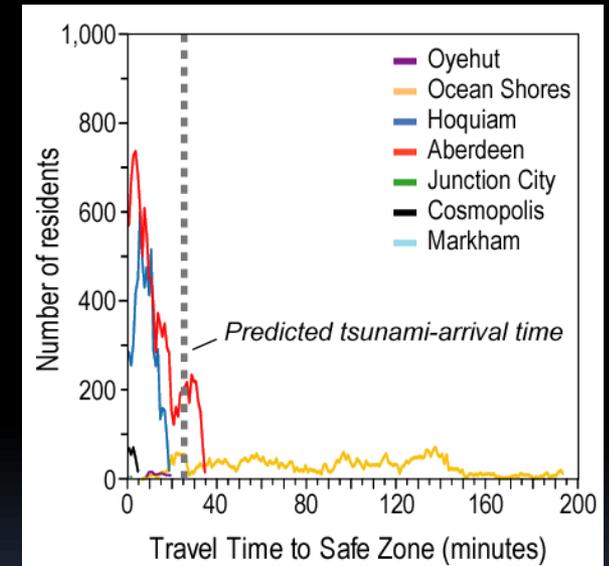
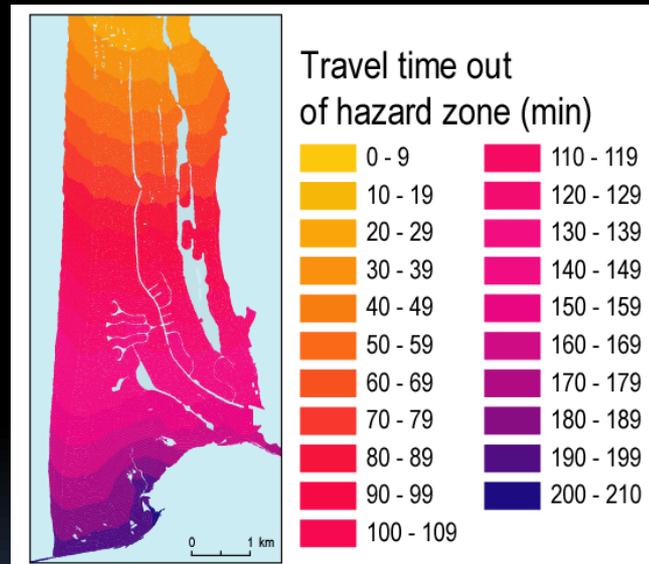
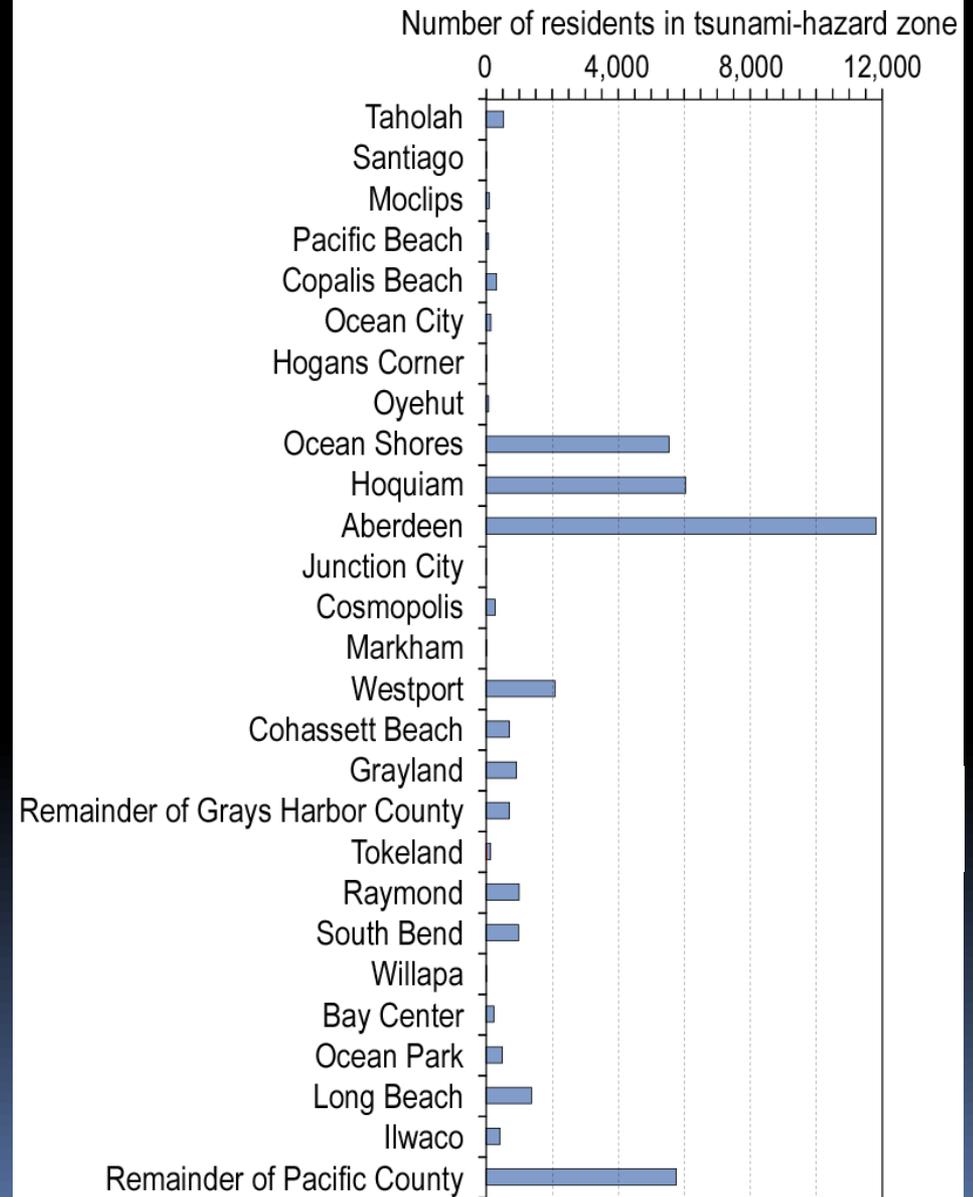


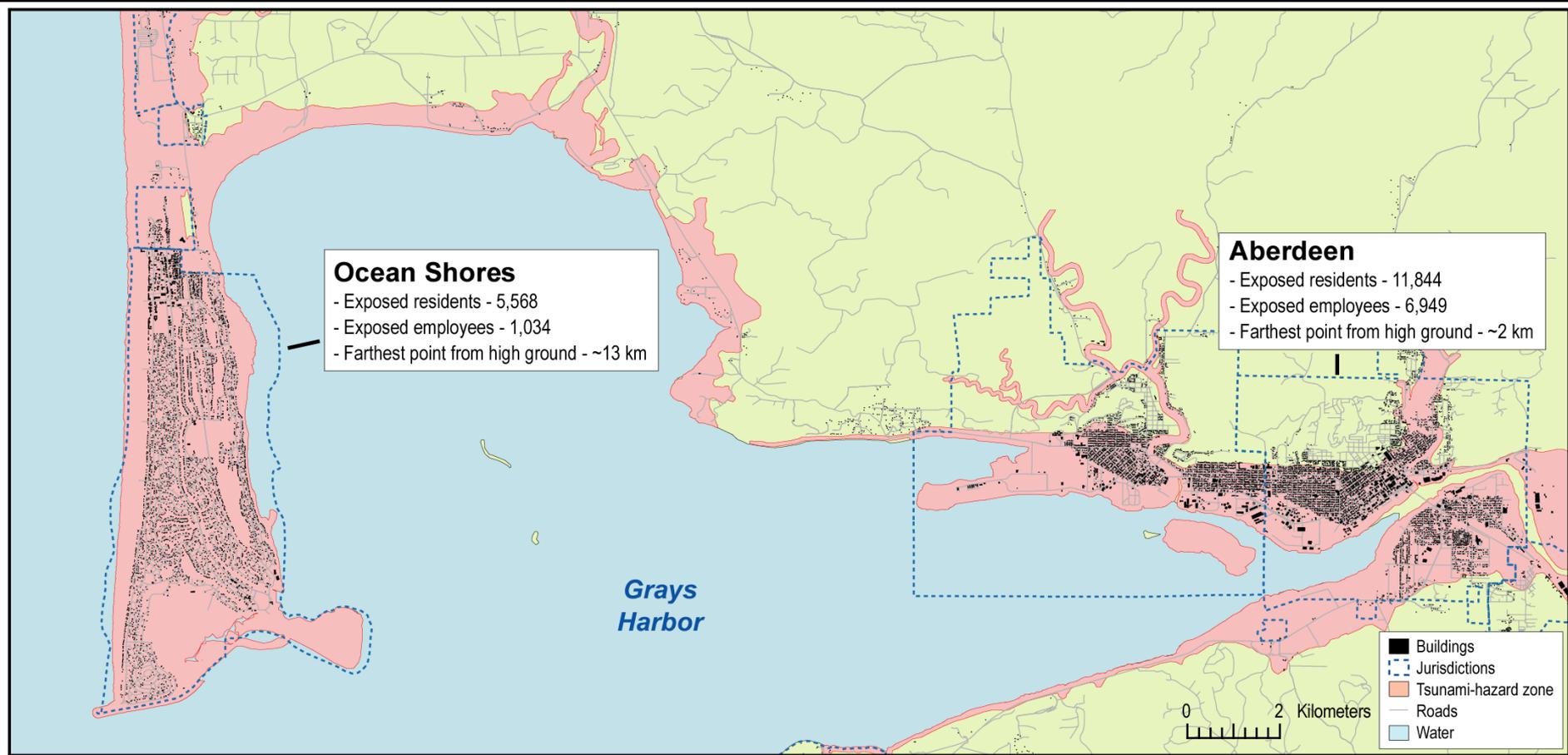
Pedestrian-evacuation modeling for near-field tsunami threats



