman and others, 2014).

Christchurch CBD businesses adapted to the cordon by relocating with similar businesses and sharing work spaces, in other business locations, in homes by teleworking, by using cafes outside of the cordoned area for meetings, and in vacant rental space (observed by A. Wein during an EERI reconnaissance trip in 2011; Bowden, 2011; Donnelly and Proctor-Thomson, 2013). Businesses were reluctant to move because of financial, social, and market costs, but feasible relocations occurred in waves that increased in distance from their original location over time (Brown and others, 2015). The spatial shifts of businesses pushed out of the Christchurch CBD cordon appeared as hotspots of business activity change in the suburbs (Brown and others, 2015). The eventual demolition of 70 percent of the buildings in the Christchurch CBD (Kim and others, 2017) left a hole in the middle of the city. As the CBD was rebuilt, business activity trickled back, but the redevelopment of the CBD has been patchy for a number of years (for example, Anderson, 2014).

Similarly, one year after Hurricane Katrina (which adversely affected several states in the southern United States in 2005), Xiao and Nilawar (2013) describe the core disaster area as a doughnut hole of low income and employment growth surrounded by an edge of high growth counties and parishes within 60 miles. Although growth picked up in the core disaster area in subsequent years, employment and income still lagged behind four years later. The competitive advantages of the high-growth edge were lower transportation time and costs for customers. Xiao and Nilawar (2013) recognize that the edge sustained high growth from higher levels of educated labor, resident income, and growth prior to Hurricane Katrina. In both the Christchurch earthquake and Hurricane Katrina examples, recovery of business and residential neighborhoods with concentrated damage lagged behind less-impacted areas and spatial shifts in business activity were mapped

from holes in the cities to the suburbs and the edges, respectively. Similarly, duPont and others (2015) detect long-term shifts in population, income, and employment away from the core disaster area of the 1995 Kobe earthquake.

Damages to employee homes and neighborhoods have contributed to declines in business productivity when distracted employees check on their families and homes immediately after an earthquake (Chang and others, 2014). After the 2011 Christchurch earthquake, some employees (including executives) departed to keep their children in school and some workplaces provided for basic needs of employees (for example, shower and laundry facilities) (Malinen and others, 2018; observed by A. Wein during an EERI reconnaissance trip in 2011). Employee well-being impacts persisted during the Canterbury earthquake sequence because of stresses of aftershocks and resolving homeowner insurance (Neilsen, 2018) and was a top issue for businesses (Brown and others, 2015).

Xiao and Van Zandt (2011) were the first to quantify a relation between business and residential recovery; the return of households and businesses were mutually dependent across space in Galveston, Texas, after Hurricane Ike in 2008. They found that the re-opening of businesses influenced nearby (within 2.42 kilometers [km]) households' decisions to return to their homes and the return of households in the market area (within 3.22 km) increased the chances of those businesses returning. How to manage this interdependence was a question asked by city council members of visiting social scientists during a reconnaissance of the 2011 Christchurch earthquake (observed by A. Wein during an EERI reconnaissance trip in 2011).

Xiao and Van Zandt (2011) did not differentiate among business sectors, but the interdependence of residents and retail businesses (Chang and Falit-Baiamonte, 2002) has been noted—retail businesses are more likely to fail if residents leave a neighborhood, whereas closure of neighborhood retail businesses can reduce the ability of residents to stay in an impacted area. The vulnerability of impacted retail businesses was seen after the 1989 Loma Prieta earthquake, where retail business losses in damaged areas were picked up as gains elsewhere in the region (Brady and Perkins, 1991).

Analytical Framework

The analytical framework combines information from building damage analyses of HayWired scenario earthquake hazards (Seligson and others, 2018) and fire following earthquake (Scawthorn, 2018) with data available through the U.S. Census Bureau. We describe the analytical steps and terms used to identify areas with concentrated damages and summarize the building damage, employment levels, and workplace-home relation by geography in these areas. We conclude this section by recognizing the limitations of our approach and its scope.

The Spatial Building Blocks in Hazus: Census Tracts

The HayWired scenario mainshock building-damage assessment for earthquake hazards produces results down to the census-tract level using tract boundaries from the 2000 census (Seligson and others, 2018). Fire-following-earthquake building damages (Scawthorn, 2018) were allocated to the 2000 census tracts and integrated with the earthquake hazard damages (Johnson and others, Concentrated Damage, in prep.; planned to be published as part of this volume). For this analysis, the results for the 2000 tract boundaries were redistributed into 2010 tract geographies to allow for comparisons to more recent employment data available through the U.S. Census Longitudinal Employer-Household Dynamics (LEHD) Program and LEHD Origin-Destination Employment Statistics (LODES) datasets (U.S. Census Bureau, 2017). To redistribute building damages from 2000 census tracts to 2010 census tracts, housing units in 2010 tracts were used to weight the distribution of losses. For example, a 2000 census tract split into two tracts in 2010 uses the relative share of housing units in each tract to break up the losses for the original tract. This method is more accurate for housing (residential) distribution but may be less representative for commercial distributions where there is less housing in those areas (Johnson and others, Concentrated Damage, in prep.; planned to be published as part of this volume). In all, there are 2,386 census tracts (of the 2010 vintage) analyzed in the HayWired scenario building-damage assessment, of which 1,588 are in the nine-county San Francisco Bay region, with the remainder located in adjacent counties to more fully account for commute flows beyond the region.

Building Damage States

Seligson and others (2018) use Hazus to estimate building losses from HayWired scenario mainshock shaking, liquefaction, and landslides. An intermediate step in this calculation was the estimation of building damage states. Building square footage was tallied for five damage states: none, slight, moderate, extensive, and complete. The additional square footage of buildings burned by fire following earthquake damage is classified as complete damage (Johnson and others, Concentrated Damage, in prep.; planned to be published as part of this volume). Recall that the four mainshock hazards plus fire hazards are referred to as all hazards and earthquake hazards refers to only the mainshock hazards without fire. Building square footage in each damage state can be converted to building counts in each damage state using the Hazus correspondence table in appendix 1.

Extensive building damage state repairs may take weeks to months. The complete building damage state repairs or replacements may take months to years. This analysis focuses only on concentrations of extensively or completely damaged building square footage for defining the areas of concentrated damage, consistent with HayWired community-at-risk analyses that focus on residential population displacement and consequences for

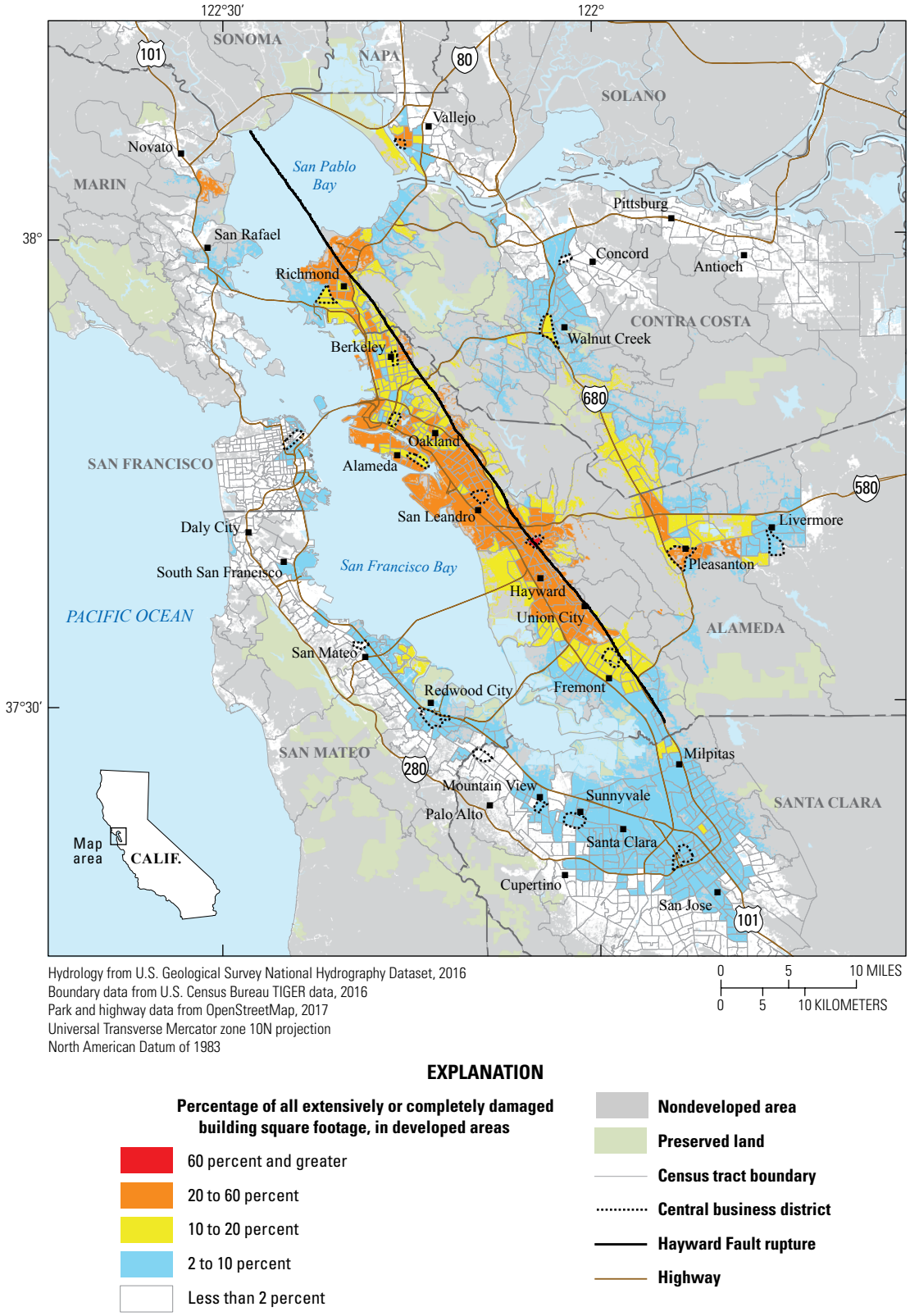

Figure 1. Map of the San Francisco Bay region, California, showing the percentage of building square footage that is extensively or completely damaged across all occupancy groups as a result of all HayWired earthquake scenario mainshock hazards (ground shaking, landslide, liquefaction, and fire following earthquake). Modified from Johnson and others (Concentrated Damage, in prep.; planned to be published as part of this volume).

housing recovery (Johnson and others, Population Movements and Long-Term Recovery chapters, in prep.; planned to be published as part of this volume). A map showing the percentage of all building occupancy square footage that has extensive or complete damage caused by all hazards in each census tract is shown in figure 1. Maps of damage concentration for each building occupancy group are presented by Johnson and others (Concentrated Damage, in prep.; planned to be published as part of this volume).

Areas of Concentrated Damage

Based on literature reviews and other information sources, Johnson and others (Concentrated Damage, in prep.; planned to be published as part of this volume) determined that a threshold for causing significant displacement of businesses and households following a major disaster was 20 percent or more of extensive or complete damage to total building square footage in an area. If the threshold is applied to census tracts in the San Francisco Bay region, 11 percent (173 tracts) of the total meets this concentrated damage threshold for all hazards damages. Of these, 115 tracts qualify as concentrated-damage areas from earthquake hazard damages (7 percent of the tracts in the area). These tracts are predominantly in Alameda County with the remainder in Contra Costa County; the addition of fire following earthquake damage is responsible for concentrated-damage areas in the cities of Novato and Vallejo, as shown in figure 2. Santa Clara County is broadly impacted but contains no tracts where concentrations of damage exceed the 20 percent extensive or complete building damage threshold. Significant damage in most of the areas in Santa Clara County is within the range of 2 to 10 percent of all buildings. For additional information about concentrated-damage areas for the HayWired earthquake scenario, please refer to Johnson and others (Concentrated Damage, in prep.; planned to be published as part of this volume) (for methods) and Jones, Johnson, and others (2020) (for data).

Subareas

Concentrated-damage areas were aggregated into county subareas: northern Alameda County, central Alameda County, southern Alameda County, Dublin-Pleasanton, western Contra Costa County, Novato, and Vallejo (fig. 2). We defined these subareas to provide a general geographic context for the most significant concentrations of damage from the HayWired scenario mainshock. Although the subareas were defined using census tract boundaries, the cities with concentrated-damage areas included in each subarea are listed below; all census tracts within the subareas are defined in the accompanying data release for this chapter (Jones, Au, and Olsen, 2020).[7]

- Northern Alameda County: Berkeley, Emeryville, north Oakland, West Oakland, downtown Oakland, Albany, and Alameda
- Central Alameda County: east Oakland, San Leandro, Castro Valley, San Lorenzo, Hayward, and Union City
- Southern Alameda County: Fremont and Newark
- Dublin-Pleasanton: Dublin and Pleasanton
- Western Contra Costa County: El Cerrito, Richmond, San Pablo, and Pinole
- Novato: Novato
- Vallejo: Vallejo

Figure 3 shows the distribution of tracts with concentrated damage from all hazards and earthquake hazards by subarea. The tracts shown in dark orange in this figure are additional tracts added to the concentrated-damage footprint if fire is incorporated into the HayWired scenario damages; the sum of dark orange and light orange represents the all hazards footprint (fig. 3). In general, subareas are referred to by name, and unless otherwise noted, the references to subarea impacts only consider tracts with concentrated damage within each subarea, not every tract in the subarea. The tracts in subareas with less-concentrated damage are accounted for as, for example, "Alameda County remainder."

Building Occupancy Groups

The building damage results are broken out into 33 detailed building occupancy classes (defined by Hazus), which represent uses of the buildings. For the purposes of this analysis, the building occupancies are collapsed into five nonresidential occupancy groups: industrial/warehouse; offices; retail/commercial; household serving; and agricultural uses. Residential classes are aggregated into three occupancy groups: single family/duplex; multifamily; and group living. A correspondence between Hazus building occupancies to occupancy groups is shown in table 1.

Industry Employment Groups

The 2015 LEHD dataset from the U.S. Census Bureau provides information on employment by industry (U.S. Census Bureau, 2017). LEHD's employment data are reported for 20 industry sectors. As for the occupancy groups, we collapsed the more detailed sector data from LEHD into five broad industry groups that correspond to the occupancy groups: industrial/warehouse; offices; retail/commercial; household serving; and agricultural uses. A correspondence between LEHD industry sectors to industry groups is shown in table 2. Please note that although the names of nonresidential occupancy groups and industry groups are the same, these terms are not used interchangeably. Occupancy groups relate to the Hazus building inventory data, whereas industry groups describe employment data. The data subset used for this analysis is provided by Jones, Au, and Olsen (2020).

[7]Multicity subareas avoided the problem of census tract boundaries crossing city lines; a single tract can straddle two cities.

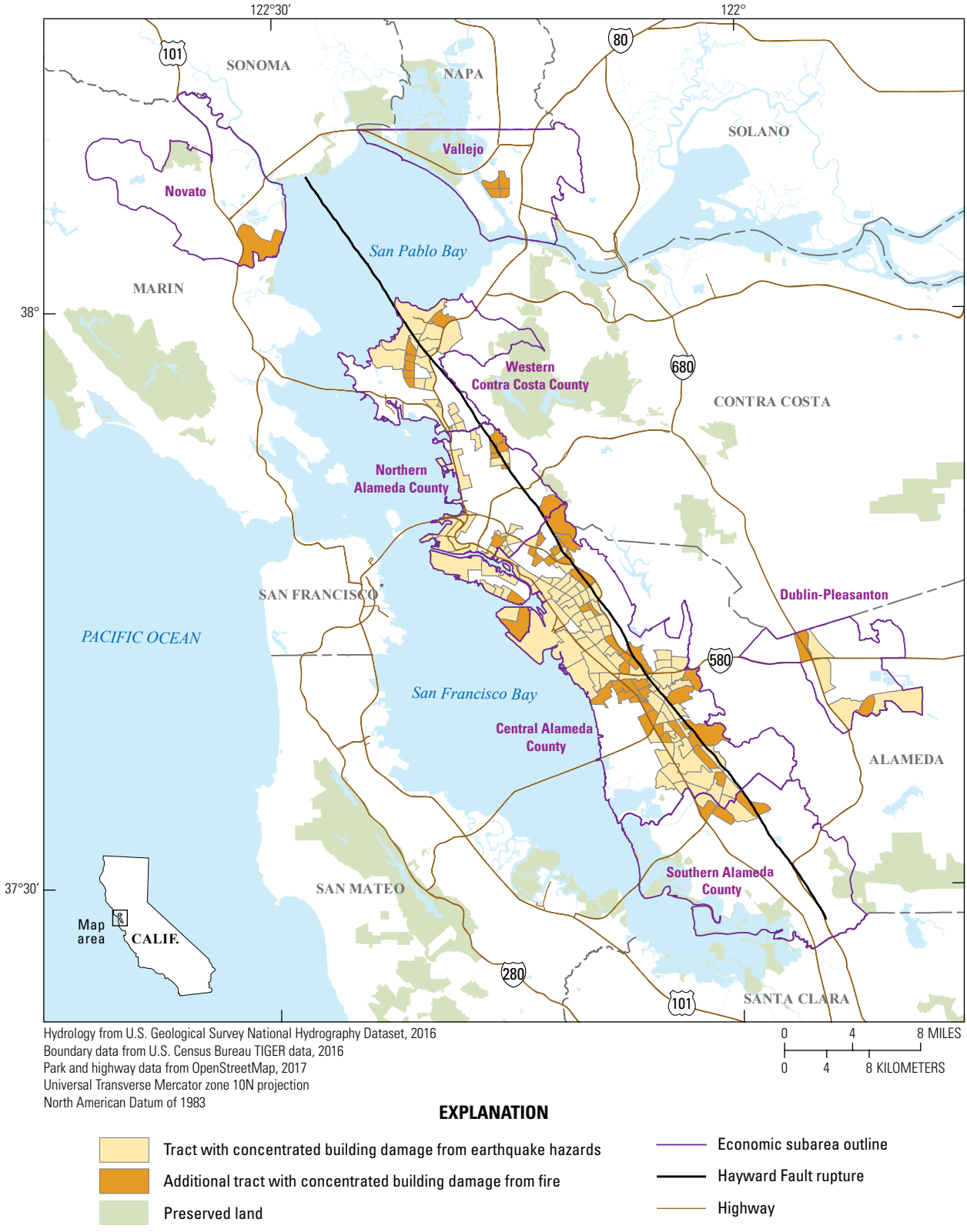

Figure 2. Map of the San Francisco Bay region, California, showing concentrated-damage areas and subareas as a result of hazards caused by the HayWired earthquake scenario mainshock on the Hayward Fault. Concentrated-damage areas are defined as census tracts with 20 percent or more of their total building square footage in extensive or complete damage according to the Hazus analysis (Seligson and others, 2018). Light orange areas are those affected only by earthquake hazards (ground shaking, liquefaction, and landslide) and dark orange areas are added if fire following earthquake damages are included.

Table 1. Hazus occupancy classification to occupancy group correspondence.

Occupancy group	Hazus classification	Hazus occupancy description
Nonresidential		
Industrial/warehouse	COM2	Warehouse
	IND1	Industrial-Heavy
	IND2	Industrial-Light
	IND3	Industrial-Food/drugs/chemicals
	IND4	Industrial-Metals/minerals processing
	IND5	Industrial-High tech
	IND6	Industrial-Construction
Offices	COM4	Professional/technical services
Retail/commercial	COM1	Retail trade
	COM10	Parking
	COM3	Personal and repair services
	COM5	Banks
	COM8	Entertainment and recreation
	COM9	Theaters
	RES4	Hotel/motel
Household serving	COM6	Hospital
	COM7	Medical office/clinic
	EDU1	Grade schools
	EDU2	Colleges/universities
	GOV1	Government-General services
	GOV2	Government-Emergency response
	REL1	Church/non-profit
Agricultural uses	AGR1	Agriculture
Residential		
Single family/duplex	RES1	Single family
	RES3A	Duplex
	RES2	Mobile home
Multifamily	RES3B	Multifamily (3–4 units)
	RES3C	Multifamily (5–9 units)
	RES3D	Multifamily (10–19 units)
	RES3E	Multifamily (20–49 units)
	RES3F	Multifamily (50+ units)
Group living	RES5	Dormitories
	RES6	Nursing home

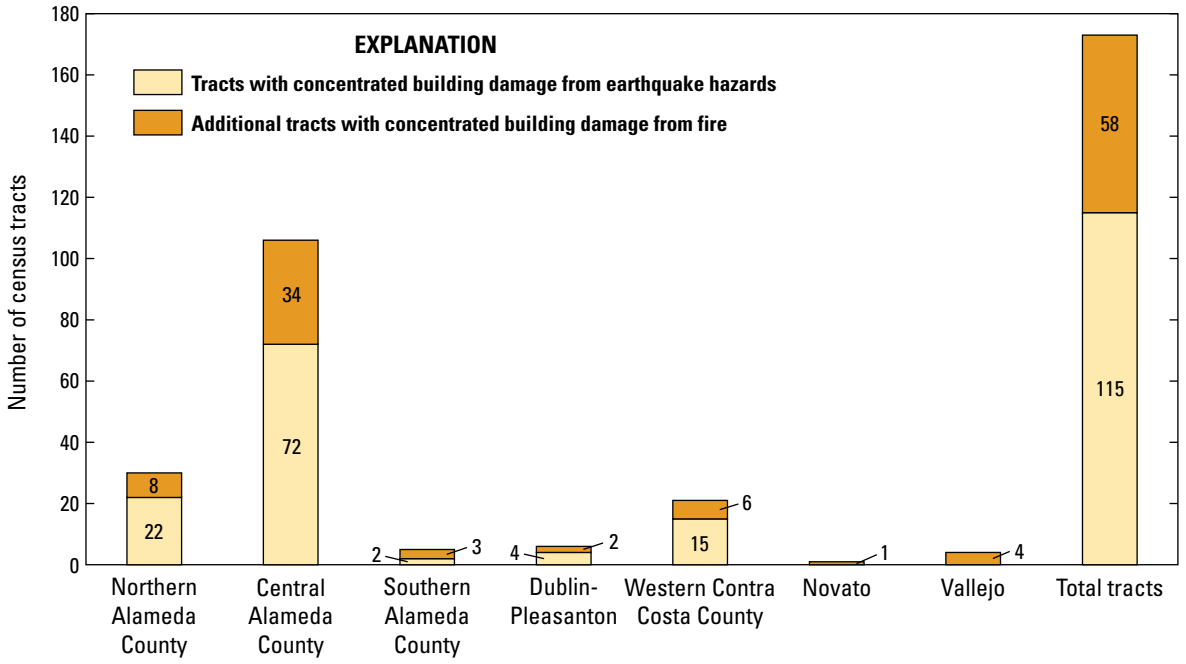

Figure 3. Bar chart showing census tracts with concentrated damage by subarea, identified by damages from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. Consistent with the map in figure 2, light orange represents tracts with concentrated damage from earthquake hazards (ground shaking, liquefaction, and landslide) and dark orange represents additional tracts when fire following earthquake damages are included.

