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Employment accessibility and rising seas

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ABSTRACT

Recent projections suggest worst-case scenarios of more than six ft (1.8 m) of global mean sea-level rise by end of century, progressively making coastal flood events more frequent and more severe. The impact on transportation systems along coastal regions is likely to be substantial. An analysis of impacts for Atlantic and Cape May counties in southern New Jersey is conducted. The impact on accessibility to employment is analyzed using a dataset of sea-level increases merged with road network (TIGER) data and Census data on population and employment. Using measures of accessibility, it is shown how access will be reduced at the block-group level. An additional analysis of low and high income quartiles suggest that lower-income block groups will have greater reductions in accessibility. The implication is that increasing sea levels will have large impacts on people and the economy, and large populations will have access to employment disrupted well before their own properties or places of employment may begin to flood (assuming no adaptation).

1. Introduction

Transportation systems are built to provide access for people and in particular access to employment opportunities. Both highway and transit systems have been designed to make this access possible. However, the accessibility of existing transportation systems, and therefore employment opportunities, is likely to face significant disruption over the coming decades as sea-levels rise, leading to more frequent and intense coastal flooding. Global sea level rise (SLR), due to climate change, may exceed 24 cm in 2050 and 48 cm in 2100, even if global temperatures are stabilized at 1.5 °C, a scenario increasingly viewed as out of reach (Rasmussen et al., 2018). More recent research suggests that, in the case of unchecked growth of global carbon emissions and catastrophic Antarctic ice sheet collapse, sea levels could plausibly climb more than 6 ft (2 m) by end of century (Kopp et al., 2017; Bamber et al., 2019), and land subsidence (about 1.5 mm per year in southern New Jersey (Sun et al., 1999)) will further add to relative local SLR. This research examines the impact of rising sea levels on accessibility patterns in Atlantic and Cape May counties in the southern part of New Jersey. Our aim is to highlight the changes in accessibility that will occur and also to provide a useful method for planners and engineers to understand these changes.

Transportation planners use various measure of accessibility to determine the ease with which people can access locations (Handy and Niemeier, 1997; Geurs and Van Wee, 2004). The simplest measures specify how many types of activities are available within a certain distance or travel time. For example, the number of potential jobs within a specified distance is a simple metric for measuring accessibility, although it says nothing about whether the jobs available match the skills of the population. However, it does represent

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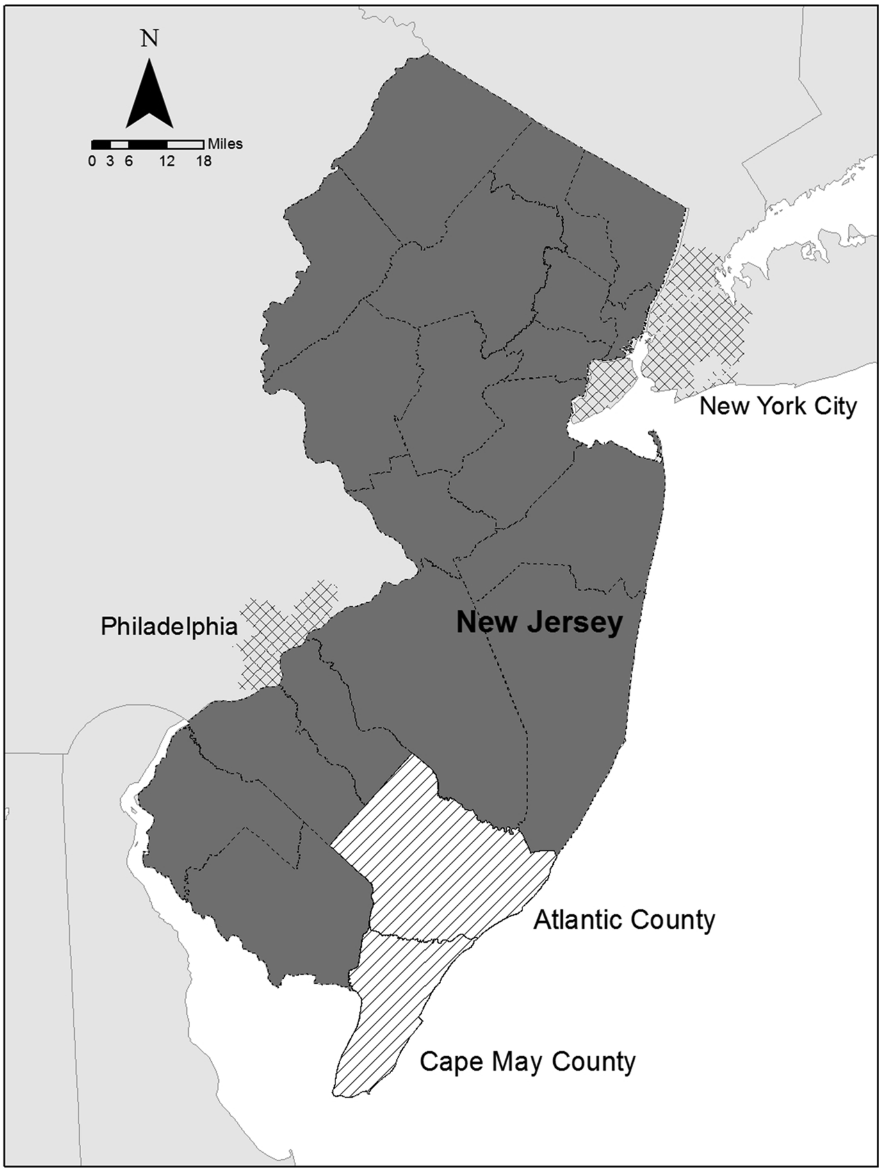

Fig. 1. Atlantic and Cape May counties in New Jersey.

potential interactions between home and potential job locations (Miller, 2018). These metrics are known as gravity-based measures as they assume an impedance function (i.e., distance or time) separating the attractors of employment locations. These can be easily calculated based on network distances or preferably travel times and can cover an entire region. Most analysts examine access to employment opportunities, although other destinations and activities can also be analyzed, as can the impacts on different socio-economic groups (Golub et al., 2013; Sehatzadeh, 2017). Access to employment by a larger labor pool, can lead to productivity benefits (i.e., agglomeration economies); thus, any reduction in access can have economic costs that reduce overall productivity (Rosenthal and Strange, 2004). These issues are not accounted for in most analysis of the costs of climate change (Hsiang et al., 2017).