2010 resident exposure to tsunami hazards in Pacific and Grays Harbor Counties, Washington



Basic exposure numbers don't tell the full risk story



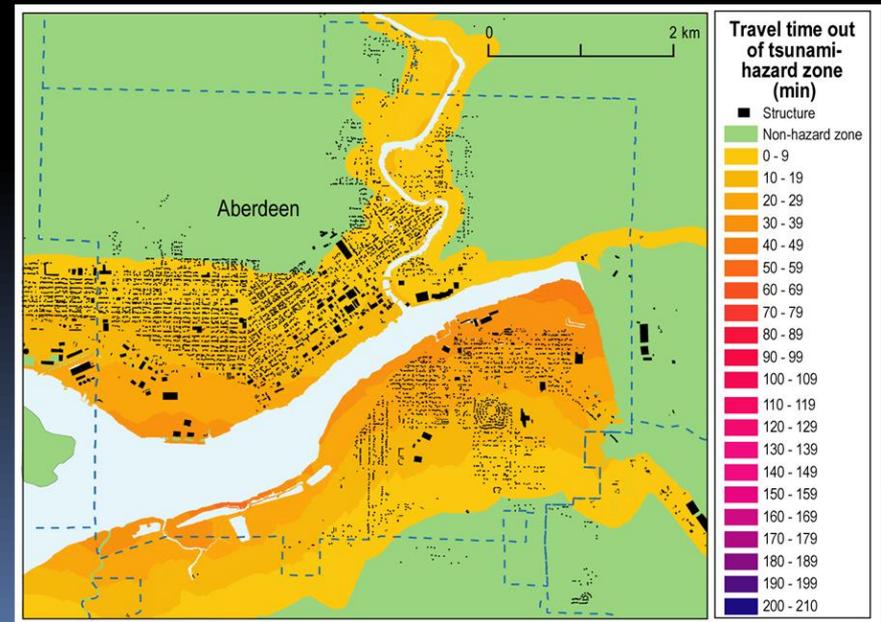
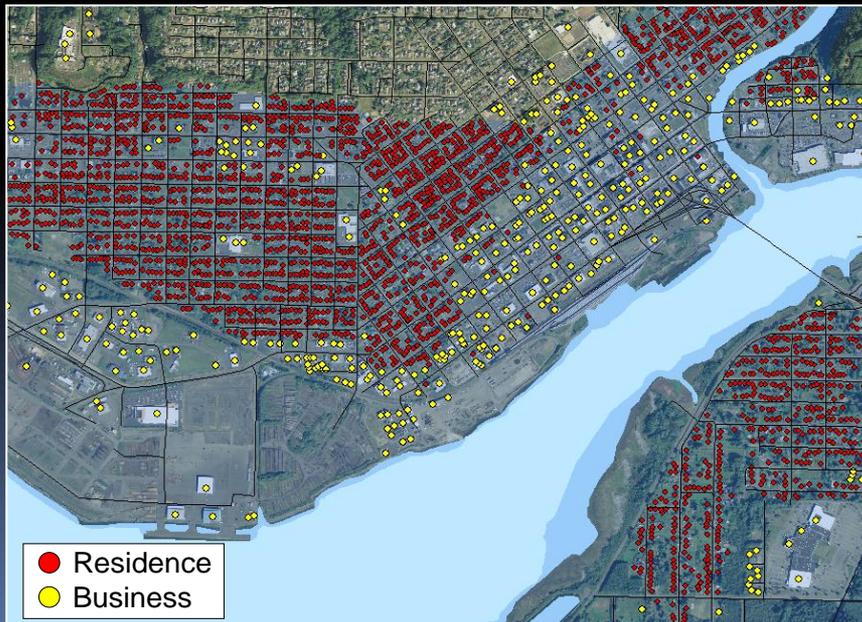
Modeling Pedestrian Evacuation

Agent-based

- **Approach** - tracks individual movement across network (roads)
- **Product** – mortality estimates
- **Results** – sensitive to people number, distribution, and interactions
- **Use** - specific scenarios; bottlenecks

Least-cost distance

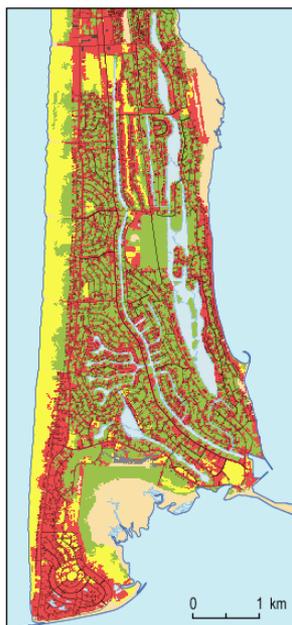
- **Approach** - calculates “costs” associated with travel across entire landscape
- **Products** – maps, time/exposure profiles
- **Results** - flexible with regard to arrival times, population dynamics
- **Use** – outreach, priority setting, response



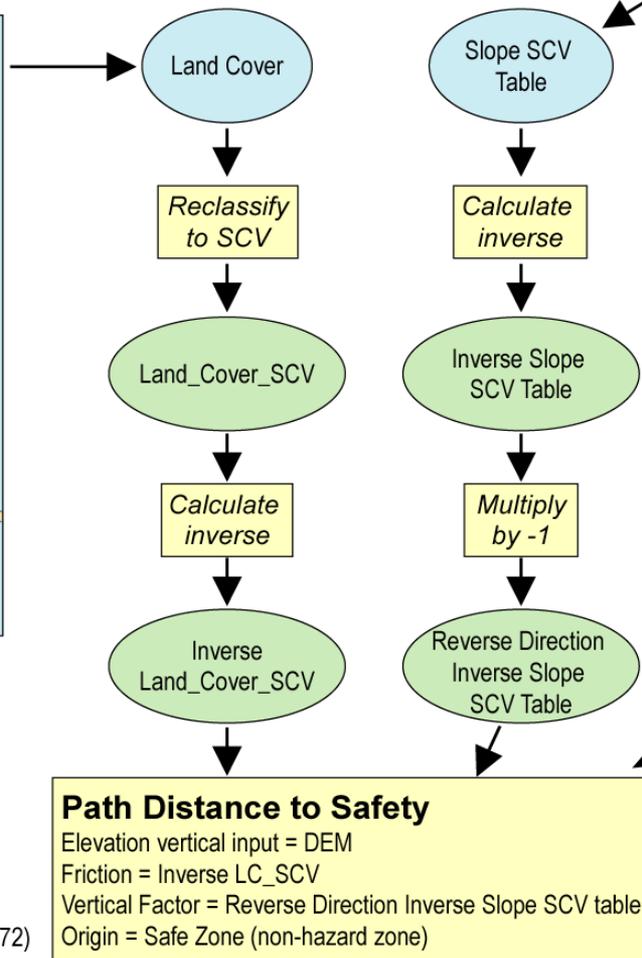
Anisotropic Path Distance Modeling



- 2009 NAIP Imagery
- eCognition boundary delineation
- Manual interpretation
- Ancillary data
 - Tax parcels
 - Roads (State of WA, OpenStreetMap)



