Sustainable Urban Planning and Climate Change Scenarios: an investigation of Staten Island's urban planning

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Introduction

Recent events like Hurricane Sandy, which struck Staten Island, NY on October 29, 2012, serve as a costly reminder of how unsustainable designs and mounting social pressures can contribute to extensive structural damage and subsequent financial cost, from storm surge inundation and coastal flooding. It is unlikely that Hurricane Sandy was a one-time event but rather a warning of what can occur over the next century without proper mitigation strategies. Based on climate change projections, such extreme events are expected to become more frequent and intense due to warmer sea surface temperatures and rising sea levels (Emmanual, 2005; Kirtman et. al., 2013). To mitigate impacts and improve resiliency, we need to devise and implement robust planning strategies that reduce society's exposure and vulnerability to extreme environmental hazards.

Hurricane Sandy presents an opportunity to rethink existing designs and place environmental constraints to development at the forefront. In the 1960s, Ian McHarg conducted a land use suitability on Staten Island and deemed most of the extensively damaged areas unsuitable for urbanization (McHarg 1969, Wagner et al,. forthcoming). Best practices suggest, urban areas should be buffered from coastlines and riverbanks to reduce their exposure to flooding. The next best approach is to devise and implement stormwater management and other mitigating measures. As part of the recovery process, a number of resilient strategies on Staten Island such as elevating urban structures, expanding greenbelts, and incorporating natural buffers have been proposed to ameliorate existing threats and those attributable to climate change (e.g., sea level rise and increased coastal flooding). While these designs address vulnerability to inundation, questions arise as to how resilient these strategies will be to future coastal flooding and extreme events.

Background

The type, location, and amount of successful mitigation strategies can be identified through landscape and greenway planning and the policies implemented to support them. Best management practices for coastal adaptation to climate change are flood-control adaptation strategies that place environmental constraints to development at the forefront of design. For example, green infrastructure measures (e.g., greenbelts, bluebelts, bioswales, and living shorelines) have been successful in mitigating inundation (Demuzere et al., 2014). More proactive measures, such as managed retreat, could be required in extreme risk cases (Kousky, 2014). All solutions are situation specific.

To mitigate, resiliency measures specific to Staten Island post-Hurricane Sandy, are buyouts, elevated structures, dune nourishment, and buried seawall. Following McHarg's defensive approach, voluntary buyouts have been proposed to eliminate development in extreme flood risk areas. These areas could become part of the Mid-Island Bluebelt or a greenway (GOSR, 2014, 2015; Wagner et al., forthcoming). In high risk flood zones, urban structures are being elevated to mitigate flood vulnerability, but are costly and locked-in strategies (Aerts et al., 2013; GOSR, 2014, 2015; Wagner et al., forthcoming). Offensive measures, such as dune nourishment, buried seawall, and living shorelines, ensure future conservation and provide recreation amenities (Fabos et al. 2004; Conine et al., 2004). These draw on ecosystem services and would help protect eastern and southern shores (e.g., Great Kills and Tottenville Dunes project, Living Breakwaters design).

Goal and objectives

This paper seeks to assess 1) how will future threats impact existing and proposed land use on Staten Island and 2) how ‘robust’ are current and proposed resiliency measures to handle future biophysical threats.

Methods

Study Area

The study was conducted on Staten Island, New York because the massive impact of Hurricane Sandy resulted in recovery and response strategies designed to mitigate potential damage from future extreme events. Furthermore, Staten Island was the case study for the seminal work by Ian McHarg, which guided the land use classification in this work.

Staten Island is a 152.8 square kilometer island located between the states of New York and New Jersey (Figure 1). With 468,730 inhabitants, it is the least populated borough of New York City (U.S. Census, 2014). The northern and eastern shores are extensively developed, making these areas vulnerable to coastal inundation. The southern shore is comprised of mixed-use with conservation, recreation, and urban areas while the western shore is a mixture of wetlands and industries.

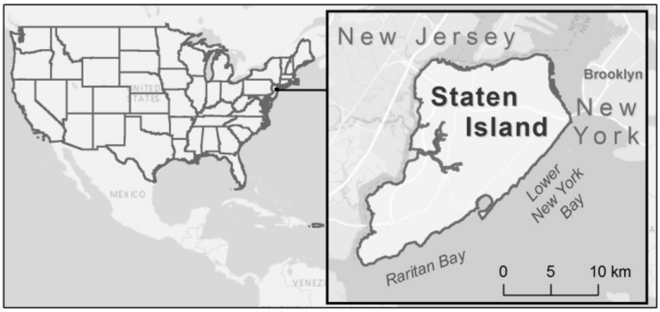

Figure 1. Study area of Staten Island, New York

Land Use
McHarg's land use suitability was used as a guide to classify land use (McHarg, 1969). The land use layer was created from a combination of municipal, state, and federal datasets based on Wagner et al., forthcoming.