In the analysis presented here, we examine the accessibility impact of breaking the road transportation network due to increasing water heights associated with sea-level rise and the coastal floods it will aggravate. We specify a baseline of accessibility given current employment locations and the existing road network. As water heights rise, we examine how access to these employment locations is affected. We also examine the impact on lower and higher income block groups. Unsurprisingly, our findings show that access is reduced; this implies that increases in sea levels and the associated periodic inundations from high tides and storm surges are likely to have impacts far sooner than when full inundation occurs, and affect many individuals whose property is not itself flooded. These impacts also affect inland areas that lose access to coastal jobs or that are affected by inundated roads crossing inland estuaries.

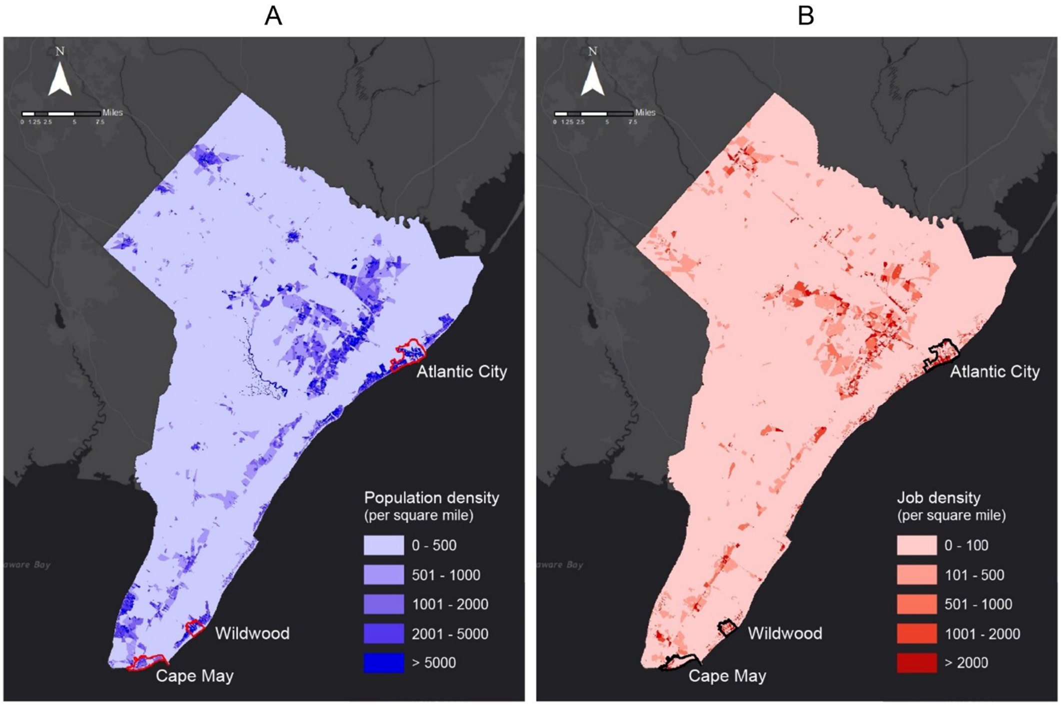

Fig. 2. Population and job density (per sq mile) by Census block for Atlantic and Cape May counties.

2. Study area

Atlantic and Cape May counties, along the southern New Jersey coastline (Fig. 1), were selected for this analysis. Much of the land here is low-lying and flat, and known to be particularly vulnerable to sea-level rise and coastal flooding (Strauss et al., 2013; Kulp and Strauss, 2017). One prior study examined the vulnerability of Cape May County to sea-level rise and in particular flooding events from storms (Wu et al., 2002). They examined social vulnerability and found that the county would be at increased risk, while using an estimate of sea-level rise of 60 cm (1.96 ft) by 2100, based on the best available evidence at that time (Najjar et al., 2000).

According to the 2016 American Community Survey 5-year estimates, the population of Atlantic County was 274,026, and Cape May County was 95,404. The majority of residents are concentrated in municipalities along the shore, including the communities of Brigantine, Atlantic City, Ventnor City, Margate City, Ocean City, Sea Isle City, Avalon, Stone Harbor, the Wildwoods, and Cape May (see Fig. 2). In contrast, inland areas have a relatively low population density. Egg Harbor Township in Atlantic County is the most populous municipality in the study area, and Ventnor City in Atlantic County has the highest density (U.S. Census Bureau, n.d.). Atlantic City is the second most populous municipality (about 38,000) and one of the more densely populated in the study area (U.S. Census Bureau, n.d.). Most shoreline cities are located on barrier islands and connected to the interior by bridges.

Based on 2015 Census Longitudinal Employer-Household Dynamics (LEHD) data there are a total 149,803 jobs in these two counties. The distribution of jobs is shown in Fig. 2 and broadly matches the population distribution. This suggests that many jobs are near residences, but says nothing about whether people have jobs near their home. The largest proportion of jobs (24%) is in the accommodation and food services sector, representing the tourist and leisure industry of the New Jersey shore. The second largest sector with 15% of jobs are in health care and social assistance. Median incomes in both counties are above the US average ($56,778 in Atlantic County and $59,338 in Cape May county) but below the New Jersey average (https://datausa.io/).

These characteristics are suitable for our case study, as the shoreline is highly vulnerable to rising sea-levels and flood risks (Strauss et al., 2013, National Oceanic and Atmospheric Administration, n.d.). The area is also sufficiently small to serve as a proof of our methodology without requiring substantial computing time.

3. Data and methods

Data for this analysis is obtained from several sources and merged using ArcGIS. Employment data was obtained from the Census Bureaus' LEHD program, specifically the 2015 New Jersey LEHD Origin-Destination Employment Statistics (LODES) (US Census and Bureau, n.d.). These data, distributed at the Census block level, are aggregated to the Census block-group level. Population and the median household income by block-group for Atlantic County and Cape May County in 2016 were from the Census American Community Survey (ACS) 5-year averages. Three block-groups with no income data were not included. For both counties there are a total of 271 block-groups with data.