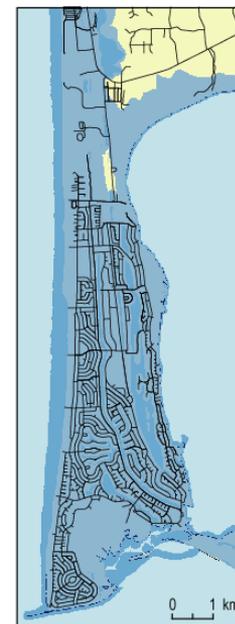
- Land Cover and Speed Conservation Value (SCV)
- Buildings - 0.00
 - Developed - 0.91
 - Light Brush - 0.83
 - Heavy Brush - 0.67
 - Unconsolidated - 0.56
 - Water - 0.0
 - Roads - 1.0 (Soule and Goldman, 1972)



$$\text{Speed} = 6e^{-3.5 \times \text{abs}(\text{slope} + 0.05)}$$

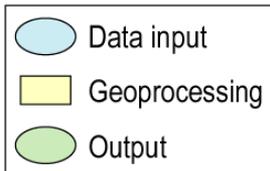


1-m Digital Elevation Model (DEM)

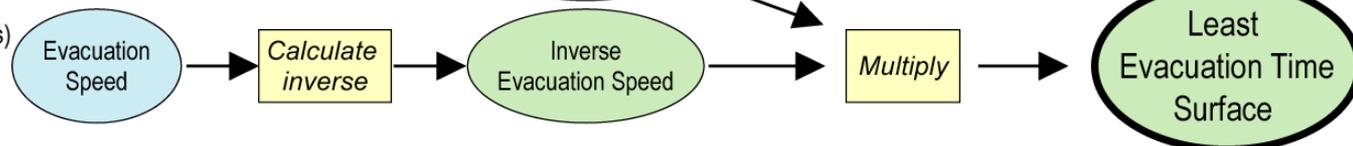


Tsunami Hazard Zone

(Watershed Sciences, 2010) (Walsh et al., 2000)



- Base Speed (1.1 m/s)
 Walk - moderate (1.2 m/s)
 Walk - fast (1.5 m/s)
 Run - slow (1.8 m/s)



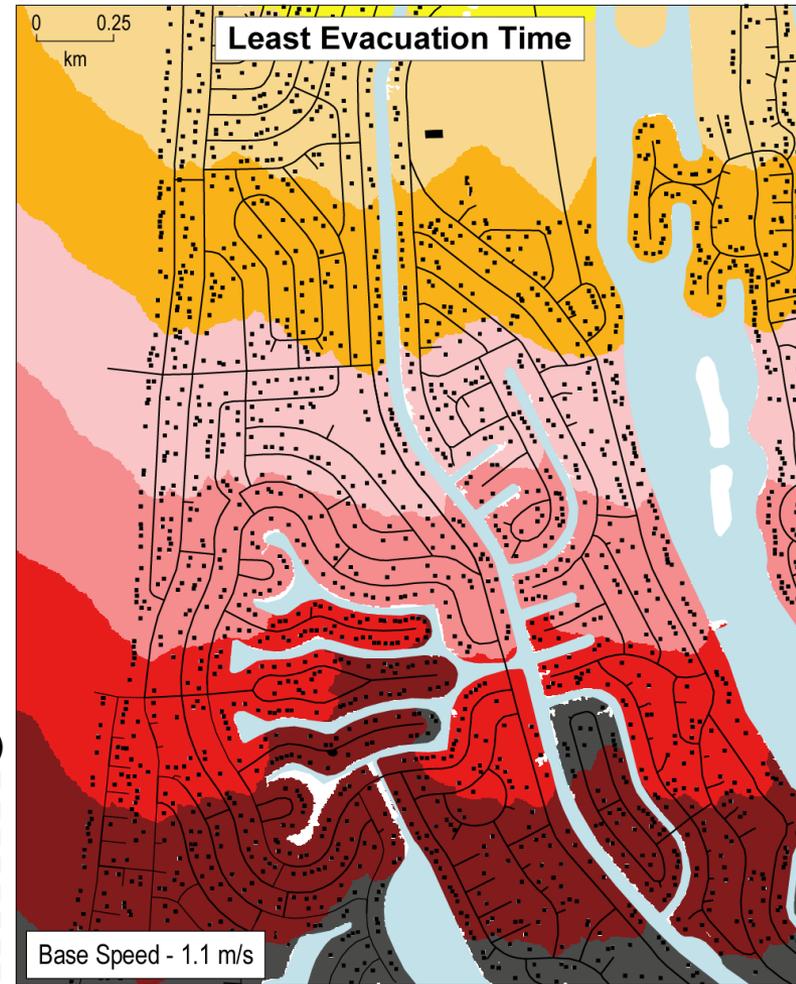
Least Evacuation Time Surfaces for Ocean Shores, Washington



- Land cover**
- Buildings
 - Developed
 - Light Brush
 - Heavy Brush
 - Unconsolidated
 - Water
 - Roads

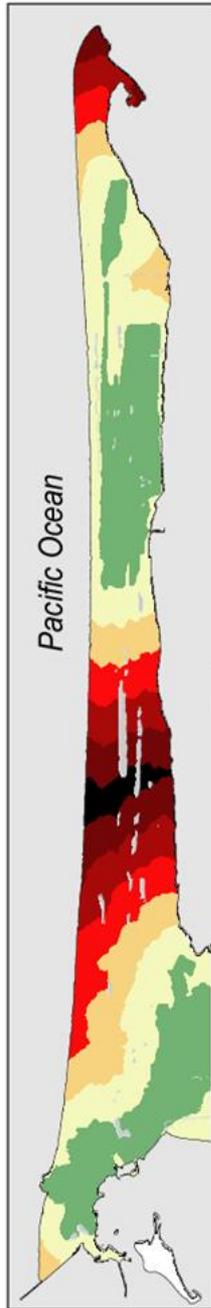
Travel time to safety (min)

- 70 - 79
- 80 - 89
- 90 - 99
- 100 - 109
- 110 - 119
- 120 - 129
- 130 - 139
- 140 - 149

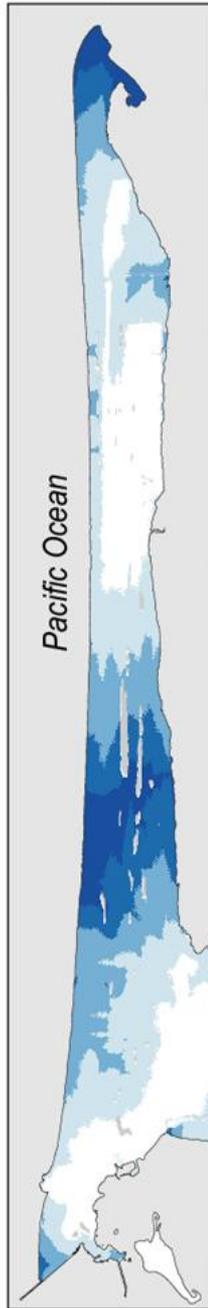


Deviating from anisotropic approach impacts evacuation results

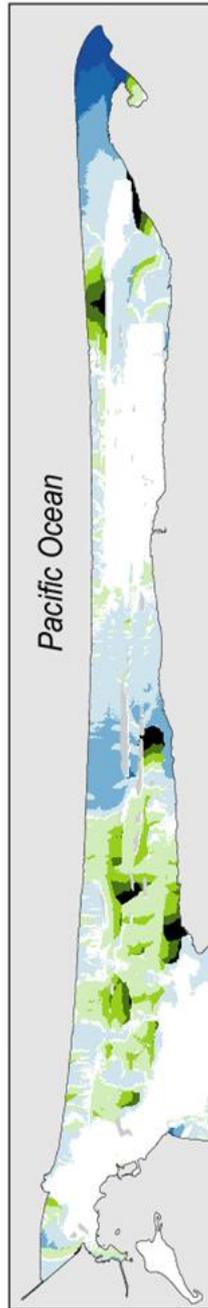
a) Anisotropic Model



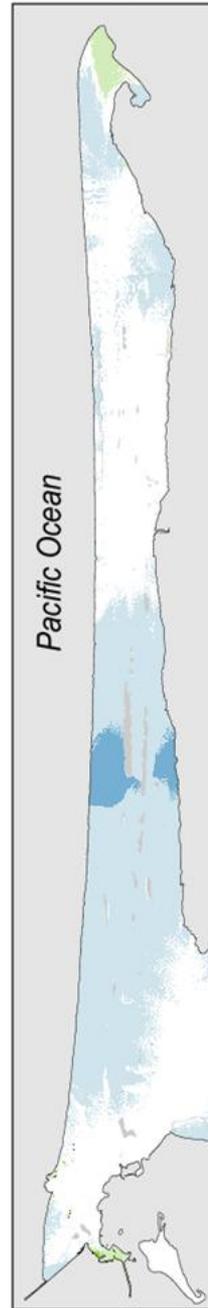
b) Distance model minus anisotropic model



c) Roads model minus anisotropic model



d) Isotropic model minus anisotropic model



□ Ocean or inland lake

(a) Travel time to safety based on anisotropic model (minutes)

