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Using Information at Different Spatial Scales to Estimate Demand to Support Asset Management Decision Making

FINAL REPORT
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Submitted by:

Israt Jahan
Research Assistant

Joseph Trainor
Associate Professor

Sue McNeil
Professor

Alex Greer
Assistant Professor
Oklahoma State University
(formerly Research Assistant)

Disaster Research Center
166 Graham Hall
University of Delaware
Newark DE 19716

External Project Manager
Frank Lawrence, Sea Bright, NJ
External Reviewer
David Heller, Program Manager, SJTPO

In cooperation with
Rutgers, The State University of New Jersey
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16. Abstract

Quantifying disaster recovery is important to be able to match resources to needs. The research explores the use of survey data, FEMA assessment data, aerial photographs and LIDAR data in the context of recovery from 2012 Hurricane Sandy in Sea Bright, New Jersey. The data cover the period 2010 to 2015. Each of the data sources differ in terms of completeness, resolution, accuracy, coverage and the time period in which it was collected. Using spatial analysis, the analysis found that different data sources gave similar estimates for recovery for the entire borough. More careful analysis of specific plots using data from different sources found that the redevelopment was slow and, in some cases, stagnant when the damage was extensive or demolition required. This report documents the sources of the data, presents a framework for data analysis and presents Sea Bright as a case study. These methods show promise and document the value in periodic analysis of publicly available data from different sources to document recovery. There are further opportunities to develop time series analysis with more recent data to both understand how to leverage this data and document the recovery process.

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INTRODUCTION

DESCRIPTION OF THE PROBLEM

Extracting information from data to support decision making in general and asset management in particular is challenging. The data are available at different spatial scales, use different spatial referencing, are collected by different organizations for different purposes at different times and frequencies, and need to be integrated to support decision making. This problem is further exacerbated in the case of information needed to support decisions during post disaster recovery. This project considers the specific case of understanding housing recovery following a hurricane. Such data is one of the many types of data needed to understand the demand for transportation infrastructure and asset management decision making. To illustrate the processing and interpretation of the data, data following Hurricane Sandy from Sea Bright, New Jersey is used. This project builds on and complements three completed CAIT projects:

- The University of Delaware (UD) project "Understanding the Relationships between Household Decisions and Infrastructure Investment in Disaster Recovery: Cases from Superstorm Sandy" (McNeil et al., 2016),
- A second UD data collection project “Tracking Housing Recovery in Sea Bright, NJ and the Relationship to Infrastructure Renewal” (McNeil et al., 2017), and
- The collaborative project (involving UD, Rutgers and Utah) "Big Data: Opportunities and Challenges in Asset Management" (Gong et al., 2016).

These projects have identified some important large data sources, including survey and sensor data that are relevant to forecasting demand and understanding the needs of communities. In addition, other parallel efforts provide map-based data on infrastructure vulnerability (for example, "Climate Change Vulnerability and Risk Assessment of NJ's Transportation Infrastructure" (Cambridge Systematics, 2011)). Furthermore, the project is consistent with the MAP-21 and FAST Act requirements for states to develop risk-based asset management programs.

Overview

The research began with a literature review building on relevant new research and initiating an inventory of relevant data and methods. A framework for integrating the data to support asset management functions is developed. This is more comprehensive, in terms of the types of data, than the other research projects and more focused on demand estimation than the exploratory research that is part of the "big data" collaborative project but uses the case study data collected for Sea Bright, NJ. The work builds on a previous project focusing on Sea Bright (Greer, 2015, McNeil et al, 2016, McNeil et al 2017).

Background

An important component of the asset management framework is demand estimation and other external influences. To date little attention has been paid to this component as it has been assumed that demand is either constant or steadily growing. In areas where events (for example, Hurricane Sandy) have disrupted daily life as well as the improvement, renewal and maintenance of infrastructure, understanding these relationships is more important. Furthermore, there are many rich sources of this data but much of the data occurs at disparate spatial scales and is collected at different points in time. Building on survey data, FEMA data (FEMA-MOTF, 2014) and Lidar data of damage (Gong, 2013), we explore how this large volume of data fits into the asset management process for a community.

Goals and Objectives

Our goal is to better understand how diverse, large data sets support asset management decision making and explore tools to facilitate this process. In particular the focus is on integrating sensor, survey, demographic, vulnerability and condition data. The specific objectives are to:

1. Identify new and emerging data that can be used to support the decision-making process.
2. Characterize the spatial scale, temporal frequency of data collection, and trends in the data to support strategies for aggregating and updating data for use in asset management.

