Perceptions of visual and in situ representations of sea level rise and tidal flooding: the blue line project, Norfolk, Virginia

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Abstract Future maps and visualizations of sea level rise struggle to convey the salience of evolving coastal hazards on the ground. This study engaged three Norfolk, Virginia communities in the "Blue Line" project to identify the appealing components of various types of visualizations and determine which images increase risk perceptions, contribute to the selection of adaptation or mitigation strategies, and elicit protective actions. Participants viewed models of future high tide shorelines for 2050, 2080, and 2100 as digitized maps and photographs of the lines marked on the ground with tape, spray chalk, and flags at three different communities: a residential neighborhood and park; a downtown museum and open space; and a working waterfront. Results indicate that while the combination of maps and photographs were preferred for the realism conveyed, maps were better able to show a larger area and photographs were more personal. Photographs balanced the reactions to maps, which were preferred, and increased the perception of sea level rise, but also elicited built solutions. Citizens expressed greater immediacy for action in residential areas even if the perceived risk was higher in heritage areas. These results can inform the balance of visualization types utilized by planners and community organizations to create a comprehensive plan through participatory processes.

Introduction

The United States East Coast and Mid-Atlantic Region are subject to land subsidence that exacerbates the effects of sea level rise (SLR). Without proactive adaptation, cultural resources will be lost, socio-economic opportunities limited, and vulnerability to hazards increased (Titus et al. 2009; Yin and Goddard 2013). However, the level of uncertainty and long term, cumulative effects of SLR present difficulties for those trying to convey information about it.

Research on mitigation and adaptation preferences is especially applicable to Norfolk's approximately 245,000 residents. SLR is an imminent threat to the diverse uses of the City's shorelines. Norfolk has a low-lying historic port and is the home of the largest naval base in the world (Fig. 1). The city is dissected by several coastal rivers, including the James River mouth at the southern end of the Chesapeake Bay to form the Hampton Roads Harbor, and tidal rivers and tributary creeks including the Elizabeth River and Lafayette River. SLR affects a range of land uses

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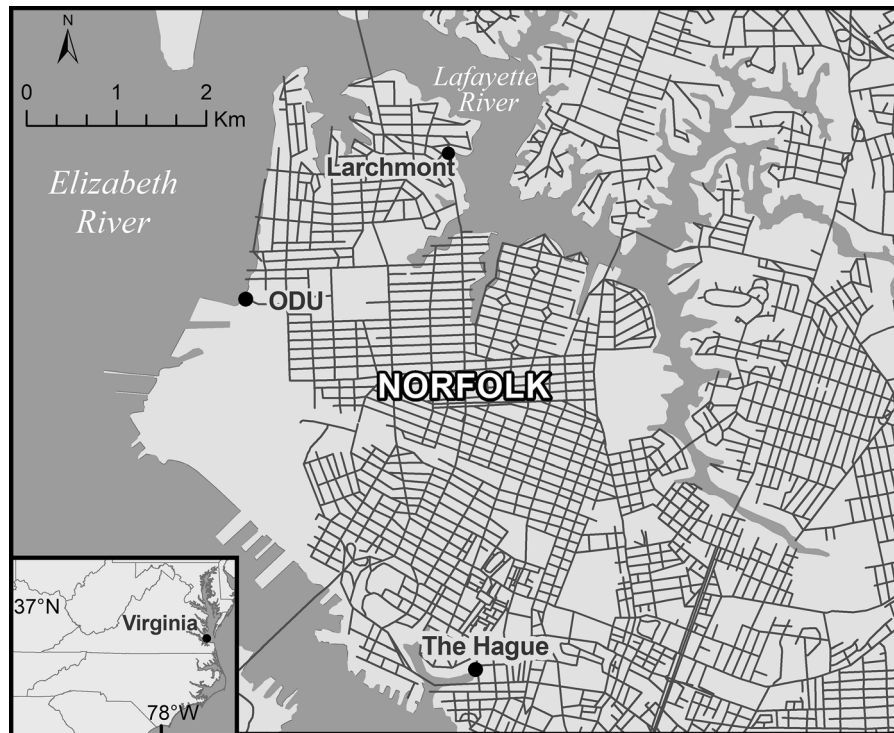e-mail: nhuttons@odu.edu

Fig. 1 Study area location, City of Norfolk, Virginia, USA

throughout the Norfolk that are recognizable by other coastal communities. Because Norfolk is a developed urban area, ecosystems that would otherwise bounce back from or adapt to SLR cannot without damage to infrastructure. Streets, green spaces, cultural institutions, recreational facilities, and homes will be at risk by 2100 if not earlier.

Effective communication of local SLR risk facilitates community integration with adaptation planning by informing and encouraging residents to take proactive steps toward addressing their specific needs (Maibach et al. 2009; Harvatt et al. 2011). Models that synthesize SLR and climate change scenarios with natural and human vulnerability can improve risk communication in coastal communities. Photographs and maps have been used to illustrate potential SLR impacts at the local scale (Nicholson-Cole 2005; Sheppard 2005). Stephens and Richards (2020) showed that communicating risk is more effective when lived experiences are georeferenced and integrated into interactive visualization tools. Their work shows that story maps offer a linear way to assimilate risk data and overcome fatalistic or powerless feelings. Story maps combine geographic maps with text narratives, and multimedia images to create an application that the user can interact with to better understand the drivers of and ways to address SLR. Additional research is needed to determine how the visual components of story maps, such as photographs and maps, separately and collectively influence awareness, behavior, and protective strategy selection.

This exploratory case study (aka the "Blue Line" project) of three locations (residential area, university campus, and heritage site) in Norfolk, Virginia integrates tidal flooding processes accompanying SLR with geospatial analysis into surveys to explore the role of visualizations in resident perceptions of SLR and desirability of various mitigation and adaptation options. The driving questions are: (1) Are maps, photographs, or a combination thereof preferred and/or more effective for increasing awareness of SLR? and (2) Are maps or photographs more likely to elicit a preference toward green infrastructure, grey infrastructure, or retreat-based strategies to SLR? The study contributes a more nuanced understanding of responsiveness to various types of SLR visualizations.