■ 0 (non-hazard zone)

■ 1 - 24

■ 25 - 49

■ 50 - 74

■ 75 - 99

■ 100 - 124

■ 125 - 150

(b - d) Difference between model approaches (minutes)

■ -40 to -30

■ -29 to -20

■ -19 to -10

■ -9 to -1

□ 0

■ 1 to 9

■ 10 to 19

■ 20 to 29

■ 30 to 40

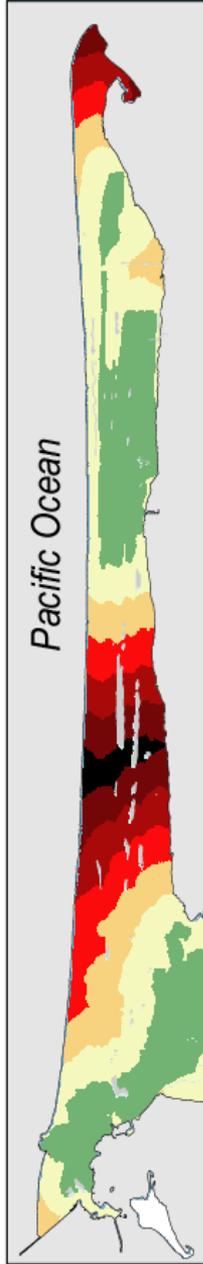
0 2 Miles

0 2 Kilometers

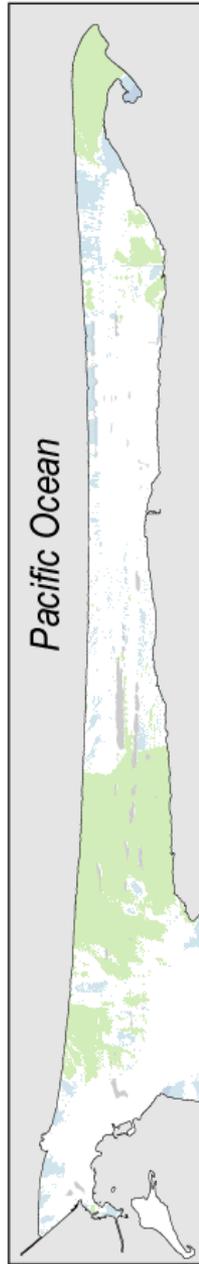


Poor input elevation and land cover data results in poor modeling results

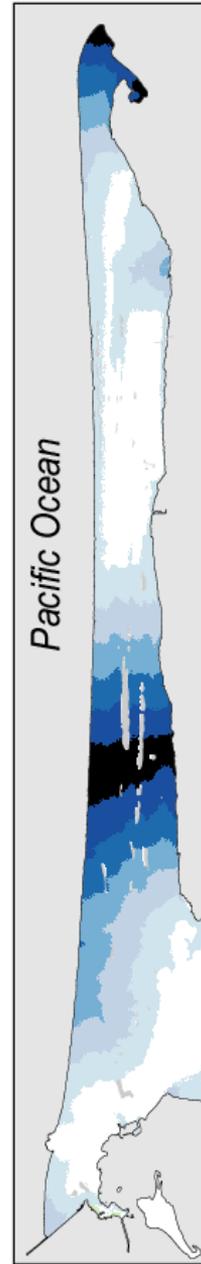
a) 1-m elevation and 1-m land cover (manual)



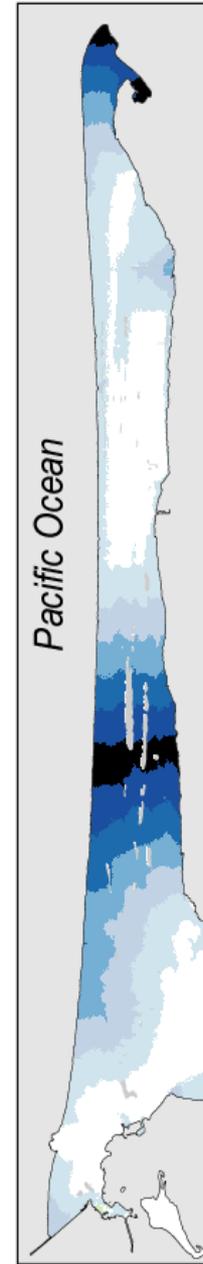
b) 1-m elevation and 30-m land cover (NLCD)



c) 10-m elevation and 1-m land cover (manual)



d) 10-m elevation and 30-m land cover (NLCD)



Grey Ocean or inland lake

(a) Travel time to safety based on anisotropic model and 1-m elevation and 1-meter land cover data (minutes)

0 (non-hazard zone)

1 - 24

25 - 49

50 - 74

75 - 99

100 - 124

125 - 150

(b - d) Difference in travel times between model runs using 1-m/1-m data (fig. a) and other data resolutions (minutes)

-90 to -75

-75 to -60

-60 to -45

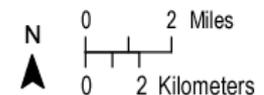
-45 to -30

-30 to -15

-15 to -1

0

1 to 15



Least-Evacuation-Time Surfaces for Study Area

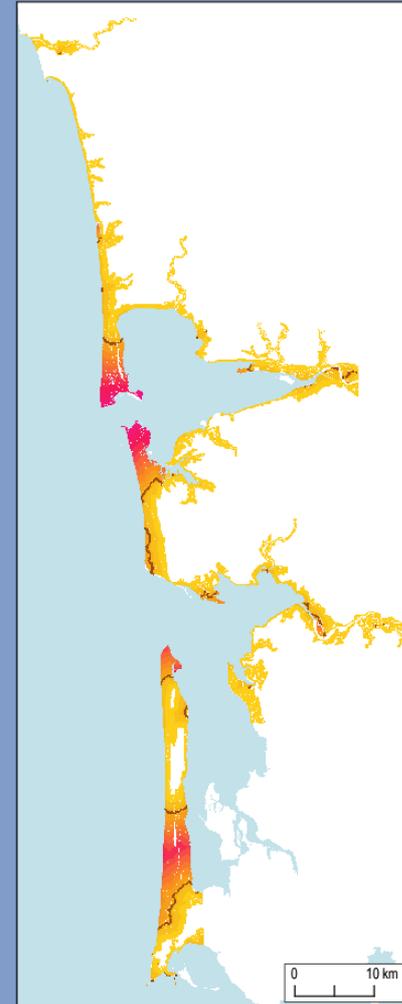
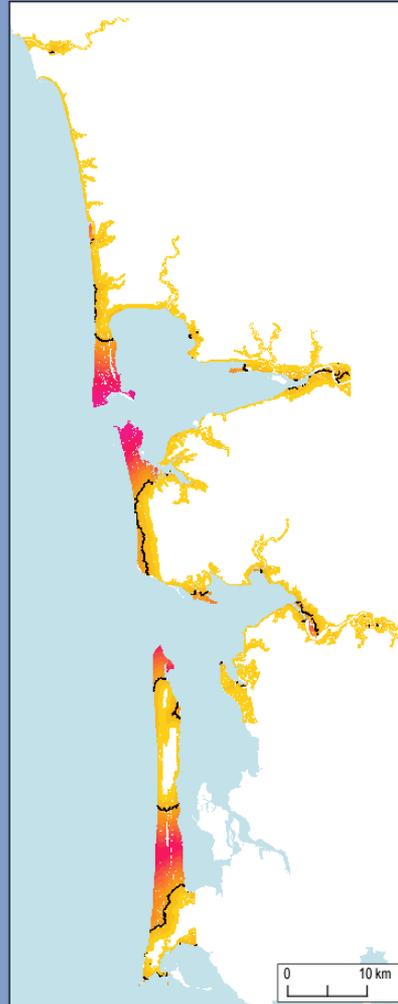
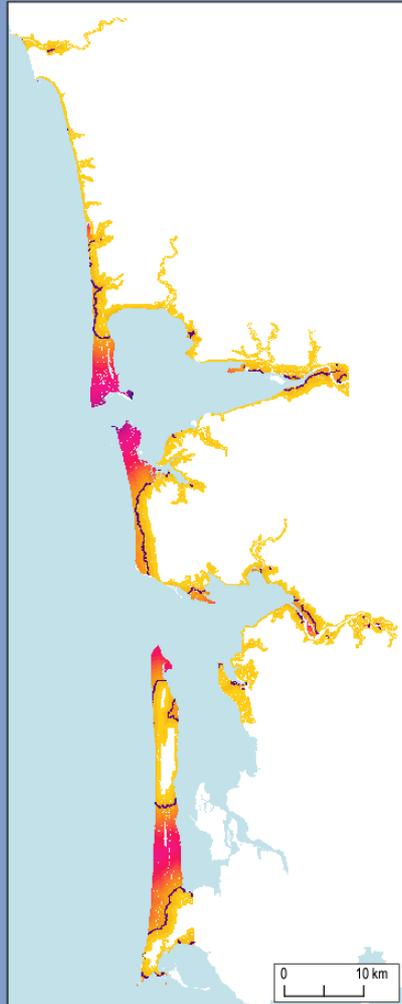
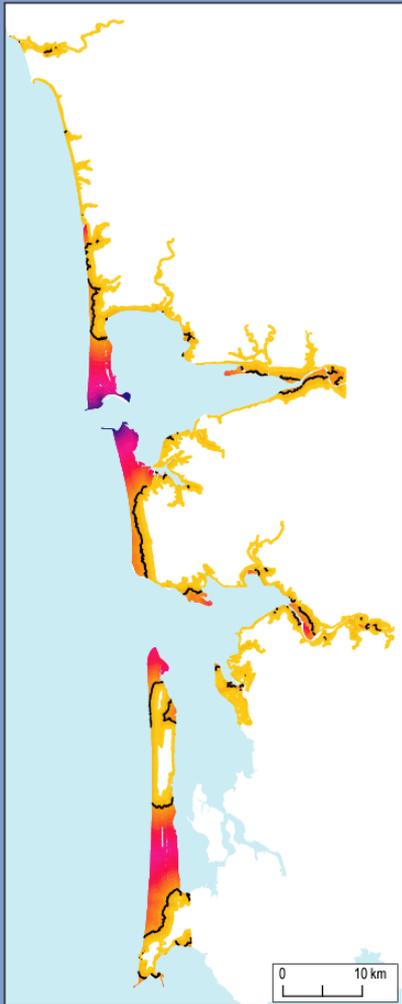
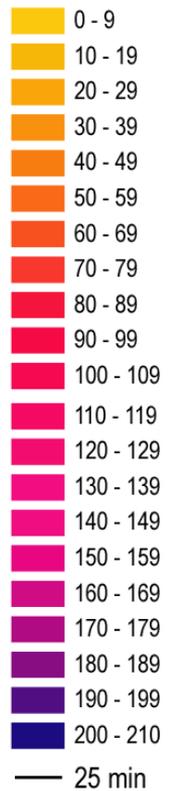
Base Speed (1.1 m/s)