3. Explore role of tools including "big data" tools, and GIS.
4. Develop a case study
5. Identify lessons learned.

The following outcomes are expected:

1. A catalog of relevant data including guidance on appropriate levels of aggregation.
2. A framework for integrating and synthesizing data for demand forecasting in the context of asset management.
3. Documented case study of how community data can be used at the local, regional and state level.

Context

Maintaining a state of good repair (SOGR) is particularly challenging when changes occur. Vulnerable environments; hazards such as storms and the resulting damage to infrastructure, properties and businesses; community and stakeholder input; and the range of condition of the transportation assets all influence the demand for services and the decisions that are made in the context of asset management. While forecasting demand is a clearly identified step in asset management it has not been given a lot of attention beyond the use of simple growth rates. As asset management is a data drive decision process, this project will focus on the data to support that process. At the same time this data is also likely to be useful in support of all of the USDOT Strategic Goals.

APPROACH

Literature Review

Estimates of demand are key to decisions in asset management (Gordon et al., 2011; Ingenium and Institute of Public Works Engineering of Australia, 2011). However little attention is paid to demand. In this work we focus on estimating demand based on housing recovery. This chapter reviews the literature on post event recovery and reviews data available from past studies. This literature also provides some insights on what transportation infrastructure is required during the recovery phase.

Jahan (2015) and Greer (2015) provide a review of the recovery literature but both acknowledge that the recovery phase is still considered the least understood phase in the disaster management cycle with limited theory to explain it. These observations are also supported by others (Chang, 2010; Smith & Wenger, 2007, pg. 234). Although there are many dimensions to disaster recovery, this research focuses on long-term permanent housing recovery as a critical element for household/family and community recovery, probably the least planned among all parts of disaster management cycle, which in turn influences the demand for travel and the need for infrastructure repair, replacement, maintenance and renewal.

Recovery is best thought of as a continuous process without any logical order involving emergency period; restoration period; replacement and reconstruction period; and commemorative, betterment, and developmental reconstruction period (Kates & Pijawka, 1977; Phillips et al., 2011; Rubin et al., 1985). The recovery process does not always begin immediately and it requires *'balancing the more immediate need to return the community to normalcy and reduce vulnerability in the long term'* (Haddow et al., 2007). Post-disaster recovery is not *how soon to start but how long it will take* (Phillips et al., 2011). The recovery phase is divided in to two terms, short and long term, based on the time required to return to regular activities. Phillips et al. (2011) mentioned that local organizations are still working to rebuild hurricane affected private and public sectors in four states in 2010, though five years have passed since Hurricane Katrina. The data used for this study represent the status almost four years after Hurricane Sandy, the impacted areas were still recovering from the damage.

Measuring the Recovery Rate

Different scholars have used different types of data sources in evaluating the speed and progress of housing recovery over time quantitatively, for example, data on building permit (permission for repair or demolish then rebuilt) (Comerio & Blecher, 2010; Rathfon et al., 2013; Stevenson et al., 2010); tax appraisal, land-use change and census data (Zhang & Peacock, 2009); remote sensing satellite images and geo-referenced GIS maps (Brown et al., 2008;

Rathfon et al., 2013); occupancy certificates, property appraisals, property sales, FEMA's temporary housing, and temporary roof installation (Rathfon et al., 2013).

The first challenge in recovery goes in assessment of damage (Phillips et al., 2011). Immediately after a disaster, the building's damage status can be classified as no damage, minor, moderate, severe, or catastrophic damage (Rathfon et al., 2013). Comparing the initial damage with the improvements over time, i.e. by defining the change from initial condition, the housing recovery rate can be computed.

Influences on Progress of Housing Recovery

There are many factors that impact the progress rate of recovery for example, *"the availability of undamaged housing, economic conditions, the disaster management system, local land use and building practices and, especially, the availability of financing"* (Wu & Lindell, 2004, p.64). In recovery and rebuilding process, the complications are finance, short time periods, racial mistrust and discrimination (Esnard & Sapat, 2014, p. 57; Olshansk et al., 2010). Researchers have paid very little attention to the socio-political aspects of the long-term recovery process. The structure, available resources and capacity of a community or country's government impact the recovery speed and duration after major disasters and catastrophes (Esnard & Sapat, 2014, p.53). Foley (1980) described housing as a trickle-down process in the United States where new housing is provided to the people who can afford it. Displaced people, excluding those voluntarily relocated or property owners who rebuilt, take more time to recover completely (Esnard & Sapat, 2014, p.53). Low income people and minority households face many challenges dealing with housing recovery. They 'tend to suffer disproportionately higher levels of damage in disasters' (Peacock et al., 2007). The institutional assistance gap is responsible for uneven recovery including mismatch between time and type of assistance, assisted people and people or organizations responsible for the help (Esnard & Sapat, 2014, p. 54). In another case, ownership patterns (owner occupied and rental housing, single family housing), financial resources (public and private funding), insurance coverage, etc. also impact permanent housing recovery (Peacock et al., 2007). According to Zhang & Peacock (2009), low-income households, the rental houses, and minority groups recover more slowly where the owner-occupied houses and single-family housing gets advantage in quick recovery.