Background

SLR will continue to increase, and its impacts, such as shoreline erosion and loss of marshes, will worsen, particularly in coastal cities, as global temperatures rise (IPCC 2014; Owrangi et al. 2015). The effects of SLR are not evenly distributed. Land subsidence is believed to be responsible for exacerbating SLR on the eastern seaboard of the U.S. from Florida to Maine (Yin and Goddard 2013). In particular, the Mid-Atlantic coastline from North Carolina to New Jersey is subject to a SLR of 3–5 mm a year (Titus et al. 2009). Coastal Virginia is especially at risk from the dangers of SLR (Kleinosky et al. 2007), with a predicted SLR in Hampton Roads of between 0.57 and 3.5 m (1.9–11.5 feet) within the next 100 years. The negative effects of shoreline loss in the Chesapeake Bay Area involve both short-term effects of hurricanes as well as the longer term effects, such as tidal flooding and high water levels from more frequent slower moving Atlantic hurricanes passing offshore (Ezer 2018), exacerbating a regional SLR "hotspot" where inundation rates are 3–4 times the global average (Sallenger et al. 2012). In addition, tectonic isostatic adjustment from the post-glacial rebound and a sinking glacial forebulge across the region yields a relatively high rate of vertical land motion in the area. Subsidence rates ranging from 1.1 to 4 mm per year (mm/yr) continue today (Eggleston and Pope 2013). This process is compounded by groundwater extraction and filling of estuarine creeks for land development in the Hampton Roads area, which includes Norfolk, Virginia. Thus, the Relative rate of Sea Level Rise (RSLR) is effectively higher in the region and a contributor to flooding problems. Understanding the variability of subsidence across the region is dependent largely upon a sparse network of long-term NOAA tide gauges (Zervas 2009), a USGS extensometer station in Suffolk, Virginia (Pope and Burbey 2004), and a set of Continuously Operating Reference Stations (CORS) operated by the National Geodetic Survey (NGS 2013). Newly available satellite Interferometric Synthetic Aperture Radar (InSAR) are also developing fine-scale products with improved spatial and vertical accuracy, and initial results using ALOS-1 SAR highlight both the high rate of subsidence and large spatial variability (Bekaert et al. 2017).

It is recognized that collaborative research is required to understand and mitigate SLR (Yusuf et al. 2018). Stafford and Abramowitz (2017) identify the socio-economic differences within and between communities in the Chesapeake Bay and quantify what risks are more pertinent to a given locality's exposure to SLR. Covi and Kain's (2016) work in coastal North Carolina, much like eastern Virginia, shows difficulties in conveying SLR information through risk messaging alone. Their participants express fear, fatalism, skepticism and loss towards potential SLR future scenarios (Covi and Kain 2016). An alternative strategy for conveying SLR information is via visualizations, including projections for future scenarios based on current SLR models. There are national tools such as Surging Seas (Climate Central; http://sealevel.climatecentral.org/maps) or the NOAA Sea Level Rise Viewer (https://coast.noaa.gov/digitalcoast/tools/slr.html) as well as local tools such as AdaptVA (http://www.adaptva.com/) that allow users to view potential effects of flooding, storm surges or hurricanes on a variety of temporal scales. However, the freely available visualization tools require some knowledge of the issues and scenarios or have spatial scale limits that preclude site-specific visualization. City planners, local and national governments and other decision-makers are the most likely users for these products not community members.

Stephens et al. (2017) and Allen et al. (2018) developed frameworks and matrices to facilitate community engagement with decision-making processes that integrate these tools into resilience planning. The Resilience Matrix, for example, addresses SLR resilience by assessing and prioritizing physical, cognitive, informational, and social resources (Allen et al. 2018). Resilience is the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events (The National Academies 2012). In the case of SLR, resilience to flooding, erosion, and salt-water intrusion must be improved (Sutton-Grier et al. 2015; Wamslet et al. 2016). A spectrum of mitigation and adaptation strategies should be considered in conjunction with communities to ensure functionality of social-ecological systems can be maintained or quickly restored (Meerow and Newell 2017).

Two primary infrastructural options are available: grey and green. However, without engagement in dialogue about SLR risk, individuals are less likely to implement adaptation or mitigation measures (Siegrist

and Gutscher 2008). Grey infrastructure, also known as hard, engineered, or built solutions, is the most common used by property owners including local government to defend shorelines. This is in part because permitting processes, consultants, and contractors are most familiar with them. However, grey solutions include flood gates, dikes, canals, levees, and sea walls that may damage ecosystems and create a sense of false security amongst residents (Schaffler and Swilling 2013; Hutton et al. 2018). Grey infrastructure can also limit the capacity to implement alternative solutions (Schaffler and Swilling 2013).

With increased awareness of other options, a shift may occur toward green infrastructure, which allows for an interim step between grey infrastructure and natural restoration through retreat. Green infrastructure is also referred to as "blue-green" in coastal settings. Blue-green infrastructure produces ecological benefits, such as, oyster reefs, which stabilize shorelines and improve water filtration, alone or with hard structural reinforcement. These living shorelines help to achieve a dual objective: protect against erosion and restore coastal ecosystems (Dietz 2007; Bilkovic et al. 2016; Toft et al. 2013; O'Donnell 2016).

While both green and grey infrastructure require maintenance, retreat offers an option with reduced future risk and labor requirements. On the one hand, once property is bought-out and remediated, environmental processes can take over. On the other hand, pairing retreat with green or grey infrastructure would offer additional protections and mid-range cost-benefits. In fact, balancing these types of mitigation and adaptation strategies through community driven, location specific designs can reduce both socio-environmental disparities commonly associated with grey infrastructural fixes and gentrification from greening projects (Wolch et al. 2014).

In the United States, green infrastructure has gained traction for storm water control, but there is room to improve its utilization for flood and erosion prevention (Sutton-Grier et al. 2018). The Netherlands, for example, is a pioneer in designing alternative solutions to flood mitigation (Brinkhuijsen and Steenhuis 2015). A neighborhood in Rotterdam has bicycle and walking paths that double as buffers along waterways and other frequently flooded areas (Tillie and van der Heijden 2016). For unified built and natural infrastructure to continue to gain traction at all levels of governance the ability to tailor plans to localities are important (Demuzere et al. 2014; Wamsler et al. 2016). Delays in implementation are partially attributed to limited national understandings of how community capacity can be integrated into the site assessment process. Bey's (2018) work on perceived climate risk and green infrastructure solutions in two diverse communities in Long Beach, California shows that raising resident awareness of both the issues and potential solutions is desirable for city planners attempting to unify disparate community interests within budgetary restrictions. If undertaken, priorities may better align with cultural and economic necessities and improve overall resilience. With limited investment into coastal infrastructure available, feasibility reports reveal opportunities to prioritize site selection and identify designs that contribute to ecological, socio-economic, and cultural resilience (Fox-Lent et al. 2015).