Moderate Walk (1.2 m/s)

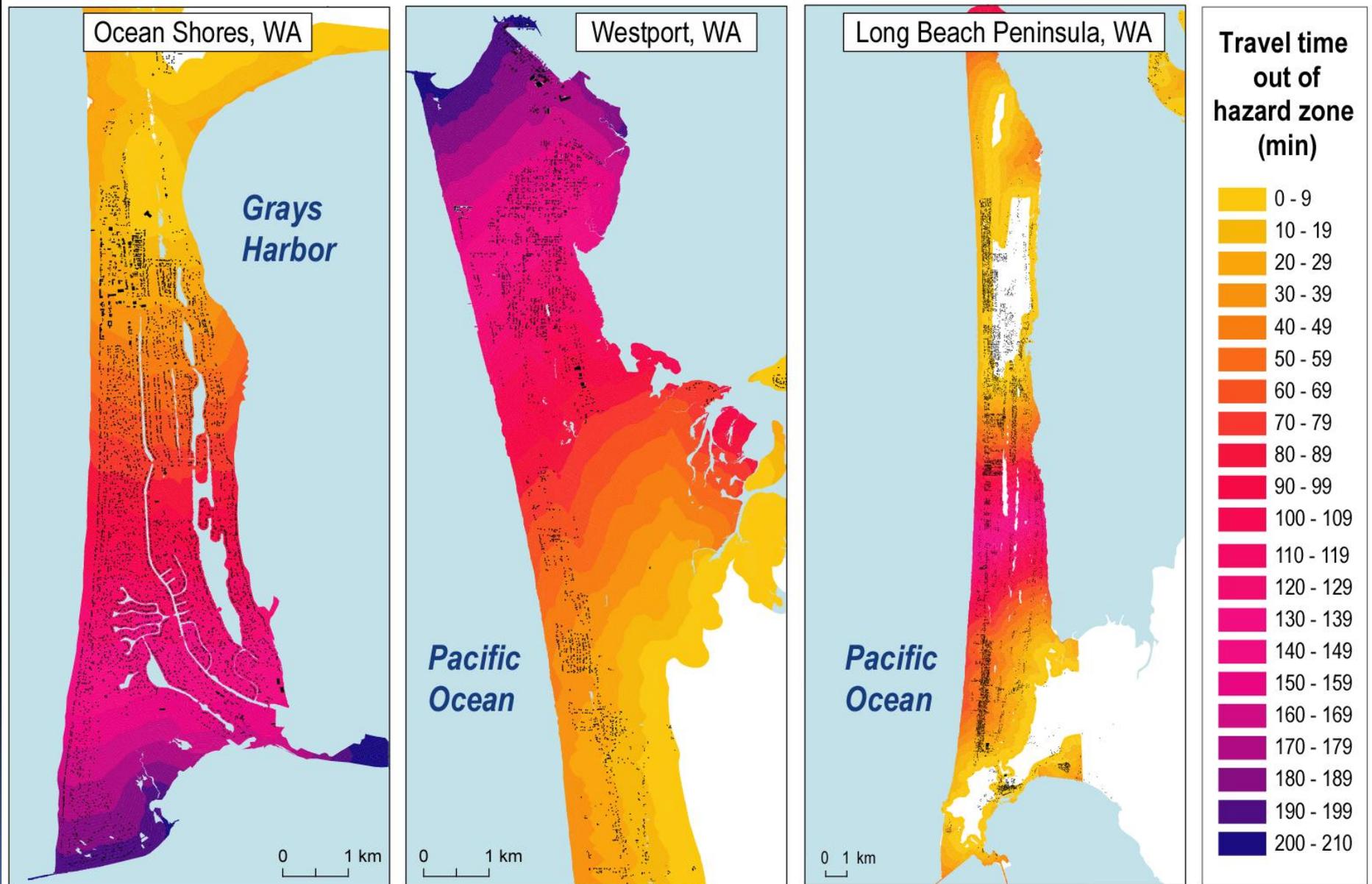
Fast Walk (1.5 m/s)

Slow Run (1.8 m/s)

Travel time
out of
hazard zone
(min)