Furthermore, policies and programs such as buyouts influence the need for reinvestment (Binder and Greer, 2016; Greer and Binder, 2017).

Consequences of Recovery

Recovery has many positive and negative consequences over the affected community. These consequences have been focused on by many researchers (Haddow et al., 2007; Kates & Pijawka, 1977; Phillips et al., 2011) in the emergency management field. Recovery gives the opportunities to newly rebuild environmental friendly communities with proper planning (Phillips et al., 2011) and improve pre-disaster conditions (Kates & Pijawka, 1977). Also provides opportunity to the individual and community to be economically sustainable, safe, and improve their quality of life (Haddow et al., 2007). Recovery planning in the pre-disaster time increases the hazard mitigation process and improves the recovery process (Wu & Lindell, 2004).

Data Sources and Tools

For this research secondary data sources are assembled based on availability and relevance to study area. They cover government, non-government, private, voluntary organizations involved in recovery from Hurricane Sandy. Free sources for this project include remote sensing images (satellite and airborne), GIS based shape files and geodatabases, LiDAR point clouds (pre- and post-hurricane Sandy) data from Federal Emergency Management Agency (FEMA), United States Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), New Jersey GIS data clearing house, and Census data. While some data, for example, LiDAR, was not collected expressly for this project, we were able to leverage this data. One of the major sources of data used in this research is a mail-based questionnaire data (McNeil et al., 2016; McNeil et al., 2017).

GIS as an Analysis Tool to Support Recovery Assessment

The local governments and emergency managers use Geographic Information System (GIS) increasingly to plan for hazards and disasters (Smith & Wenger, 2007, p. 241). Brown et al. (2008) and Rathfon et al. (2013) used remote sensing satellite images and geo-referenced GIS maps to quantitatively measure the post disaster housing recovery. GIS provides an important tool to compute spatially the differences and change in the physical properties in different time frame regarding previous and after situation. Thus, it helps to distinguish areas demanding more attention regarding recovery or future preparedness or other plans in emergency management and concern relating policy issues.

METHODOLOGY

The recovery rate of damaged structures or buildings or infrastructures in the affected area over time is studied based on quantitative methods. A detailed case study is developed based on the borough of Sea Bright in Monmouth County, New Jersey. The location with respect to surrounding states is shown in Figure 1. Sea Bright is in northeast New Jersey, south of New York and east of Pennsylvania.

Study Area

As mentioned the study area, Sea Bright, was selected to leverage earlier studies that provided detailed survey data. The earlier study focused on relocation decisions and the relationships with travel decisions. Sea Bright provided an example of a community focused on rebuilding. (Greer, 2015, McNeil et al., 2016, McNeil et al., 2017)

At the time of this study, Sea Bright borough in New Jersey, the chosen study area, was still in the process of recovery from the destruction of Hurricane Sandy, and like other areas still rebuilding. In 2010, there were 1,412 residents with 1,211 homes (35% owner-occupied and 34.6% vacant). The median income was $74,550 with 94.6% white people according to Census data (http://www.census.gov). Appendix A includes detail data on the community profile of the study area according to Census 2010 and American Community Survey (ACS) 2011. Sea Bright's municipal budget relies heavily on local property taxes that are jeopardized by Hurricane Sandy (Ashman et al., 2013).

Figure 1: Geographic location of the study area, Sea Bright, New Jersey

Sea Bright is a barrier island with water bodies in two sides of the land as shown in Figure 1 with an area of approximately 0.64 square miles. The land is geographically vulnerable and historically susceptible to severe and recurrent coastal storm damage with regular flooding (Ash Wednesday storm of 1962, The Nor'easter of 1992; (Ashman et al., 2013)). In Hurricane Sandy, Sea Bright was within 100 to 120 km buffer zone from the nearest trajectory of the hurricane eye. Figure 2 shows the image of the Hurricane path and the buffer zones for Sea Bright, New Jersey indicating that Sea Bright was within 120 km of the eye of the hurricane.