Engaging residents in visualization exercises of SLR's and identifying palatable solutions elevates community awareness and input into mitigation and adaptation efforts. Also, community level research can explore individuals' willingness to act and their expectations of others to intervene (Bulkeley et al. 2014). Bukvic and Harrald's (2019) work with SLR in Hampton Roads identified conflicting priorities between residents, who want quick fixes, and policy makers, who are trying to address the full complexity of the issues. They also reported a priority shift toward the inclusion of green infrastructural options and intermittent utilization of buy-outs. Additional research on how visualizations influence the range of mitigation and adaptation planning priorities is needed to inform participatory planning processes.

Methods

This study, the "Blue Line" project, integrates maps of future shorelines and photographs of those lines marked on the ground into surveys to assess community perceptions of SLR and receptivity to various mitigation and adaptation strategies. Three study areas were selected in consultation with the City of Norfolk Office of Resilience. Sites were chosen based on: (1) being prone to tidal flooding and (2) including a publicly accessible street and easement. Selections were also stratified to capture a landmark, a public space, and a residential community. The sites were the

ODU Sailing Center on the Elizabeth River, Cambridge Crescent in Larchmont, a neighborhood on the Lafayette River, and the Chrysler Museum in The Hague, a tidal creek with extensive reclaimed land and a lagoon near downtown (Fig. 2).

Survey generation

The forty-four-question survey was created in Qualtrics. Participants entered responses in a repetitive order to gauge how interaction with various parts of the project may have influenced their responses. All participants were asked if they saw the project in person and then regardless of their response were shown photographs and finally saw maps of each study site. Reactions were collected for each type of interaction (in-person, photographs, and maps). The goal was to examine the role of visualizations in influencing SLR awareness and perceived appropriateness of possible solutions to mitigate and/or adapt to area specific challenges. Questions generated data in several categories: residential, such as, which if any project area they lived near and the number of years lived in the area; interaction with the project whether in person or electronically; initial perceptions of SLR and interest in adaptation and mitigation options; photograph influenced SLR perceptions and mitigation and adaptation preferences; map influenced SLR perceptions and mitigation and adaptation preferences; and visualization preference.

Web map and visualizations

The survey utilized a map of future shorelines created by ODU's Fall 2019 Coastal Geography class to generate visuals. The map was produced using NOAA Light Detection and Radar (LiDAR) digital elevation model (DEM) data acquired from the NOAA Digital Coast and aerial photography collected with support from ODU's Center for Geospatial Science, Education, and Analytics (GeoSEA) team to indicate how SLR projections will increase the mean higher high water mark (MHHWM) from 2020 to 2050 (+ 0.46 m), 2080 (+ 0.91 m), and 2100 (+ 1.37 m). The DEM was hydrocorrected to reflect the effects of low-relief features such as bridges, culverts and ditches (Allen and Howard 2015) and resampled to 5 m resolution grid. The vertical datum of the DEM was also transformed from NAVD88 to local tidal datum for Mean Higher High Water (MHHW) using VDATUM software (NOAA 2013.) The future height of SLR assumed a static change in hydrodynamics to effect tidal inundation, allowing the use of projected SLR curves from the US Army Corps of Engineers' Sea Level Rise Calculator (Huber and White 2015). Among the several potential SLR scenario curves, the project adopted the same NOAA Intermediate High scenario as the Hampton Roads Coastal Resilience Working Group. The SLR Intermediate High curve also incorporated local subsidence with eustatic rise projected by Sweet et al. (2017). The projected mean SLR and MHHWM accepted by the Hampton Roads Planning District Commission's Coastal Resiliency Working Group included MHHW tidal heights for 2050 (45.7 cm or 1.5 ft.), 2080 (91.44 cm or 3 ft.) and 2100 (137.16 cm or 4.5 ft.). Static images of the study areas were captured for use in the survey by zooming into those extents in the web map (Fig. 3). Photographs were taken at each location following the completion of field mapping where blue lines were marked on the ground via GPS positioning with spray chalk, tape, and flags to indicate the future shorelines (Fig. 4).

Fig. 2 Delineation of "Blue Line" markings at intensive study area locations—**a** The Hague, **b** ODU Sailing Center, and **c** Cambridge Crescent and Larchmont neighborhood. (Color figure online)
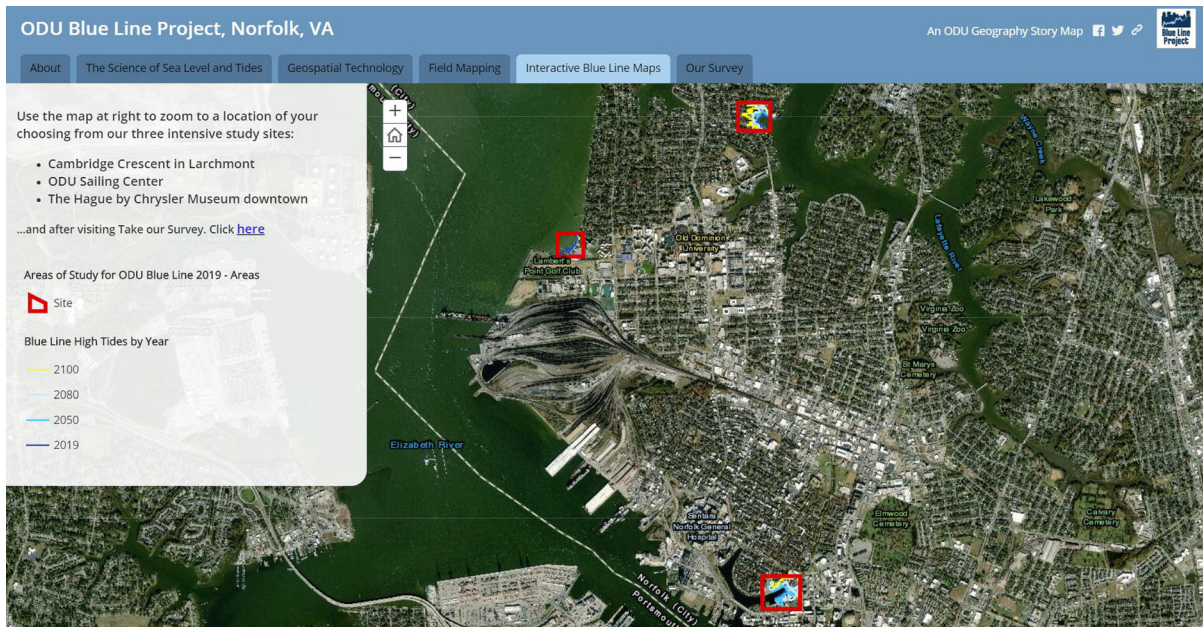
Fig. 3 Web map embedded in "Blue Line" project story map (https://arcg.is/4mLmr). (Color figure online)

A story map (Fig. 3) was published to provide background information on the project, key conceptual terms, an overview of the future SLR scenarios, and to share the interactive maps of future tidal shorelines. The story map also described the types of markings and the process of mapping in the field. The web map included the three future tidal shorelines for 2050, 2080, and 2100 with color symbology, legend, and labels and an orthophoto base map for spatial context. A tab with instructions and link to the survey were also included. To capture public participation, a companion website was published via WordPress (https://sites.wp.odu.edu/blueline/) with a link to the story map.