Table 2. U.S. Census Bureau industry classification to industry group correspondence.

[NAICS, North American Industry Classification System]

Industry group	NAICS sector	NAICS industry description
Industrial/warehouse	21	Mining, quarrying, and oil and gas extraction
	22	Utilities
	23	Construction
	31–33	Manufacturing
	42	Wholesale trade
	48–49	Transportation and warehousing
Offices	51	Information
	52	Finance and insurance
	53	Real estate and rental and leasing
	54	Professional, scientific, and technical services
	55	Management of companies and enterprises
Retail/commercial	44–45	Retail trade
	71	Arts, entertainment, recreation
	72	Accommodation and food
	81	Other services
Household serving	56	Administration, support and waste management, and remediation
	61	Education
	62	Health and social services
	92	Public administration
Agricultural uses	11	Agriculture, forestry, fishing, and hunting

Household and Workplace Relation

The LODES dataset provides detailed spatial distributions of workers' employment and residential locations (U.S. Census Bureau, 2017). Our analysis tallies workers and employed residents working and (or) living in concentrated-damage areas according to where they live and work in subareas and beyond. However, since the San Francisco Bay region workforce extends beyond the nine counties bordering San Francisco Bay, this analysis includes employees that commute from the San Joaquin Valley region (Merced, San Joaquin, and Stanislaus Counties), the Sacramento Valley region (Sacramento and Yolo Counties), the central coast region (Monterey, San Benito, and Santa Cruz Counties), and other areas within California to work in concentrated-damage areas. Please note that LODES aggregates the origin-destination industry sector data into three segments: goods producing; trade, transportation, and utilities; and all other services. These data cannot be broken out into the individual industry groups listed in table 2. A correspondence between LEHD industry sectors to LODES industry segments is provided in appendix 1. In addition, LODES data used in this analysis are focused on within-state workers. Because of this, the worker totals will vary slightly compared to the LEHD employment totals, which look at workers in the region regardless of where they reside. The data subset used for this analysis is provided by Jones, Au, and Olsen (2020).

Limitations and Knowledge Gaps of the Analytical Framework

We define concentrated-damage areas as tracts with at least 20 percent of the building square footage in an extensive or complete damage state. This threshold for defining concentrated damage is based on available data and expert opinion (Johnson and others, Concentrated Damage, in prep.; planned to be published as part of this volume). The definition has not considered whether the 20 percent threshold for neighborhood effects could vary by building height (commonly found in dense downtown areas) or the mix of building uses (for example, primarily single family/duplex versus industrial/warehouse or retail/commercial).

Census tracts could be impacted by other disruptive forces, including utility and transportation damages (such as Tierney, 1997) or toxic plumes. For example, in Johnson and others (Communities at Risk Overview, in prep.; planned to be published as part of this volume), areas with utility and transportation issues were illustrated by coarsely identifying areas where at least two services could potentially be disrupted for more than a month. We find that most (141 of the 173) tracts with concentrated damage from all hazards are contained or overlapping with these areas and another 107 tracts with less-concentrated damage are contained in or overlap with these areas. The average concentration of extensive and complete damage in these less-concentrated-damage tracts is 14 percent. Among the 17 tracts with less-concentrated damage that are completely contained within the long-term utility/transportation restoration areas, the average extensive and complete building damage is 16 percent. This suggests that tracts classified here with less-concentrated damage could potentially become areas with significant displacement of businesses and households because of long restoration times of multiple utility and transportation services. We find these borderline tracts in areas with high probability of ground failure and along the Hayward Fault and they may include areas with strong shaking and better performing buildings (for example, single family homes or offices).

For each step, it is necessary to use crosswalks between sector data in the form of 33 Hazus building occupancies, 20 LEHD employment sectors, and 3 LODES employment segments. Nonetheless, the sector results are in reasonable agreement, except for the household-serving group, where the Hazus square footage for education and government occupancies is less than the LEHD employment data suggests (which becomes evident in a comparison of results). Hazus building inventory data has been found to underestimate square footage of educational building occupancy (H. Seligson, Seligson Consulting, written commun., 2017).

Subareas are defined to reduce the detail of summarizing data and relations between census tracts and to capture spatial variations within the broader county geographies, since the tract boundaries do not necessarily correspond to city boundaries. The central Alameda County subarea is the largest area and defines the core of the disaster area. The subareas group tracts with concentrated damage within counties rather than transportation zones, meaning that the results are less specific about additional commute disruption between the homes and workplaces.

Building Occupancy Damages

In this section, we show how extensive and complete building damage is distributed between concentrated and less-concentrated-damage areas in the region. The spillover effect in the concentrated-damage areas means that otherwise usable buildings could suffer from neighborhood effects. Results, shown in figures and tables, vary by building occupancy class and subarea; more detailed tables of results are provided in appendix 2.

Regional

Figures 4 and 5 show the amount and percentage of building occupancy square footage in the nine-county San Francisco Bay region, divided into four categories based on two categories of building damage states (disruptive building damage, defined as extensive or complete damage to building square footage, or less-disruptive building damage, defined as none, slight, or moderate damage to building square footage) and two types of location (in concentrated-damage areas or less-concentrated-damage areas). The distinction here is that 20 percent or more disruptive building damage defines concentrated damage, indicating a spatially impaired neighborhood, whereas disruptive building damage in less-concentrated-damage areas is assumed to be contained to the building, not impairing the neighborhood.

We see that most building square footage is in residential classes, particularly single-family/duplex occupancy, and residential classes compose the largest amount of disruptive building damage (light and dark reds, fig. 4). A smaller percentage of single-family/duplex housing types incur disruptive building damage because they out-perform industrial and commercial building types (light and dark reds, fig. 5), making them a small contributor to concentrations of damage. Consequently, for earthquake hazards, disruptive building damage for single-family/duplex housing is largely in tracts with less-concentrated damage (light red). However, conflagrations concentrate residential damages such that disruptive damage is only slightly more present in less-concentrated-damage areas for all hazards than earthquake hazards (light red bars in fig. 5).

The multifamily and group living housing, industrial/warehouse, and retail/commercial occupancies have a larger share of their building square footage in concentrated-damage areas (compared to single-family/duplex residences and offices) (dark colors, fig. 5), which corresponds to these building occupancy types being more vulnerable to the effects of the mainshock hazards (light and dark reds, fig. 5) and fire (in the case of multifamily and group living occupancies) (all hazards versus earthquake hazards, fig. 5). The household-serving industry group is also disproportionately affected by fire based on the distribution of burned square footage relative to schools, applying 1995 Northridge earthquake burn data (where fires were initiated in school laboratories) to an underestimation of square footage in the occupancy class.

Neighborhood disruption from concentrated damage to otherwise usable buildings is larger than the square footage that is directly impacted in those tracts (shown in dark blue). This is an artifact of using the 20 percent disruptive building damage threshold for defining concentrated-damage areas. Most notably, less-disruptive single-family/duplex building damage in concentrated-damage areas (dark blue) is more than the total disruptive single-family/duplex building damage in the entire nine-county region (light and dark red combined) and usable homes are potentially more exposed to neighborhood disruptions than other usable building occupancies.

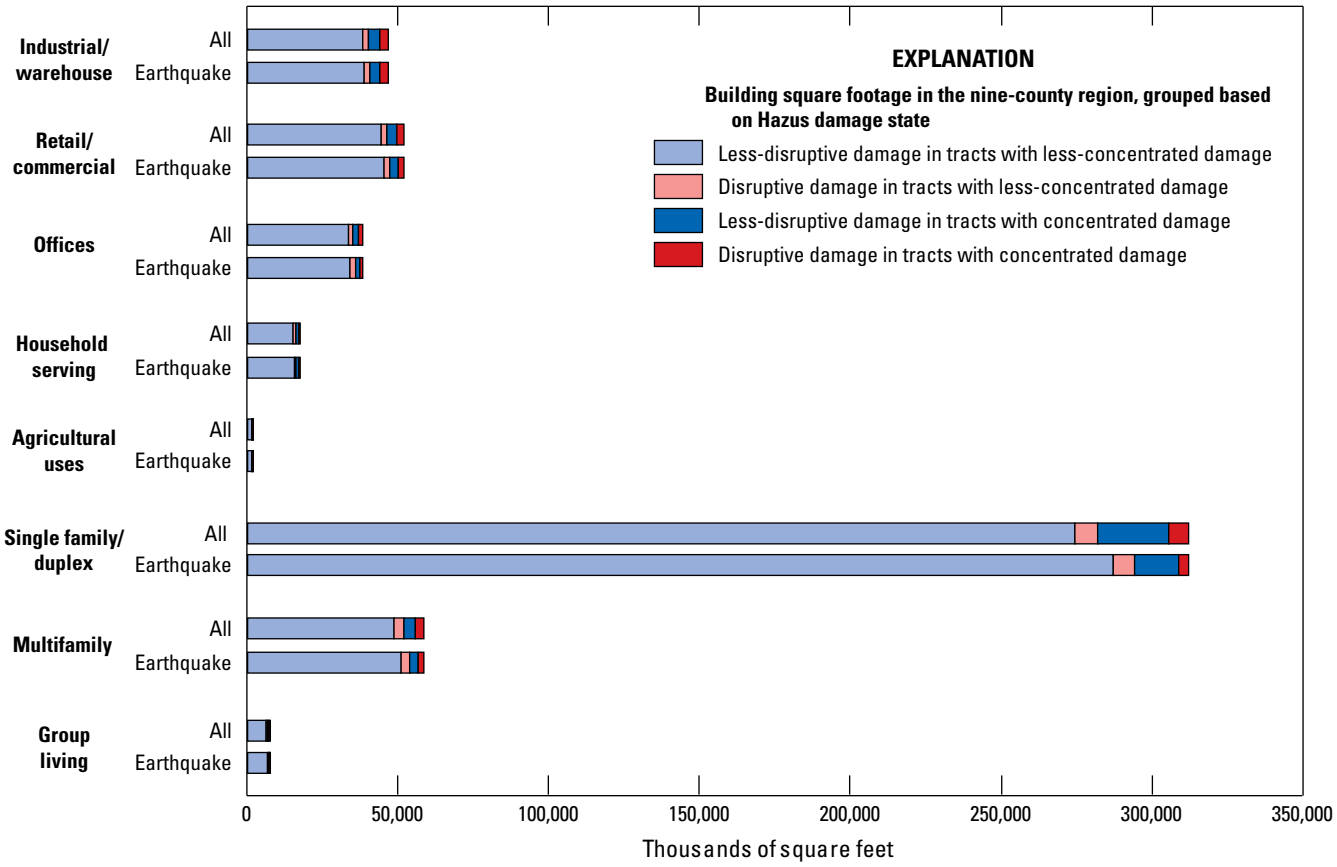

Figure 4. Bar chart showing building occupancy square footage damage for the HayWired earthquake scenario mainshock in the nine-county San Francisco Bay region, California. Results are separated into less-disruptive damage (none, slight, and moderate damage; blue colors) and disruptive damage (extensive and complete damage; red colors) according to the Hazus analysis and also separated based on location within less-concentrated-damage areas (<20 percent of building square footage is disruptively damaged; light colors) and concentrated-damage areas (≥20 percent of building square footage is disruptively damaged; dark colors). "All" refers to damage from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. "Earthquake" refers to damage from earthquake hazards only: ground shaking, landslide, and liquefaction.

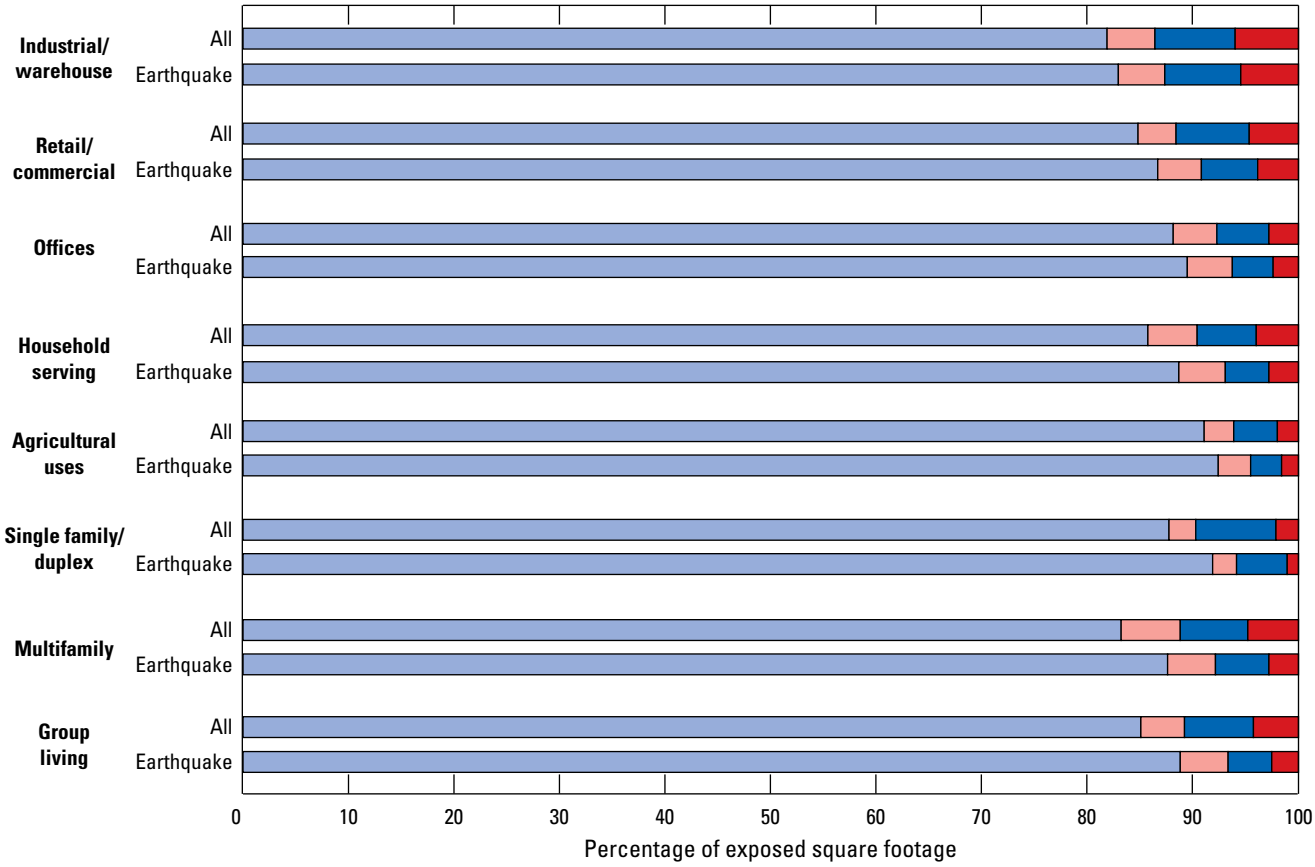

Figure 5. Bar chart showing the percentage of building occupancy square footage damage for the HayWired earthquake scenario mainshock in the nine-county San Francisco Bay region, California. Results are separated into less-disruptive damage (none, slight, and moderate damage; blue colors) and disruptive damage (extensive and complete damage; red colors) according to the Hazus analysis and also separated based on location within less-concentrated-damage areas (<20 percent of building square footage is disruptively damaged; light colors) and concentrated-damage areas (≥20 percent of building square footage is disruptively damaged; dark colors). "All" refers to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. "Earthquake" refers to damages from earthquake hazards only: ground shaking, landslide, and liquefaction.

Concentrated-Damage Areas

Considering only concentrated-damage areas, 30 percent of building square footage from all hazards is disruptive (extensive and complete) building damage; 26 percent of residential square footage and 41 percent of nonresidential square footage is disruptive building damage (table 3 and dark colors compared to light colors in fig. 6). The single-family/duplex occupancy group has the most disruptive building damage square footage in concentrated-damage areas (dark purple color in fig. 6),[8] however, disruptive damage to multifamily and industrial/warehouse buildings is more common in concentrated-damage areas, followed by retail/commercial (dark colors compared with light colors in fig. 6 and lower percentages in table 3). The percentages of disruptive building damage in concentrated-damage areas range from 19 percent (single family/duplex, earthquake hazards) to 44 percent (industrial/warehouse, all hazards). The disruptive building damage percentage for an occupancy group can be less than the concentrated-damage threshold of 20 percent depending on the mix of occupancy groups in census tracts.

Subareas

Concentrated building occupancy damage results vary across subareas (that contain the concentrated-damage areas). The central Alameda County subarea covers the largest area, has the largest building square footage in concentrated-damage areas (light and dark bars in fig. 7*A*, *B*), and the largest share of disruptive (extensive and complete) building damage by square footage (dark bars in fig. 7*A*, *B*). The central Alameda County subarea contains 60 percent of the total square footage in

[8]In terms of buildings, 59 percent of square footage in concentrated-damage areas (for all hazards) is in residential use but represents 94 percent of the buildings in the same extent because, on average, nonresidential buildings tend to be bigger than residential buildings. For example, a single warehouse building could have approximately the same square footage as four single-family homes.

Table 3. Disruptive building damage in concentrated-damage areas by occupancy group for the HayWired scenario in the San Francisco Bay region, California.

[Disruptive building damage is defined as extensive or complete damage according to Hazus. Concentrated-damage areas are defined for both all hazards and earthquake hazards. All hazards are defined by damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards are defined by damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Occupancy group	Earthquake hazards		All hazards	
	Disruptive building damage, in ft^2	Disruptive building damage, in percent	Disruptive building damage, in ft^2	Disruptive building damage, in percent
Nonresidential				
Industrial/warehouse	25,492,796	44	27,599,713	44
Retail/commercial	19,636,682	41	24,030,474	40
Offices	8,744,959	37	10,479,760	36
Household serving	4,734,527	39	7,000,208	42
Agricultural uses	247,644	35	313,649	33
All nonresidential	**58,856,608**	**41**	**69,423,804**	**41**
Residential				
Single family/duplex	33,582,773	19	65,198,410	22
Multifamily	16,331,727	36	28,022,305	43
Group living	1,841,762	37	3,121,621	39
All residential	**51,756,262**	**22**	**96,342,336**	**26**
Total	**110,612,870**	**29**	**165,766,140**	**30**

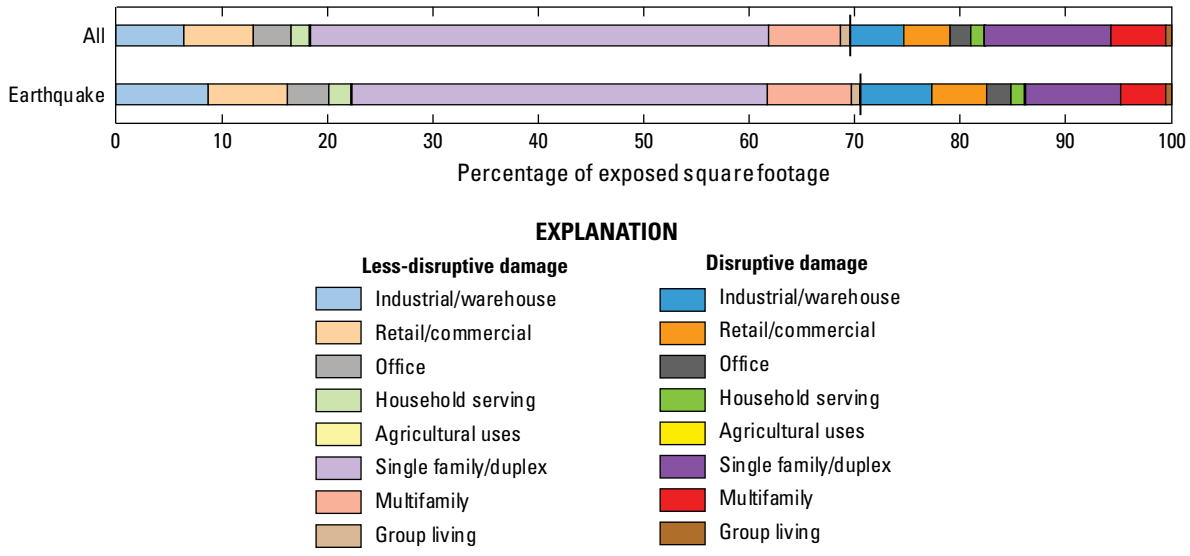

Figure 6. Bar chart showing the percentage of building occupancy square footage in concentrated-damage areas that is disruptive (extensive or complete damage according to Hazus) and less disruptive (none, slight, or moderate damage according to Hazus) for the HayWired earthquake scenario mainshock in the nine-county San Francisco Bay region, California. "All" refers to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. "Earthquake" refers to damages from earthquake hazards only: ground shaking, landslide, and liquefaction. The black vertical line on each row of stacked bars represents the break point between disruptive and less-disruptive building damage.