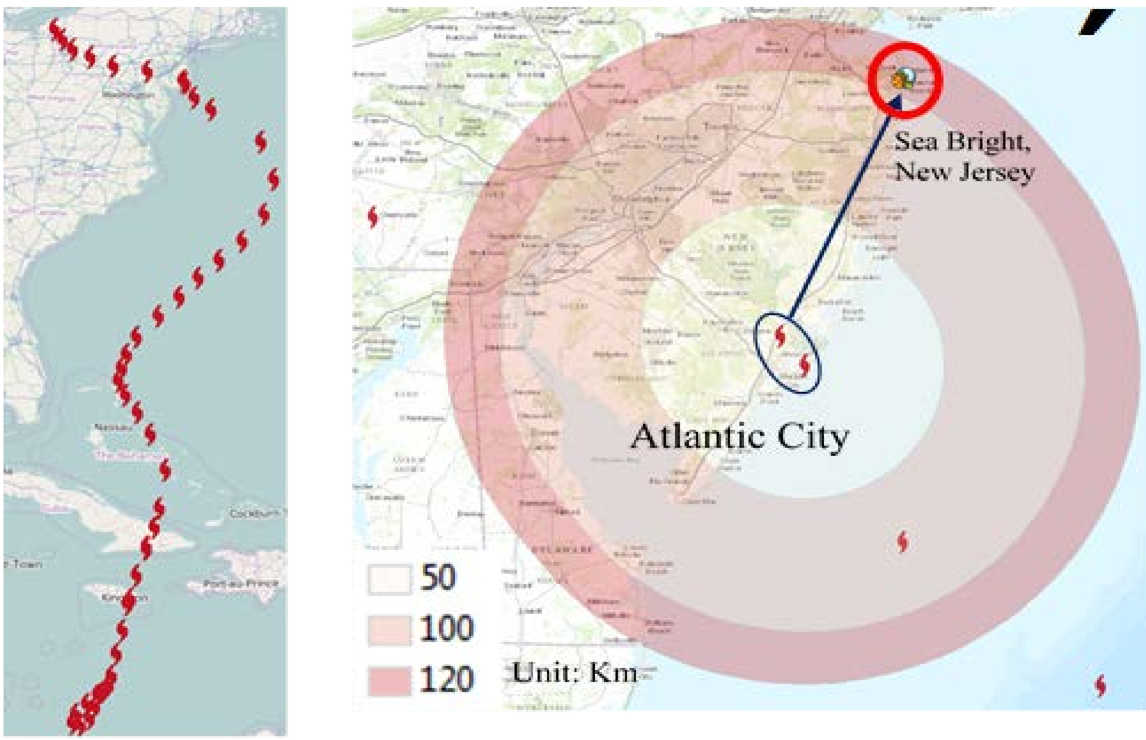

Figure 2: Hurricane Sandy path with buffer distance of the study area from nearest eye of the hurricane.

In Hurricane Sandy 1,028 out of 1,126 housing units were damaged; assessed loss in property values of $72.1 million US dollar; immediate aftermath of hurricane there was 6 feet of sand on the main road Ocean Avenue; also, many community facilities were destroyed. Hurricane Sandy had major negative impacts to homeowners, renters and the businesses. As of April 2013, approximately 50% of Sea Bright's residents were back (Ashman et al., 2013). FEMA records shows 759 structures damaged in Sea Bright (FEMA-MOTF, 2014). According to US Department of Housing and Urban Development (HUD), Hurricane Sandy damaged 720 structures in Sea Bright; the first floor of 376 buildings had 4 feet of flooding. Among the damaged property owners 92 persons had no insurance with 268 owners had insurance i.e. 25% without any insurance (HUD, 2014). There are inconsistencies in data from different sources that made this research more important to have a clear view on the actual scenario of recovery based on housing damage.

Measuring Housing Recovery

From the literature, it is apparent that there are various methods to measure the progress of housing recovery. In many studies on housing recovery, improvement or change in physical properties at a specific location are identified by comparing data over various time intervals. The data, over time, include GIS based maps, remote sensing satellite imageries, tax appraisal data, building permit data, land-use change and census data and so on. For this study, data satisfying the following criteria has collected to measure disaster recovery with respect to housing. The possible measures of damage and the attributes that may impact damage that are to be used in analysis of this research include:

- Scales of damage (no damage, affected, minor damage, major damage, or catastrophic damage i.e. destroyed)
- Damage estimates in monetary terms
- Ownership pattern (own/rent)
- Type of home (single-family/multi-family/apartment/condo/other)
- Occupancy type (Occupied/ unoccupied)

The measures of housing recovery are derived from these measures including measures of individual variables, multiple measures, and derived measures. Some measures are applied to a specific housing unit where others are applied to an area. Examples include:

- Single measures:
    - Single measures for individual housing unit whether experienced damaged or non-damaged.
    - By area that includes

        - Number (#) of housing units occupied or unoccupied.
        - Percentage (%) of housing units occupied or not.
        - Number (#) of housing units damaged.
        - Number (#) of housing units under repair.
        - Percentage (%) of area with a specified level of recovery.
- Derived measures:
    - Recovery scale (say 1 to 4, or 1 to 10, or 1 (damaged), 2 (partially recovered), and 3 (fully recovered)).