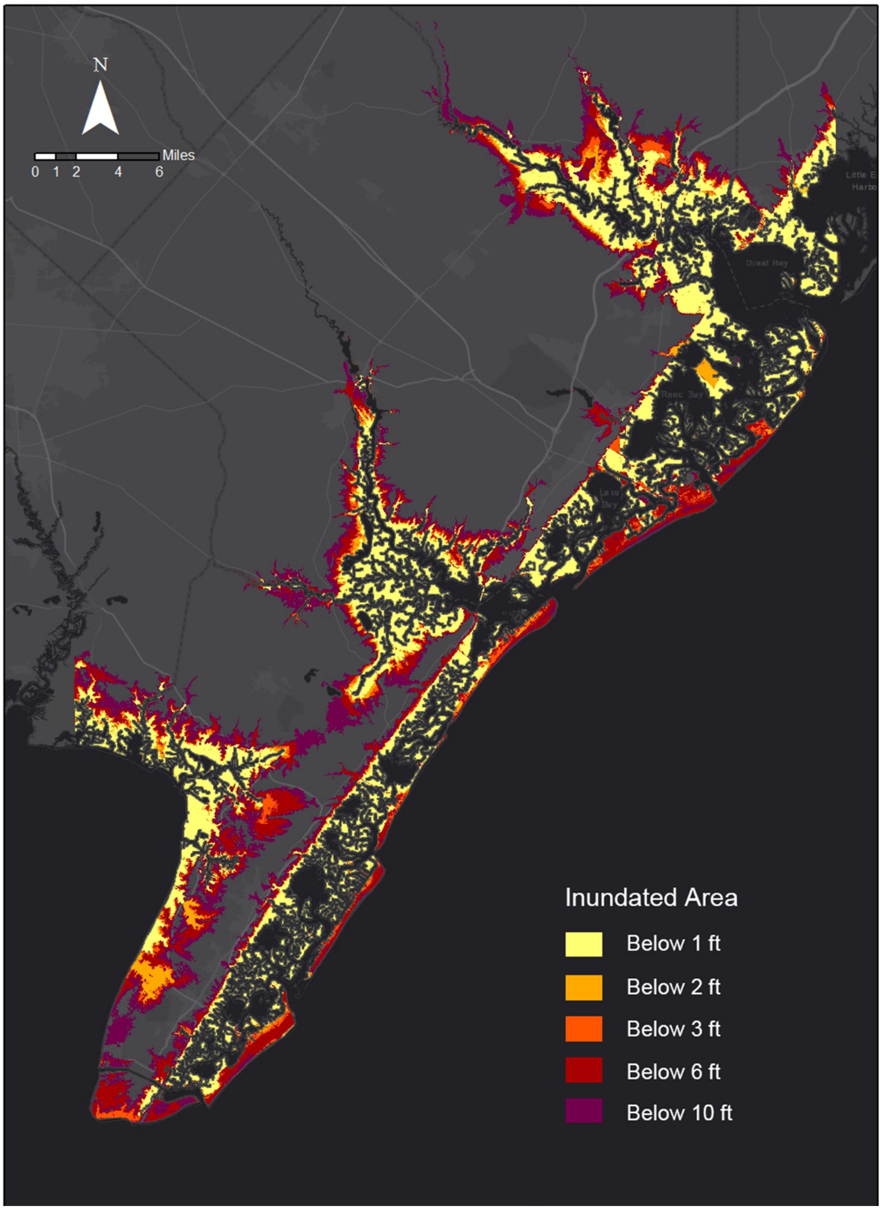

Fig. 3. Topographically vulnerable areas for different levels of inundation in Atlantic and Cape May Counties, NJ. Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community.

Census block and block-group boundary data comes from the 2010 US Census. Road network data was obtained from Topologically Integrated Geographic Encoding and Referencing (TIGER) files, a public-use geographic database developed by the U.S. Census Bureau (US Census and Bureau, n.d.). Roads over wetland areas, as delineated by the National Wetland Inventory (US Fish and Wildlife Service, 2012), are assumed to be bridges and high enough to not be exposed to flooding. Inundation mapping follows the framework of Strauss et al. (2012). Topography is based on LIDAR-derived digital elevation models (DEMs) compiled and distributed by NOAA (n.d.), and we use NOAA's VDatum software (version 2.3.5) (Parker et al., 2003) to transform elevations to reference local mean higher high water (MHHW).

The resulting DEM is thresholded (bathtub model) at 1, 2, 3, 6, and 10-foot water heights, chosen as representative samples of potential combined sea level rise (permanent) and storm surge (temporary), to produce inundation surfaces above MHHW (Fig. 3). A more detailed map of Atlantic City is also shown in Fig. 4 for 3 ft (0.9 m) and 10 ft (3 m) surfaces above MHHW. Connected components analysis (Rosenfeld and Pfaltz, 1966) is used to refine these flood maps, incorporating levee data from the 2013 Mid-term Levee Inventory, provided to us by FEMA, to identify and remove low-lying areas isolated from the ocean. This levee dataset does not contain information on height nor conditions, so in this analysis we make the conservative assumption that levees are sufficiently high and strong to protect against any flood.