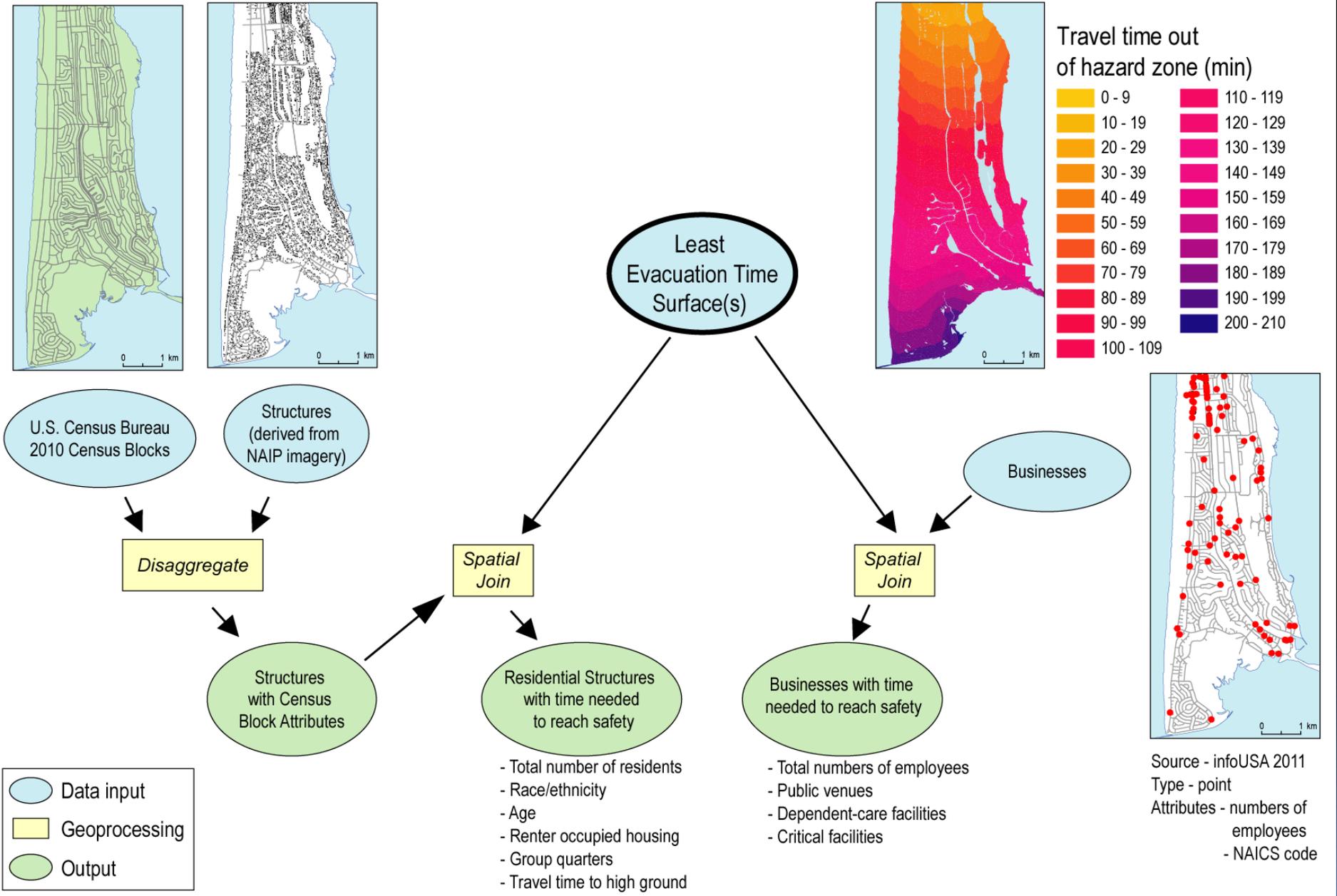


Hotspots of Evacuation Challenges

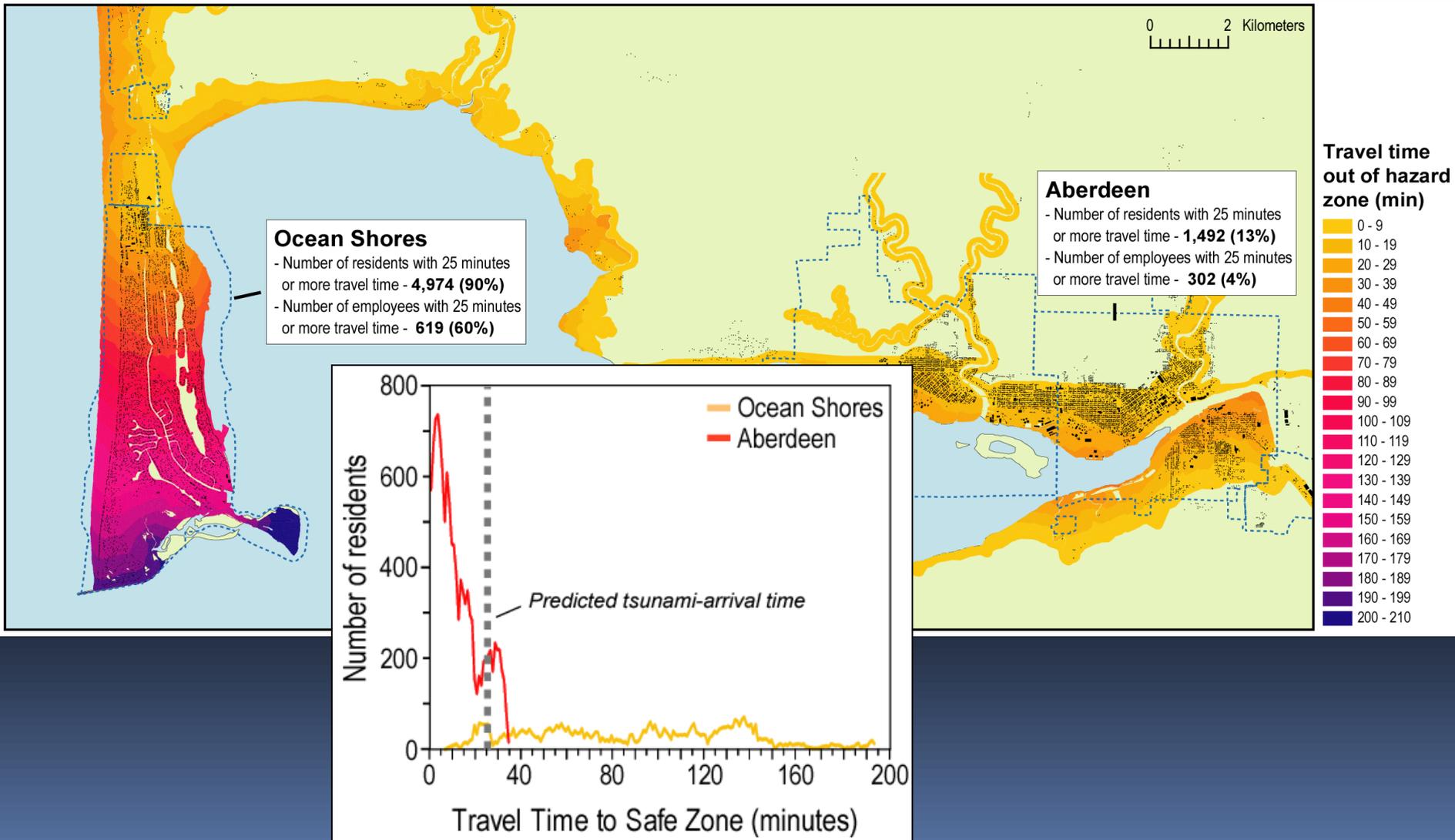


Based on 1.1 m/s travel speed

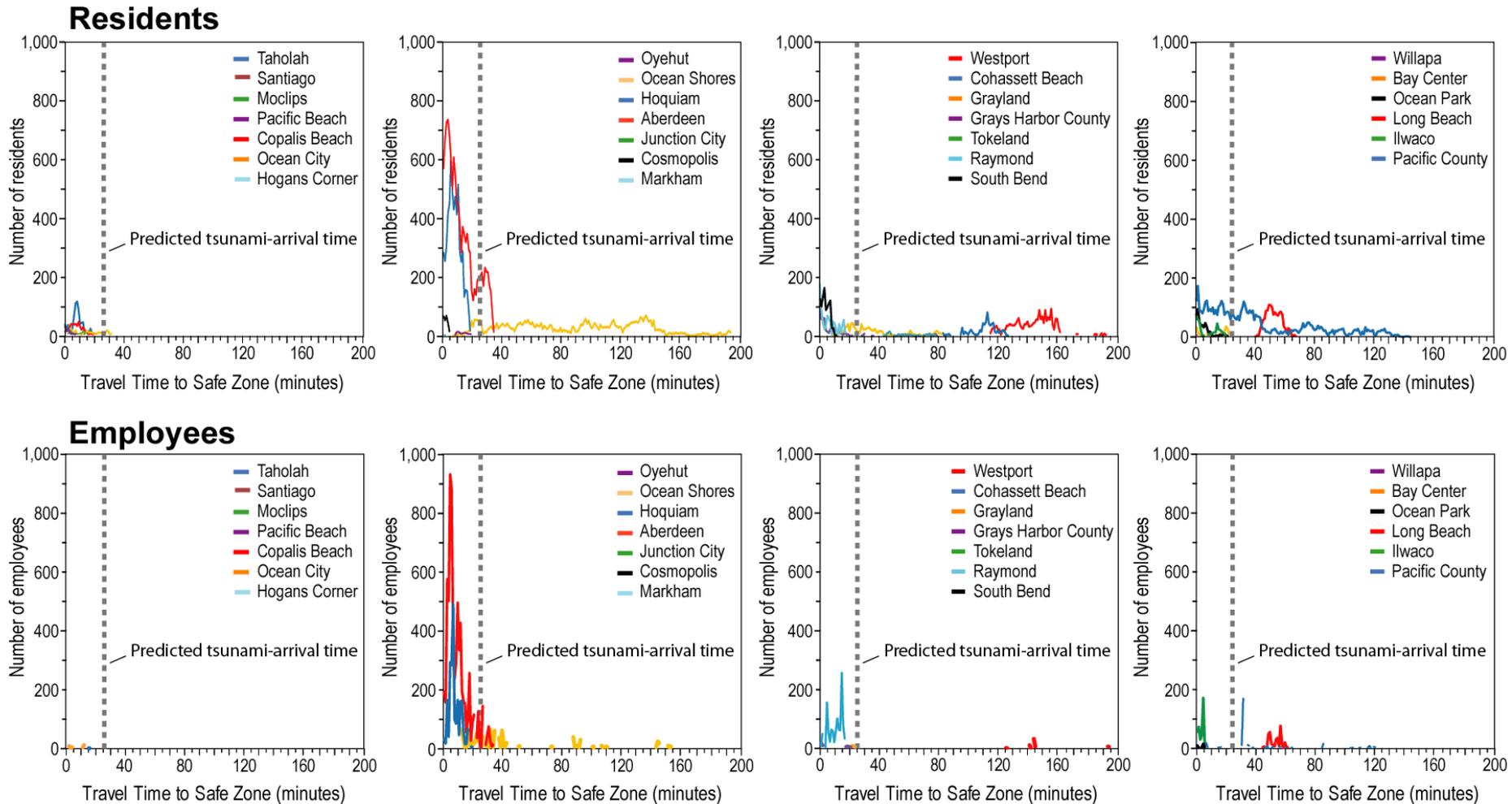
Integrating Evacuation Results with Population Data