Data Collection Techniques

Available data from secondary sources has been collected, and analyzed to fulfill the purpose of the research. The data includes mail-based questionnaire, remote sensing images, GIS based data, air borne LiDAR data and so on.

Surveys and Interviews

This research uses data from other related projects (Greer, 2015; McNeil et al., 2016; McNeil et al., 2017). A mail-based questionnaire was designed and implemented in 2014 to collect information related to damage from Hurricane Sandy and people's perception on issues related to recovery and resettlement (McNeil et al., 2015; Greer, 2015). The questionnaire included 75 questions. In the first phase the questionnaire was sent to 1252 addresses followed by second and third round mailing that exclude completed and undeliverable addresses to encourage participation. Finally, 303 responses from the households were recorded from the survey, representing 29.8% response rate, here incorrect or unreachable addresses are not counted. In this proposed research, only data relevant to the research questions will be considered for analysis from the survey.

A second survey was undertaken in December 2015 (McNeil et al., 2017). This survey based on the 2014 survey was all sent to all households (1021 households) in Sea Bright. One hundred and forty-two responses were received representing a 14% response rate. The 120 questions included many of the same questions as the 2014 survey. Additional questions were developed based on media coverage, interventions and responses to the 2014 survey.

LIDAR data

Airborne LiDAR data, as more accurate, high resolution and precise data, is used to provide geospatial information on housing condition both for pre and post disaster. At the initial stage of this research, these data were assembled by Professor Jie Gong, Assistant Professor, Department of Civil and Environmental Engineering, Rutgers, the State University of New Jersey for the purpose of academic research (Gong, 2013; Gong et al., 2016). He collected this conditional data from United States Geological Survey (USGS). At present the data is also publicly available from the National Oceanic and Atmospheric Administration (NOAA) coastal websites. So, the after-Hurricane Sandy LiDAR data only within the boundary of study area is downloaded from this free source and used for detailed analysis. The National Oceanic and Atmospheric Administration (NOAA) also conducted some aerial photography of the east coast Hurricane Sandy affected areas on the day after it hit these areas. These data at various time intervals have been assembled to spatially compare the damage scenario of physical properties as an element of housing recovery through change detection.

Data Summary

Table 1 summarizes the data sources with detail that are used in assessing housing recovery of Sea Bright, the scale at which the data is collected and the time frame for data collection.

Two problems arise regarding the data. First, the study area is very small and very little demographic and economic data are available. Second, the response rate from the mail survey is relatively low so there is insufficient information from the mail survey to cover the whole borough. Besides these data also present some interesting challenges, such as:

1. The LiDAR data represent elevations. Interpreting changes in elevation to indicate damage, or rebuilding requires assumptions, extensive data processing and local knowledge.

2. Parcel level data from the surveys must be handled in a way to maintain confidentiality.

3. The survey data are samples and the recovery measurements required assumptions to assist in their interpretation.

Table 1: Summary of Available Data.

Data Source	Coverage	Scale	Time Frame	Measure
Survey Results	303 Households (29.8%)	Household	Summer 2014	Property Status: Abandoned; Repairs completed; Repairs in progress; Structure was or will be totally rebuilt; Structure was or will be demolished Condemned; Repairs completed; Repairs scheduled to begin; Property for sale or sold.
	142 Households (14%)	Household	December 2015	Property Status: Abandoned; Repairs completed; Repairs in progress; Structure was or will be totally rebuilt; Structure was or will be demolished Condemned; Repairs completed; Repairs scheduled to begin; Property for sale or sold.
FEMA-MOTF data	100%	Projected Coordinate system	2012 Hurricane Sandy impact	Measures the damage level, inundation data and other impact data.
LiDAR data (USGS)	100%	Projected Coordinate system	Pre-Sandy and Post Sandy	Change in Elevation Indicates Structure Damage
Aerial Imagery (NOAA, FEMA)	100%	Projected Coordinate system	2010, 2012, 2013, 2014	Visual interpretation of the land use change comparing pre-sandy and post-sandy images.
Google-Earth images in time series	100%	Satellite image	2010, 2012, 2013, 2014	Visual interpretation of the land use change comparing pre-sandy and post-sandy images.
Census	100%	Block	2010	Demographics