Survey distribution

The survey was available electronically from October 26, 2019 to November 16, 2019. A convenience sample was also collected by project personnel at each location on October 27, 2019. A total of 116 people took the survey.

The project launch was planned to coincide with the third annual Catch the King flood mapping event, which included about 300 participants throughout the Chesapeake Bay. The King Tide is a common term for the twice annual spring perigean tides, the highest of

the year. Catch the King collected data points of the tidal extent around the project sites including: 742 in Larchmont, 1064 in the Hague, and 2 at ODU (Catch the King 2019). Signs with the survey link were placed along the shoreline markings and flyers were distributed to those that came out to see the project or utilize the space for any other reason. The Hip Hop Caucus community arts group interviewed project personnel that day as well, which further expanded participation.

Prior to the launch, the project's WordPress and story map sites were advertised in local news outlets: Wavy News 10, WVEC, and the Virginia Pilot. Promotion, including press releases and social media, was available through Virginia Sea Grant, ODU Resilience Collaborative, CCRFR, Wetlands Watch, ODU ICAR, and geography faculty, particularly in classes taught by project personnel: GEOG 422/522 Coastal Geography, GEOG 306 T Hazards Natural and Technological and GEOG 101S Cultural Geography (approximately 116 students collectively). All advertisements included a QR code or link to the survey. These recruitment strategies likely biased the sample toward individuals with an existing awareness of SLR.
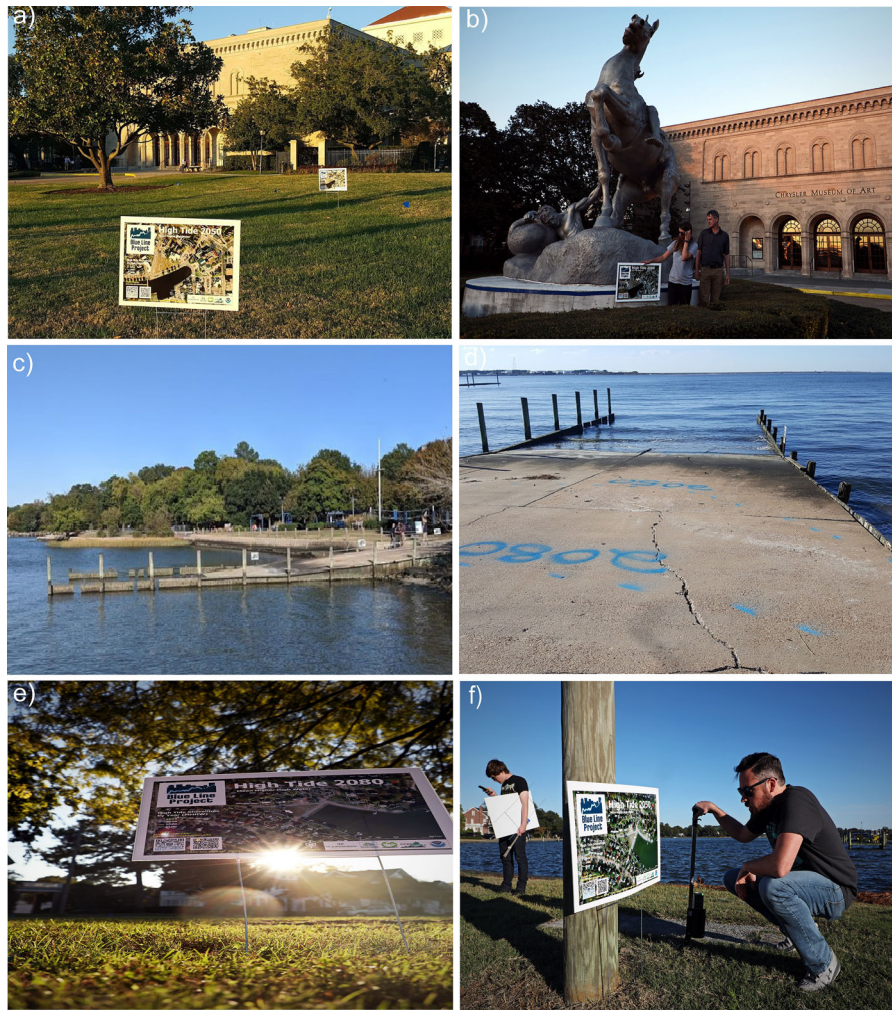
Fig. 4 Photos from Virginia Sea Grant of "Blue Line" markings at study area locations—**a** and **b** The Hague, **c** and **d** ODU Sailing Center, and **e** and **f** Cambridge Crescent and Larchmont neighborhood. (Color figure online)

Survey analysis

This exploratory study used a mixed methods approach and functions available in the Qualtrics software to highlight trends in the data. The subset of questions used for analysis appear in "Appendix". Frequency counts, percentages, and cross-tabulation were employed to derive quantitative data from multiple choice responses. Statistical significance was not recorded due to the small sample size and nature of the questions. Text responses were used to generate word clouds and quotes were selected to integrate qualitative data about behavioral intentions and recommendations as well as word associations with each image type into the analysis. Text responses

were manually coded based on their ability to fit into a provided solution category or not. Results contribute to a better understanding of how interaction with different components of the project influenced risk perception, behavioral expectations, and solution desirability.

Results

Participants were asked to provide the most specific option for the area in which they lived. Most participants lived in the Hampton Roads region (39.2%) or City of Norfolk (37.1%) but not a specific study site and had lived in the area for 16 or more years

Table 1 Residency Locations and Durations

Measure (% of total)	Larchmont (12.4)	The Hague (0.0)	Old Dominion University (11.3)	Norfolk (37.1)	Hampton roads/tidewater (39.2)
1 year or less (12.4)	0.0	0.0	36.4	19.4	0.0
2–5 years (18.0)	8.3	0.0	54.5	13.9	10.5
6–15 years (18.0)	50.0	0.0	0.0	16.7	10.5
16–30 years (25.8)	25.0	0.0	0.0	22.2	31.6
Over 30 years (25.8)	16.7	0.0	9.1	22.2	31.6

(Table 1). Hampton Roads had the longest residency durations, and Old Dominion University had the shortest. These results of residential location and duration analysis suggest most of the respondents will have some familiarity with the SLR and tidal flooding susceptibility of the region.