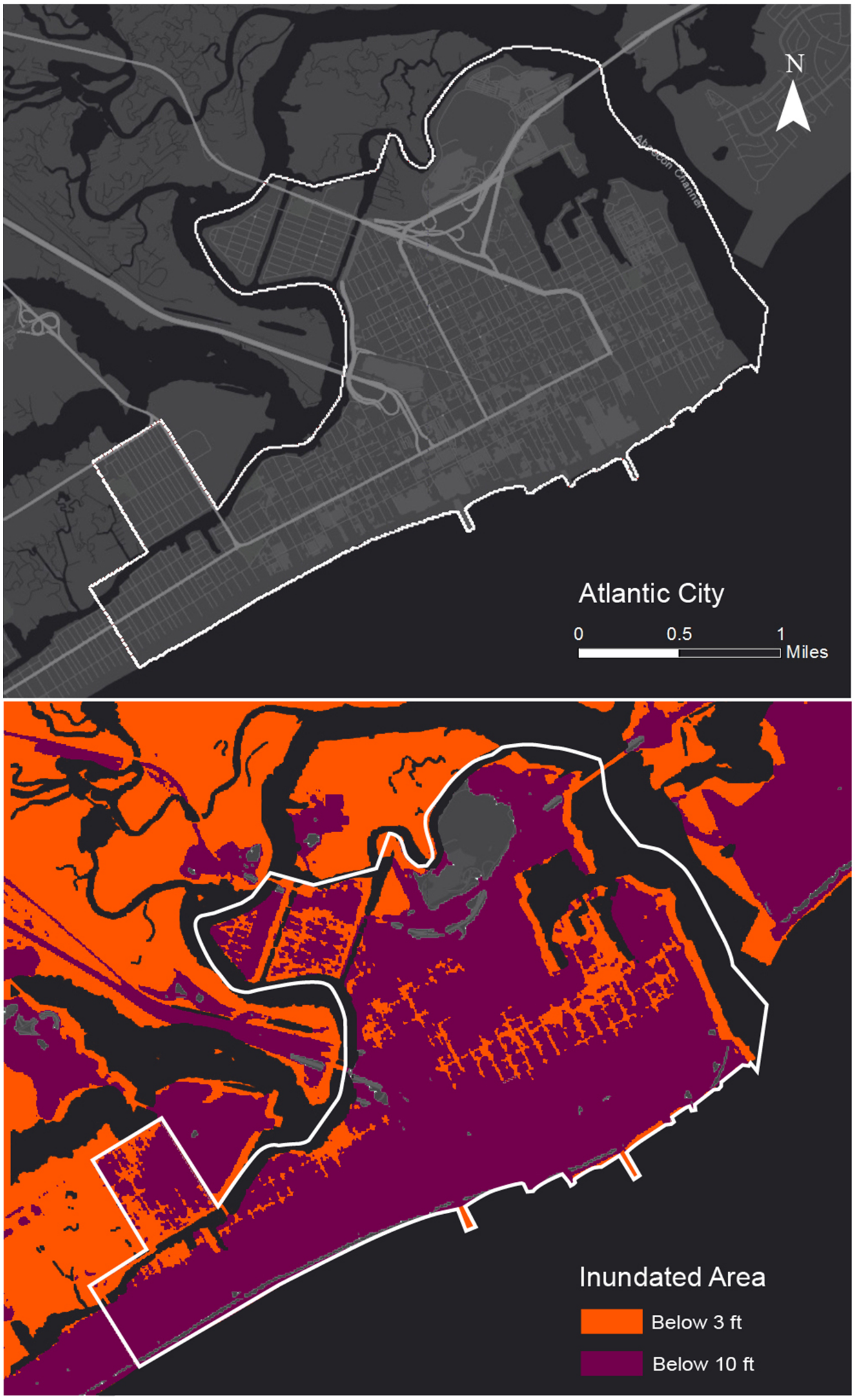

Fig. 4. Inundation in Atlantic City, NJ for 3 ft (0.9 m) and 10 ft (3 m) inundation levels. Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community.

We use two measures to examine accessibility to jobs. One is a simple measure of jobs available within a 10-mile distance, while the other uses a gravity-based accessibility measure. In both cases travel distance, d_{ij}, is calculated from the block-group centroid using network analysis to identify distance on road links. The accessibility index (A_i) of a block-group, i, is an inverse distance-weighted sum of available jobs in all block-groups (a_j) within our study area, scaled by the block-group's total population (P_i).

Generally, the power function and the exponential function are used as the weighting term in gravity models (Martínez and

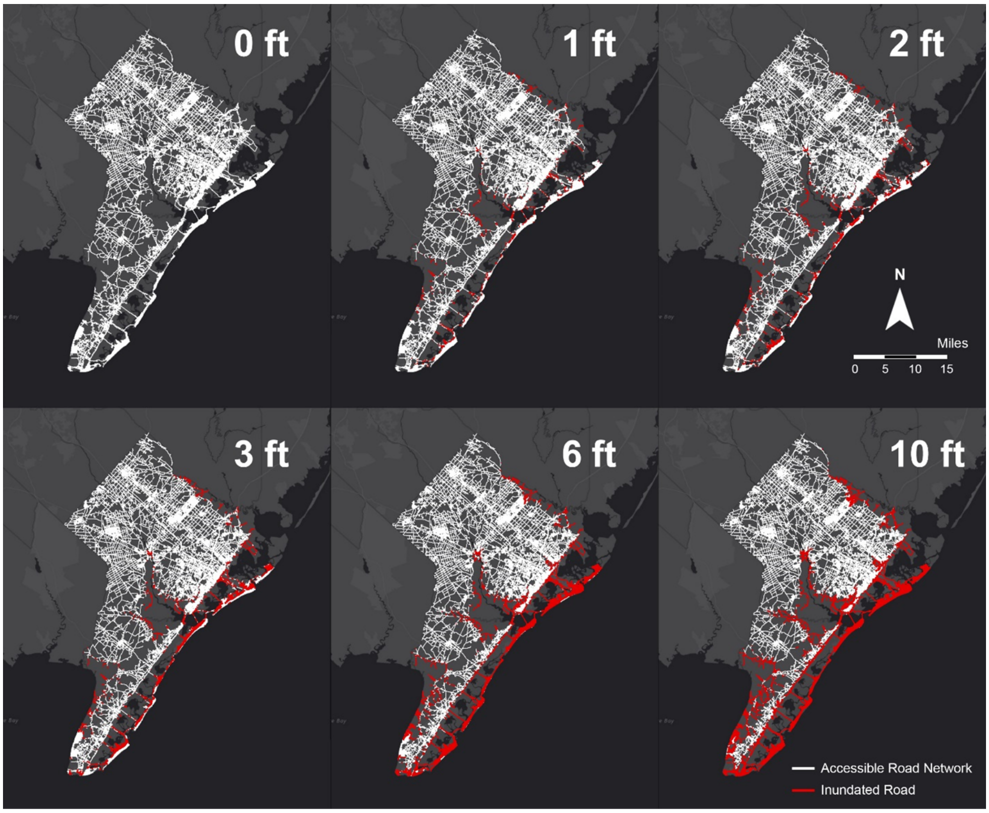

Fig. 5. Road network below different water heights, relative to Mean Higher High Water, Atlantic and Cape May counties, NJ. Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community.

Viegas, 2012) with the exponential decay function being the most commonly used (Geurs and Van Wee, 2004). The exponential term in the decay function can be derived from a travel demand model; however, for simplicity we use a value of -1. Thus, the accessibility index is calculated as follows:

$$Ai = \left(\sum_j^n a_j d_{ij}^{-1} \right) * P_i \tag{1}$$

Road networks are intersected with the inundation surfaces, and flooded segments are removed (Fig. 5). For each resulting network, we compute network distances, starting and ending at centroids, between all pairs of block-groups to produce the gravity accessibility indices (Eq. (1)) for each inundation surface.