Climate Change Scenarios
To examine climate change threats, we constructed five climate change scenarios of sea level rise (SLR) and future storm surge inundations. SLR was simulated using the 'bathtub' method and LiDAR data, obtained from United States Geological Survey (USGS, 2016). These data were provided at 2-meter resolution in bare earth Digital Elevation Model (DEM). Divots or voids, attributable to urban structures, were filled in using focal statistics to provide a continuous DEM. A 1 meter SLR was selected and subtracted from the continuous DEM, producing a SLR DEM (NPCC, 2013).

Future extreme events were depicted as storm surge depths. The depths were created from NOAA's National Hurricane Center (NHC) Sea Lake and Overland Surge from Hurricane (SLOSH model). Using SLOSH’s composite approach, Maximum Envelopes of Water (MEOWs) were selected. Based on climatology, NNE landfall direction, a forward moving speed of 30 mph, and high tide levels were used to determine category 1, 2, 3, and 4 storm surge depths (Colle et al, 2010).

Storm surge scenarios were produced using a GIS-based overlay analysis. Storm surge heights that exceed the SLR DEM were classified as inundated for each categorical storm. Each inundation layer was intersected with the land use layer to determine the magnitude of land affected by storm surge scenarios.

Analytical Approach
The potential magnitude of land protected by each proposed resiliency measure was calculated. Two classes were considered: urban (buyouts and elevated structures) and infrastructure (dune nourishment and sea wall) measures. Buyout locations were digitized and georeferenced using publically available buyout maps (GOSR, 2015). The magnitude of land that could be protected via buyout measures were calculated by intersecting buyout areas with flood effected land use. To simulate elevating structures, an adjusted DEM layer was created using NOAA's flood frequency data (FFD), FEMA base flood elevation (BFE), and Staten Island DEM. Within the FFD high flood risk boundary, the Staten Island DEM was adjusted to the Flood Resistant Construction Elevation (FRCE) by adding 4ft to the BFE (Aerts et al., 2103). Proposed infrastructure measures of dune nourishment and buried sea wall were digitized and georeferenced. Dune and seawall heights were set to 14 ft and 17 ft, respectively, above the DEM (Roelvink et al., 2009; UASCOE, 2015). The magnitude of land that could be protected by elevating structures, dune protection, and seawall measures, were evaluated by combining adjusted Staten Island DEMs with storm surge depths, creating new inundation layers. The change between original and new inundation layers led to areas protected by resiliency measures.

Potential Areas for Resiliency Measure Expansion
A layer showing areas for expanding resiliency measures was produced focusing on current open space. Proposed resiliency measures and wetlands were subtracted from the conservation-recreation land use to create this layer.

Results

Future extreme events could have a significant impact on Staten Island especially in urban areas (Figure 2a-b). With increasing storm intensity, there is an increase in total area of inundation (Figure 2b). As expected, the effects of SLR alone would be highly localized, while storm surge inundation from a Category 4 storm could impact almost 9,000 ha. Urban areas would be most vulnerable to storm surge inundation than any other land use. In fact, the amount of area affected by storm surge from a Category 4 more than doubles the surge associated with a Category 1 storm. In terms of land use, urban areas, more than any other class, would be the most vulnerable to storm surge inundation.

Resiliency measures assessed in this study are predominantly located along the southern and eastern shores (see Figure 3). Buyout areas would protect only 24.0.ha and 52.9 ha, from SLR and Category 1 storms respectively (See Table 1). Elevating structures would only be effective to Category 1 storm, protecting 359.4 ha. Dune nourishment would protect 4.4 and 8.2 ha from SLR and a Category 1 storm, respectively. The buried seawall would preserve 0.7 and 4.5 ha from SLR and Category 1 storm, respectively. In addition to enhancing current measures, others could be expanded in open spaces areas in southern and western sections of Staten Island (see Figure 4).