Pre-existing awareness

Preliminary SLR perceptions showed that 86.5% agreed to some extent that SLR was getting worse in Norfolk (Table 2). The green, retreat, and grey solutions were suggested in order of most to least preferred before seeing the "Blue Line" project (Table 3). These questions provide a baseline for awareness and solution preference prior to viewing the electronic version of the project.

Reactions to photographs

The majority (67.3%) of participants interacted with the project electronically. Photographs and later maps were shown to identify their influence upon perceived SLR, desirability of solutions, perceived risk at the study sites, recommendations for action, and willingness to act. Whenever possible responses were

Table 3 Desirable solutions

	Preliminary (%)	Photo-based (%)	Map-based (%)
Green	40.5	45.3	40.4
Grey	26.7	26.7	29.8
Retreat	32.8	28.0	29.8

compared to preliminary data and between visualization types.

Viewing the photographs changed what 51.5% of participants thought about SLR and tidal flooding in Norfolk. The photographs changed the solutions that 40.4% of participants felt were appropriate. Of those whose thoughts about SLR changed, 90.0% agreed to some extent that SLR was getting worse in Norfolk. Strongly agree and strongly disagree increased from the original perception and agree, neither agree or disagree, somewhat disagree, and disagree decreased (Table 2). Appropriate solutions were still selected in the same order when compared to preliminary responses (green, retreat and grey), but there were 4.8% more green and 4.8% fewer retreat selections after viewing the photos (Table 3).

Table 2 Perceived SLR risk in Norfolk

	Preliminary (%)	Photo-based (%)	Map-based (%)
Strongly agree	50.0	56.0	60.4
Agree	30.8	28.0	31.2
Somewhat agree	5.7	6.0	4.2
Neither agree or disagree	2.9	2.0	0.0
Somewhat disagree	1.0	0.0	2.1
Disagree	2.9	0.0	0.0
Strongly disagree	6.7	8.0	2.1

The most perceived damage was expected to occur at the Hague (42.4%) and the least at ODU (Table 4). There was a 6.2% difference in damage potential at the Hague and Larchmont; however, recommendations for protective action on the part of the property owner(s) or city reflected a slightly different distribution with Larchmont being the highest priority (39.8%), the Hague 1.9% behind, and ODU receiving the lowest priority (Table 4).This shows an increased desire for the residential area to take action despite a higher perceived risk in the heritage area.

When asked if the photographs were more or less convincing than other visualizations they had seen, the majority (67.8%) said more (Table 5). The majority (55.4%) were also likely to take action to protect themselves after viewing the photographs.

Reactions to maps

Viewing the maps changed what 52.7% of participants thought about SLR and tidal flooding in Norfolk. The maps changed the solutions 48.9% of participants felt were appropriate. After viewing the maps 95.8% of the participants agreed to some extent that SLR was getting worse in Norfolk. Strongly agree and somewhat disagree increased from the photograph-based perception and agree returned to the original percentage from prior to viewing the project. Somewhat agree, neither agree or disagree, and strongly disagree decreased, while disagree remained the same as the reactions to the photographs. Agreement generally increased after viewing the maps (Table 2). Green remained the preferred solution, but grey and retreat options received equal percentages of the remaining responses. Comparison of percentages with the photo-driven solution desirability shows that grey increased, retreat increased too but remained below the original

Table 5 Visualization was more or less convincing that others

	Photo-based (%)	Map-based (%)
More	67.8	59.0
Less	4.3	2.2
The same	20.4	34.4
Had not seen others	7.5	4.4

desirability, and green decreased to that of the original desirability (Table 3). The influence of maps away from green options is documented in the literature. It appears that despite the ability of the photographs to increase interests in green solutions, it was not maintained flowing the influence of the maps. Interest in retreat was reduced by both visualizations but more so with photographs, which indicates that maps may better influence residents to consider it. This could be related to the feelings expressed in qualitative comparative comments of the visualizations where photographs were seen as more personal than maps.

A majority (52.7%) stated that potential SLR appeared different when comparing the maps and the photographs. Of those that perceived a change in potential SLR, the locations with perceived damage were distributed approximately the same as for photographs (Table 4). However, slight increases were reported at the Hague, and Larchmont, as well as, in no expected damage.

Half (50.55%) of the participants stated that the locations at which they would recommend action changed after they viewed the maps. Among those reporting changed recommendations, a similar distribution occurred as with the photographs with Larchmont being the highest priority (37%) and the Hague only 1% below (Table 4). This still showed an

Table 4 Damage expectations and suggested action

		Photo-based (%)	Map-based (%)
Larchmont	Most damage expected	36.2	40.0
	Action recommended	39.8	37.0
The Hague	Most damage expected	42.4	43.6
	Action recommended	37.9	36.0
Old dominion university	Most damage expected	18.6	12.7
	Action Recommended	20.9	25.0
None	Most damage expected	2.8	3.6
	Action recommended	1.4	2.0

increased desire for residential areas to take action than others despite a higher perceived risk in the heritage area. Recommendations for protective action showed minimal change when compared to the photograph-based reactions. Responses for Larchmont and the Hague decreased and those at ODU and requiring no action increased. The decreased concern was in areas with higher perceived need for action and increased concern in areas with lower perceived need for action. Additional research is needed to explore these differences.

The likelihood of acting did not change after viewing the maps for the majority (60.7%) of respondents. For those that changed, all but 2.9% were likely to take action to protect themselves after viewing the maps. Although many were not, this is a positive behavioral outcome for those influenced by the maps.

When asked how convincing the maps in the project were than those they had seen before 59.0% said they were more convincing. The maps received a lower percentage of more convincing, less convincing, and not seen before responses than the photographs by between 2.2 and 4.4%, but a higher percentage answered that they were about the same (Table 5). This may be attributed to being a continuation of the same project.