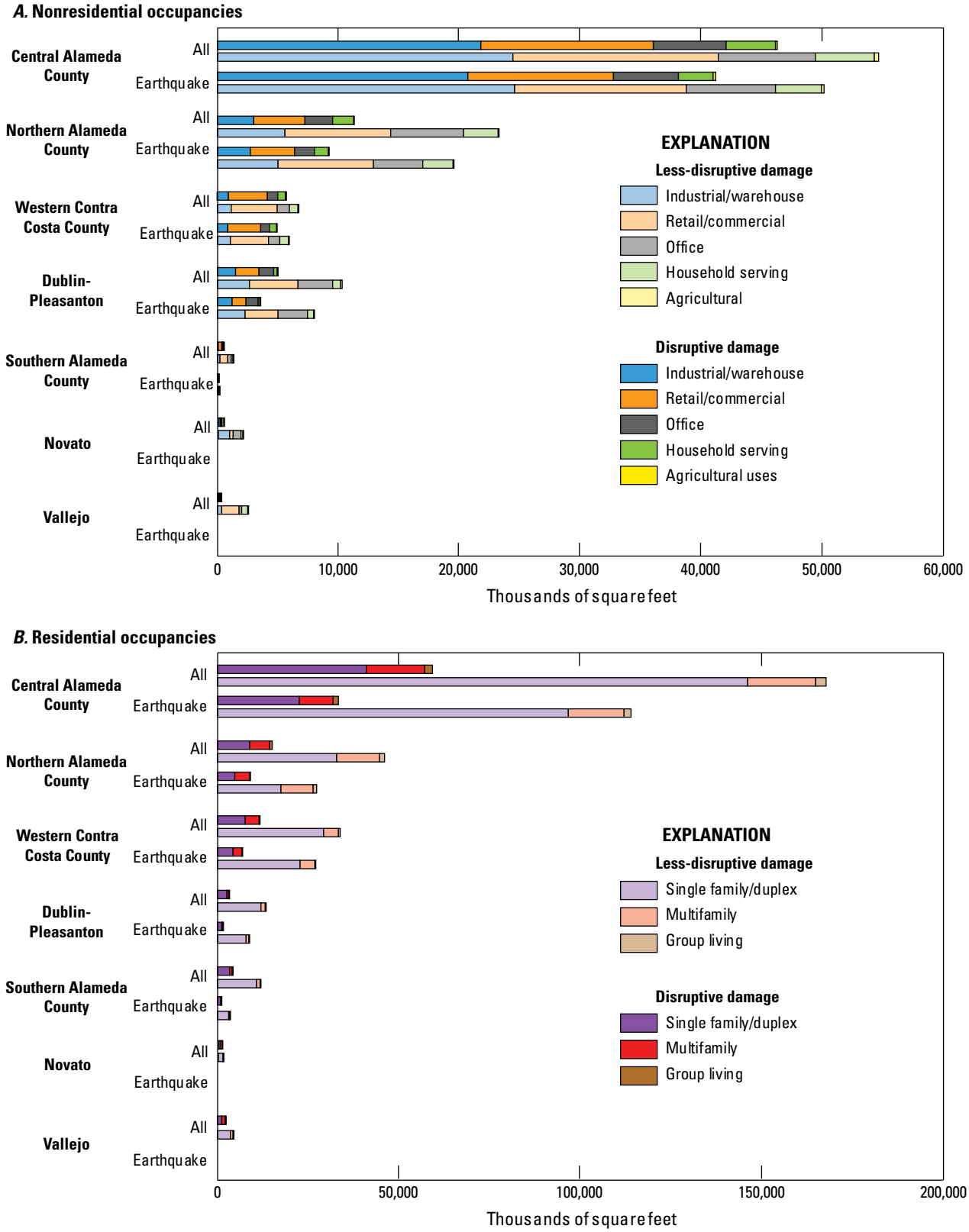

Figure 7. Bar charts showing building occupancy square footage in concentrated-damage areas by subarea for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. "All" refers to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. "Earthquake" refers to damages from earthquake hazards only: ground shaking, landslide, and liquefaction. Dark colors represent disruptive (extensive or complete damage according to Hazus) building damage; light colors represent less-disruptive (none, slight, or moderate damage according to Hazus) building damage.

concentrated-damage areas for all hazards and accounts for 67 percent of the total disruptive building damage in the all hazard concentrated-damage areas. As such, damages in the central Alameda County subarea are largely driving the results for the San Francisco Bay region.

There are some notable building occupancy differences across the subareas:

- Central Alameda County subarea hosts most (about 74–77 percent) of the industrial/warehouse building square footage in concentrated-damage areas (blue colors) and most of the disruptive damage to these buildings occurs in this subarea (fig. 7*A*).
- Western Contra Costa County subarea hosts relatively more retail/commercial square footage in concentrated-damage areas than other subareas (orange in fig. 8*A*) and most of the disruptive damage in this subarea is to buildings in these occupancies group (dark orange in fig. 8A).
- Dublin-Pleasanton subarea hosts relatively more office buildings in concentrated-damage areas except for Novato (gray in fig. 8*A*), which shows the largest proportion of disruptive damage to these building occupancies (dark purple in fig. 8*A*) compared to other subareas.
- Northern Alameda County subarea shows relatively more multifamily and group living housing in its residential square footage than other subareas (likely related to student housing) and the largest percentage of multifamily and group living residential building square footage with disruptive damage (light and dark red) as compared to other subareas (fig. 8*B*).
- Southern Alameda County subarea's concentrated-damage areas predominantly host residential buildings (fig. 7*A*, *B*).
- Fires in the Novato subarea result in the largest percentages of residential building square footage with disruptive building damage in concentrated-damage areas relative to other subareas—that is, 34 percent of single-family/duplex and 93 percent of multifamily building square footage (fig. 8*B*).

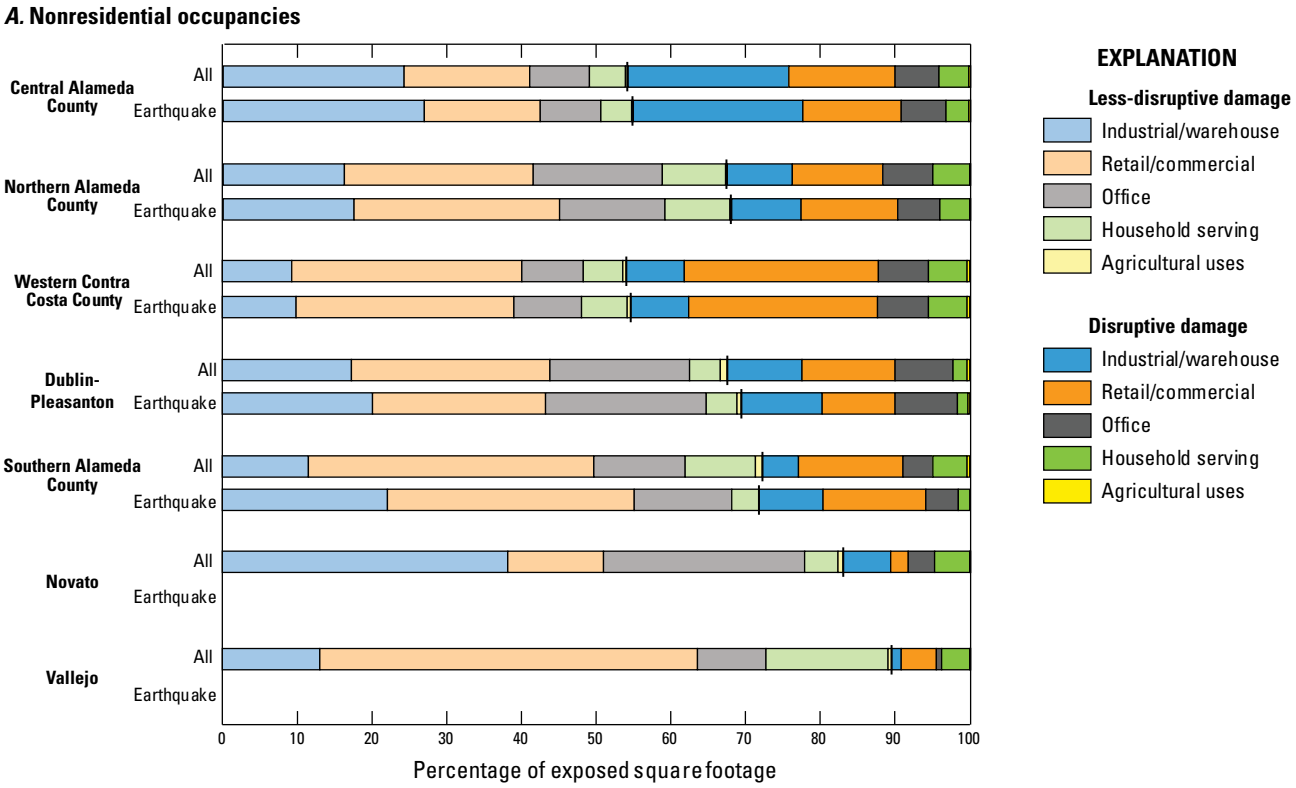

Figure 8. Bar charts showing the percentage of building occupancy square footage in concentrated-damage areas of subareas for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. "All" refers to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. "Earthquake" refers to damages from earthquake hazards only: ground shaking, landslide, and liquefaction. Dark colors represent disruptive (extensive or complete damage according to Hazus) building damage; light colors represent less-disruptive (none, slight, or moderate damage according to Hazus) building damage. The black vertical line on each row of stacked bars represents the break point between disruptive and less-disruptive building damage. Figure continues on page 16.

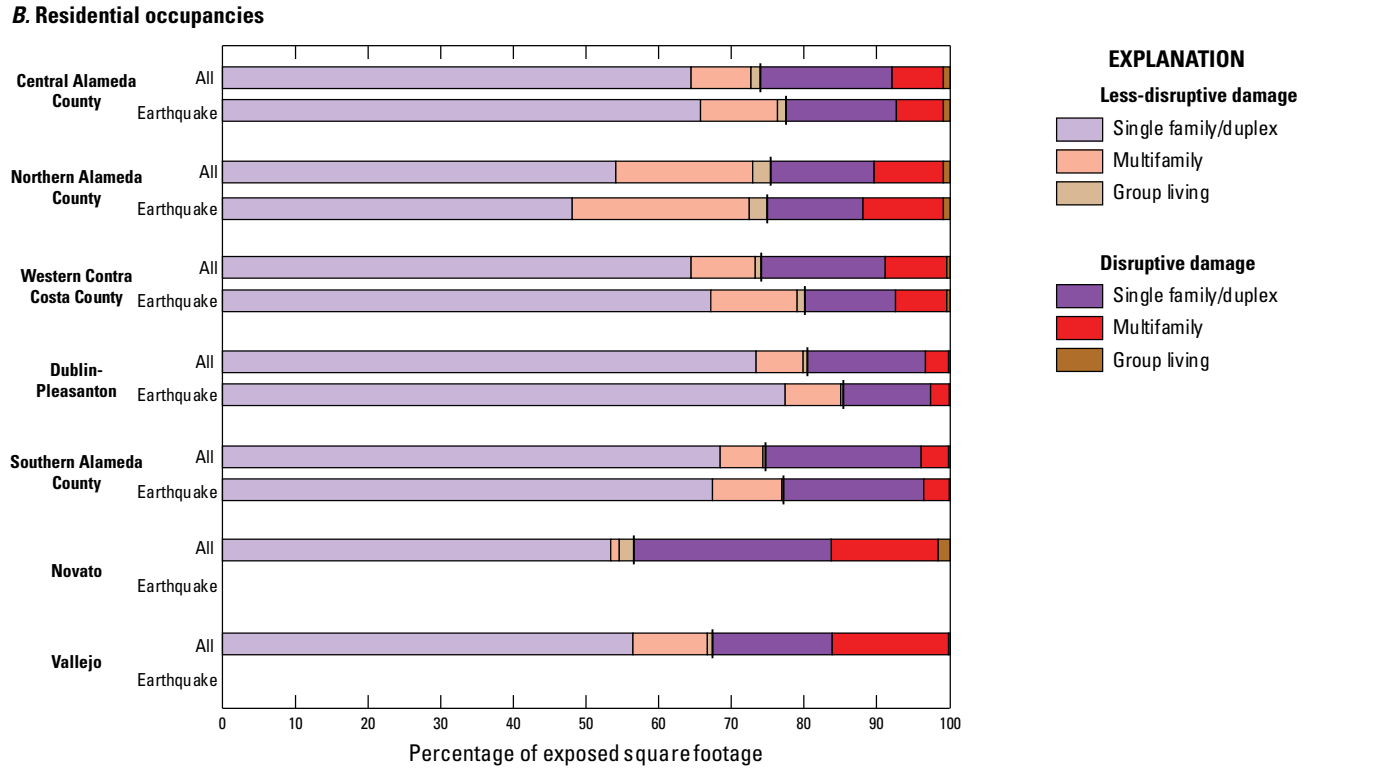

Figure 8. Bar charts showing the percentage of building occupancy square footage in concentrated-damage areas of subareas for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. "All" refers to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. "Earthquake" refers to damages from earthquake hazards only: ground shaking, landslide, and liquefaction. Dark colors represent disruptive (extensive or complete damage according to Hazus) building damage; light colors represent less-disruptive (none, slight, or moderate damage according to Hazus) building damage. The black vertical line on each row of stacked bars represents the break point between disruptive and less-disruptive building damage.—Continued

Employment by Industry Group

The U.S. Census Bureau's LEHD 2015 dataset (U.S. Census Bureau, 2017) includes information on employment by 20 industry sectors. As with the nonresidential occupancy groups in the previous section, the data are collapsed into five industry groups: industrial/warehouse; retail/commercial; offices; household serving;[9] and agricultural uses. A correspondence between LEHD industry sectors to industry groups are shown in table 2.

Regional Employment

In 2015, there were approximately 330,000 jobs distributed across concentrated-damage areas from all hazards (10 percent of San Francisco Bay region jobs). The employment mix in these concentrated-damage areas is diverse: 39 percent were in the household-serving industry group (approximately 127,000), followed by 27 percent in industrial/warehouse (approximately 88,000), 24 percent in retail/commercial (approximately 80,000), and 11 percent in office jobs (approximately 35,000) (fig. 9*A*). In comparison to figure 9*B*, figure 9*A* shows the disproportionate effect of fire on household-serving employment (because the model applies the 1995 Northridge earthquake fire data). The percentage of employment in agricultural uses is less than one percent in concentrated-damage areas (all hazards and earthquake hazards), which is not surprising, because agriculture is generally found in rural areas outside the concentrated damage in urbanized areas. However, more recently, the cannabis industry has been expanding into large warehouses in the San Francisco Bay region (Roach and Chapple, 2018).

The industry employment mixes in areas of concentrated damage from all hazards differ somewhat from the industry mixes for the four counties that contain concentrated-damage areas and for the region (fig. 9). The concentrated-damage areas have a markedly higher proportion of industrial/warehouse jobs, and a much lower percentage of office jobs, which is consistent with the building occupancy damage results discussed above. The overall larger share of household-serving jobs is

[9]The household-serving occupancy group includes government, education, healthcare, and religious building occupancies.

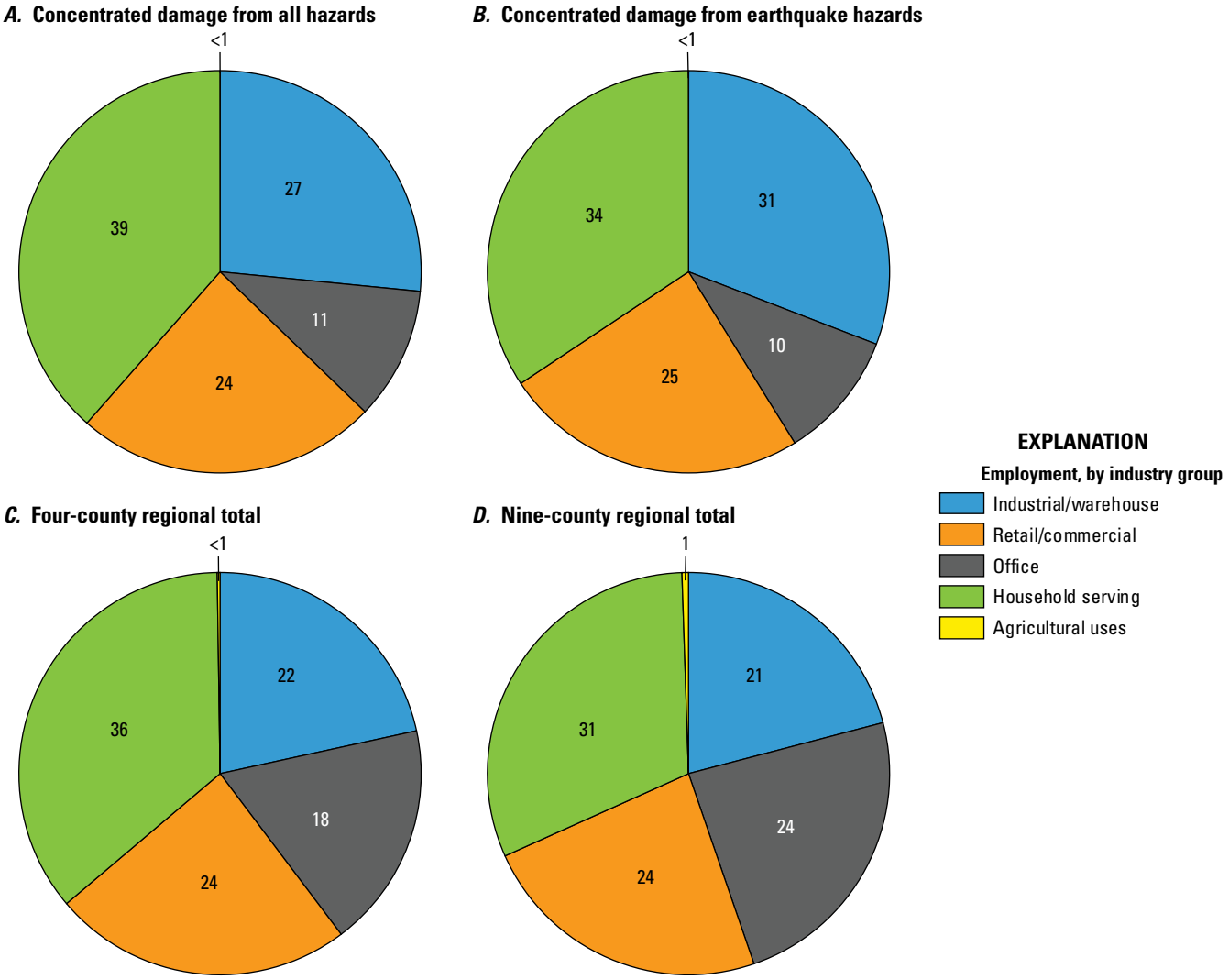

Figure 9. Pie diagrams showing employment by industry group for concentrated-damage areas for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. Number indicates percentage of total employment in concentrated-damage areas for an individual industry group. *A*, Employees affected by concentrated-damage areas from all hazards (ground shaking, landslide, liquefaction, and fire following earthquake); total number of employees is 330,159. *B*, Employees affected by concentrated-damage areas from earthquake hazards (ground shaking, landslide, and liquefaction); total number of employees is 259,095. *C*, Total employment by industry group for the four counties that encompass all of the concentrated-damage areas (Alameda, Contra Costa, Solano, and Marin Counties); total number of employees is 1,367,946. *D*, Total employment by industry group for the nine counties bordering San Francisco Bay; total number of employees is 3,730,011.

not commensurate with the square footage results discussed above and likely reflects a known underestimation of education occupancy square footage, and perhaps other government occupancies as well, in the Hazus inventory (H. Seligson, Seligson Consulting, written commun., 2017).

Subarea Employment

Fifty-seven percent of the 330,159 jobs in concentrated-damage areas from all hazards are located in the central Alameda County subarea (fig. 10), commensurate with the percentage of nonresidential square footage in the subarea. To put this number in further context, the jobs in the central Alameda County subarea's concentrated-damage areas represented one-quarter of all jobs in Alameda County. The subarea has a larger share of industrial/warehouse jobs and smaller share of office jobs (fig. 11) than other counties in the region. Jobs in the northern Alameda County subarea's concentrated-damage areas account for nearly one-quarter of all jobs in concentrated-damage areas (78,514 jobs), and account for 10 percent of Alameda County jobs overall. In contrast to central Alameda County, northern Alameda County has larger shares of office and household-serving jobs than industrial/

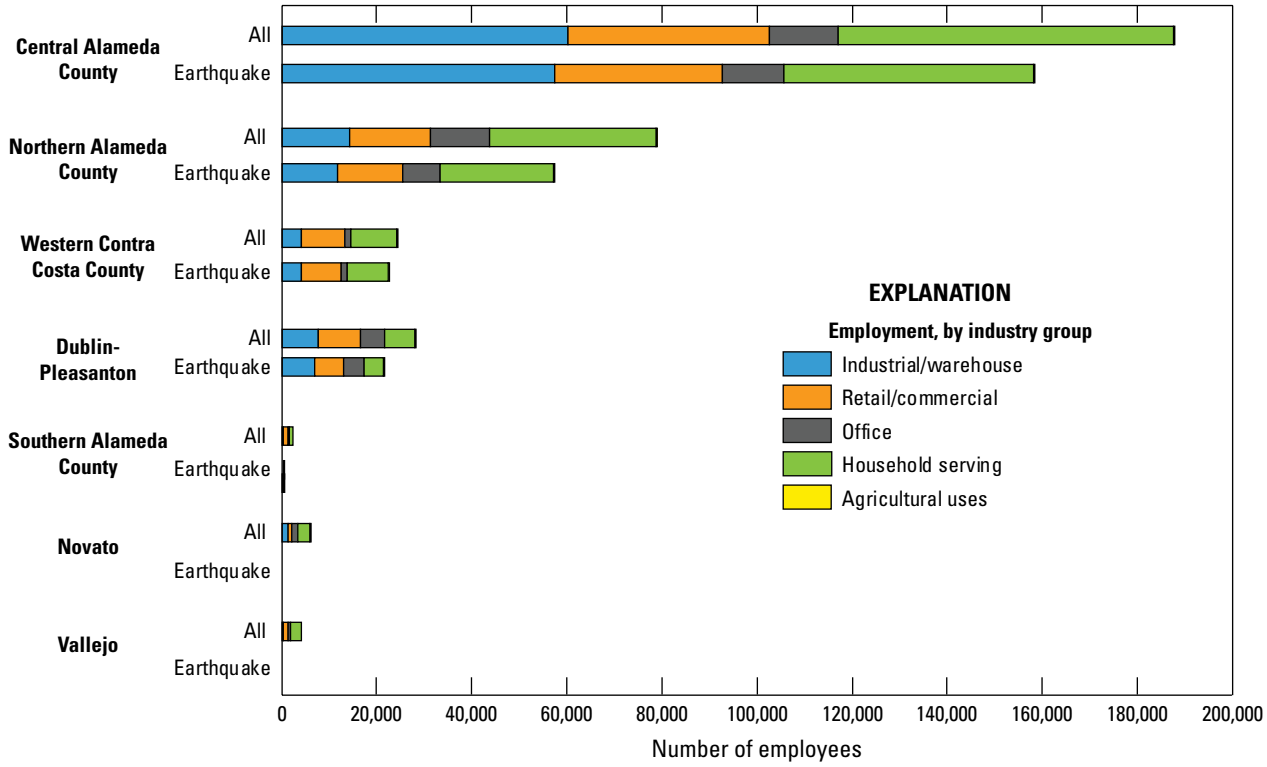

Figure 10. Bar chart showing employment in concentrated-damage areas by industry group in subareas for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. "All" refers to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. "Earthquake" refers to damages from earthquake hazards: ground shaking, landslide, and liquefaction.