Distance to safety changes the risk story



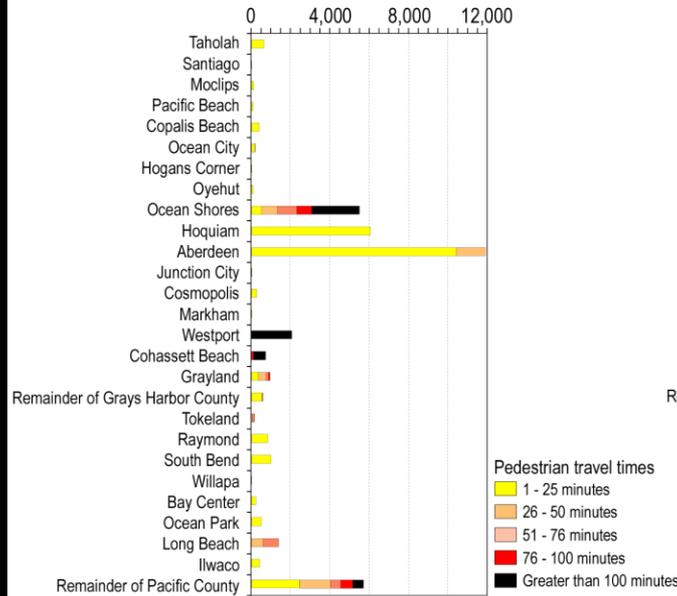
Distribution of residents and employees based on pedestrian travel time to safety



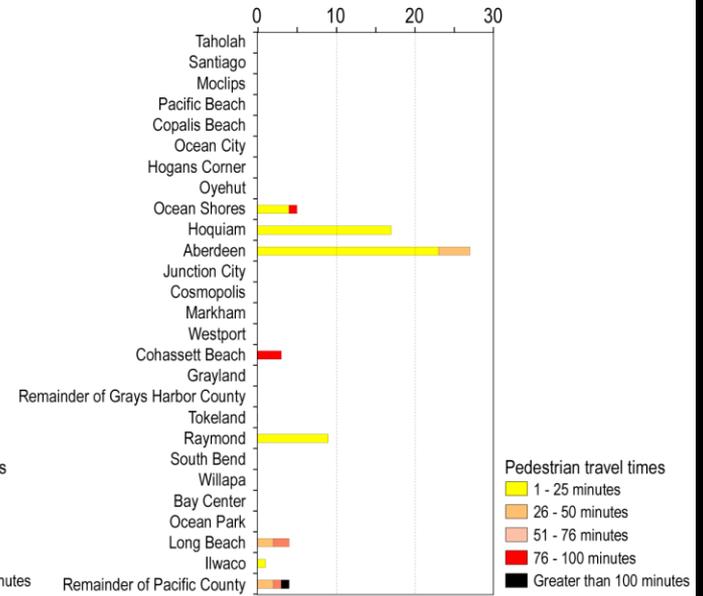
All graphs assume a pedestrian travel speed of 1.1 m/s ("base speed")

Variations in population exposure as a function of pedestrian travel time to safety

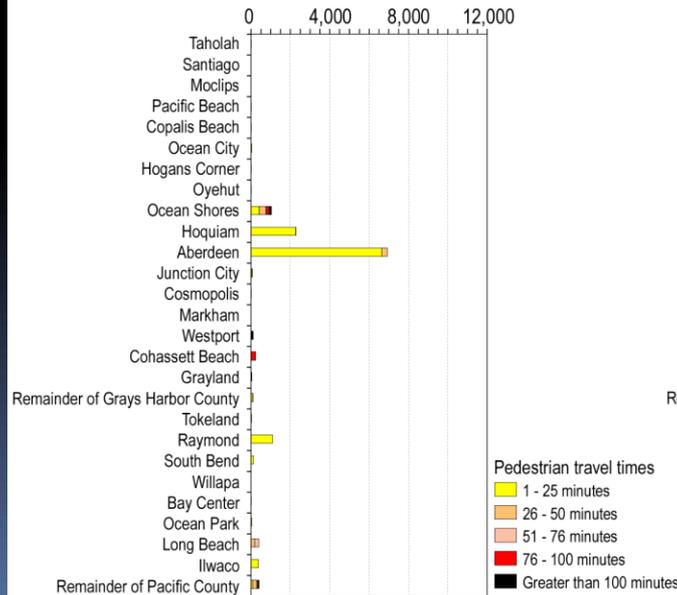
Number of residents as a function of pedestrian travel times to safety out of tsunami-hazard zone



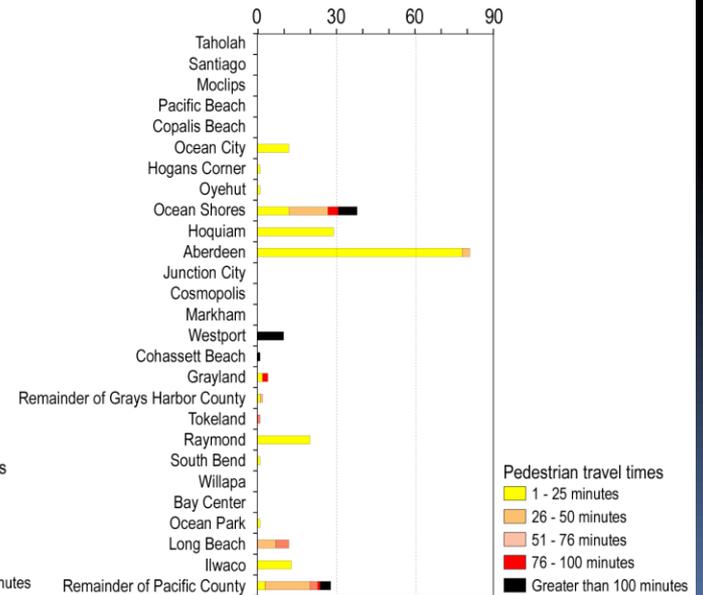
Number of dependent-care facilities as a function of pedestrian travel times to safety out of tsunami-hazard zone



Number of employees as a function of pedestrian travel times to safety out of tsunami-hazard zone