Recommendations for action

Qualitative responses to photographs revealed that participants would suggest similar but site-specific adaptations for property owners at the study locations and themselves. When suggesting actions for property owners, participants provided a range of responses associated with green and grey infrastructure, retreat, awareness raising, and governance. It was suggested that warning signs be posted and evidence-based strategies be developed. Policy change motivated by voting and tax allocation was proposed. Individual and city investment in infrastructure and climate change reduction was mentioned more than once. Green solutions included marsh expansion, natural shorelines, permeable pavers, rain gardens, and storm water collection. Grey solutions included built flood protection such as flood walls or dikes on rivers and shorelines, as well as raising roads and houses. Retreat appeared often, more so than when individuals were asked about their own adaptation intentions, perhaps because some already lived outside the floodplain.

Participants indicated that they would be willing to purchase insurance, move, reduce their carbon footprint, elevate their homes, restore landscaping, change communing routes, mitigate erosion, purchase sandbags, advocate, and engage in educational opportunities. Others did not know what they might do. Barriers to implementing these types of individual adaptations arose if participants were not home owners, were moving, believed the government should be responsible, owned outside the floodplain, could not afford to, were elderly, or did not believe the SLR data. What individuals were willing to do and what they would recommend be done were relatively well aligned. The issues preventing implementation reflect the reasons community input from vulnerable populations is important for planning.

After viewing the maps, one concerned participant posited that "property development in these locations was apparently for the view and ambiance." That individual continued to say he/she was unsure of what to do. Several other responses echoed that uncertain sentiment. One participant characterized the future of the area by saying, "In time, the potential flooded properties will be vacant." The list of adaptation and mitigation options suggested included a range of awareness raising for residents and policy makers, retreat, natural landscaping, and built solutions, such as sea walls, elevating homes, filling land and basements. Priorities were suggested in one response: "In order of priority: natural solutions, hardened solutions, then buybacks." Another responded as if he/she was the property owner, "Since the Hague is already hardened, more of the same may be OK. But if I were the Chrysler, I'd start planning for a move. I think Cambridge Crescent could start with soft shoreline solutions like Birdsong Wetland." Fig. 5 compares the text from recommendations suggested after viewing photographs versus maps. Similar foci on property, solutions, walls, retreat, and natural options can be identified. The framing is different though. The photographs elicit a flood focus whereas the maps have a real estate focus. Additional research beyond the scope of this study is needed to understand how these varying associations are connected.

Similar individual action options were suggested based on the maps. Retreat was again a frequent response. Others included carbon footprint reduction, natural landscapes, increased awareness for oneself and others, preparation for floods, house improvement

Fig. 5 Action recommendations to property owners based on: **a** maps and **b** photographs

projects, insurance purchase, changes to commutes, and buying smart. Perhaps the similarities showed the limited options communities had or were aware of; although this list was broad, it also reflected the options provided in the survey questions except for the tangentially related carbon footprint and insurance options. These later connections show creativity on the part of the participants. The only restriction listed after viewing the maps was cost. This may reflect an implied lack of change in restrictions from one visualization to the next or increased empowerment compared to reactions to the photographs.

Visualization preferences

When assessing only the "Blue Line" images 78.9% stated that a combination of both types of visualization most increased awareness of SLR. Beyond the combination, maps were preferred 13.1% more than photos (Table 6). This was similar to which type of visualization was reported to change perceptions of SLR where maps affected 1.2% more participants but differs from which type of visualization was reported as more convincing than the other (Table 5) indicating that the photographs were more convincing but less informative than the maps. It may also indicate that the influence of photos decreased as the survey progressed and new images were introduced. When finding a

balance for the combination of images used in participatory planning processes, both the varied effects and possible retention issues should be considered.

In terms of which visualizations would most likely motivate them to act, a similar distribution emerged: 67.8% preferred a combination, and maps were preferred 13.4% more than photos (Table 6). In both cases the combination of visualizations was most desirable followed by maps and then photographs.

Figure 6 shows the most used terms when indicating why one type of visualization was more compelling than another. Those that preferred the photographs liked that they had the future shorelines, people, and landmarks in them. Supporting statements for the photographs included: "showed more and how much of land was affected;" "photographs help bring it home;" and "alone, the photographs are the most compelling as they are personal in nature." Those that preferred the maps liked the way they showed "timelines," "how much more property will be affected," "the different color lines as to the different levels of sea rise," and "the lines drawn on the map around the houses." A persuasive argument for the maps was "I think mapping is a better reference as it shows the lateral extent of flooding at an appropriate scale. In Larchmont, for example, in just a few seconds you can see how many homes are at risk, especially

Table 6 "Blue Line" visualization comparisons	Raise awareness of SLR (%)	Likely to motivate action (%)
Combination	78.9	67.8
Photos	1.1	5.5
Maps	14.4	18.9
Neither	5.6	7.8

Fig. 6 What made visualizations compelling (size of the word correlates with the frequency of use. Words map and photo removed)

considering this is showing a high tide level, not a flood event level." Other supporting statements for the maps included: "allows one to be able to view the larger picture rather than one spot with a photo;" "more clearly delineate the differences;" and "the maps show the overall area." A take-away from the maps was "the maps showed exactly what is going to happen if we as people don't become aware on our impact with the world." Thus, maps overall were perceived to convey accuracy and precision for potential SLR adaptation and mitigation planning.

Some responses connected with the intention of the project. One stated, "the maps showed how large areas would be affected. The blue lines gave a realistic view of how far the water would come up." Another participant summarized their interaction with the full project as "Seeing the lines on the actual roads helped me put the maps in context—like here's how bad it will be for just one road, but then seeing the maps made me realize that there's a pretty large area that will be affected just like the lines on the streets." A third participant said, "photographs show the proof where maps provide the specific details." A couple participant responses seemed to include in person interaction. One respondent reflected, "the comparison lines and seeing those in a detached sense before standing at the lines in the areas themselves and seeing how deeply I would truly be affected." Another participant shared, "the markings on the streets/land really drive the point."

Additional experience with and availability of interactive technology was of interest to some participants. One response called for the creation of a website, which was available but perhaps should have been featured more prominently in advertisements,

> Seeing tangible markings of what will eventually become water had a very serious effect. Then being able to put it in context with a map helps paint a full picture. I think a useful online tool to help demonstrate the impact would be an interactive map with interpolated water lines and a slider to allow people to see the gradual creep of the high tide line. Especially if filled in, it would show the unnerving expansion of the river as the tide continues to rise.

Some wanted features that were not available in this project: "maps that let you plug in your address make it more personal/important to me;" and "maybe the photographs would be more convincing if shot by a drone?".