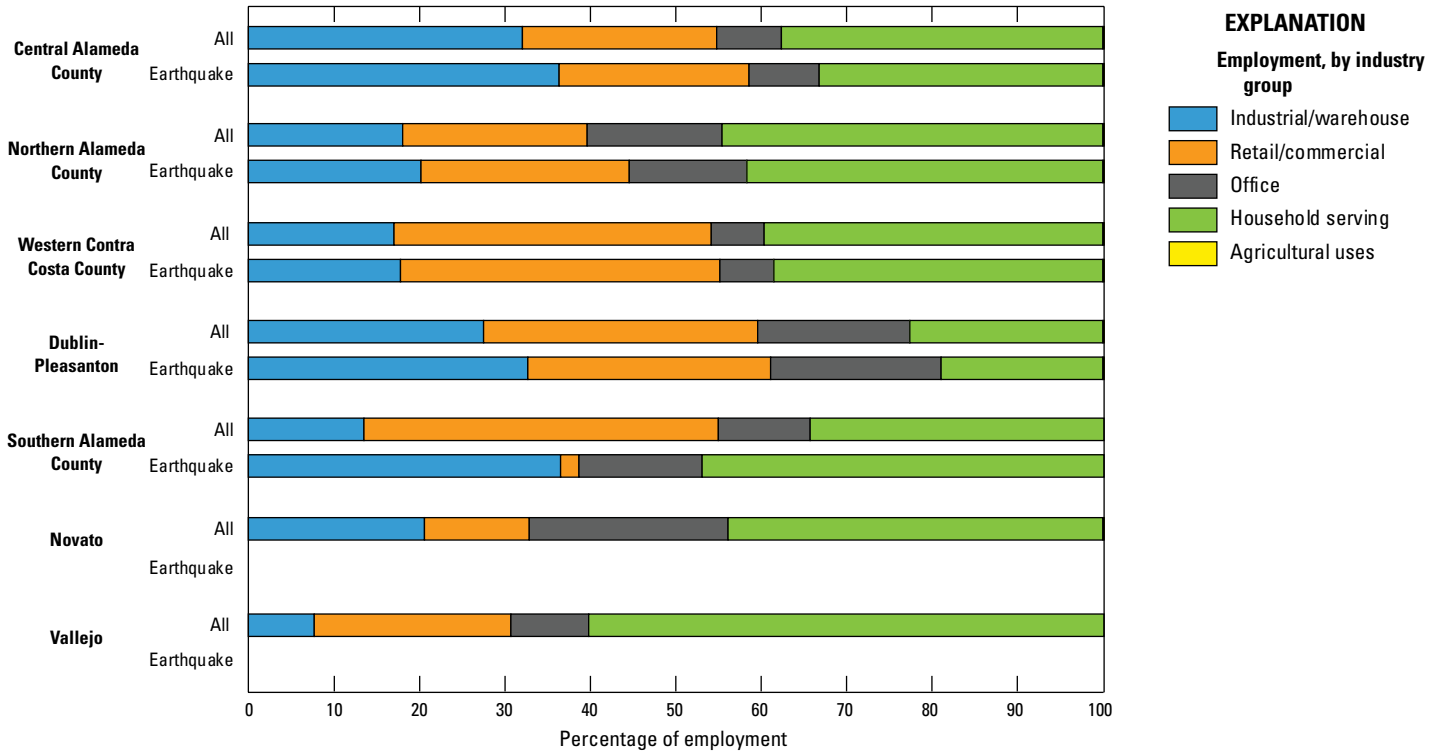

Figure 11. Bar chart showing the percentage of employment by industry group in concentrated-damage areas by subareas for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. "All" refers to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. "Earthquake" refers to damages from earthquake hazards: ground shaking, landslide, and liquefaction.

warehouse jobs. Very little employment is in concentrated-damage areas in the southern Alameda County subarea, which agrees with the predominance of residential buildings in the concentrated-damage areas in this subarea.

The area of concentrated damage from all hazards in the Dublin-Pleasanton subarea contain 8 percent of total jobs in concentrated-damage areas (27,843 jobs). However, these tracts accounted for 23 percent of all jobs in the Tri-Valley area (defined as the cities of Dublin, Pleasanton, and Livermore).

The areas of concentrated damage from all hazards in the western Contra Costa County subarea contained about 24,000 jobs, composing 7 percent of all jobs in concentrated-damage areas, and 7 percent of Contra Costa County employment. However, these areas accounted for half of all jobs in the cities of El Cerrito, Richmond, San Pablo, Pinole, and Hercules. Areas of concentrated damage in western Contra Costa contain less employment in offices and more in retail/commercial.

Concentrated-damage areas from the fire hazard in Novato and Vallejo expose office and household-serving jobs, in particular, respectively (fig. 11).

Employee Residence and Workplace Relation

A major earthquake event on the Hayward Fault would impact businesses beyond the concentrated-damage areas through the geographic relations of residences and workplaces. For example, people who work in concentrated-damage areas but live in communities with less-concentrated damage could lose their jobs or be out of work for an extended period without a paycheck, spreading impacts to areas less affected by physical damage. People who live in concentrated-damage areas may be displaced or burdened in a way that interferes with their productivity, even if their job is in a less-concentrated-damage area.

We broadly calculate how many workers live and (or) work in concentrated-damage areas in the region and subareas. More detailed analysis by industry group follows, but is limited, because, though the LEHD employment data allow for establishing industry groups that could be easily organized to match occupancy groups, the LODES data are reported for only three aggregated industry segments: goods producing; trade, transportation, and utilities; and all other services. (A correspondence between LEHD industry sectors to LODES industry segments is provided in appendix 1.)

Regional

Home and workplace relations are defined as one of the following: employees (1) live and work in areas with concentrated damage, (2) live in areas with concentrated damage but work in areas with less-concentrated damage, (3) work in areas with concentrated damage but live in areas with less-concentrated damage, or (4) live and work in areas with less-concentrated damage (fig. 12).

Table 4 presents numbers of employees that live in concentrated-damage areas (employed residents) and (or) work in

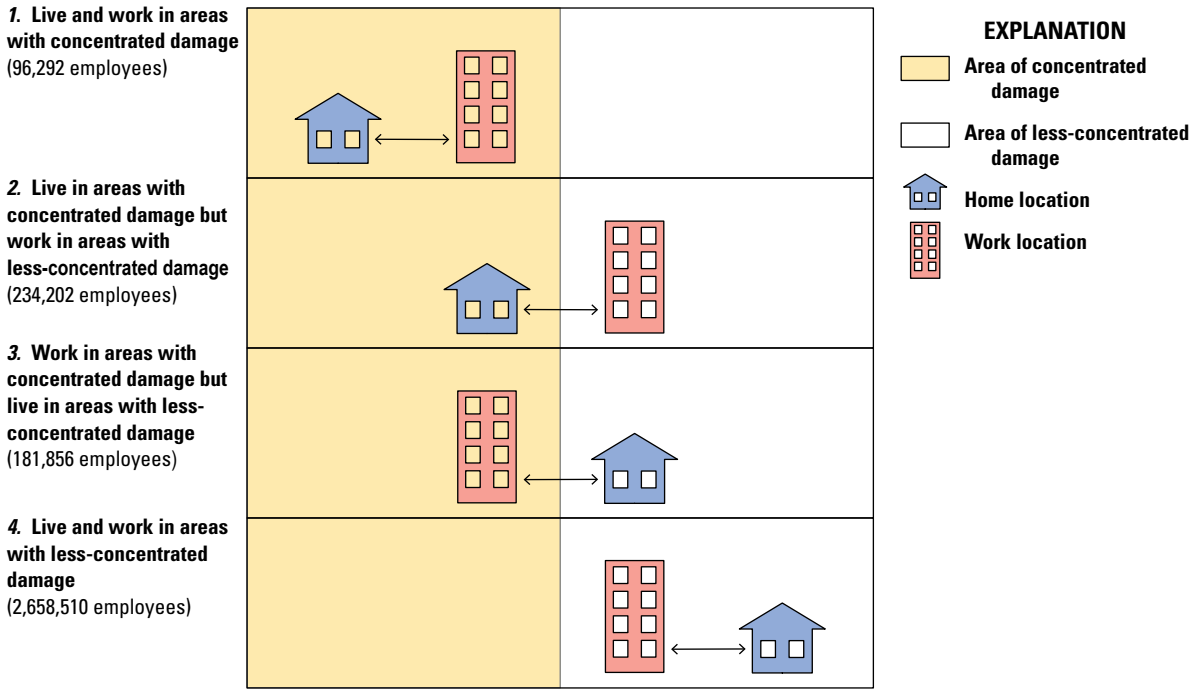

Figure 12. Cartoon showing possible home-workplace relations associated with areas of concentrated and less-concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. Employee numbers are calculated for the nine counties for all hazards (ground shaking, landslide, liquefaction, and fire following earthquake).

concentrated-damage areas (workers) in 2015. Note that the region of study expands to a larger 17-county region to capture workers living beyond the nine counties that border San Francisco Bay. In total, almost 600,000 employees work and (or) live in areas of concentrated damage from all hazards (and 25 percent fewer employees if only earthquake hazards are considered).

In the nine-county region, 96,292 employees both live and work in areas of concentrated damage from all hazards—that is, 3 percent of the nine-county region's employment. This is almost double the number of employees working and living in areas of concentrated damage from earthquake hazards. Another 5 percent of employees work in concentrated-damage areas and another 6 percent of employees live in concentrated-damage areas, which have the potential to greatly widen impacts. In the four counties that contain concentrated-damage areas (Alameda, Contra Costa, Marin, and Solano Counties), 26 percent of the employees work and (or) live in areas of concentrated damage from all hazards, accounting for 6 percent of the 17-county region's employment. Analogous numbers for earthquake hazards are given in table 4; notably, 19 percent of employees in the two counties that contain concentrated-damage areas (Alameda and Contra Costa Counties) work and (or) live in concentrated-damage areas, accounting for 5 percent of the nine-county region's employment.

In 2015, there were more employed residents (about 364,000) than workers (about 328,000) in areas of concentrated damage from all hazards, indicating that these tracts are an overall net exporter of workers (although not for all subareas). For the earthquake hazards case, concentrated-damage areas are a net importer of workers from other locations (about 258,000 workers compared to about 236,000 employed residents). This switch is a result of the disproportionate effect of conflagrations on residences in the HayWired scenario, which increases the number of affected residents more than affected workers. Furthermore, of the approximately 96,000 employees that both work and live in areas of concentrated damage from all hazards, about 70 percent work and live in the same subarea (blue in fig. 13), most commonly in central Alameda County, and the rest live and work in concentrated-damage areas across other subareas (orange in fig. 13).

Industry Segment

For context, employment in the LODES data in the San Francisco Bay region is composed of 15 percent goods-producing jobs, 17 percent trade, transportation, and utilities jobs, and 68 percent all other services jobs. Using the LODES data to track employee residences and workplaces by industry segments, we find that only the industry distribution of workers in concentrated-damage areas (for all hazards) diverges from the region's job composition—10 percent more in trade, transportation, and utilities, and 11 percent less in other services (fig. 14), relating to the lower seismic performance, larger exposure to fire, and more impacted location of industrial/warehouse buildings that strongly determine the designation of concentrated-damage areas compared to other occupancies. The relatively larger percentage of trade, transportation, and utilities industry workers employed in concentrated-damage areas highlights another path by which impacts may spread: if goods shipment to local producers is slowed by damage in the east bay.

Table 4. Employees (in thousands) living and (or) working in concentrated-damage areas for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. Values in thousands of people. Percentages may not sum exactly because of rounding. Numbers for employed residents and workers change with area because some people work or live (respectively) outside of the region. %, percent]

	All hazards			Earthquake hazards		
	Four-county region	Nine-county region	Total region	Four-county region	Nine-county region	Total region
Total employment	1,361	3,708	5,511	1,361	3,708	5,511
People living and working in concentrated-damage areas	96 (7%)	96 (3%)	96 (2%)	51 (4%)	51 (1%)	51 (1%)
Employed residents living in concentrated-damage areas only	121 (9%)	234 (6%)	267 (5%)	91 (7%)	163 (4%)	184 (3%)
Workers working in concentrated-damage areas only	130 (10%)	182 (5%)	232 (4%)	122 (9%)	164 (4%)	206 (4%)
Total employees living and (or) working in concentrated-damage areas	348 (26%)	512 (14%)	595 (11%)	264 (19%)	379 (10%)	442 (8%)

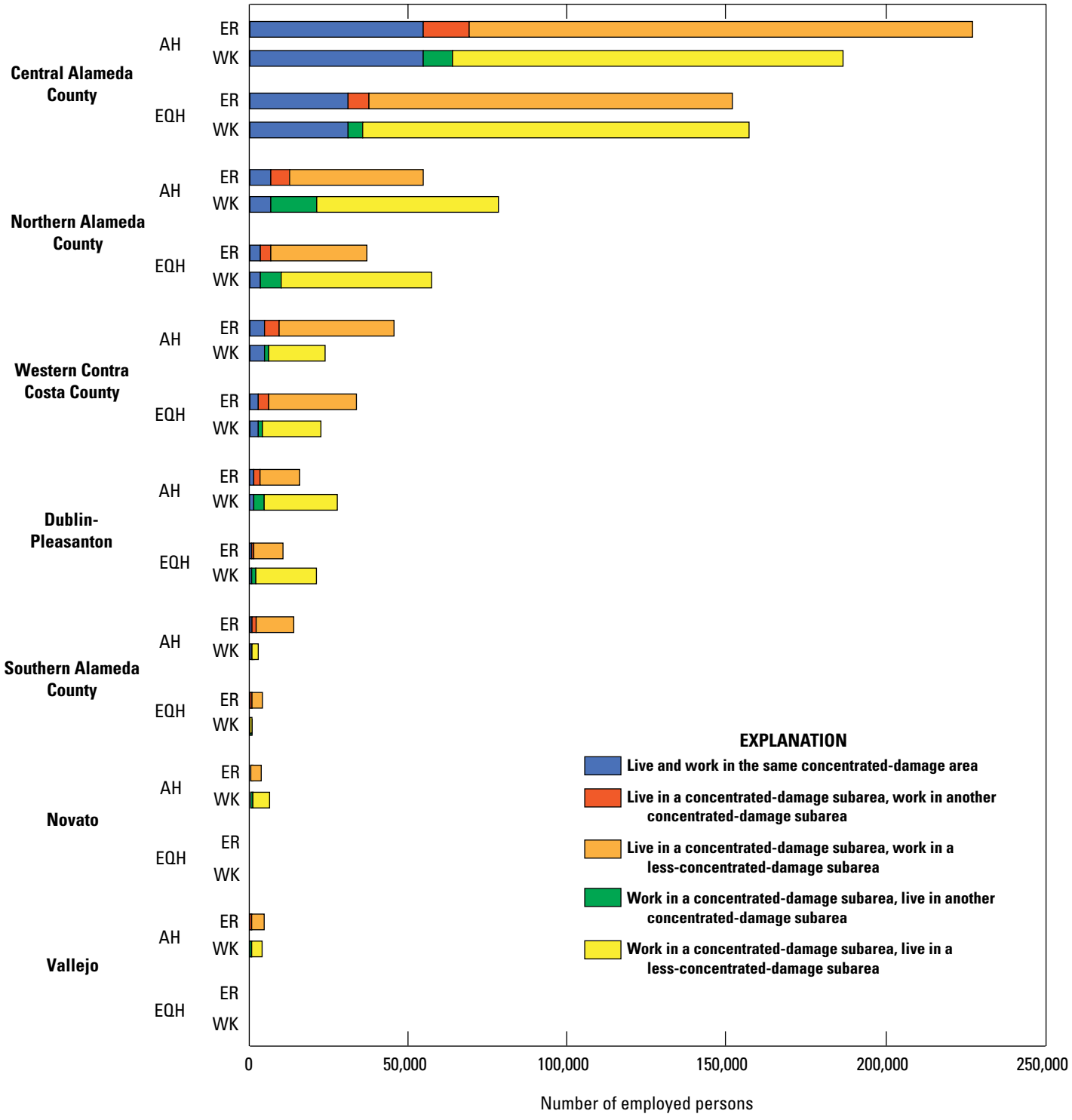

Figure 13. Bar chart showing employed residents and workers in concentrated-damage areas by subarea for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. EQH, earthquake hazards (ground shaking, landslide, liquefaction); AH, all hazards (earthquake hazards plus fire); WK, workers; ER; employed residents.

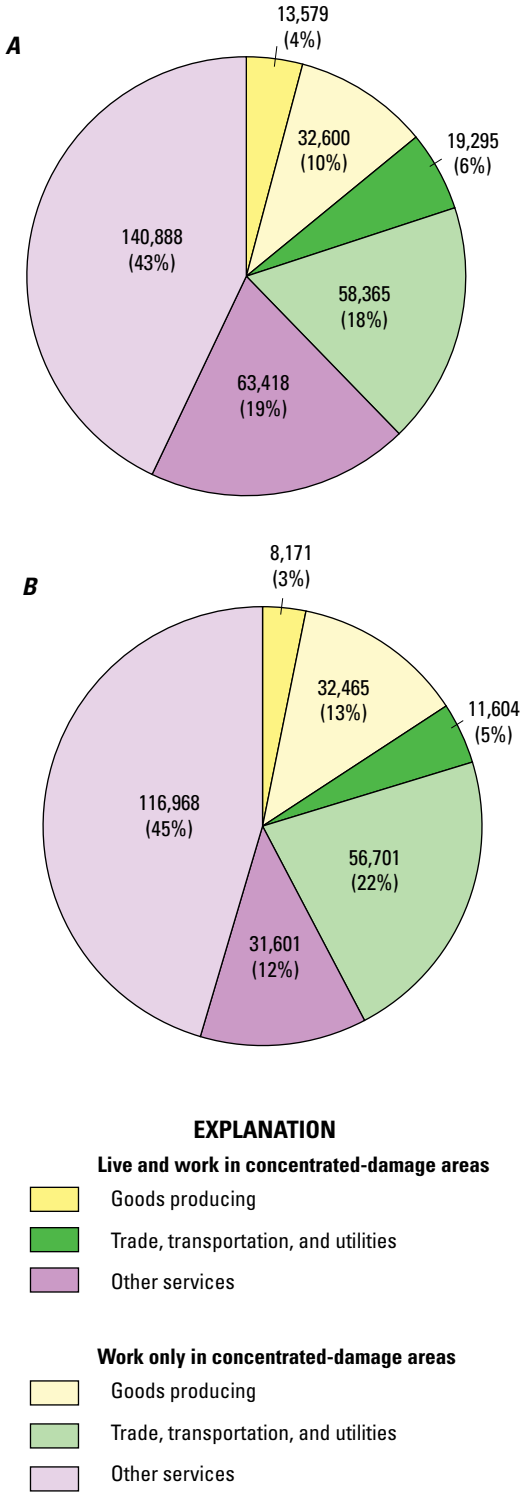

Figure 14. Pie diagrams showing percentages of workers by industry segment in concentrated-damage areas resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California. *A*, All hazards (ground shaking, landslide, liquefaction, and fire following earthquake). *B*, Earthquake hazards (ground shaking, landslide, and liquefaction).

Subarea and Industry Segment

Employed Residents

Figure 15 shows work locations of employed residents living in areas of concentrated damage from all hazards to show the spread of impacts to jobs from employees living in concentrated-damage areas. More than half of these residents have jobs in less-concentrated-damage areas: 81,000 (22 percent) commute to jobs in the remainder of Alameda County (outside of the northern, central, and southern Alameda County subareas), about 51,000 (14 percent) commute to San Francisco, 32,000 commute to Santa Clara County, 25,000 commute to San Mateo County, and 28,000 work in the remainder of Contra Costa County (outside of the western Contra Costa County subarea). Employment districts with less concentrated damage, such as downtown San Francisco, could be adversely affected if many of the people who work in that district have lost their homes, are dealing with repairs, and (or) can no longer get to work because of transportation and (or) relocation challenges (Kroll and others, this volume, explore the economic impacts of commute disruptions). Extensive workforce disruption could occur for about 267,000 employees who live in concentrated-damage areas and work in less-concentrated-damage areas; the degree and duration of impact will depend on the types of plans businesses, responding agencies, and organizations have for employees displaced from their homes or living under difficult conditions.

Breaking out the jobs of employed residents who live in areas of concentrated damage (from all hazards) by industry segment, figure 16 shows that the majority of the goods-producing jobs are in concentrated-damage areas or the less-concentrated-damage areas in the remainder of Alameda County. Santa Clara County is also a significant goods-producing job destination for 13 percent of employed residents in the segment. Trade, transportation, and utilities and other services jobs of resident employees were more distributed across the region. San Francisco is a significant destination for both of these types of jobs and hosts 11 percent of trade, transportation, and utilities jobs and 16 percent of other services jobs held by employed residents living in concentrated-damage areas.

Workers

Figure 17 shows home locations of workers who work in areas of concentrated damage from all hazards to show the spread of impacts to residential neighborhoods and communities. Figures 13, 17, and 18 show that, of the approximately 328,000 workers employed in areas of concentrated damage from all hazards, most would be commuting primarily from three main residential locations: nearly 72,000 (22 percent) from Alameda County remainder, 69,000 (21 percent) from concentrated-damage areas in the central Alameda County subarea, and more than 42,000 (14 percent) from Contra Costa County remainder.