Based on the ACS data, quartiles for the median household income by block-group were calculated. Block-groups that fall into the lowest quartile (below $43,400) and those in the highest quartile (above $75,290) were classified as "low income" and "high income" areas, respectively, allowing for an accessibility assessment and comparison based on income group.

4. Results

Job accessibility (as measured by Eq. (1)) at each water height, including the baseline case (0 ft), is presented in Fig. 5). In the absence of flooding, we see the area around Atlantic City, one of the main population and employment centers, is highly accessible. Unsurprisingly, as water heights increase, access is reduced. The number of jobs within 10-miles of each block group is shown in Fig. 7, with similar results to those in Fig. 6. Fig. 7 displays the percent change in the accessibility index for each level of water height. These maps reveal a rapid reduction in accessibility close to the coastline, with a number of areas seeing a 100% reduction as the local road networks become nearly entirely inundated. The block-groups that see the least reduction in accessibility are located in the center of Atlantic County, but along some inland tributaries there are decreases in accessibility, starting at water heights of 3 ft (0.9 m). Major portions of Cape May county have large reductions in accessibility at the 3 ft (0.9 m) level.

In Fig. 9 the distribution of percent reduction in the accessibility index is plotted for water height levels of 1 ft (0.3 m) and 3 ft (0.9 m). Of the 271 block groups in the analysis, about 60% have a minimal decrease in the accessibility index (2% or less) and 31 block groups have no reduction in accessibility, with a 1 ft (0.3 m) increase in water height. This rapidly changes with increases in

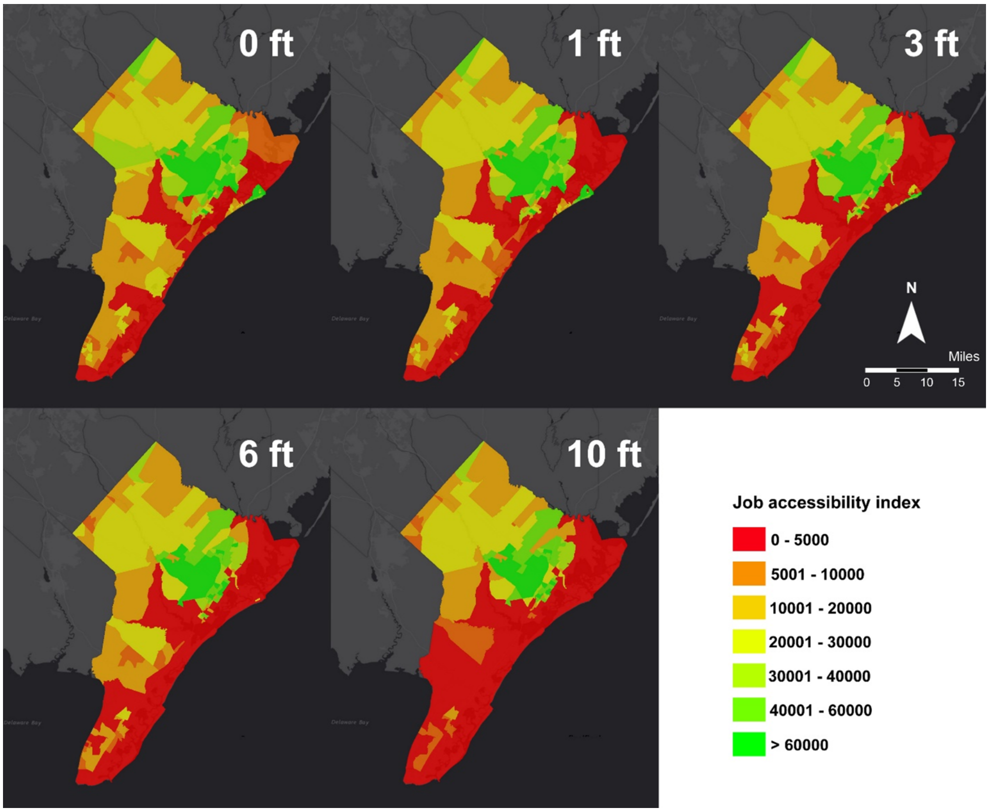

Fig. 6. Accessibility index by block-group for different levels of water height, Atlantic and Cape May counties, NJ, based on Eq. (1). Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community.

water height level and at a 3 ft (0.9 m) level less than 5% of the block groups have a minimal decrease in the accessibility index. The reduction in access for more block groups suggests that it is not just coastal block groups that suffer from reductions in access to jobs.

The percent reduction in accessibility for three cities is shown numerically in Table 1. This shows that even at a 1 ft (0.3 m) rise in water height, job accessibility in Atlantic City drops by over 60%. For the City of Cape May (located at the southern tip of New Jersey), and the City of Wildwood (just north of the southern tip on the Atlantic shore), our accessibility reductions are also large, and even greater at 3 ft (0.9 m) levels. At 6 ft (1.8 m), accessibility is near zero in all three cities, due to inundation.

Another way to look at the impact on jobs, is to evaluate how many jobs (within a block-group) are vulnerable to inundation, as opposed to how many are no longer accessible. In Table 2 we show the number of total jobs in each of the three cities and the number and percent of total jobs vulnerable at each water height level (based on jobs in each block group). While impacts are severe, they are less than the impact from reduced access. For example, at 6 ft (1.8 m), 51% of jobs in Atlantic City are vulnerable to inundation, while access is reduced by 99%. For the City of Wildwood, while only about 15% of jobs are below a 3 ft (0.9 m) water height, the reduction in access to these jobs is 100%. This indicates the value of examining accessibility impacts, as even if jobs (and land) are above water, the ability of people to access those jobs is affected.

Several inland areas appear to have large reductions in accessibility. One area is shown in Fig. 10 where a large reduction is seen at a 1ft (0.3 m) increase in water height. This is caused by the Patcong Creek estuary flooding the only road connection in the area, county road 559. Another example is shown in Fig. 11. In this case a 2 ft (0.6 m) increase in water height reduces the accessibility of Cape May Court House, likely due to flooded wetlands between the town and the shore. In Fig. 12, another case of a large reduction in access is shown at the 2 ft (0.6 m) level, due to wetland flooding north of Villas, NJ. In this case the flooding is from the Delaware Bay.