One participant explained his/her own biases, "I think it depends on the person. I work a lot with maps, including flood maps. Others may not have seen the recurrent flood maps, or don't understand maps as well. The blue line project does a good job for those who aren't great with maps as well as gets that information out to people who are unaware of the maps." A couple responses revealed a connection between residence and experience: "knowing the area and seeing those maps helps visualize the structures in the area;" and "if I still lived there, the photographs would have been most compelling—the ability to see exactly how far the water will reach." Another respondent reiterated this through disconnection, saying "I don't know Norfolk neighborhoods. The maps told me more."

Generalizations for what made either or both types of visualizations more compelling included that they were "realistic" and showed "the amount of change." There did appear to be some confusion between what is called a photograph or a map though, as indicated by the statement "the overhead photographs with the markings were the most compelling as they gave me a better sense of the larger context." It is possible that this person was referring to the maps as photographs or saw the Google Earth images on the website or story map before completing the survey, but no overhead photos were included in the survey. This overlap in the perceived definition of photographs and maps may have contributed to the preference toward combined sets of visualizations.

Conclusions and future research

Findings from the survey offer exploratory insights into the role of various visualization types for assessing community resilience, risk awareness, and the desirability of future mitigation and adaptation projects. Overall, respondents preferred a combination of maps and photographs. Both visualization types featured appealing realistic aspects. Maps were preferred over photographs by those who did not prefer a combination for their ability to include a large area and show clear lines where future shorelines would be for each timeframe. Photographs were of interest, albeit less, because they were personal. Qualitative responses to both the visualization preference and action recommendation questions indicated that the sample was likely biased toward those with pre-existing awareness of SLR, which was expected based on the distribution methods.

In terms of the ability to increase awareness of SLR, photographs generally increased decisiveness when stating agreement or disagreement, while maps increased agreement broadly. Both were effective for different reasons, and together they had a positive result. Green solutions to SLR had more support after viewing photographs than maps, which was expected from the literature. Grey solutions had the same amount of support when viewing photographs as it did originally, but more support resulted from seeing the maps. Support for retreat was reduced for both types of visualizations but more so from viewing photographs. The visualizations built awareness as participants progressed through the survey, but they do not appear to be the most conducive means with which to improve desirability of green solutions.

The likelihood of taking action to protect oneself increased with both types of visualization. This willingness was not only from those living in the affected study areas, which indicates that location specific education does have perceived implications for other areas at least within the same city and region. Similar actions were proposed after viewing photographs and maps including options aligned with those presented in the survey: awareness raising, green infrastructure, grey infrastructure, and retreat. Additional action suggestions included reducing carbon footprints, engaging in civic duties, and purchasing insurance. Detractors to action were associated with socio-economic factors, residence location, and

shifted responsibility after viewing photographs, but at the close of the project they were exclusively cost related. The individual actions were similar but smaller in scale than those recommended for property-owners at the study locations. Although the highest risk perception was at the Hague, Larchmont had more recommendations to ac. This may be partially because no participants lived in the Hague. This preference in protecting the residential area may also have to do with the land use or existing mitigation structures. Responses indicate that local organizations, policy makers and planners may find these areas, from local to regional levels receptive to a range of solutions and means of implementation if they can raise awareness, bridge socio-economic concerns, and engage in co-creation of flood management projects. However, a challenge remains in balancing the negative reactions common in response to visualizing projected impacts with the potential for green and hybrid solutions that are increasingly preferred by communities with awareness of SLR solutions.

This study contributes preliminary steps toward integrating community perceptions with Norfolk's SLR planning efforts by building an understanding of the capacities and interests in these three areas. Findings may be transferable to other coastal university, residential and heritage areas. Further, they may be synthesized to get a preliminary understanding of initiatives that could gain traction across the city. The survey could also be scaled-up and deployed throughout Norfolk and/or in the other six cities in Hampton Roads to get a better understanding of how awareness and priorities differ within the region. A vulnerability analysis could also be added to the visualizations as well to identify the role of socio-economic disparities in mitigation priorities.

Conducting the survey annually would allow for longitudinal data collection and comparison. Later iterations of the survey will seek a representative sample so that correlations between responses and residence can be assessed and to identify: (1) demographic information, (2) the appropriate balance and order of photographs and maps to improve awareness of SLR, (3) the desired balance of green, grey, and retreat options for each area, (4) variation in response to current and future SLR, (5) expected responsibilities for implementation, and (6) reactions to visualizations of how implementation of those solutions

would change interactions with the built environment during high tides.

Availability of data and materials The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflict of interest.

Consent to participate Consent was collected per the protocols in Package # 1504628–1.

Consent for publication Publication of data was allowed per the protocols in Package # 1504628–1.

Ethical approval Package # 1504628–1 was declared Exempt by the Old Dominion University Arts & 32 Letters Human Subjects Review Committee on October 7, 2019.

Appendix: Blue line survey questions

1. Do you live in any of the areas involved in the project? (select the most specific option that applies to you)

   - Larchmont
   - The Hague
   - Old Dominion University
   - Norfolk
   - Hampton Roads/Tidewater

   - None of the above

   Display This Question: If Do you live in any of the areas involved in the project? (select the most specific option that ap… ≠ None of the above

2. Approximately how long have you lived in the area?

   - 1 year or less
   - 2–5 years
   - 6–15 years
   - 16–30 years
   - Over 30 years
   - Sea level rise and tidal flooding are getting worse in Norfolk.

3. Sea level rise and tidal flooding are getting worse in Norfolk.

   - Strongly Disagree
   - Disagree
   - Somewhat disagree
   - Neither agree nor disagree
   - Somewhat agree
   - Agree
   - Strongly agree

4. Which of the following solutions do you feel are appropriate to address tidal flooding with future sea level rise: (select as many as apply)

   - Constructing natural or nature-based infrastructure, such as natural vegetation alone or stabilized by oyster reefs
   - Building engineered hard (gray) structures, such as seawalls, dikes or flood gates
   - Buying out repeated flooding property and other forms of "retreat"
   - None of the above

5. Did you see any of the Blue Line Projects markings of future shorelines made with chalk paint, flags, or blue tape in-person?