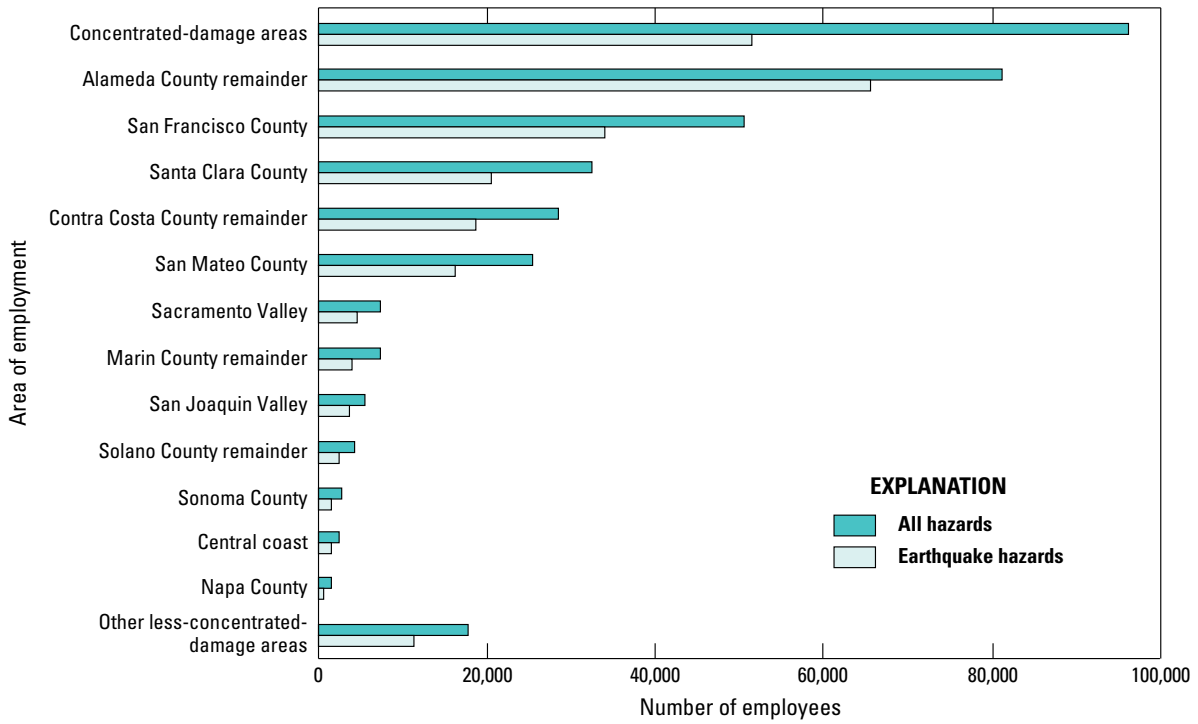

Figure 15. Bar chart showing job locations of employed residents who live in concentrated-damage areas resulting from the HayWired earthquake scenario in the San Francisco Bay region, California. Results are shown for areas of concentrated damage from all hazards (ground shaking, landslide, liquefaction, and fire following earthquake) and earthquake hazards (ground shaking, landslide, and liquefaction). This figure shows the spread of impacts to jobs from workers living in concentrated-damage areas.

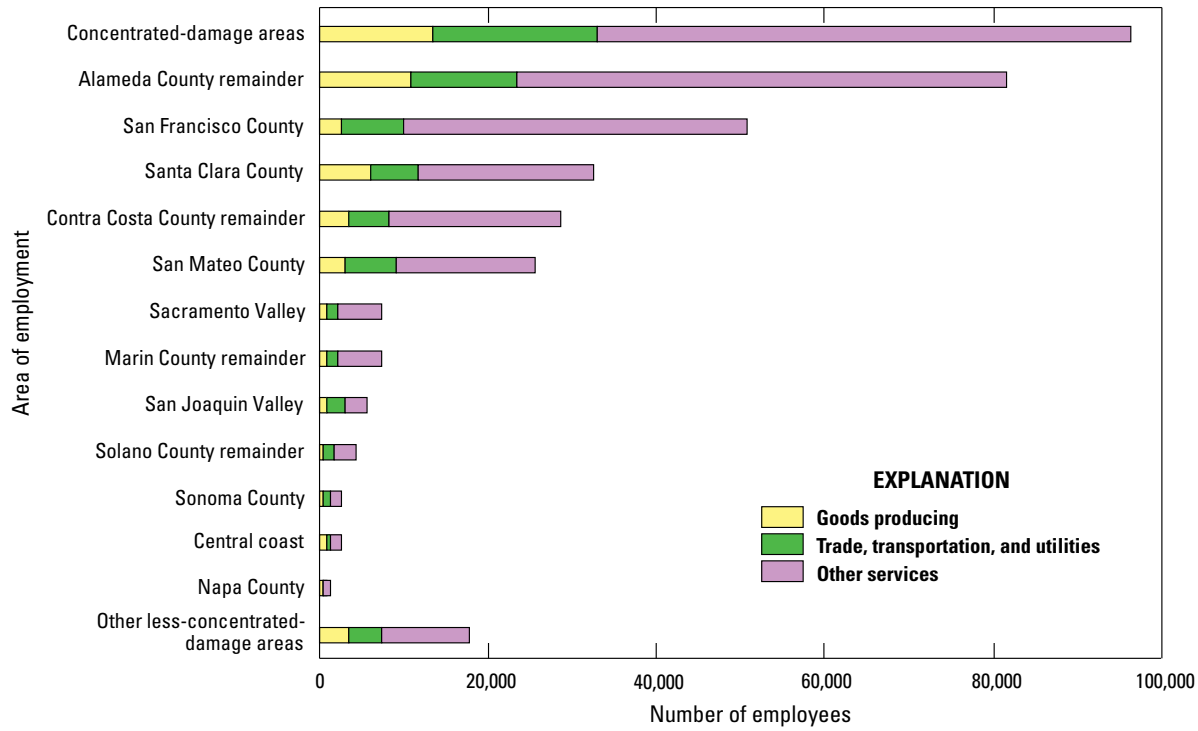

Figure 16. Bar chart showing job locations by employment segment of employed residents who live in concentrated-damage areas from all hazards (ground shaking, landslide, liquefaction, and fire following earthquake) resulting from the HayWired earthquake scenario in the San Francisco Bay region, California.

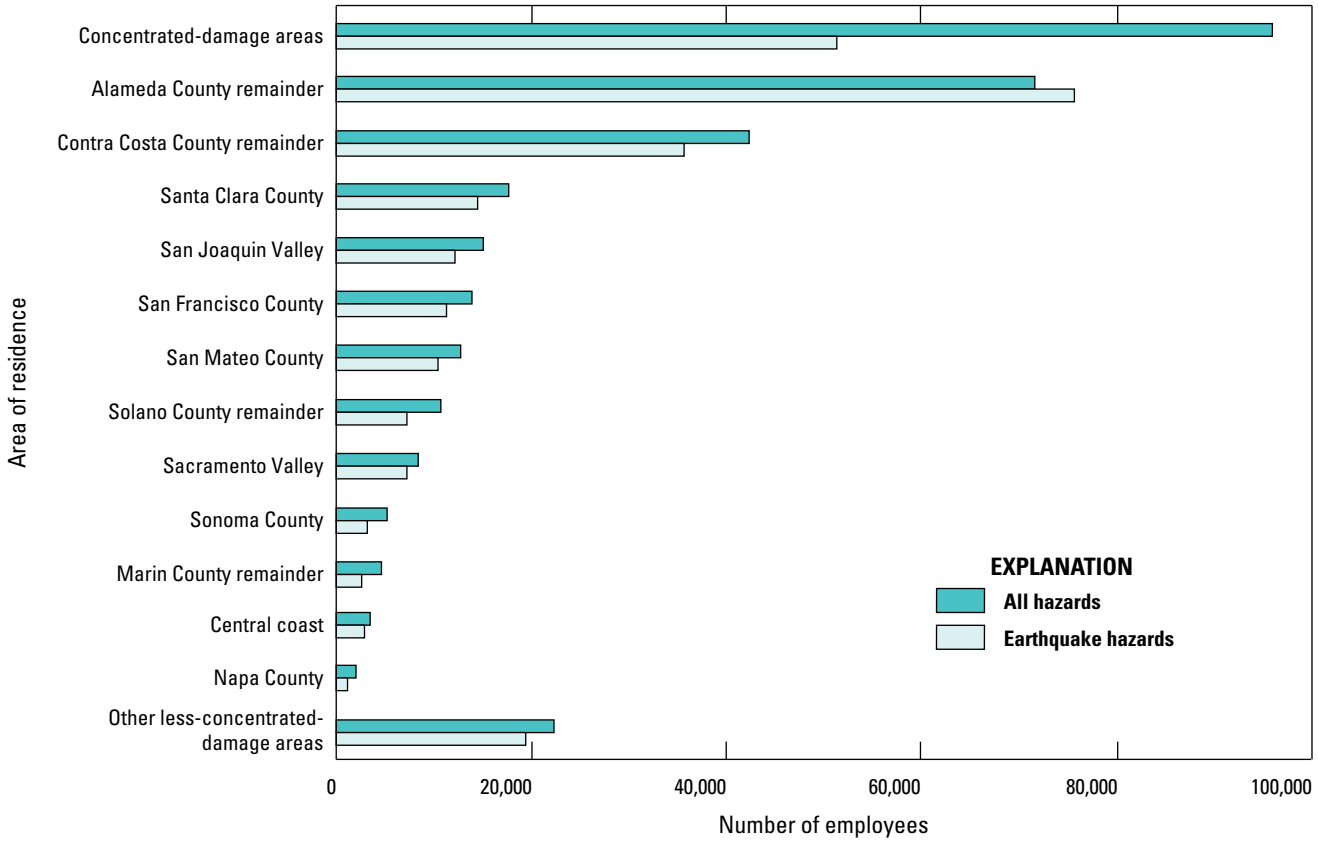

Figure 17. Bar chart showing residential locations of workers employed in concentrated-damage areas resulting from the HayWired earthquake scenario in the San Francisco Bay region, California. Results are shown for areas of concentrated damage from all hazards (ground shaking, landslide, liquefaction, and fire following earthquake) and earthquake hazards (ground shaking, landslide, and liquefaction).

Figure 18 shows where workers in concentrated-damage areas live, and what kinds of jobs they work, broken out into the three industry segments. Outside the concentrated-damage areas, workers mostly live in the remainder of Alameda and Contra Costa Counties. Workers living in the Alameda County remainder composed 21 percent of goods-producing workers, 17 percent of trade, transportation, and utilities workers, and 24 percent of other services workers. About 13 percent of workers employed in concentrated-damage areas in each segment live in the remainder of Contra Costa County. About 7 percent of both goods-producing and trade, transportation, and utilities workers live in Santa Clara County.

Although some of the workers living in less-impacted homes might have jobs that lend themselves to telecommuting, this may be a less-viable solution for the 124,000 people who work in the goods-producing and trade, transportation, and utilities segments that have low rates of working from home (U.S. Bureau of Labor Statistics, 2016).

This section emphasizes home-workplace relations of different industrial types and different subareas. The predominant flows are intra-county; homes and jobs are within or between county subareas that have concentrated-damage areas and the remainder of that county. Notably, most affected employees are commuting within the central Alameda County subarea or between this subarea and the remainder of Alameda County. These intra-Alameda County flows account for almost one-third of the affected home-workplace relations.

More than half of employed residents living in areas of concentrated damage in central Alameda County, approximately 226,500 people, are employed along Bay Area Rapid Transit (BART) routes and the major east bay highways in concentrated-damage areas, the remainder of Alameda County, and San Francisco. These commutes could be challenged (or impossible) if their routes were incapacitated for extended times (see Jones and others, this volume, for damage and restoration estimates of transportation systems, and Kroll and others, this volume, for economic impacts of disrupted commutes).

Other notable inter-county relations are illustrated in tables 3.5–3.8 of appendix 3 and can be summarized as follows:

- 25 percent of northern Alameda County and 19 percent of western Contra Costa County employed residents who live in concentrated-damage areas work in San Francisco.

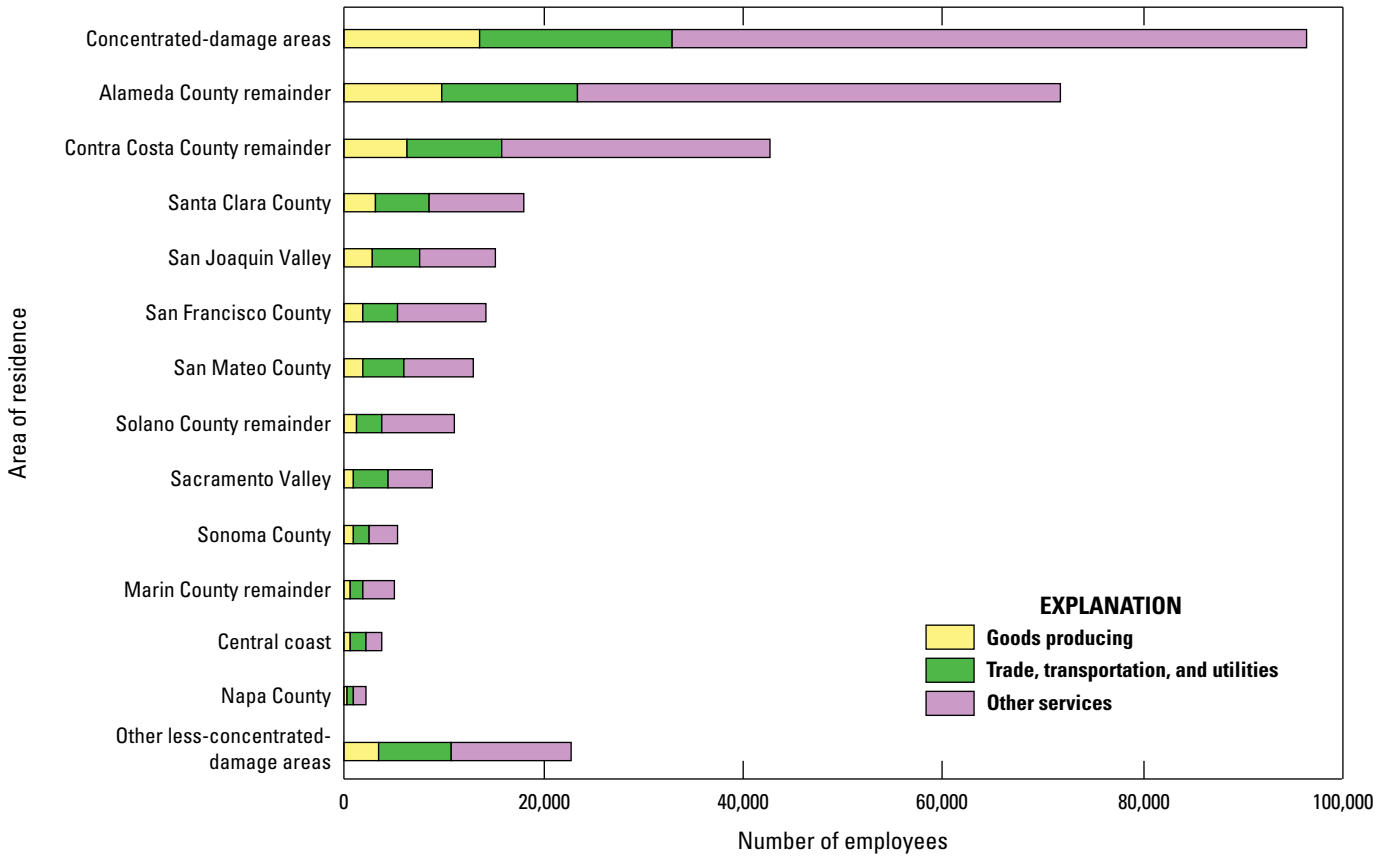

Figure 18. Bar chart showing residence locations of workers by employment segment in concentrated-damage areas from all hazards (ground shaking, landslide, liquefaction, and fire following earthquake) resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

- 31 percent of southern Alameda County and 16 percent of Dublin-Pleasanton employed residents who live in concentrated-damage areas work in Santa Clara County.
- 16 percent of northern Alameda County and 18 percent of Dublin-Pleasanton workers employed in concentrated-damage areas live in the remainder of Contra Costa County.

To illustrate the home-work commute relation, an example of commute flows for the areas of concentrated damage from all hazards in the central Alameda County subarea is provided below. Figure 19 shows, by subregion, how workers flow into the central Alameda County concentrated-damage areas. Figure 20 shows the inverse flow—how residents flow out of the central Alameda County concentrated-damage areas to commute to work. The commute flow of employees completely within the concentrated-damage areas of central Alameda County (the 54,463 people who both live and work in the same subarea) is represented by a circle where the flow arrows converge to (fig. 19) or diverge from (fig. 20).

Commute flow between the areas of concentrated damage from all hazards in central Alameda County and the remainder of Alameda County is the largest flow for both workers and employed residents. Comparing figures 19 and 20, however, it becomes obvious that more employed residents leave the concentrated-damage areas in central Alameda County to go to work than workers enter the same area. More employees commute into San Francisco and San Mateo County than vice versa, whereas the remainder of Contra Costa County sends more employees into the concentrated-damage areas in central Alameda County than the inverse.

Taking into account the distribution of industry segments, (tables 3.9 and 3.10 of appendix 3), we note several other observations.

- Other services workers with jobs in concentrated-damage areas are more likely to also be living in a concentrated-damage area or live in Alameda County remainder compared to workers in the goods-producing and trade, transportation, and utilities segment. However, residents employed in other services who have homes in concentrated-damage areas are less likely to have jobs in concentrated-damage areas compared to the other two industry segments.

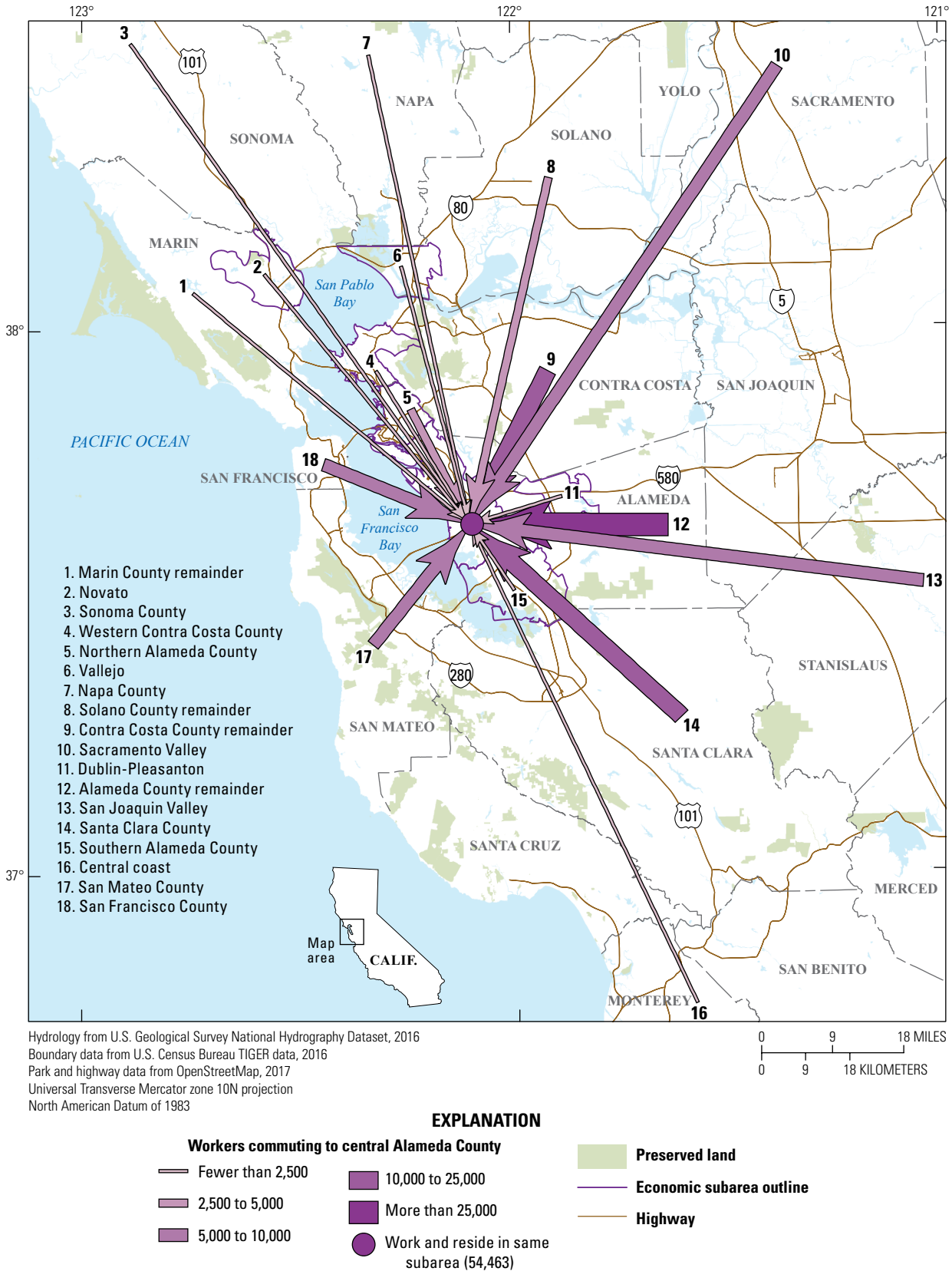

Figure 19. Map showing worker commute flow into areas of concentrated damage from all hazards in the central Alameda County subarea, San Francisco Bay region, California. All hazards refers to damages from all hazards considered for the HayWired earthquake scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Areas with "remainder" in the name are parts of counties outside the defined subareas, and other counties that do not have concentrated-damage areas are also included. More distant counties are aggregated into larger subregions: Sacramento Valley (Sacramento and Yolo Counties), San Joaquin Valley (Merced, San Joaquin, and Stanislaus Counties), and the central coast (Monterey, San Benito, and Santa Cruz Counties).