Based on Executive Order 12898, transportation agencies are required to consider how policies and plans will affect lower income and minority communities (Office of the President, 1994). As stated in the regional plan for the south Jersey Metropolitan Planning Organization an objective is to "Ensure adequate accessibility and mobility options to the transportation-disadvantaged populations, including those zero-car households and other environmental justice communities" (South Jersey Transportation Planning Organization, 2016). With this in mind, we conduct an analysis of how water height increases affect low-income versus high-income (based on quartiles) block-groups. Results are shown in Table 3. Higher income block groups actually have lower access to jobs than lower income block groups. However, as water height levels increase, accessibility for low-income block groups decreases substantially and at the 6 ft (1.8 m) and 10 ft (3 m) levels is lower compared to the remaining accessibility for higher income block-groups.

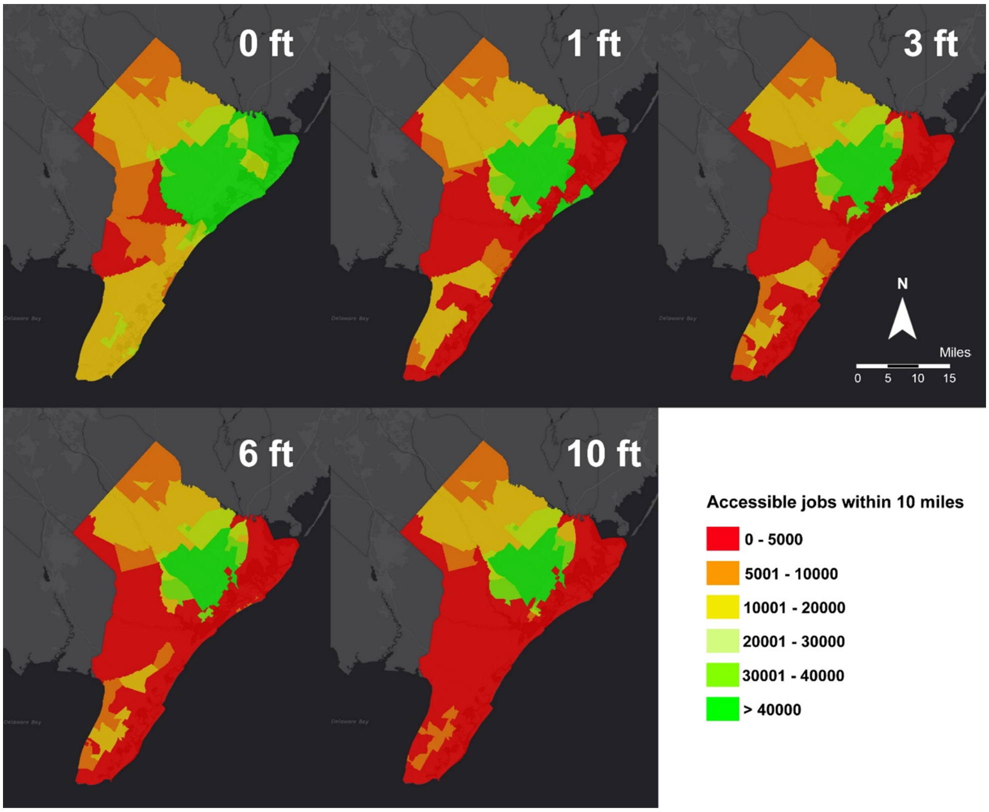

Fig. 7. Jobs within 10-miles by block-group for different levels of water height, Atlantic and Cape May counties, NJ. Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community.

5. Discussion

These results reveal the substantial impact rising sea levels associated with climate change will have on the accessibility of jobs in southern New Jersey, highlighting the need for planners to consider priority locations for sea-level defenses, where future jobs should be located and how the transportation network can connect all jobs in the future. The methods presented here indicate where and by how much accessibility will be affected, and show that while shore communities are deeply vulnerable, inland estuaries will also be impacted. Other inland areas will likewise be affected by reduction in accessibility to jobs, even if not located near inland estuaries. Disrupted road networks will lead to longer trips due to rerouting, increased congestion, and in some cases, the inability to make a trip. If job locations are frequently underwater, this will lead to relocations, so over time, impacts will be less; however, the costs of relocation will affect both coastal and inland areas.

Rising mean water heights are already affecting some coastal regions, and their impacts are expected to increase. Instances of nuisance flooding are associated with large tides and can occur under calm weather conditions. Recent projections suggest that by the 2040s, such sunny day flood incidents may become twice as frequent, compared to the 2010s in Atlantic and Cape May (Climate Central, 2018), potentially occurring for about six days a month throughout the fall and winter seasons. These can disrupt local transportation networks, in addition to damaging local infrastructure.

While areas threatened by permanent inundation over the coming decades are a serious concern, the most immediate dangers come from heightened and more damaging coastal storm surge. While such events are, by definition, temporary, they will still cause economic damage to the local community following loss of services and expected income/revenue. Near Atlantic City, the 1-year return level storm is about 2 ft (0.6 m) high, and the 10 year storm exceeds 3 ft (0.9 m) above the current high tide line (Tebaldi et al., 2012). With just 1 ft (0.6 m) of sea level rise, the annual storm will become as damaging as the current 10-year event; for Atlantic City, our results suggest that job access is reduced by 67% once a year, and more frequently as sea levels continue to rise. Moderate forecasts of SLR (RCP 4.5, 50th percentile, using the projection model from Kopp et al. (2014)) see 10-year flood heights reaching 4.2 ft (1.3 m) above the current high tide line and extreme forecasts (RCP 8.5, 95th percentile) see 100-year floods potentially reaching nearly 6 ft (1.8 m) by 2040. At this level, we estimate about 50% of jobs in Atlantic City are temporarily submerged. But as shown in our results, access to jobs is reduced even more (a 99% reduction in the accessibility index at 6 ft (1.8 m)).

Expected sea-level rise and associated increases in water height are also dependent on what progress is made in reducing greenhouse-gas emissions. Uncontrolled emissions will increase SLR faster, but such differences are more visible beyond 2050.