   - Yes
   - No
     Photo collection—Photos of the chalk paint,

tape, and flags marking future shorelines for the Blue Line Project from each location are included below. These depict preliminary future high tide estimates. This analysis used 2013 Norfolk LIDAR DEM First-Order Estimates of Mean Higher High Water (MHHW) with relative SLR (RSLR) for Hampton Roads of 1.5, 3.0 and 4.5ft (scenarios that are adopted by a resolution of the Hampton Roads Coastal Resilience Working Group, coordinated by Hampton Roads Planning District Commission). *Images redacted for publication. See Fig. 4 for a subset of included images.*

Based on viewing the Blue Line Project, please respond to the following:

6. Did viewing the Blue Line Project change what you think about sea level rise and tidal flooding in Norfolk?

   - Yes
   - No

Display This Question: If Did viewing the Blue Line Project change what you think about sea level rise and tidal flooding i… = Yes

7. Sea level rise and tidal flooding are getting worse in Norfolk.

   - Strongly disagree
   - Disagree
   - Somewhat disagree
   - Neither agree nor disagree
   - Somewhat agree
   - Agree
   - Strongly agree

8. Did viewing the Blue Line Project change what solutions you feel are appropriate to address tidal flooding with future sea level rise?

   - Yes
   - No

Display This Question: If Did viewing the Blue Line Project change what solutions you feel are appropriate to address tidal… = Yes

9. Which of the following solutions do you feel are appropriate to address tidal flooding with future sea level rise?

   - Constructing natural or nature-based (green) infrastructure, such as natural vegetation alone or stabilized by oyster reefs
   - Building engineered hard (gray) structures, such as seawalls, dikes or flood gates
   - Buying out repeated flooding property and other forms of "retreat"
   - None of the above

10. At which location(s) does it appear that the most damage will occur as a result of sea level rise and tidal flooding? (select as many as apply)

    - Larchmont
    - The Hague
    - Old Dominion University's Sailing Center
    - Damage will not occur at any of these locations

11. At which location(s), if any, would you recommend the landowner(s) or city take action to protect residents, visitors, and/or the property? (select as many as apply)

    - Larchmont
    - The Hague
    - Old Dominion University's Sailing Center
    - None

Display This Question: If At which location(s), if any, would you recommend the landowner(s) or city take action to protect… ≠ None

12. What actions would you recommend be taken to protect residents, visitors, and/or the property? —

13. Are you likely to take any actions to protect yourself, your family, and/or your property as a result of seeing the Blue Lines Project?

    - Yes
    - No

Display This Question: If Are you likely to take any actions to protect yourself, your family, and/or your property as a re… = Yes

14. What actions are you most likely to take?
     —

Display This Question: If Are you likely to take any actions to protect yourself, your family, and/or your property as a re… = No

15. What, if anything, is preventing you from taking action?
     —

16. As compared to other maps or digital visualizations you may have seen before, how did seeing the Blue Line Project affect your perception of sea level rise including future shorelines?

     - Less realistic and convincing
     - About the same
     - More realistic and convincing
     - I have not seen any other maps or visualizations of sea level rise
       Maps from which the Blue Line Project was derived—The future shorelines that were marked for the Blue Line Project were based on the maps below. *Images redacted for publication. See Fig. 3 for site locations for which maps were derived.*
       Based on viewing the maps on which the Blue Line Project is based, please respond to the following:

17. Did viewing the maps from which the Blue Line Project was derived change what you think about sea level rise and tidal flooding in Norfolk change?

     - Yes
     - No

Display This Question: If Did viewing the maps from which the Blue Line Project was derived change what you think about sea… = Yes

18. Sea level rise and tidal flooding are getting worse in Norfolk.

     - Strongly disagree
     - Disagree

     - Somewhat disagree
     - Neither agree nor disagree
     - Somewhat agree
     - Agree
     - Strongly agree

19. Did viewing the maps from which the Blue Line Project was derived change what solutions you feel are appropriate to address tidal flooding with future sea level rise change?

     - Yes
     - No

Display This Question: If Did viewing the maps from which the Blue Line Project was derived change what solutions you feel… = Yes

20. Which of the following solutions do you feel are appropriate to address tidal flooding with future sea level rise?

     - Constructing natural or nature-based (green) infrastructure, such as natural vegetation alone or stabilized by oyster reefs
     - Building engineered hard (gray) structures, such as seawalls, dikes or flood gates
     - Buying out repeated flooding property and other forms of "retreat"
     - None of the above

21. Do the amounts of damage resulting from sea level rise and tidal flooding appear different in the maps than in the photos?

     - Yes
     - No
     - I don't know

Display This Question: If Do the amounts of damage resulting from sea level rise and tidal flooding appear different in the… = Yes

22. At which location(s), if any, does it appear that the most damage will occur as a result of sea level rise and tidal flooding? (select as many as apply)

     - Larchmont
     - The Hague
     - Old Dominion University's Sailing Center

- Damage will not occur at any of these locations

23. Did the locations at which you would recommend the landowner or city take action to protect residents, visitors, and/or the property change as a result of viewing the maps from which the Blue Line Project was derived?

    - Yes
    - No

Display This Question: If Did the locations at which you would recommend the landowner or city take action to protect resid… = Yes

24. At which location(s), if any, would you recommend the landowner(s) or city take action to protect residents, visitors, and/or the property?

    - Larchmont
    - The Hague
    - Old Dominion University's Sailing Center
    - None
      Display This Question: If Did the locations at which you would recommend the landowner or city take action to protect resid… = Yes And At which location(s), if any, would you recommend the landowner(s) or city take action to protect… ≠ None.

25. What actions would you recommend be taken to protect residents, visitors, and/or the property?
    —

26. Did the likelihood of you taking action to protect yourself, your family, and/or your property change as a result of viewing the maps from which the Blue Line Project was derived?

    - Yes
    - No

Display This Question: If Did the likelihood of you taking action to protect yourself, your family, and/or your property ch… = Yes

27. Are you likely to take any actions to protect yourself, your family, and/or your property?

    - Yes
    - No

Display This Question: If Are you likely to take any actions to protect yourself, your family, and/or your property? = Yes

28. What actions are you most likely to take?
    —

Display This Question:If Are you likely to take any actions to protect yourself, your family, and/or your property? = No

29. What, if anything, is preventing you from taking action?
    —

30. As compared to other maps or digital visualizations you may have seen before, how did seeing the maps the Blue Line Project was derived from affect your perception of sea level rise including future shorelines?

    - Less realistic and convincing
    - About the same
    - More realistic and convincing
    - I have not seen any other maps of sea level rise

31. Which visualizations increased your awareness of sea level rise and tidal flooding most?

    - Photos
    - Maps
    - A combination of both
    - Neither
      Based on viewing all visualizations associated with the Blue Line Project, please respond to the following:

32. Which visualization is most likely to motivate you to take action to protect yourself, your family, and/or your property?

    - Photos
    - Maps
    - A combination of both
    - Neither

33. What made some visualizations more compelling than others?

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