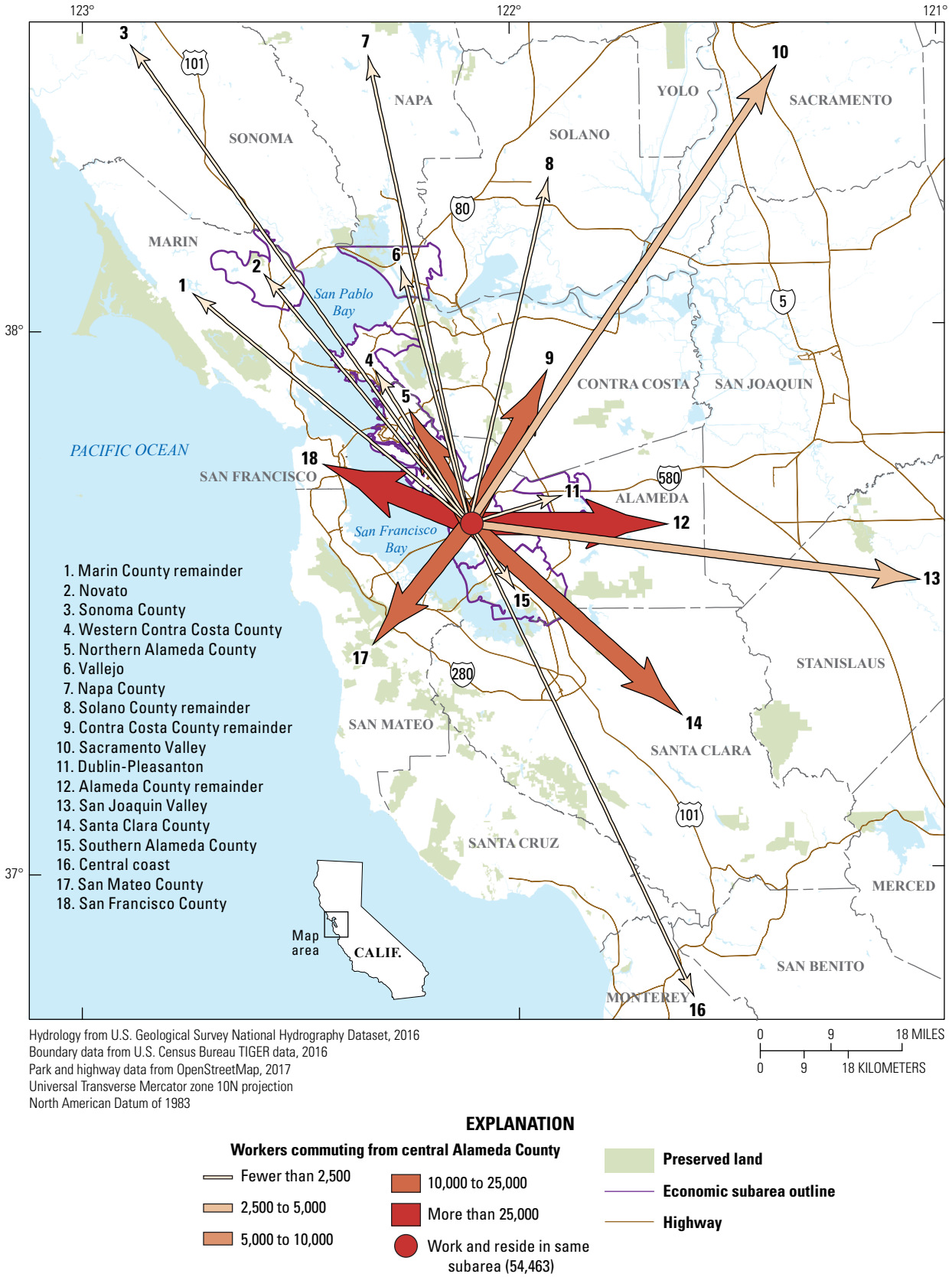

Figure 20. Map showing employed resident flow out of areas of concentrated damage from all hazards in the central Alameda County subarea, San Francisco Bay region, California. All hazards refers to damages from all hazards considered for the HayWired earthquake scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Areas with "remainder" in the name are parts of counties outside the defined subareas, and other counties that do not have concentrated-damage areas are also included. More distant counties are aggregated into larger subregions: Sacramento Valley (Sacramento and Yolo Counties), San Joaquin Valley (Merced, San Joaquin, and Stanislaus Counties), and the central coast (Monterey, San Benito, and Santa Cruz Counties).

- Residences of trade, transportation, and utilities and goods-producing workers with jobs in concentrated-damage areas are more dispersed than other services workers, including a large share of affected workers in Sacramento Valley and the central coast, where trade, transportation, and utilities workers' jobs almost equaled other services jobs in number.
- 13 percent of goods-producing employed residents living in concentrated-damage areas work in Santa Clara County; 11 percent of trade, transportation, and utilities employed residents living in concentrated-damage areas work in San Francisco.

Employee Well-Being

Employee productivity would likely decrease with stress. Employees could be stressed by displacement from their homes and neighborhoods, difficult living conditions, insurance and financial issues, commute disruptions, and business relocations. The enduring stress of aftershocks during the earthquake sequence could persist for all affected populations. Further productivity losses could result from declines in employee well-being because of the loss of loved ones or sustained injuries during the earthquake. Seligson and others (2018) estimate 800 fatalities, 500 life-threatening injuries, 3,000 major injuries, and 12,000 minor injuries that could affect the workforce.

Summary and Discussion

Macroeconomic impact analyses of building and infrastructure damage assessments provide an aggregate estimate of impacts the HayWired scenario could have on the regional economy (Sue Wing and others, in prep. [planned to be published as part of this volume]; Kroll and others, this volume). However, these analyses do not adequately capture the uneven spread of the HayWired scenario's impacts across the San Francisco Bay region. The spatial analysis discussed in this chapter provides a geographical examination of potential business disruption from concentrated damage and considers impacts on both employee workplaces (by industry group or segment) and homes (by single-family/duplex, multifamily, or group living type). Moreover, the spatial analysis reveals the potential spread of direct job impacts in concentrated-damage areas to the communities where those workers live, and the spread of home impacts in concentrated-damage areas to businesses where those residents are employed. This study follows the analytical framework of the communities at risk chapter by Johnson and others (Concentrated Damage, in prep.; planned to be published as part of this volume) and complements its examination of impacts of concentrated damages on housing and communities, potential population displacement, and long-term recovery challenges.

Following a summary of study findings, we draw deeper insights regarding industrial trends from regional studies of the San Francisco Bay region and published literature. We conclude with policy implications for earthquake mitigation, preparation, response, and recovery for emergency managers, businesses, communities, and (or) regional entities. Policies pertain to neighborhood effects of concentrated damage, disproportionate impacts on industrial/warehouse sectors, spread of impacts through home-workplace relations, and spatial economic demand shifts.

Summary of Study Findings

Concentrated Damages

As reported by Johnson and others (Concentrated Damage, in prep.; planned to be published as part of this volume), the total number of census tracts with areas of concentrated damage (where the percentage of extensive or complete damage across all building occupancy groups is greater than 20 percent) across the seven subareas used in this analysis for the all hazards case (ground shaking, landslide, liquefaction, and fire following earthquake) is 173. These 173 tracts make up about 11 percent of the total number of tracts in the nine-county region and are primarily located in Alameda and Contra Costa Counties with fire impacts in Marin and Solano Counties. Of these tracts, 115 (about 7 percent of the census tracts in the nine-county region) are in concentrated-damage areas for the earthquake hazards case (ground shaking, landslide, and liquefaction) within the two primary counties (Alameda and Contra Costa Counties).

A few concentrated-damage tracts correspond to downtown areas. The cities of Hayward and San Leandro have aging downtown cores with concentrations of vulnerable building stock that are heavily damaged in the HayWired scenario (fig. 1). Downtown Pleasanton also sustains concentrated damage from high intensity shaking. Downtown Oakland and San Francisco, which have some even older buildings, are spared from the most intense shaking in the HayWired scenario (but could be highly vulnerable in a different earthquake scenario).

Analyses of concentrated damage from the HayWired scenario show that the building square footage (and consequently businesses and residents at risk) in concentrated-damage areas ranges from more than double to nearly five times more than the square footage that is directly impacted by disruptive (extensive or complete) building damage.

Concentrated Damages and Building Occupancy

Industrial/warehouse, retail/commercial, and (or) multifamily buildings are most likely to contribute to neighborhood damage concentrations from all hazards.[10] The affordable housing crisis could be further distressed by the greater vulnerability of more

[10]Concentrated-damage areas are predominantly determined by industrial/warehouse and retail/commercial classes even before fire following earthquake impacts on residential areas are considered.

affordable housing (for example, aging multifamily housing) (Johnson and others, Communities at Risk Overview and Long-Term Recovery chapters, in prep.; planned to be published as part of this volume).

Group-living housing, most prevalent in the northern Alameda County subarea, is also vulnerable to significant damage, but represents only a very small share of residential square footage. Offices and single-family/duplex buildings generally perform fairly well with respect to damage but may be more affected by their location in neighborhoods composed of more vulnerable buildings.

Household-serving industries are less affected by concentrated damages than other industries but are more closely tied to the households they serve. Household-serving industries could be affected if their customers—the households they serve—are displaced because of damage to multifamily residential buildings. Conversely, single-family/duplex residential neighborhoods would have trouble re-establishing themselves without household services (for example, schools) available (Johnson and others, Communities at Risk Overview and Long-Term Recovery chapters, in prep. [planned to be published as part of this volume]; Xiao and Nilawar, 2013).

Concentrated Damages and Employment

The 2015 workforce in concentrated-damage areas (from all hazards) represents 6 percent of the larger 17-county region, 9 percent of the nine-county region, and 24 percent of the four counties that contain concentrated-damage areas. In Alameda County (the most impacted county in the region), about one-quarter of the total county employment and 57 percent of central Alameda County subarea employment is in concentrated-damage areas. Nearly half of some city-based employment could be located in concentrated-damage areas in Contra Costa County.

Consistent with building occupancy results, industrial/warehouse employment is disproportionately located in concentrated-damage areas. Future work could delve deeper into income losses to employees affected by concentrated damages using more detailed sector data with income distributions or U.S. Bureau of Labor Statistics data. Effects on local expenditures could be estimated using an input-output analysis.

Home and Workplace Relations

Home and workplace relations are defined as one of the following: employees (1) live and work in concentrated-damage areas, (2) live in concentrated-damage areas but work in less-concentrated-damage areas, (3) work in concentrated-damage areas but live in less-concentrated-damage areas, or (4) live and work in less-concentrated-damage areas. About 15 percent of the nine-county San Francisco Bay region's employees are affected by one of the first three relations if all hazards are considered. Of the 96,000 employees who live and work in concentrated-damage areas, 70 percent do so in the same subarea, and 57 percent of these employees live and work in the central Alameda County subarea. The proximity of employee homes to workplaces in Alameda County is corroborated by lower vehicle miles traveled in Alameda County than in other counties in the region (Chapple and others, 2017).

With nearly 420,000 employees with a job or home in a concentrated-damage area in the nine-county region, job losses or relocation and residential population displacement have the potential to greatly widen business impacts. Approximately 81,000 people living in areas of concentrated damage from all hazards commute to jobs in less-concentrated-damage areas in Alameda County (referred to as Alameda County remainder). Further afield, around 51,000 people commute to San Francisco and about 32,000 commute to Santa Clara County. Employment districts, such as downtown San Francisco and some cities in Santa Clara County, could be adversely affected if many of the people who work in these locations are stranded on the day of the earthquake, lose their homes, utility services, and (or) community services (for example, schools are closed), are stressed by living conditions and home repairs, and (or) can no longer get to work because of transportation disruptions. Since fire following earthquake disproportionately affects residences, some businesses could struggle to fill jobs, as their preexisting and potential workforce no longer has housing accessible to jobs, similar to the outcome of the 2017 Santa Rosa fires (D. Guhin, Planning and Economic Development Director for the City of Santa Rosa, oral commun., 2018).

Of the 232,000 people working but not residing in concentrated-damage areas (from all hazards), half of these workers (114,000) are in residential neighborhoods in the remainder of Alameda and Contra Costa Counties. These workers could lose their jobs or be out of work for an extended period with no income, possibly leading to relocation. Such losses would be expressed as declines in spending (sales tax) in local communities and income taxes. Telework from home may be possible; office work generally has more flexibility for telework, but it is a less-viable option for some of the 90,000 employees living in less-concentrated-damage areas who work in goods-producing and trade, transportation, and utilities industry jobs located in concentrated-damage areas.

The movement within concentrated-damage areas and between concentrated- and less-concentrated-damage areas in central Alameda County, Alameda County remainder, San Francisco, and Santa Clara County shows, in addition, how challenging commutes would be if BART as well as the major highways in Alameda County were incapacitated for extended periods of time. The fourth home-workplace relation, between less-concentrated-damage areas, is also not immune to incapacitated major highways and BART lines that could disrupt commutes, especially given that commutes in 2019 were already encumbered in the San Francisco Bay region. Jones and others (this volume) present HayWired scenario transportation system disruptions, and Kroll and others (this volume) use this study with those disruptions to estimate economic impacts of commute disruptions.

Drawing Insights from other Regional Research and Experience

Regional results of concentrated damage from the HayWired scenario are largely driven by the results for the central Alameda County subarea and by industrial/warehouse and retail/commercial damages concentrated within. Industrial buildings in Alameda County are older than in many other parts of the region, with an average age of 60 years (Chapple and others, 2017). The prevalence of these older vulnerable buildings near the epicenter of the earthquake intensifies concentrated damage in the HayWired scenario. Industrial/warehouse and repair (included in our retail/commercial class) are already a focus in regional planning efforts for production, distribution, and repair (PDR) (Chapple and others, 2017, Roach and Chapple, 2018) and warehouse (da Silva and others, 2017) sectors. These studies provide insight into industrial and logistics trends that could influence job diversity, business survivability, and spatial economic demand shifts after a large earthquake on the Hayward Fault.

- The industrial/warehouse industry group that is widely affected by concentrated damage is a primary source of jobs with middle income wages that require fairly low levels of educational attainment (Chapple and others, 2017) and are significant sectors for retaining the region's economic diversity and options for middle-skill workers (Terplan and others, 2014). Significant damage to this building stock could result in eliminating many of these kinds of businesses/jobs in the San Francisco Bay region as businesses may choose to relocate permanently outside of the region, where land and construction costs are lower, and where housing prices for workers are lower.

- Half of the PDR industries in Alameda County are in decline and most are in decline in Contra Costa County (Chapple and others, 2017), particularly in a few manufacturing and construction sectors.[11] Using the employment distributions across counties and subareas (table 2.14 in appendix 2 and table 4.6 in appendix 4 of Wein, Haveman, and others, this volume), we calculate that 32 percent of San Francisco Bay region manufacturing and construction employment is located in Alameda and Contra Costa Counties. Manufacturing employment specifically is disproportionately larger in the subareas (containing all concentrated-damage areas), particularly in Alameda County and the central Alameda County subarea, than in the rest of the region. Construction employment is disproportionately larger in the western Contra Costa County subarea than in the rest of the region. Concentrated damages in these sectors, along with a shrinking share of San Francisco Bay region manufacturing and construction jobs, could exacerbate these trends.

- Concentrated damages could disrupt the efficiency of industrial clusters of manufacturing, research and development, corporate offices, and suppliers in the San Francisco Bay region (Chapple and others, 2017) for the high-tech sector. Many high-tech companies are moving towards manufacturing close to large office operations to enable quicker response time and more collaboration between design, production, and marketing teams (Chapple and others, 2017).

- Two trends are increasing demand for industrial/warehouse buildings in the areas more prone to concentrated damage: (1) the growing "maker movement," on-demand production, and productivity increases made possible by the Internet of Things (IoT), all of which create a demand for small industrial spaces that are in the urban core to be closer to customers; and (2) the rise of just-in-time delivery, which has increased the demand for small warehouses close to dense urban centers (Chapple and others, 2017). These two trends are more tightly coupling customers and suppliers geographically, which potentially intensifies these dependencies in areas of concentrated damage.

- Increased in-sourcing (of previously out-sourced industries) for more customized production and on-demand delivery is occurring in new buildings on the periphery of the urban core in less-developed areas because converting old buildings to modern manufacturing and distribution standards is prohibitively expensive (Chapple and others, 2017). This high-tech contract manufacturing allows companies to prototype products, protect intellectual capital, and decrease turnaround time relative to offshore operations (Chapple and others, 2017). These industries on the region's urban periphery may lose manufacturing customers located in the concentrated-damage areas of the urban core.

- Alameda County offers low rents for PDR production facilities, whereas headquarters might be in high rental areas, such as San Francisco (Chapple and others, 2017). This means that manufacturing will be sensitive to rent increases that occur in response to a scarcity of space from damages or competition with higher uses in mixed-use industrial lands. Businesses that do not own their land and buildings may experience rent increases and thus involuntary displacement. Even those that own their land and buildings may decide to profit from the conversion of their land and move away, in a process of voluntary displacement (Chapple and others, 2017). Headquarters, research and development, and suppliers in close proximity could also relocate from high-rent space in Santa Clara County and San Francisco to be close to the manufacturing facilities that move away.

[11] Industries in decline or losing jobs include boat building, black magnetic and optical recording, semiconductor, electrical instrument measuring, computer storage device, electronic computer manufacturing, drywall and installation contractors, commercial printing, specialty trade contractors, highway and bridge construction, and electric power distribution (Chapple and others, 2017).

- In the "Bay Area Plan 2040," there are some industrial land-use conflicts with priority development areas (PDAs), places identified by San Francisco Bay region communities as areas for investment, new homes, and job growth (Chapple and others, 2017). The industrial land use and PDA areas overlap in concentrated-damage areas along the BART line near the Port of Oakland. Damages to industrial buildings could accelerate the gradual displacement of PDR industries on industrial land with conversion of these lands to other high density uses, including housing.

- Goods-producing workers residing in the remaining areas of Contra Costa and Alameda Counties could be a post-earthquake factor in shifting manufacturing to the outer reaches of those counties if a damaged transportation network decreases access to the industrial concentrations on the eastern shore of San Francisco Bay. However, these areas may be competing for the employers located further from the earthquake impacts, either in neighboring counties or more distant locations.

- Although PDR employment has declined in the region, need for PDR space continues to grow to meet demand for more land for parking and loading. Recent expansion of manufacturing has occurred along Interstate 880 (as has one-third of new research and development activity) with the newest construction located in the southern part of Alameda County, which would be less impacted by the HayWired scenario and could be positioned to absorb more growth.

- Growing industries are mostly in wholesale, transportation, and logistics services (for example, electronic parts and equipment merchant wholesalers), sectors that use few workers per square foot of space. These types of small warehousing spaces close to the urban core enables just-in-time delivery to manufacturers as well as first/last mile delivery of consumer goods to online shoppers. New warehouse spaces are more evenly distributed than manufacturing in the San Francisco Bay region (Chapple and others, 2017). The small urban warehouse spaces work in tandem with large logistics facilities as demonstrated by warehouse growth in Stockton (California) and Reno (Nevada), which has outpaced that in the San Francisco Bay region (da Silva and others, 2017). If more warehousing is absorbed in Sacramento and other outlying areas after a large earthquake, increases in vehicle miles traveled would challenge just-in-time delivery and aggravate an environmental concern for regional planning (da Silva and others, 2017).

- Electronic shopping generates additional demand for large logistics and transportation industries and large e-commerce warehouses. These large entities have been locating on the periphery of the urban core for at least a decade (Chapple and others, 2017). A major earthquake could boost electronic shopping at the expense of more local retail stores at least temporarily, and possibly permanently.

In summary, in addition to the direct loss of jobs from damage and commuting disruption, concentrations of damage from a large earthquake on the Hayward Fault could: (1) accelerate the exit of declining industries; (2) exacerbate the already precarious position of specialized industrial clusters in old manufacturing buildings and move manufacturing to more affordable places, which would create ripple effects to suppliers, customers, research and development, and headquarter operations; and (3) accelerate the gradual conversion of industrial to higher uses in mixed land uses and PDAs, dislocating jobs.

Policy Implications

Learning from prior disasters and insights from regional studies, numerous policy implications are identified below. See Johnson and others (Communities at Risk Overview, in prep.; planned to be published as part of this volume) for other policy implications from the perspective of housing, communities, and local and regional governments affected by areas of concentrated damage.

Concentrated Damages

In areas with concentrated damages, businesses with a local customer base are at risk of losing customers that are displaced from their homes, deterred by physical damage in the business neighborhood, and (or) the loss of neighboring businesses. Where retail and household-serving businesses are already stressed and suffer permanent closure, this would make it harder to draw people back to the neighborhood. Reducing the impacts of neighborhood damage on business may include:

- More resilient businesses have broader customer bases and can more easily relocate, telework, and serve customers online. For businesses that are more dependent on local customers, adaptations would be critical and may even include temporary or permanent closure (for example, Hatton, 2015).

- Contingent business interruption insurance is important to cover losses from indirect causes, such as businesses that are inaccessible to customers (caused by cordons, checkpoints, or fear) resulting from concentrated damage (for example, Battisto and others, 2018).[12]

- Temporary and permanent business losses could potentially be reduced by post-disaster temporary installations of retail/commercial business space near customers. After the 1989 Loma Prieta earthquake, the

[12]CoreLogic (2018) estimated that only 20 percent of commercial losses from damage would be insured for the HayWired scenario.

City of Santa Cruz demonstrated how the provision of temporary retail space near customers can aid recovery (Kroll and others, 1990).

The neighborhood effects of concentrated damages indicate that disaster planning is as important for neighborhoods as it is for individual businesses:

- When a business invests in building retrofits or other mitigations, the action can benefit not just the business itself but also its neighbors (Xiao and Van Zandt, 2011; Johnson and others, Communities at Risk Overview, in prep. [planned to be published as part of this volume]). Conversely, as seen in the 2014 South Napa earthquake, failure of one building spreads risk and impacts to the rest of a block or neighborhood of businesses and residences (Almufti and others, 2016).
- After Hurricane Sandy, grants to repair corridors of concentrated damage and market reopening aimed to bring back foot traffic to all the affected businesses (Battisto and others, 2018).
- Establishing links with neighboring establishments or businesses with similar production processes can provide a support network to call on after an event (for example, see Almufti and others, 2016; Stevenson and others, 2014).

In areas of concentrated damage, cordons may restrict access to blocks of businesses and residences for health and safety reasons because of infrastructure and building damage, aftershock risk, or environmental contamination—the first two conditions precipitated implementation of the central business district cordon following the February 2011 Christchurch earthquake (Chang and others, 2014). In the HayWired scenario, a few downtowns have concentrated damage, but not the dense downtowns of Oakland and San Francisco. The HayWired scenario is only one of many possible outcomes, just as an earthquake is only one of many possible damaging events. Lessons learned about cordons from recent earthquakes include:

- Businesses could improve their chances of survival should they find themselves located in a cordoned area if they bolster their preparedness beforehand to be able to quickly relocate, including moving critical records and supplies (for example, see Chang and others, 2014).
- Planning by emergency managers and building departments to manage a cordon prior to a disaster includes legal mechanisms for establishing a cordon and methods for determining the appropriate spatial extent, identified resources to secure the cordon, a communications plan, a system for deciding who gets access to the cordoned area and under what circumstances (to address the tension between safety and contents retrieval or business resumption), an arrangement for alternate sites where displaced businesses can relocate, and support for legal matters involving leases and civil liberties (Chang and others, 2014; Underwood and others, in press).
- Cordons around concentrations of damage can also be used to accelerate demolition, facilitate construction logistics, ensure that contractors meet professional standards, and enable greater debris sorting and waste management (Chang and others, 2014). Cordons could also increase the risk of long-term displacement to the original businesses and residents, especially if there is major redevelopment or upgrades to the aging building stock or infrastructure (Chang and others, 2014). Cities are cautioned to pursue such transformation opportunities only with full participation of stakeholders in the planning (Johnson and Olshansky, 2017).