Analyzing the Data and Assessing Housing Recovery

There are several potential sources of data available for measuring housing recovery. The data are available in different time periods at different scales. One of the challenges is to integrate these disparate sources of data. ArcGIS software is used to prepare the maps and do spatial analysis based on sample data. The survey responses are geocoded to locate their position in field. After geocoding, the data from the survey is imported to an ArcGIS attribute table including individual household responses. Spatial analyst tools in ArcGIS are utilized with visual inspection to identify locations with damage and differential recovery progress of recovered, unrecovered or less recovered or continuing recovery and to compare recovery in certain time interval. The findings are presented in maps. Also, the data are analyzed statistically using MS Excel by creating tables and graphs of comparative features. In the case of LiDAR data, the change detection is done using Quick Terrain Modeler software to identify the damage location with color codes and value in elevation change. Having LiDAR data at several distinct times after Hurricane Sandy would enable comparative analysis over time.

The maps produced using survey data, GIS and remote sensing data and LiDAR data are compared to find out the variation over time. In this case the maps are made in same scale and various geo-processing techniques like overlay or others are used for further analysis. In case of statistical analysis of the data, percentage change, change in numerical values are utilized to have more acceptable and reliable results. Finally, the analysis result comes up with the number and percentage of houses repaired, rebuild or reconstructed to show the change over time to level recovery from the damage at that time of disaster to improved present situation.

The findings are presented in maps, charts, and tables to have a comparative view over time. A series of map at different points in time shows the area experiencing change in housing recovery to compare the progress. Several charts or graphs shows trend line with diminishing or increasing pattern considering the correlation between destroyed property and occupancy of the plot in later times with 2012 as base year of hurricane occurrence. The government and other organizations related to housing recovery can use these maps with identified location where more attention should be given to improve the situation based on factors contributing slow recovery from disaster.

ANALYSIS AND FINDINGS

This chapter describes the data analysis and the findings from the data analysis in support of the research goal and objective. The research assembles and uses data from different sources and integrates them to document the recovery of damaged properties over time for the case of Hurricane Sandy. The data related to disaster housing recovery in different time periods has been identified, assembled and analyzed to track the improvements to the housing stock in Sea Bright, New Jersey.

To fulfill the objective of the study, available data covers three time frames: before the disaster, immediately after the disaster and about two years after the event. The data comes from secondary sources. These include:

1. A mail-based questionnaire, as part of the on-going project titled 'Understanding the Relationships between Household Decisions and Infrastructure Investment in Disaster Recovery: Cases from Superstorm Sandy' sent in August 2014. The survey provides the information from residents impacted in Hurricane Sandy who responded to the survey.

2. Different aerial images of the study area in four time periods collected in 2010, 2012, 2013 and 2014, and Google Earth satellite images in different time periods used to compare the spatial change over time after Hurricane Sandy.

3. FEMA damage data in tabular, report and spatial format in GIS provides the data on immediate damage, inundation and other information.

4. LiDAR point clouds capture the immediate Hurricane impact. These data are compared to visually interpret the extent of the damaged site.

Data are analyzed to distinguish the areas experiencing destruction during the Hurricane occurrence, and afterward how much of those areas, or how many properties have been repaired or rebuilt to measure trends in the recovery process over time. The analyses follow a step by step approach. First the FEMA damage data and the survey data are compared to interpret the present situation based on the status of the physical properties considering the repair of damaged properties. In parallel the aerial imagery from four time periods, 2010, 2012, 2013 and 2014, are compared to visually demark the areas with differential changes. In addition, the LiDAR data identifies the location with changes in elevation that demarks the damage sites too. Later the data findings are compiled and compared to provide a clearer view of the damaged and redeveloped plots and determine the progress in the level of recovery for the study area.

Damage to Structures

Findings from FEMA-MOTF

In order to have a detailed idea of the damage after Hurricane Sandy and relevant information, publicly available data prepared by FEMA-MOTF (FEMA- Modeling Task Force) is used. This data was published in 2014 and available in Web-GIS using an ArcGIS account (link: http://www.arcgis.com/home/webmap/viewer.html?webmap=307dd522499d4a44a33d7296a5da5ea0) and downloadable GIS format (data source: https://data.femadata.com/MOTF/Hurricane_Sandy/; accessed on 7/6/19).

The FEMA Modeling Task Force (MOTF), a group of modeling and risk analyst experts from FEMA Regions VIII (Denver) and IV (Atlanta), may be activated by the FEMA National Response Coordination Center (NRCC) for Level 1 events in support of disaster response operations. One of their responsibilities is to develop consensus for best estimates of impacts before, during, and after events coordinating data and hazard and modeling information from multiple variety of sources. During Hurricane Sandy, the MOTF deployed to the National Hurricane Center (NHC) to better and more expeditiously integrate NOAA-National Hurricane Center (NHC) modeling into MOTF situational awareness and impact assessment products.