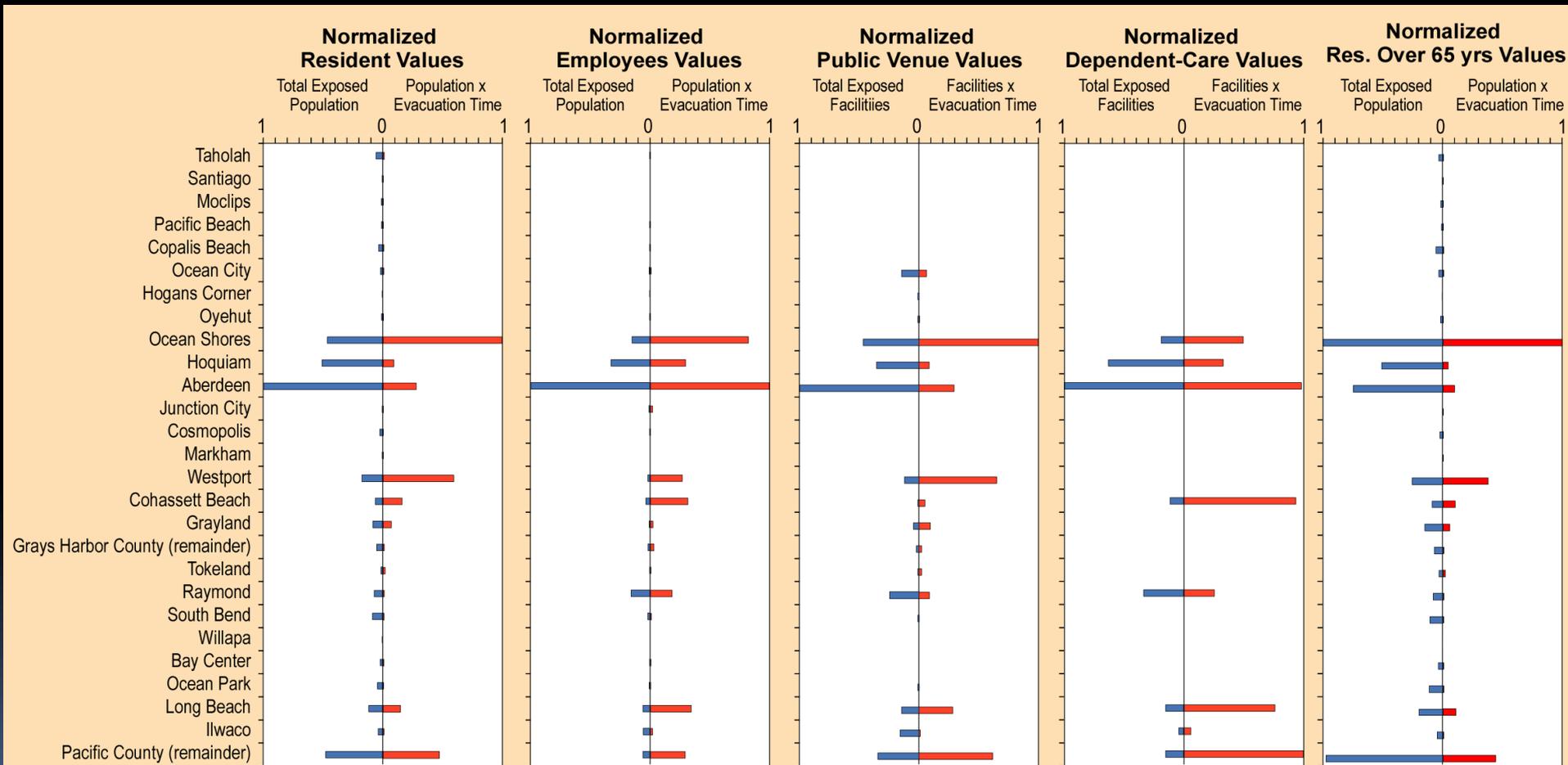


Number of public venues as a function of pedestrian travel times to safety out of tsunami-hazard zone



Based on 1.1 m/s travel speed

Normalized values of total exposed population and weighted population that incorporates travel time to safety (population x time)

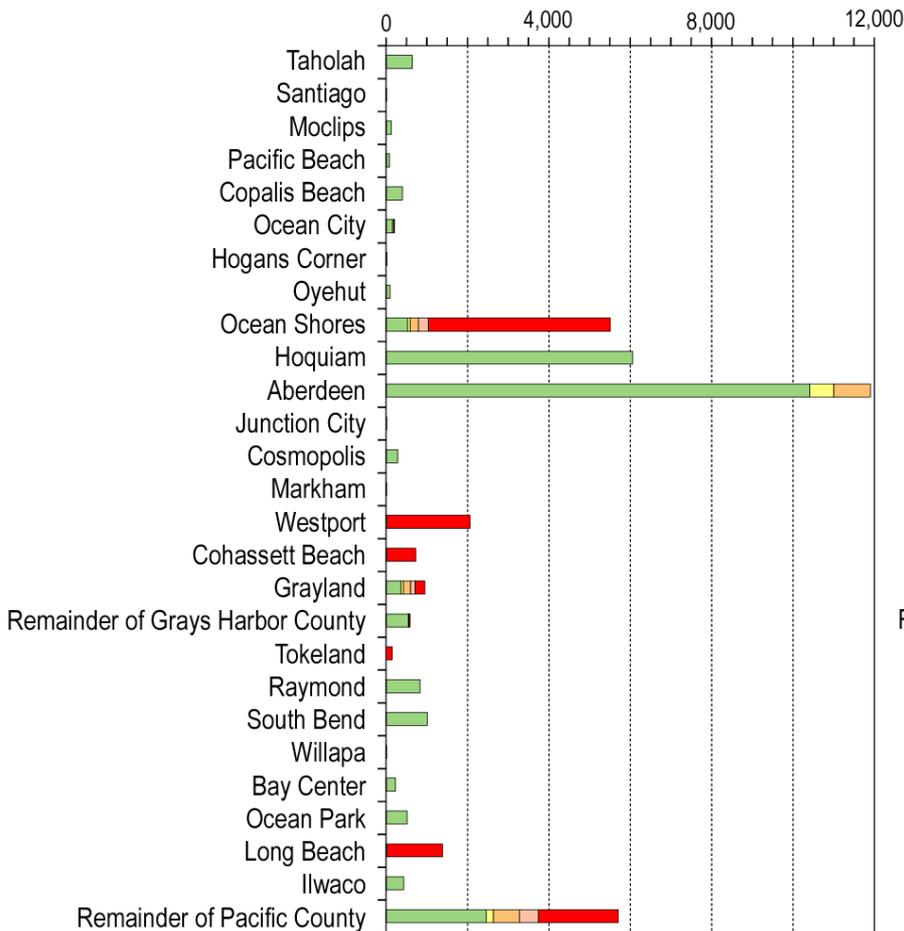


All values were normalized to the maximum value in that category

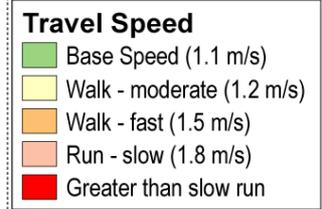
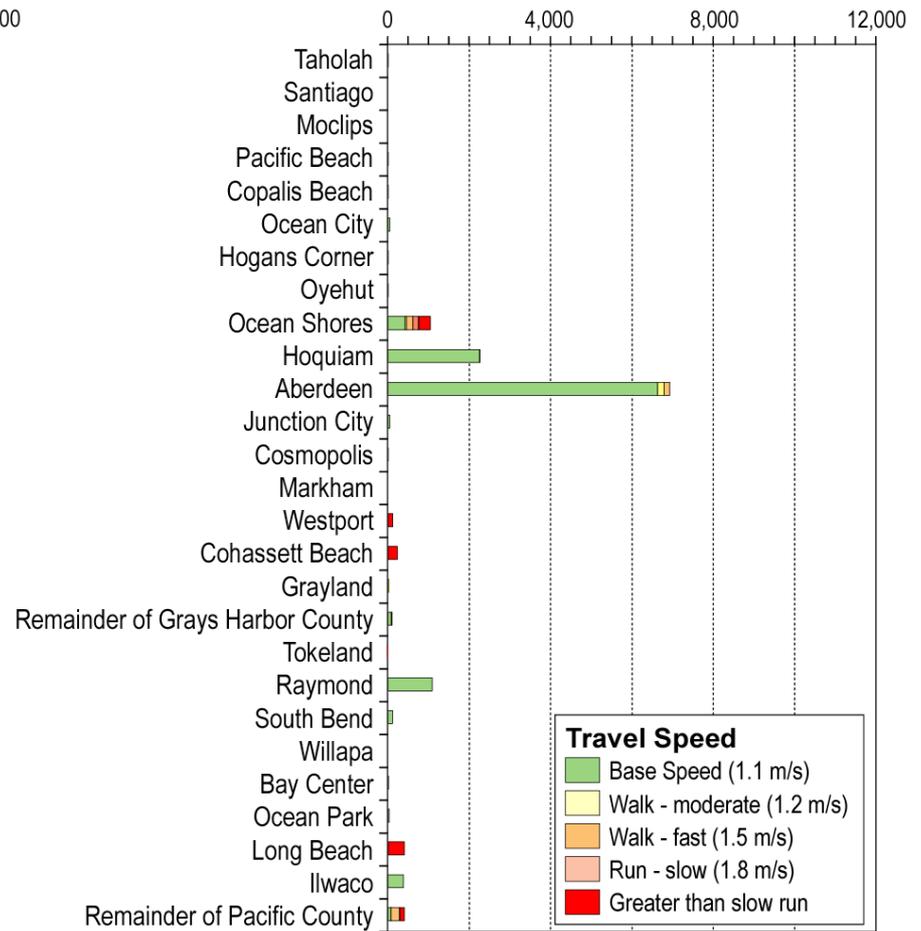
Based on 1.1 m/s travel speed

Cumulative number of residents and employees with increasing travel speed assumptions

Cumulative number of residents with 25 minutes or less of travel time to safety with increasing travel speed assumptions



Cumulative number of employees with 25 minutes or less of travel time to safety with increasing travel speed assumptions



Conclusions

- Population vulnerability is an essential element of tsunami loss estimation, especially for near-field tsunami threats
- Population vulnerability is a function of landscape conditions and individual's ability
- Traditional exposure assessments can be inadequate for estimating life loss
- Exposure indices weighted by travel times to safety are a better way to characterize population vulnerability than simple overlays

More information on methods

Wood, N., and Schmidlein, M., in press, Anisotropic path modeling to assess pedestrian-evacuation potential from Cascadia-related tsunamis in the U.S. Pacific Northwest, *Natural Hazards* (free download available)