When planning for neighborhood recovery from concentrated damages before and after a disaster, addressing both residential and business recovery needs are mutually beneficial to the recovery (Xiao and Van Zandt, 2011). Successful economic neighborhood revitalization lets businesses, property owners, and residents bring their resources to bear, weaving them together in support of a shared built vision and assessment of community needs (International Economic Development Council, 2015). Examples include:

- Efforts to address housing and household services in order to bring staff back to Tulane University (new Orleans) after the population displacement caused by Hurricane Katrina (Cowan, 2007).
- After the northern California wildfires in 2017, Sonoma County is developing a Renewal Enterprise District through a new county-wide joint power authority created to plan for and finance new housing in areas within walking distance of transit and shopping districts to help small businesses (Battisto and others, 2018).

Concentrated Damages by Industry Sector

Disproportionate building and concentrated damages in the industrial/warehouse industry group prompts consideration of resilience planning for these sectors:

- Collaborative resilience planning among industrial clusters would help prepare them for the impacts of concentrations of damage. This could be combined with broader planning for resilience of these clusters as described in the newly adopted Comprehensive Economic Development Strategy for the San Francisco Bay region (found at https://abag.ca.gov/sites/default/files/complete_ceds_with_all_appendices.pdf).
- Programs to protect disproportionate impacts to middle income jobs (particularly in the industrial/warehouse industry group) and training to develop skills to match jobs would be of regional concern. Programs could be developed as part of an economic action plan in support of the Comprehensive Economic Development Strategy.
- Regional agencies are developing a Priority Production Area program for "Plan Bay Area 2050" that identifies

geographies where measures are needed to preserve manufacturing, distribution and repair services, and middle wage jobs. The programs targeted to these areas could include consideration of resilience measures that would be helpful pre- and post-earthquake and integrate such measures into the Priority Production Area program.

Home-Workplace Relations Affected by Damage Concentrations

For business continuity planning, the home-workplace relation highlights the need for:

- Plans and resources for employee well-being in response to stress of displacement from their homes, difficult living conditions, or insurance and financial issues, and need for temporary accommodation; and
- Plans for telework and alternative work places if workplaces become inaccessible.

Many cities could lose jobs, residents, and (or) resident income. This has ramifications for the tax base when property tax revenues drop for distressed properties, sales tax revenues decline from reduced spending, and workplaces or homes are vacated. The most badly damaged cities are likely to experience the highest losses relative to total budget and have neither the insurance nor a reserve base large enough to deal with the cost required for recovery.

- State government and local jurisdictions may need to plan together to determine how the revenue losses of a widespread event should be shared and ensure that the local governments most in need of revenue for recovery have access to necessary resources. This could involve developing a reserve fund through contributions from state and local sources or an insurance program to cover lost revenues in impacted areas.

Spatial Economic Demand Shifts

Planning and resource allocations for spatial economic demand shifts would be a regional issue for the San Francisco Bay region and beyond. In the initial recovery, economic demand may shift spatially from slow growth in the damaged core to high growth outside. The nature of growth in areas near the core damaged area may change, with short-term "fixes" having long-term implications (for example, see Xiao and Nilawar, 2013; Brown and others, 2015). Various planning initiatives could need to be funded after a large earthquake in the east bay part of the San Francisco Bay region. These include:

- Leveraging current regional industrial and logistic planning discussions with respect to mitigating, preparing, responding, and recovering from an earthquake—for example, application of the criteria for industrial preservation and conservation, as proposed by Chapple and others (2017).
- Using major disruption of land use and routes as an opportunity to improve planning for greenhouse gas reductions. Regional and local jurisdictions would need to be prepared beforehand to launch a planning process that addresses the needs of local property owners and residents as alternative travel patterns, land uses, and land use intensity are considered.
- Considering earthquake impacts to supply chains (including the ports) in regional transportation planning. The Association of Bay Area Governments (ABAG), for example, funded a study on the role of airports in a disaster (Perkins, 2015) as part of a larger initiative reviewing vulnerabilities in transportation and utilities systems (available at http://resilience.abag.ca.gov/projects/transportation_utilities_2014/).
- Dove-tailing earthquake planning and policy making with the currently energized regional planning for climate change. East bay shoreline liquefaction hazards overlap with flood hazards and sea level rise as is recognized in the "Stronger Housing, Safer Communities" effort by ABAG (available at http://resilience.abag.ca.gov/projects/stronger_housing_safer_communities_2015/). The San Francisco Bay Area Planning and Urban Research Association (SPUR) promotes a regional strategy for improving resilience to multiple natural hazards (Tam and Johnson, 2020).
- Within the alternatives that will be considered for rebuilding after the earthquake, seizing opportunities for other parts of the 21-county northern California megaregion (Bellisario and others, 2016). Balancing relocation and rebuilding within the east bay with opening up megaregion opportunities will need to weigh resilient logistics, reduced risk of concentrated damage to vulnerable housing, and sustainable workplace-home relations against the risks of further supply chain disruptions should another earthquake occur. Substantial planning, infrastructure, and business network support might be needed to facilitate potential shifts in development of the megaregion, in circumstances where rebuilding the pre-earthquake business and community networks is not feasible.

Stakeholder Considerations

Our analysis of concentrated-damage areas raises considerations for various stakeholders:

- For emergency managers and building departments, considerations include preparing to manage many issues around neighborhood safety, demolition efficiency, and business resumption in areas with concentrated damage where cordons may be necessary.
- For businesses, considerations include preparing for neighborhood effects on their business operations

and critical infrastructure, impacts of employee living situations, work relocation plans with respect to their customers and employee residences, particular vulnerabilities of their sector, and their role in neighborhood resilience and recovery. This preparation could benefit from being done cooperatively with similar types of businesses and within the context of city or regionwide resilience plans, to be able to address the differing needs of businesses of different sizes and sectors.

- For communities and city and county jurisdictions, considerations include policies for effective mitigation of vulnerable neighborhoods, providing services to keep residents in their homes, identifying space and resources for business resumption, commitment to retaining PDR sectors, acquiring and coordinating resource allocations for recovery of residences and businesses in tandem, and planning for a reduced tax base after an earthquake through effects on employment and displaced employed residents.
- For regional scale government, considerations include mitigating, preparing for planning, and allocating resources to areas that lag in recovery, and to manage spatial economic demand shifts.
- For multiple levels of government and the private sector, considerations include exploring insurance mechanisms to respond to the fiscal consequences of a major earthquake, fire, and related damage (see Johnson and others, Communities at Risk Overview, in prep.; planned to be published as part of this volume).

Each of these stakeholders face budget and time constraints that may impede taking steps in advance to address the large but uncertain risks posed by a major earthquake along the Hayward Fault. However, budgeting for planning and mitigation efforts in advance of an event will allow more effective responses that address a broad range of stakeholders' needs when an event occurs. Much of the planning and preparation that is required to be prepared is also an investment that addresses the region's future more widely.

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Appendixes 1–3

Appendix 1. Correspondence Tables

Table 1.1. Building count correspondence from Hazus-MH 2.1.

[ft², square feet]

Hazus building occupancy	Description	Average size (ft²)
RES1	Single family	1,600
RES2	Mobile home	1,080
RES3A	Duplex	3,000
RES3B	Multifamily (3–4)	3,000
RES3C	Multifamily (5–9)	8,000
RES3D	Multifamily (10–19)	12,000
RES3E	Multifamily (20–49)	40,000
RES3F	Multifamily (50+)	60,000
RES4	Hotel/motel	135,000
RES5	Dormitories	25,000
RES6	Nursing home	25,000
COM1	Retail trade	110,000
COM2	Warehouse	30,000
COM3	Personal and repair services	10,000
COM4	Professional/technical services	80,000
COM5	Banks	4,100
COM6	Hospital	55,000
COM7	Medical office/clinic	7,000
COM8	Entertainment and recreation	5,000
COM9	Theaters	12,000
COM10	Parking	145,000
IND1	Industrial-Heavy	30,000
IND2	Industrial-Light	30,000
IND3	Industrial-Food/drugs/chemicals	45,000
IND4	Industrial-Metals/minerals processing	45,000
IND5	Industrial-High tech	45,000
IND6	Industrial-Construction	30,000
AGR1	Agriculture	30,000
REL1	Church/non-profit	17,000
GOV1	Government-General services	11,000
GOV2	Government-Emergency response	11,000
EDU1	Grade schools	130,000
EDU2	Colleges/universities	50,000

Table 1.2. LODES industry segment correspondence.

[LODES, LEHD Origin-Destination Employment Statistics; LEHD, Longitudinal Employer-Household Dynamics; NAICS, North American Industry Classification System]

LODES industry segment	NAICS sector	Industry description
Goods producing	11	Agriculture, forestry, fishing, and hunting
	21	Mining, quarrying, and oil and gas extraction
	23	Construction
	31–33	Manufacturing
Trade, transportation, and utilities	22	Utilities
	42	Wholesale trade
	44–45	Retail trade
	48–49	Transportation and warehousing
Other services	51	Information
	52	Finance and insurance
	53	Real estate and rental and leasing
	54	Professional, scientific, and technical services
	55	Management of companies and enterprises
	56	Administration, support and waste management, and remediation
	61	Education
	62	Health and social services
	71	Arts, entertainment, and recreation
	72	Accommodation and food
	81	Other services
	92	Public administration

Appendix 2. Building Damages

Table 2.1. Disruptive damage for nonresidential buildings by occupancy group in concentrated-damage areas resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Occupancy group	Disruptive damage (ft^2)	Concentrated-damage areas (ft^2)	Percentage of occupancy group with disruptive damage	Percentage of total disruptive damage
All hazards				
Industrial/warehouse	27,599,713	62,921,624	44	17
Retail/commercial	24,030,474	60,025,720	40	14
Offices	10,479,760	29,497,195	36	6
Household serving	7,000,208	16,807,935	42	4
Agricultural uses	313,649	963,800	33	0.2
Total	**69,423,804**	**170,216,274**	**41**	**42**
Earthquake hazards				
Industrial/warehouse	25,492,796	58,552,397	44	23
Retail/commercial	19,636,682	47,598,063	41	18
Offices	8,744,959	23,699,591	37	8
Household serving	4,734,527	12,139,383	39	4
Agricultural uses	247,644	703,489	35	0.2
Total	**58,856,608**	**142,692,923**	**41**	**53**

Table 2.2. Disruptive damage for residential buildings by occupancy group in concentrated-damage areas resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Occupancy group	Disruptive damage (ft^2)	Concentrated-damage areas (ft^2)	Percentage of occupancy group with disruptive damage	Percentage of total disruptive damage
All hazards				
Single family/duplex	65,198,410	301,216,785	22	39
Multifamily	28,022,305	64,907,344	43	17
Group living	3,121,621	8,086,883	39	2
Total	**96,342,336**	**374,211,012**	**26**	**58**
Earthquake hazards				
Single family/duplex	33,582,773	181,490,753	19	30
Multifamily	16,331,727	45,949,663	36	15
Group living	1,841,762	4,921,043	37	2
Total	**51,756,262**	**232,361,459**	**22**	**47**

Table 2.3. Total disruptive damage for nonresidential occupancy groups by subarea with concentrated damages resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Number of tracts with concentrated damage	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards					
Central Alameda County	106	46,319,962	100,977,993	46	67
Northern Alameda County	30	11,275,340	34,605,561	33	16
Western Contra Costa County	6	5,670,589	12,357,460	46	8
Dublin-Pleasanton	21	4,960,477	15,282,373	32	7
Southern Alameda County	1	497,914	1,796,104	28	1
Novato	5	408,909	2,413,169	17	1
Vallejo	4	290,613	2,783,614	10	0.4
Subarea total	**173**	**69,423,804**	**170,216,274**	**41**	**100**
Earthquake hazards					
Central Alameda County	72	41,187,231	91,392,743	45	70
Northern Alameda County	22	9,187,735	28,722,807	32	16
Western Contra Costa County	4	4,888,509	10,781,497	45	8
Dublin-Pleasanton	15	3,525,177	11,555,250	31	6
Southern Alameda County	2	67,956	240,626	28	0.1
Novato	0	0	0	0	0
Vallejo	0	0	0	0	0
Subarea total	**115**	**58,856,608**	**142,692,923**	**41**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.4. Industrial/warehouse occupancy with disruptive damage by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	21,813,702	46,248,331	47	79
Northern Alameda County	3,023,652	8,644,377	35	11
Western Contra Costa County	955,275	2,095,403	46	4
Dublin-Pleasanton	1,532,181	4,167,978	37	6
Southern Alameda County	85,982	293,486	29	0.3
Novato	152,488	1,073,913	14	1
Vallejo	36,433	398,136	9	0.1
Subarea total	**27,599,713**	**62,921,624**	**44**	**100**
Earthquake hazards				
Central Alameda County	20,694,092	45,302,326	46	81
Northern Alameda County	2,689,719	7,709,791	35	11
Western Contra Costa County	839,733	1,899,985	44	4
Dublin-Pleasanton	1,248,444	3,566,292	35	5
Southern Alameda County	20,808	74,003	28	0.1
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**25,492,796**	**58,552,397**	**44**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.5. Retail/commercial occupancy with disruptive damage by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	14,267,740	31,271,952	46	59
Northern Alameda County	4,200,828	12,931,928	32	18
Western Contra Costa County	3,212,139	7,016,672	46	13
Dublin-Pleasanton	1,908,605	5,962,536	32	8
Southern Alameda County	251,600	936,327	27	1
Novato	58,185	367,260	16	0.2
Vallejo	131,377	1,539,045	9	1
Subarea total	**24,030,474**	**60,025,720**	**40**	**100**
Earthquake hazards				
Central Alameda County	12,052,438	26,200,498	46	61
Northern Alameda County	3,703,925	11,610,384	32	19
Western Contra Costa County	2,722,179	5,874,397	46	14
Dublin-Pleasanton	1,125,075	3,800,296	30	6
Southern Alameda County	33,065	112,488	29	0.2
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**19,636,682**	**47,598,063**	**41**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.6. Offices occupancy with disruptive damage by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	5,995,458	14,019,107	43	57
Northern Alameda County	2,304,512	8,283,010	28	22
Western Contra Costa County	819,714	1,846,762	44	8
Dublin-Pleasanton	1,184,326	4,049,269	29	11
Southern Alameda County	71,135	290,456	24	1
Novato	86,314	735,504	12	1
Vallejo	18,301	273,087	7	0.2
Subarea total	**10,479,760**	**29,497,195**	**36**	**100**
Earthquake hazards				
Central Alameda County	5,418,493	12,821,908	42	62
Northern Alameda County	1,624,274	5,681,359	29	19
Western Contra Costa County	734,480	1,710,149	43	8
Dublin-Pleasanton	957,318	3,444,364	28	11
Southern Alameda County	10,394	41,811	25	0.1
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**8,744,959**	**23,699,591**	**37**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.7. Household-serving occupancy with disruptive damage by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	4,059,125	8,930,273	45	58
Northern Alameda County	1,716,836	4,631,949	37	25
Western Contra Costa County	639,340	1,295,490	49	9
Dublin-Pleasanton	285,386	918,117	31	4
Southern Alameda County	84,049	253,520	33	1
Novato	111,348	218,770	51	2
Vallejo	104,124	559,816	19	2
Subarea total	**7,000,208**	**16,807,935**	**42**	**100**
Earthquake hazards				
Central Alameda County	2,865,033	6,652,334	43	61
Northern Alameda County	1,144,831	3,621,353	32	24
Western Contra Costa County	551,822	1,203,011	46	12
Dublin-Pleasanton	169,152	650,361	26	4
Southern Alameda County	3,689	12,324	30	0.1
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**4,734,527**	**12,139,383**	**39**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.8. Agricultural uses occupancy with disruptive damage by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	183,937	508,330	36	59
Northern Alameda County	29,512	114,297	26	9
Western Contra Costa County	44,121	103,133	43	14
Dublin-Pleasanton	49,979	184,473	27	16
Southern Alameda County	5,148	22,315	23	2
Novato	574	17,722	3	0.2
Vallejo	378	13,530	3	0.1
Subarea total	**313,649**	**963,800**	**33**	**100**
Earthquake hazards				
Central Alameda County	157,175	415,677	38	64
Northern Alameda County	24,986	99,920	25	10
Western Contra Costa County	40,295	93,955	43	16
Dublin-Pleasanton	25,188	93,937	27	10
Southern Alameda County	0	0	0	0
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**247,644**	**703,489**	**35**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.9. Total disruptive damage for residential occupancy groups by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damage from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	59,139,171	226,755,128	26	61
Northern Alameda County	15,091,522	61,039,246	25	16
Western Contra Costa County	11,837,609	45,582,106	26	12
Dublin-Pleasanton	3,228,128	16,439,482	20	3
Southern Alameda County	3,986,927	15,733,799	25	4
Novato	923,639	2,127,193	43	1
Vallejo	2,135,340	6,534,058	33	2
Subarea total	**96,342,336**	**374,211,012**	**26**	**100**
Earthquake hazards				
Central Alameda County	33,215,542	147,066,446	23	64
Northern Alameda County	9,213,063	36,576,990	25	18
Western Contra Costa County	6,790,192	33,997,751	20	13
Dublin-Pleasanton	1,504,494	10,218,553	15	3
Southern Alameda County	1,032,971	4,501,719	23	2
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**51,756,262**	**232,361,459**	**22**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.10. Single family/duplex occupancy with disruptive damage by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	41,000,566	187,089,779	22	63
Northern Alameda County	8,745,996	41,706,938	21	13
Western Contra Costa County	7,778,963	37,106,849	21	12
Dublin-Pleasanton	2,668,035	14,721,031	18	4
Southern Alameda County	3,355,296	14,124,979	24	5
Novato	576,745	1,712,544	34	1
Vallejo	1,072,809	4,754,665	23	2
Subarea total	**65,198,410**	**301,216,785**	**22**	**100**
Earthquake hazards				
Central Alameda County	22,415,554	118,974,996	19	67
Northern Alameda County	4,818,541	22,402,794	22	14
Western Contra Costa County	4,250,551	27,080,846	16	13
Dublin-Pleasanton	1,228,508	9,129,562	13	4
Southern Alameda County	869,619	3,902,555	22	3
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**33,582,773**	**181,490,753**	**19**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.11. Multifamily occupancy with disruptive damage by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	15,965,391	34,625,980	46	57
Northern Alameda County	5,748,605	17,265,910	33	21
Western Contra Costa County	3,832,968	7,862,251	49	14
Dublin-Pleasanton	514,768	1,579,560	33	2
Southern Alameda County	604,852	1,525,531	40	2
Novato	311,694	335,710	93	1
Vallejo	1,044,027	1,712,402	61	4
Subarea total	**28,022,305**	**64,907,344**	**43**	**100**
Earthquake hazards				
Central Alameda County	9,490,609	25,018,380	38	58
Northern Alameda County	4,040,679	12,924,281	31	25
Western Contra Costa County	2,374,904	6,378,633	37	15
Dublin-Pleasanton	266,941	1,045,300	26	2
Southern Alameda County	158,594	583,069	27	1
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**16,331,727**	**45,949,663**	**36**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 2.12. Group-living residential occupancy with disruptive damage by subarea with concentrated damage resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Disruptive damage is defined as extensive or complete damage according to Hazus analysis. All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake (these damages were added exclusively as complete damage). Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. ft^2, square feet]

Subarea	Disruptive damage (ft^2)	Concentrated-damage area (ft^2)	Percentage of disruptive damage in concentrated-damage areas	Percentage of total concentrated-damage areas[1]
All hazards				
Central Alameda County	2,173,214	5,039,369	43	70
Northern Alameda County	596,921	2,066,398	29	19
Western Contra Costa County	225,678	613,006	37	7
Dublin-Pleasanton	45,325	138,891	33	2
Southern Alameda County	26,779	83,289	32	1
Novato	35,200	78,939	45	1
Vallejo	18,504	66,991	28	1
Subarea total	**3,121,621**	**8,086,883**	**39**	**100**
Earthquake hazards				
Central Alameda County	1,309,379	3,073,070	43	71
Northern Alameda County	353,843	1,249,915	28	20
Western Contra Costa County	164,737	538,272	31	9
Dublin-Pleasanton	9,045	43,691	21	1
Southern Alameda County	4,758	16,095	30	0.3
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**1,841,762**	**4,921,043**	**37**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Appendix 3. Employed Residents and Workers

Table 3.1. Total employed residents and workers living or working in concentrated-damage areas from HayWired earthquake scenario mainshock hazards, San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction]

Subarea	Employed residents		Workers	
	Number	Percentage[1]	Number	Percentage[1]
All hazards				
Central Alameda County	226,648	62	186,191	57
Northern Alameda County	54,363	15	78,107	24
Western Contra Costa County	44,902	12	23,882	7
Dublin-Pleasanton	15,723	4	27,742	8
Southern Alameda County	14,035	4	2,375	1
Novato	3,035	1	5,703	2
Vallejo	4,858	1	4,145	1
Subarea total	**363,564**	**100**	**328,145**	**100**
Earthquake hazards				
Central Alameda County	151,183	64	157,000	61
Northern Alameda County	36,852	16	56,874	22
Western Contra Costa County	33,348	14	22,087	9
Dublin-Pleasanton	10,268	4	21,160	8
Southern Alameda County	4,183	2	389	0.2
Novato	0	0	0	0
Vallejo	0	0	0	0
Subarea total	**235,834**	**100**	**257,510**	**100**
Regional totals				
Alameda County	750,932	49	747,446	55
Contra Costa County	476,423	31	358,028	26
Marin County	104,987	7	111,746	8
Solano County	185,506	12	143,731	11
Counties with concentrated-damage areas	**1,517,848**	**30**	**1,360,951**	**26**
Nine-county study region	**3,498,141**	**70**	**3,708,216**	**72**
17-county study region	**5,033,129**	**100**	**5,169,136**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 3.2. Employed residents who work in concentrated-damage areas, by subarea, for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction]

Residence subarea	All hazards		Earthquake hazards	
	Number	Percentage[1]	Number	Percentage[1]
Central Alameda County	69,144	72	37,095	72
Northern Alameda County	12,105	13	6,638	13
Western Contra Costa County	9,396	10	5,852	11
Dublin-Pleasanton	2,975	3	1,397	3
Southern Alameda County	1,810	2	394	1
Novato	280	0.3	0	0
Vallejo	582	1	0	0
Total	**96,292**	**100**	**51,376**	**100**

[1]Because of rounding, percentages may not sum to 100 percent.