The report (FEMA-MOTF, 2014) published by FEMA-MOTF in 2014 shows detail information on the damage during Hurricane Sandy. The data covers the latest Hurricane Sandy storm surge data (in feet); county wise impact assessment compiled from surge, wind, precipitation and snow impacts (very high, high, moderate, low); FEMA Individual Assistance (IA) Household Inspection to classify damage, and so on. For this research, only data related to Sea Bright is separated from the large data base and later compared with other data sources. According to FEMA-MOTF, surge is the primary reason of the severe impact in Hurricane Sandy and Sea Bright falls in the very high impact areas for Hurricane Sandy.

In FEMA-MOTF Hurricane Sandy Impact Analysis, the household damage has been classified in four categories based on the individual assessment. For example, FEMA inspectors estimate the amount of Personal Property (contents) Full Verified Loss (FVL), Real Property (home) FVL and a sum of both as Total FVL in field surveys initiated by a household's application for assistance. Applicant household's damage classifications is as follows:

1. Affected – Total Full Verified Loss (FVL) greater than $0 to $5,000
2. Minor – Total Full Verified Loss (FVL) $5,000 to $17,000
3. Major – Total Full Verified Loss (FVL) more than $17,000
4. Destroyed – If indicated by IA inspector

To determine the number of impacted residential building more accurately, FEMA-MOTF identified households in the same exact location as multi-family residential buildings and applied the maximum household damage classification for the entire building. Other criterion included in damage estimates are visible damage from aerial imagery and inundation-based damage assessment that provides more comprehensive estimates besides considering households that applied for FEMA Assistance. The detailed criteria followed by FEMA-MOTF to classify property damage are shown in Appendix B.

The damage scenario for Sea Bright is summarized in Table 2 after extracting the data base from the large data of Hurricane Sandy impacted areas as reported by FEMA-MOTF. Some major types of information provided in the data include the following:

- DAMAGE: Damage level estimated based on visible aerial imagery
- INUNDATED: Presence or absence of inundation based on visible aerial imagery
- DAMAGETYPE: Indicates if damage was determined based on visible imagery or observed inundation or both.
- DMG_COMBO: Damage level based on the combination of visible imagery and water depth estimated at each structure point based on the FEMA-MOTF observed inundation products.

DEPTH: The depth in feet of inundation at each structure point relative to the ground surface.

For further analysis and comparison, the data in type 'DMG_COMBO' are used as this data identifies damage based on both visible aerial imagery and inundation of each structures.

Table 2: Building damage information following the classification by FEMA-MOTF in Sea Bright, New Jersey.

Criteria of classification	**Number of buildings with damage**						
	Affected	**Minor**	**Major**	**Destroyed**	**No Damage**	**No Data**	**Total**
Based on visible damage in aerial imagery only [DAMAGE]	46	40	11	18	625	19	759
Combination of visible damage in imagery, water depth and FEMA-MOTF observation [DMG_COMBO]	108 (14.23%)	252 (33.2%)	381 (50.2%)	18 (2.37%)	-	-	759 (100%)

Based on aerial imagery, only completely destroyed plots (18 plots) are clearly identifiable. Other damage to buildings is not easily recognizable to find their actual number. Here it is seen that the numbers increase a lot when the inundation and other observations are considered in the case of buildings affected and with major and minor damage. The data in Table 2 shows that 759 structures in Sea Bright experienced damage in Hurricane Sandy. Among the total damaged, 50% had major damage in Hurricane Sandy where 33.2% had minor damage, 14.23% were affected and only 2.37% fully destroyed structures.

The location of damage sites including affected, minor, major damage and destroyed plots are shown in Figure 3. The maps show that the damage is distributed all over the borough and the whole area has gone through a somewhat similar damage experience in Hurricane Sandy. The map shows the south part had experienced more damage regarding major, minor and destroyed structures than the north part where there are no destroyed buildings but rather the damage is not negligible because there are many major and minor damaged structures.