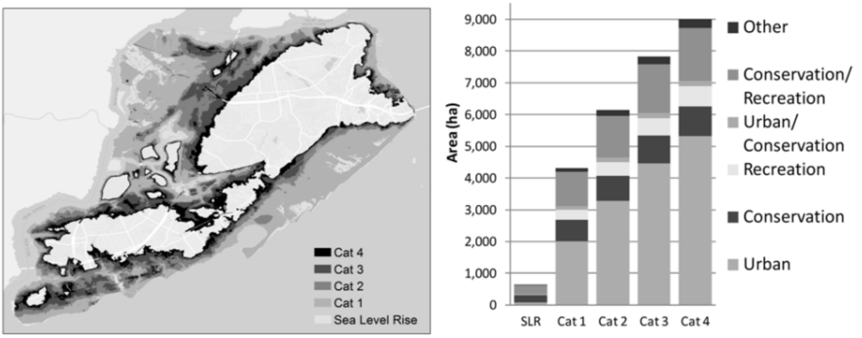

Figure 2. Staten Island storm surge inundation for a) SLR and extreme events and b) Land use affected

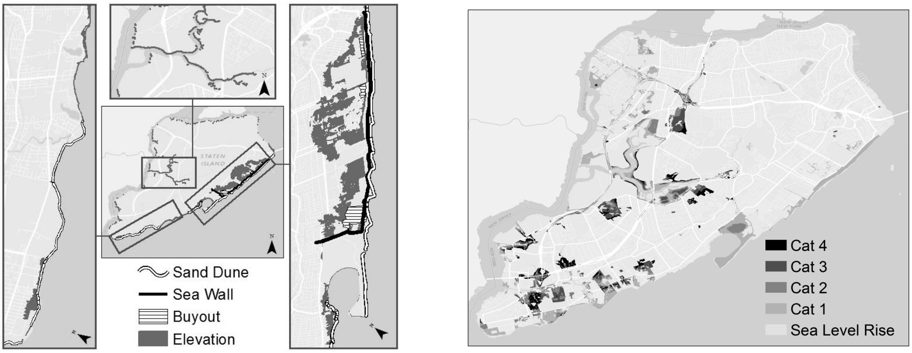

Figure 1. Areas of resiliency measures a) assessed and b) proposed expansion

Table 1. Area of protectable land by Resiliency Measure and Storm Category (ha)

Measure	SLR	Cat 1	Cat 2	Cat 3	Cat 4
Elevation		361.3	6.1	2.2	52.9
Buyout	25.4	52.9	52.9	52.9	52.9
Seawall	0.7	4.5	4.5	4.5	4.5
Dune	4.4	8.2	8.4	8.4	8.4

Discussion

The amount of land affected by storm surge inundation illustrates the need for robust resiliency measures beyond SLR and Category 1 storm. The eastern and southern shores have served as a locus for rethinking current land use and resilient designs because of extensive physical and monetary damage from Hurricane Sandy (Blake et al., 2013). Robust resiliency measures are most needed in and around urban areas based on past and future exposure to extreme events. Proposed resiliency measures assessed here would only be effective to mitigate SLR and a Category 1 storm impacts. While there are other proposed resiliency measures (e.g., the Living Breakwater) that could be more effective at mitigating more intense storms, this study assessed only four proposed resiliency measures due to data availability and time.

Buyouts in the eastern shore could be considered one of the most effective resiliency measures, as the land use change eliminates flood risk to development for all hurricane categories. These areas, severely damaged by Hurricane Sandy, recognize the magnitude of extreme flood risk by prohibiting urban development in extremely vulnerable locations (Kousky, 2014). Within buyout areas, some will be integrated into the Mid-Island Bluebelt expansion for stormwater management (GOSR, 2014), while other areas will be converted to salt-water marshes and a park (GOSR, 2014; Wagner et al., Forthcoming).

Unlike buyouts, elevated urban structures, dune nourishment and the buried seawall were most effective for Category 1 storm and SLR mitigation. This is due to storm surge heights exceeding heights of the protective barriers. Even with the aforementioned limitations, the proposed resiliency measures may not be sufficient enough to mitigate future storm surge inundation. Additional measures such as managed retreat and elevating structures higher above the FRCE may be needed in higher risk areas. In addition to strengthening existing measures, resiliency efforts could be expanded into southern and western shores and be used for greenway planning.

This study only compares storm surge height relative to the elevation of proposed resiliency measures. This approach does not take into account dynamic interactions between storm surge and proposed measures. These measures could reduce the velocity of and energy associated with storm surge waters, thereby, attenuating storm surge depths further inland. This affects how much land behind the resiliency measures would be protected from surge inundation. A hydrological model (e.g., ADCIRC) is required and has been proposed for future work.

Conclusion

Urban areas have been highly vulnerable to storm surge inundation as evidenced in the aftermath of Hurricane Sandy and will likely become even more vulnerable based on climate change projections. Resiliency measures should consider additional cushion to stronger categorical storms to be effective.

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