Table 3.3. Workers who live in concentrated-damage areas, by subarea, for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction]

Work subarea	All hazards		Earthquake hazards	
	Number	Percentage[1]	Number	Percentage[1]
Central Alameda County	63,593	66	35,674	69
Northern Alameda County	20,827	22	9,792	19
Western Contra Costa County	5,849	6	3,668	7
Dublin-Pleasanton	4,447	5	2,117	4
Southern Alameda County	736	1	125	0.2
Novato	449	0.5	0	0
Vallejo	391	0.4	0	0

[1]Because of rounding, percentages may not sum to 100 percent.

Table 3.4. People who live and work in concentrated-damage areas in the same subarea for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction]

Residence/work subarea	All hazards		Earthquake hazards	
	Number	Percentage[1]	Number	Percentage[1]
Central Alameda County	54,463	80	30,920	81
Northern Alameda County	6,793	10	3,539	9
Western Contra Costa County	4,241	6	2,701	7
Dublin-Pleasanton	1,545	2	747	2
Southern Alameda County	345	1	98	0.3
Novato	166	0.2	0	0
Vallejo	233	0.3	0	0

[1]Because of rounding, percentages may not sum to 100 percent.

Table 3.5. Employed residents living in concentrated-damage areas (from all hazards) with respect to their work locations in concentrated- and less-concentrated-damage areas resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Records are color coded from smallest (white) to largest (dark red) within each column for ease of identifying regions with the most employed residents working in them]

Place of work	Place of residence															
	Central Alameda County		Northern Alameda County		Western Contra Costa County		Southern Alameda County		Dublin-Pleasanton		Vallejo		Novato		Total for subareas	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Employees living and working in a concentrated-damage area																
Central Alameda County	54,463	24	4,670	9	2,096	5	1,106	8	1,075	7	138	3	45	1	63,593	17
Northern Alameda County	10,667	5	6,793	12	2,773	7	174	1	312	2	71	1	37	1	20,827	6
Dublin-Pleasanton	2,434	1	183	0	97	0	155	1	1,545	10	26	1	7	0	4,447	1
Western Contra Costa County	1,072	0	365	1	4,241	10	21	0	32	0	93	2	25	1	5,849	2
Southern Alameda County	340	0	28	0	12	0	345	2	10	0	1	0	0	0	736	0
Novato	100	0	48	0	108	0	7	0	0	0	20	0	166	5	449	0
Vallejo	68	0	18	0	69	0	2	0	1	0	233	5	0	0	391	0
Subtotal	**69,144**	**31**	**12,105**	**22**	**9,396**	**22**	**1,810**	**13**	**2,975**	**19**	**582**	**12**	**280**	**9**	**96,292**	**26**
Employees living in a concentrated-damage area and working in a less-concentrated-damage area																
Alameda County remainder	52,496	23	13,653	25	6,940	15	3,631	26	4,144	26	325	7	124	4	81,313	22
San Francisco County	25,667	11	13,372	25	8,706	19	912	6	1,026	7	445	9	535	18	50,663	14
Santa Clara County	20,944	9	2,721	5	1,727	4	4,305	31	2,581	16	177	4	96	3	32,551	9
San Mateo County	18,514	8	2,807	5	1,707	4	1,414	10	794	5	141	3	110	4	25,487	7
Contra Costa County remainder	14,022	6	3,602	7	7,423	15	421	3	2,150	14	611	13	136	4	28,365	8
Sacramento Valley	4,302	2	907	2	1,146	3	223	2	268	2	245	5	67	2	7,158	2
San Joaquin Valley	3,474	2	669	1	690	1	197	1	397	3	125	3	37	1	5,589	2
Marin County remainder	1,998	1	788	1	2,888	6	57	0	99	1	228	5	1,236	41	7,294	2
Solano County remainder	1,729	1	367	1	938	2	85	1	125	1	1,063	22	43	1	4,350	1
Central coast	1,591	1	326	1	287	1	102	1	115	1	26	1	11	0	2,458	1
Sonoma County	1,376	1	341	1	492	1	61	0	82	1	199	4	199	7	2,750	1
Napa County	519	0	137	0	278	1	22	0	23	0	420	9	30	1	1,429	0
Other	10,872	5	2,568	5	2,284	6	795	6	944	6	271	6	131	4	17,865	5
Subtotal	**157,504**	**69**	**42,258**	**78**	**35,506**	**78**	**12,225**	**87**	**12,748**	**81**	**4,276**	**88**	**2,755**	**91**	**267,272**	**74**
Total employed residents	**226,648**	**100**	**54,363**	**100**	**44,902**	**100**	**14,035**	**100**	**15,723**	**100**	**4,858**	**100**	**3,035**	**100**	**363,564**	**100**

Table 3.6. Workers living in concentrated-damage areas (from all hazards) with respect to their home locations in concentrated- and less-concentrated-damage areas resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Records are color coded from smallest (white) to largest (dark red) within each column for ease of identifying regions with the most workers residing in them]

Place of residence	Place of work															
	Central Alameda County		Northern Alameda County		Western Contra Costa County		Dublin-Pleasanton		Southern Alameda County		Novato		Vallejo		Total for subareas	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Employees working and living in a concentrated-damage area																
Central Alameda County	54,463	29	10,667	14	1,072	4	2,434	9	340	14	100	2	68	2	69,144	21
Northern Alameda County	4,670	3	6,793	9	365	2	183	1	28	1	48	1	18	0	12,105	4
Western Contra Costa County	2,096	1	2,773	4	4,241	18	97	0	12	1	108	2	69	2	9,396	3
Southern Alameda County	1,106	1	174	0	21	0	155	1	345	15	7	0	2	0	1,810	1
Dublin-Pleasanton	1,075	1	312	0	32	0	1,545	6	10	0	0	0	1	0	2,975	1
Vallejo	138	0	71	0	93	0	26	0	1	0	20	0	233	6	582	0
Novato	45	0	37	0	25	0	7	0	0	0	166	3	0	0	280	0
Subtotal	**63,593**	**34**	**20,827**	**27**	**5,849**	**24**	**4,447**	**16**	**736**	**31**	**449**	**8**	**391**	**9**	**96,292**	**29**
Employees working in a concentrated-damage area and living in a less-concentrated-damage area																
Alameda County remainder	38,969	21	21,876	28	2,238	9	7,468	27	793	33	238	4	137	3	71,719	22
Contra Costa County remainder	17,410	9	12,216	16	7,063	30	4,886	18	93	4	418	7	409	10	42,495	13
Santa Clara County	11,601	6	2,619	3	740	3	2,357	8	297	13	134	2	53	1	17,801	5
San Joaquin Valley	9,247	5	2,221	3	785	3	2,639	10	129	5	76	1	39	1	15,136	5
San Mateo County	8,473	5	2,701	3	589	2	762	3	85	4	151	3	23	1	12,784	4
San Francisco County	6,727	4	5,269	7	1,007	4	545	2	39	2	414	7	51	1	14,052	4
Sacramento Valley	5,163	3	1,502	2	821	3	908	3	29	1	112	2	116	3	8,651	3
Solano County remainder	4,177	2	1,939	2	1,871	8	464	2	19	1	300	5	2,042	49	10,812	3
Central coast	2,479	1	542	1	172	1	432	2	29	1	43	1	14	0	3,711	1
Sonoma County	2,129	1	897	1	532	2	305	1	18	1	1,099	19	315	8	5,295	2
Marin County remainder	1,112	1	1,382	2	652	3	125	0	10	0	1,542	27	43	1	4,866	1
Napa County	765	0	312	0	390	2	107	0	2	0	96	2	360	9	2,032	1
Other	14,346	8	3,804	5	1,173	5	2,297	8	96	4	631	11	152	4	22,499	7
Subtotal	**122,598**	**66**	**57,280**	**73**	**18,033**	**76**	**23,295**	**84**	**1,639**	**69**	**5,254**	**92**	**3,754**	**91**	**231,853**	**71**
Total workers	**186,191**	**100**	**78,107**	**100**	**23,882**	**100**	**27,742**	**100**	**2,375**	**100**	**5,703**	**100**	**4,145**	**100**	**328,145**	**100**

Table 3.7. Employed residents living in concentrated-damage areas (from earthquake hazards) with respect to their work locations in concentrated- and less-concentrated-damage areas resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. Records are color coded from smallest (white) to largest (dark red) within each column for ease of identifying regions with the most employed residents working in them]

Place of work	Place of residence															
	Central Alameda County		Northern Alameda County		Western Contra Costa County		Dublin-Pleasanton		Southern Alameda County		Novato		Vallejo		Total for subareas	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Employees living and working in a concentrated-damage area																
Central Alameda County	30,920	20	2,741	7	1,220	4	550	5	243	6	0	0	0	0	35,674	15
Northern Alameda County	4,273	3	3,539	10	1,880	6	81	1	19	0	0	0	0	0	9,792	4
Dublin-Pleasanton	1,191	1	99	0	51	0	747	7	29	1	0	0	0	0	2,117	1
Western Contra Costa County	687	0	258	1	2,701	8	17	0	5	0	0	0	0	0	3,668	2
Southern Alameda County	24	0	1	0	0	0	2	0	98	2	0	0	0	0	125	0
Novato	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vallejo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**37,095**	**25**	**6,638**	**18**	**5,852**	**18**	**1,397**	**14**	**394**	**9**	0	0	0	0	**51,376**	**22**
Employees living in a concentrated-damage area and working in a less-concentrated-damage area																
Alameda County remainder	43,973	29	10,999	30	6,136	18	3,277	32	1,085	26	0	0	0	0	65,470	28
San Francisco County	17,164	11	9,213	25	6,493	19	691	7	289	7	0	0	0	0	33,850	14
Santa Clara County	14,335	9	1,776	5	1,294	4	1,784	17	1,309	31	0	0	0	0	20,498	9
San Mateo County	12,179	8	1,842	5	1,256	4	533	5	494	12	0	0	0	0	16,304	7
Contra Costa County remainder	9,199	6	2,378	6	5,689	17	1,265	12	149	4	0	0	0	0	18,680	8
Sacramento Valley	2,827	2	604	2	847	3	152	1	70	2	0	0	0	0	4,500	2
San Joaquin Valley	2,284	2	446	1	511	2	261	3	62	1	0	0	0	0	3,564	2
Marin County	1,362	1	533	1	2,081	6	63	1	16	0	0	0	0	0	4,055	2
Solano County	1,198	1	246	1	771	2	81	1	24	1	0	0	0	0	2,320	1
Central coast	1,058	1	209	1	195	1	60	1	27	1	0	0	0	0	1,549	1
Sonoma County	920	1	223	1	380	1	55	1	23	1	0	0	0	0	1,601	1
Napa County	333	0	86	0	195	1	14	0	8	0	0	0	0	0	636	0
Other	7,256	5	1,659	5	1,648	5	635	6	233	6	0	0	0	0	11,431	5
Subtotal	**114,088**	**75**	**30,214**	**82**	**27,496**	**82**	**8,871**	**86**	**3,789**	**91**	**0**	**0**	**0**	**0**	**184,458**	**78**
Total employed residents	**151,183**	**100**	**36,852**	**100**	**33,348**	**100**	**10,268**	**100**	**4,183**	**100**	**0**	**0**	**0**	**0**	**235,834**	**100**

Table 3.8. Workers in concentrated-damage areas (from earthquake hazards) with respect to their residence locations in concentrated- and less-concentrated-damage areas resulting from the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. Records are color coded from smallest (white) to largest (dark red) within each column for ease of identifying regions with the most workers residing in them]

Place of residence	Place of work															
	Central Alameda County		Northern Alameda County		Dublin-Pleasanton		Western Contra Costa County		Southern Alameda County		Novato		Vallejo		Total for subareas	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Employees working and living in a concentrated-damage area																
Central Alameda County	30,920	20	4,273	8	1,191	5	687	3	24	6	0	0	0	0	37,095	14
Northern Alameda County	2,741	2	3,539	6	99	7	258	1	1	0	0	0	0	0	6,638	3
Western Contra Costa County	1,220	1	1,880	3	51	0	2,701	12	0	0	0	0	0	0	5,852	2
Dublin-Pleasanton	550	0	81	0	747	10	17	0	2	1	0	0	0	0	1,397	1
Southern Alameda County	243	0	19	0	29	0	5	0	98	25	0	0	0	0	394	0
Novato	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vallejo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**35,674**	**23**	**9,792**	**17**	**2,117**	**22**	**3,668**	**17**	**125**	**32**	**0**	**0**	**0**	**0**	**51,376**	**20**
Employees working in a concentrated-damage area and living in a less-concentrated-damage area																
Alameda County remainder	47,021	30	19,847	35	6,510	15	2,533	11	114	29	0	0	0	0	76,025	30
Contra Costa County remainder	15,041	10	9,671	17	3,694	19	7,543	34	13	3	0	0	0	0	35,962	14
Santa Clara County	10,269	7	1,849	3	1,919	4	702	3	46	12	0	0	0	0	14,785	6
San Joaquin Valley	8,114	5	1,200	2	2,095	4	755	3	45	12	0	0	0	0	12,209	5
San Mateo County	7,436	5	1,981	3	613	15	551	2	15	4	0	0	0	0	10,596	4
San Francisco County	5,882	4	4,148	7	447	3	960	4	0	0	0	0	0	0	11,437	4
Sacramento Valley	4,739	3	1,186	2	722	1	790	4	2	1	0	0	0	0	7,439	3
Solano County	3,735	2	1,527	3	380	6	1,837	8	1	0	0	0	0	0	7,480	3
Central coast	2,186	1	416	1	325	2	164	1	3	1	0	0	0	0	3,094	1
Sonoma County	1,917	1	721	1	257	1	494	2	7	2	0	0	0	0	3,396	1
Marin County	924	1	1,179	2	106	1	606	3	2	1	0	0	0	0	2,817	1
Napa County	692	0	252	0	87	1	351	2	0	0	0	0	0	0	1,382	1
Other	13,370	9	3,105	5	1,888	6	1,133	5	16	4	0	0	0	0	19,512	8
Subtotal	**121,326**	**77**	**47,082**	**83**	**19,043**	**78**	**18,419**	**83**	**264**	**68**	**0**	**0**	**0**	**0**	**206,134**	**80**
Total workers	**157,000**	**100**	**56,874**	**100**	**21,160**	**100**	**22,087**	**100**	**389**	**100**	**0**	**0**	**0**	**0**	**257,510**	**100**

Table 3.9. Employed residents (who live in concentrated-damage areas) by place of work and LODES industry segment for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. Records are color coded from smallest (white) to largest (dark red) within each column for ease of identifying regions with the most employed residents from each LODES industry segment working in them. LODES, Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics]

Place of work	All hazards								Earthquake hazards							
	Total		Goods producing		Trade, transportation, and utilities		Other services		Total		Goods producing		Trade, transportation, and utilities		Other services	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Employees living and working in a concentrated-damage area																
Central Alameda County	63,593	17	10,008	21	14,050	21	39,535	16	35,674	15	6,378	21	8,638	20	20,658	13
Northern Alameda County	20,827	6	2,639	6	2,417	4	15,771	6	9,792	4	1,329	4	1,517	3	6,946	4
Western Contra Costa County	5,849	2	261	1	1,530	2	4,058	2	3,668	2	157	1	914	2	2,597	2
Dublin-Pleasanton	4,447	1	548	1	1,081	2	2,818	1	2,117	1	293	1	534	1	1,290	1
Southern Alameda County	736	0	52	0	139	0	545	0	125	0	14	0	1	0	110	0
Novato	449	0	62	0	46	0	341	0	0	0	0	0	0	0	0	0
Vallejo	391	0	9	0	32	0	350	0	0	0	0	0	0	0	0	0
Subtotal	**96,292**	**26**	**13,579**	**29**	**19,295**	**29**	**63,418**	**25**	**51,376**	**22**	**8,171**	**27**	**11,604**	**26**	**31,601**	**20**
Employees living in a concentrated-damage area and working in a less-concentrated-damage area																
Alameda County remainder	81,313	22	10,918	23	12,568	19	57,827	23	65,470	28	7,848	26	9,576	22	48,046	30
San Francisco County	50,663	14	2,424	5	7,433	11	40,806	16	33,850	14	1,582	5	4,993	11	27,275	17
Santa Clara County	32,551	9	6,110	13	5,517	8	20,924	8	20,498	9	3,867	13	3,495	8	13,136	8
Contra Costa County remainder	28,365	8	3,235	7	4,829	7	20,301	8	18,680	8	2,131	7	3,237	7	13,312	8
San Mateo County	25,487	7	3,208	7	6,045	9	16,234	7	16,304	7	2,020	7	3,843	9	10,441	6
Marin County remainder	7,294	2	731	2	1,353	2	5,210	2	4,055	2	447	1	776	2	2,832	2
Sacramento Valley	7,158	2	651	1	1,670	2	4,837	2	4,500	2	408	1	1,062	2	3,030	2
San Joaquin Valley	5,589	2	907	2	2,068	3	2,614	1	3,564	2	563	2	1,316	3	1,685	1
Solano County remainder	4,350	1	595	1	1,085	2	2,670	1	2,320	1	316	1	625	1	1,379	1
Sonoma County	2,750	1	385	1	698	1	1,667	1	1,601	1	193	1	446	1	962	1
Central coast	2,458	1	641	1	647	1	1,170	0	1,549	1	412	1	381	1	756	0
Napa County	1,429	0	314	1	265	0	850	0	636	0	138	0	121	0	377	0
Other	17,865	5	3,380	7	3,932	6	10,553	4	11,431	5	2,149	7	2,554	6	6,728	4
Subtotal	**267,272**	**74**	**33,499**	**71**	**48,110**	**71**	**185,663**	**75**	**184,458**	**78**	**22,074**	**73**	**32,425**	**74**	**129,959**	**80**
Total employed residents	**363,564**	**100**	**47,078**	**100**	**67,405**	**100**	**249,081**	**100**	**235,834**	**100**	**30,245**	**100**	**44,029**	**100**	**161,560**	**100**

Table 3.10. Employees (who work in concentrated-damage areas) by place of residence and LODES industry segment for the HayWired earthquake scenario mainshock in the San Francisco Bay region, California.

[All hazards refer to damages from all hazards considered for the HayWired scenario: ground shaking, landslide, liquefaction, and fire following earthquake. Earthquake hazards refer to damages from earthquake hazards: ground shaking, landslide, and liquefaction. Records are color coded from smallest (white) to largest (dark red) within each column for ease of identifying regions with the most workers from each LODES industry segment residing in them. LODES, Longitudinal Employer-Household Dynamics (LEHD) Origin-Destination Employment Statistics]

Place of residence	All hazards								Earthquake hazards							
	Total		Goods producing		Trade, transportation, and utilities		Other services		Total		Goods producing		Trade, transportation, and utilities		Other services	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Employees working and living in a concentrated-damage area																
Central Alameda County	69,144	21	10,540	23	14,308	18	44,296	22	37,095	14	6,497	16	8,722	13	21,876	15
Northern Alameda County	12,105	4	1,358	3	1,735	2	9,012	4	6,638	3	820	2	1,131	2	4,687	3
Western Contra Costa County	9,396	3	944	2	2,167	3	6,285	3	5,852	2	581	1	1,376	2	3,895	3
Dublin-Pleasanton	2,975	1	365	1	582	1	2,028	1	1,397	1	195	0	294	0	908	1
Southern Alameda County	1,810	1	304	1	355	0	1,151	1	394	0	78	0	81	0	235	0
Vallejo	582	0	42	0	100	0	440	0	0	0	0	0	0	0	0	0
Novato	280	0	26	0	48	0	206	0	0	0	0	0	0	0	0	0
Subtotal	**96,292**	**29**	**13,579**	**29**	**19,295**	**25**	**63,418**	**31**	**51,376**	**20**	**8,171**	**20**	**11,604**	**17**	**31,601**	**21**
Employees working in a concentrated-damage area and living in a less-concentrated-damage area																
Alameda County remainder	71,719	22	9,616	21	13,505	17	48,598	24	76,025	30	11,940	29	16,761	25	47,324	32
Contra Costa County remainder	42,495	13	6,069	13	9,560	12	26,866	13	35,962	14	5,672	14	9,009	13	21,281	14
Santa Clara County	17,801	5	3,056	7	5,406	7	9,339	5	14,785	6	2,824	7	4,710	7	7,251	5
San Joaquin Valley	15,136	5	2,851	6	4,653	6	7,632	4	12,209	5	2,583	6	4,076	6	5,550	4
San Francisco County	14,052	4	1,669	4	3,439	4	8,944	4	11,437	4	1,413	3	3,134	5	6,890	5
San Mateo County	12,784	4	1,745	4	4,161	5	6,878	3	10,596	4	1,589	4	3,676	5	5,331	4
Solano County remainder	10,812	3	1,277	3	2,545	3	6,990	3	7,480	3	1,139	3	2,059	3	4,282	3
Sacramento Valley	8,651	3	915	2	3,263	4	4,473	2	7,439	3	844	2	2,917	4	3,678	2
Sonoma County	5,295	2	701	2	1,668	2	2,926	1	3,396	1	404	1	1,382	2	1,610	1
Marin County remainder	4,866	1	552	1	1,107	1	3,207	2	2,817	1	292	1	880	1	1,645	1
Central coast	3,711	1	433	1	1,583	2	1,695	1	3,094	1	394	1	1,346	2	1,354	1
Napa County	2,032	1	215	0	503	1	1,314	1	1,382	1	173	0	404	1	805	1
Other	22,499	7	3,501	8	6,972	9	12,026	6	19,512	8	3,198	8	6,347	9	9,967	7
Subtotal	**231,853**	**71**	**32,600**	**71**	**58,365**	**75**	**140,888**	**69**	**206,134**	**80**	**32,465**	**80**	**56,701**	**83**	**116,968**	**79**
Total workers	**328,145**	**100**	**46,179**	**100**	**77,660**	**100**	**204,306**	**100**	**257,510**	**100**	**40,636**	**100**	**68,305**	**100**	**148,569**	**100**