Disparate impacts on different population groups also need to be considered in future planning. While higher-income block

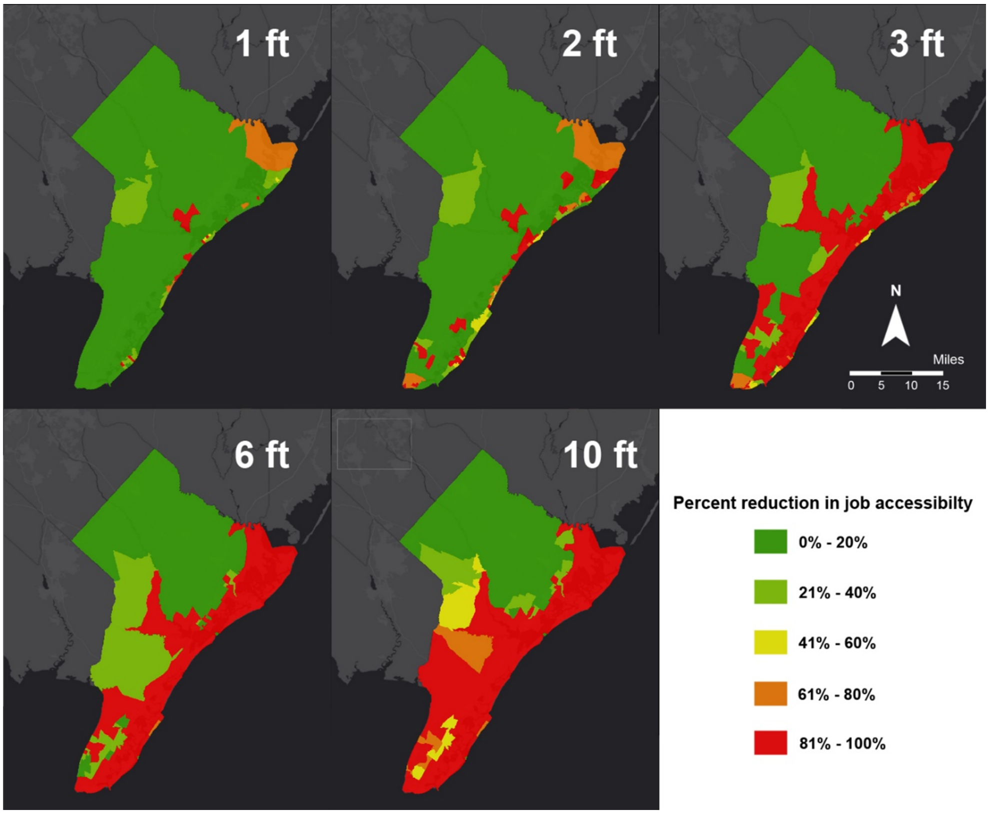

Fig. 8. Percent reduction in the accessibility index by block-group for different levels of water height, Atlantic and Cape May counties, NJ. Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community.

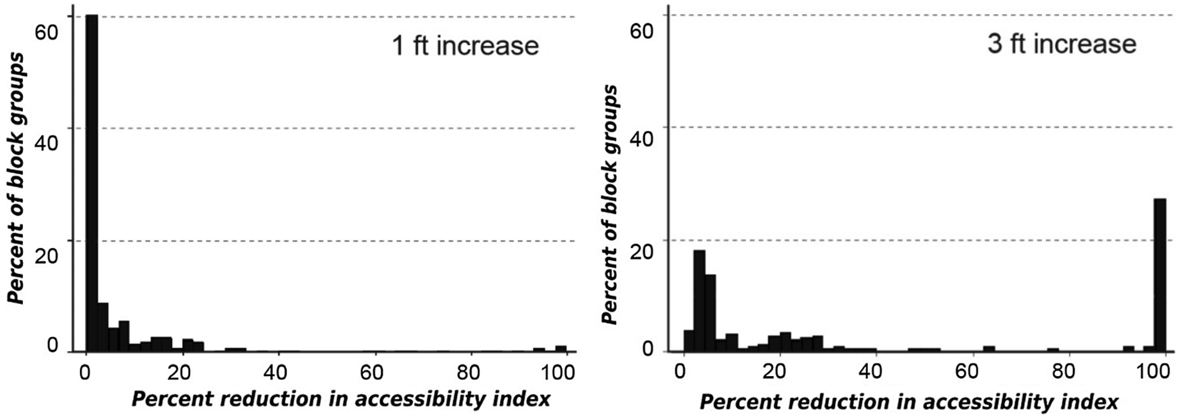

Fig. 9. Histograms of reductions in accessibility index for 1 ft (0.3 m) and 3 ft (0.9 m) increase in water height.

Table 1
Percent reduction in accessibility index for Atlantic City, City of Cape May, and City of Wildwood for each increase in water height.

	Atlantic City percent reduction	City of Cape May percent reduction	City of Wildwood percent reduction
1 ft (0.3 m)	62.8	44.7	14.9
2 ft (0.6 m)	63.6	44.7	88.5
3 ft (0.9 m)	67.4	89.0	100.0
6 ft (1.8 m)	99.1	100.0	100.0
10 ft (3 m)	100.0	100.0	100.0

Table 2
Jobs lost in Atlantic City, City of Cape May, and City of Wildwood for each increase in water height.

	Atlantic City		City of Cape May		City of Wildwood	
	Number of jobs available	Percent jobs vulnerable to inundation (%)	Number of jobs available	Percent jobs vulnerable to inundation (%)	Number of jobs available	Percent jobs vulnerable to inundation (%)
0 ft (0 m)	39,280		2435	–	2079	–
1 ft (0.3 m)	39,123	0.40	2302	5.46	2078	0.05
2 ft (0.6 m)	39,115	0.42	2302	5.46	2058	1.01
3 ft (0.9 m)	38,735	1.39	2239	8.05	1768	14.96
6 ft (1.8 m)	19,189	51.15	1336	45.13	59	97.16
10 ft (3 m)	5079	87.07	462	81.03	0	100.00

Fig. 10. Access reduction caused by the Patcong Creek estuary with 1 ft (0.3 m) increase in MHHW. Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community. Refer to Fig. 8 for legend of map on left. Google Maps is source for satellite and Street View image.

groups initially had lower accessibility in this study area than lower-income block groups, the latter have greater reductions in accessibility as water heights increase. Environmental justice requires planners to consider how to mitigate this disparate impact.

This case study was limited to only one coastal region, primarily to demonstrate the feasibility of the analysis. It can be extended to other regions including larger cities. All data used in this analysis is accessible for all coastal areas in the country, and so a full national assessment is possible. One shortcoming is that we only use distance measures rather than travel times; the latter are not available in standardized formats for the nation, but can be derived from local data or travel demand modeling. Inclusion of public transit systems is another potential line of research.

One limitation of this analysis is the use of block-group data. We opted to analyze at the block-group level due to more tractable computational times to calculate the accessibility index. However, most of the vulnerable shore communities with larger population are composed of smaller block-groups, so this is unlikely to affect our overall conclusions. A block-level analysis might provide more detailed estimates of how access will be affected and could possibly be implemented with various simulation models (MATSim is one potential approach; https://matsim.org/).

Another limitation of this work is the use of a bathtub model to generate inundation surfaces under the five water height thresholds, which assumes that X ft of sea level rise with zero storm surge would produce an equivalent flood extent as zero sea level rise and an X-ft storm surge. While we expect these results to be acceptable in the case of pure sea level rise, bathtub models are known to overestimate exposure during extreme storm events as they ignore important factors such as land friction (Seenath et al., 2016; Vafeidis et al., 2019). It is likely that a full hydrodynamic model would predict lower vulnerability than what has been presented here. Bathtubs should perform relatively well for milder floods (e.g. annual) than more extreme ones (e.g. 100-year).

One potential area of future research is to explore access to other services, such as schools and hospitals. The latter are particularly critical when emergency flood situations arise. Future work could also use actual local sea level rise projections based on different

Fig. 11. Access reduction at Cape May Court House, due to coastal flooding of wetlands from 2 ft (0.6 m) increase in MHHW. Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community. Refer to Fig. 8 for legend of map on left. Google Maps is source for satellite and Street View image.

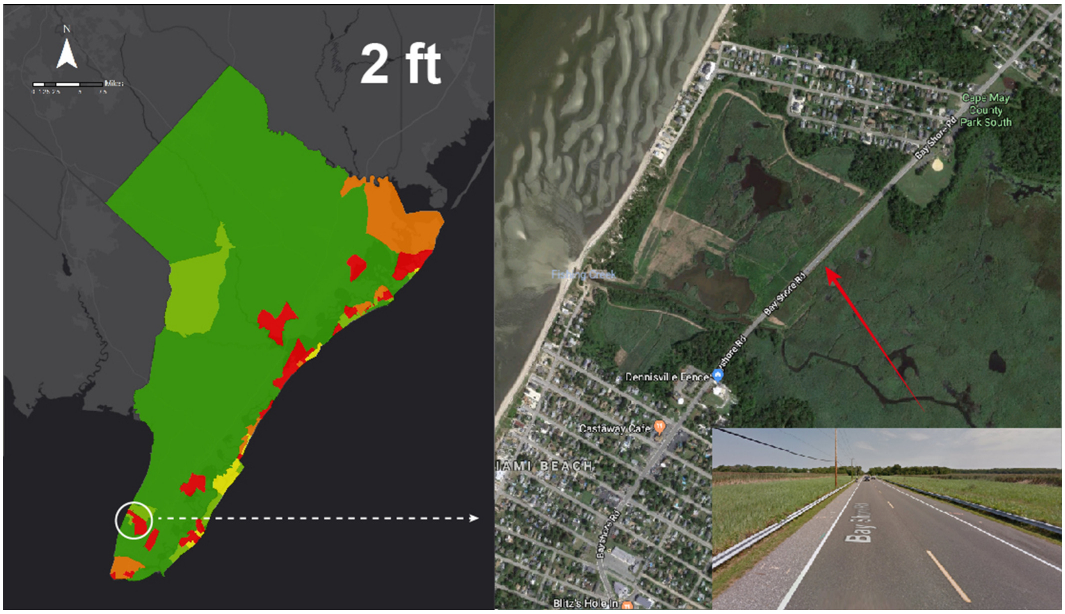

Fig. 12. Access reduction in Villas, NJ, at 2 ft (0.6 m) increase in MHHW, caused by wetland flooding from Delaware Bay. Source for base map: Esri, HERE, Garmin, © OpenStreetMap contributors, and the GIS user community. Refer to Fig. 8 for legend of map on left. Google Maps is source for satellite and Street View image.

scenarios and GHG emission pathways (Kopp et al., 2014), paired with return level curves derived from historical hourly water height observations. This would provide information on accessibility changes paired with forecast years, linked to carbon emission scenarios.

6. Conclusions

In this paper we have analyzed how rising sea levels and associated flood impacts might affect the accessibility to jobs. The transportation network is necessary for providing access; in our analysis we use TIGER line files to represent this network and

Table 3
Percent reduction in accessibility index for top and bottom median income quartiles.

	Top quartile		Bottom quartile	
	Average job accessibility	percent reduction	Average job accessibility	percent reduction
0 ft (0 m)	24,500	–	53,820	–
1 ft (0.3 m)	23,710	3.22	51,960	3.46
2 ft (0.6 m)	22,680	7.43	31,260	41.92
3 ft (0.9 m)	21,040	14.12	24,650	54.20
6 ft (1.8 m)	18,550	24.29	10,400	80.68
10 ft (3 m)	15,730	35.80	8514	84.18

inundation data for Atlantic and Cape May counties in New Jersey. Access to jobs is measured at the block-group level using an accessibility index and also the number of jobs within 10 miles. Access to jobs is naturally reduced as water heights increase and this will also affect inland areas that are not near water bodies with consequent impacts on people and the economy. These broader impacts of coastal flooding imply that these effects are not just localized near coastal communities. Even before job locations are inundated, the road network may be submerged and lead to reductions in access to those jobs. Reduction in accessibility can thus be argued to be the very leading edge of sea-level rise impacts in time. This research demonstrated the feasibility of this approach and offers multiple opportunities for exploration of more detailed impacts on accessibility. Incorporating impacts on transit routes would add more detail for those areas with extensive transit networks.

Author Contribution Statement

The authors confirm contribution to the paper as follows: Study conception and design: Noland, Strauss; Data collection: Wang, Kulp; Analysis and interpretation of results: Noland, Kulp; Draft manuscript preparation: Noland, Wang, Kulp, Strauss; All authors reviewed and approved the final version of this manuscript.

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