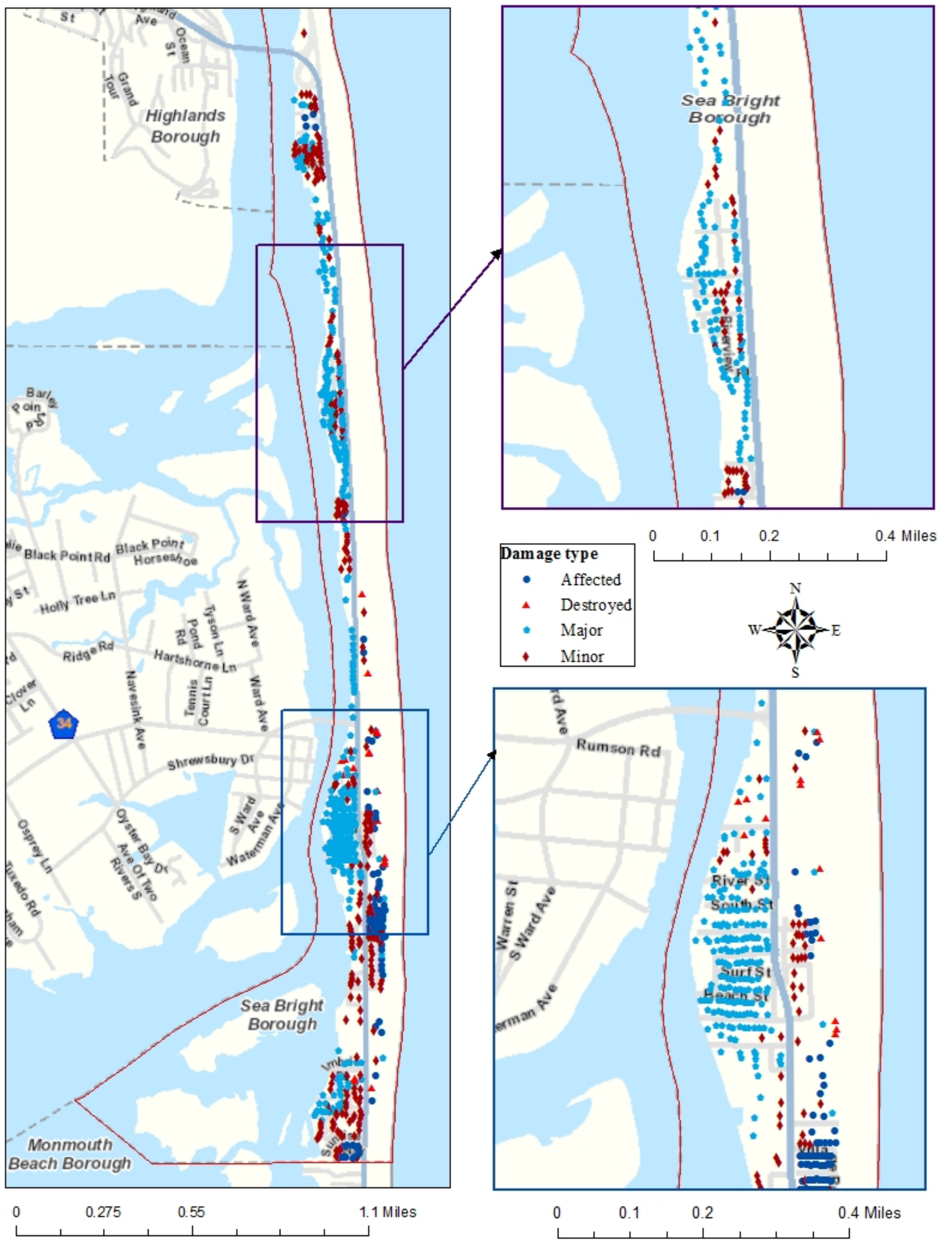

Figure 3: Spatial distribution of damaged structures by category based on FEMA-MOTF data.

The property inundation status with or without damage from FEMA-MOTF data is shown in Table 3. When the visible damage and observed inundation damage are combined [DAMAGETYPE], the information in Table 3 is found for all damaged points recorded by FEMA-MOTF.

Table 3: FEMA-MOTF data on inundation and damage of the plots.

Type	Number of structures				
	Damage & inundation	**Inundation only**	**Damage only**	**No Data**	**Total**
Affected	2	102	0	4	108
Minor	43	174	2	33	252
Major	46	269	4	62	381
Destroyed	18	0	0	0	18
Total	109 (14.36%)	545 (71.8%)	6 (0.8%)	99 (13.04%)	759 (100%)

From Table 3, it is apparent that for 71.8% of impacted structures the damage was due to inundation only, where other damage component and inundation covered 14.36% of the overall damaged structures. In the case of destroyed buildings, all of them had gone through inundation and massive damage to be destroyed in the Hurricane. For comparison only 0.8% of the damaged area in the borough faced damage without inundation.

The water depth in inundated structures after Hurricane Sandy is shown in Figure 4. Part of the map is enlarged to make the damage more visible and show that inundated locations with high water height experienced more damage. The water height recorded in FEMA-MOTF ranges from approximately 0.04 feet to 12 feet. According to USGS survey data on high water marks in five location in Sea Bright, the water level was 4 to 5.1 feet high aboveground level (FEMA-MOTF, 2014). The data points are also shown in Figure 4.

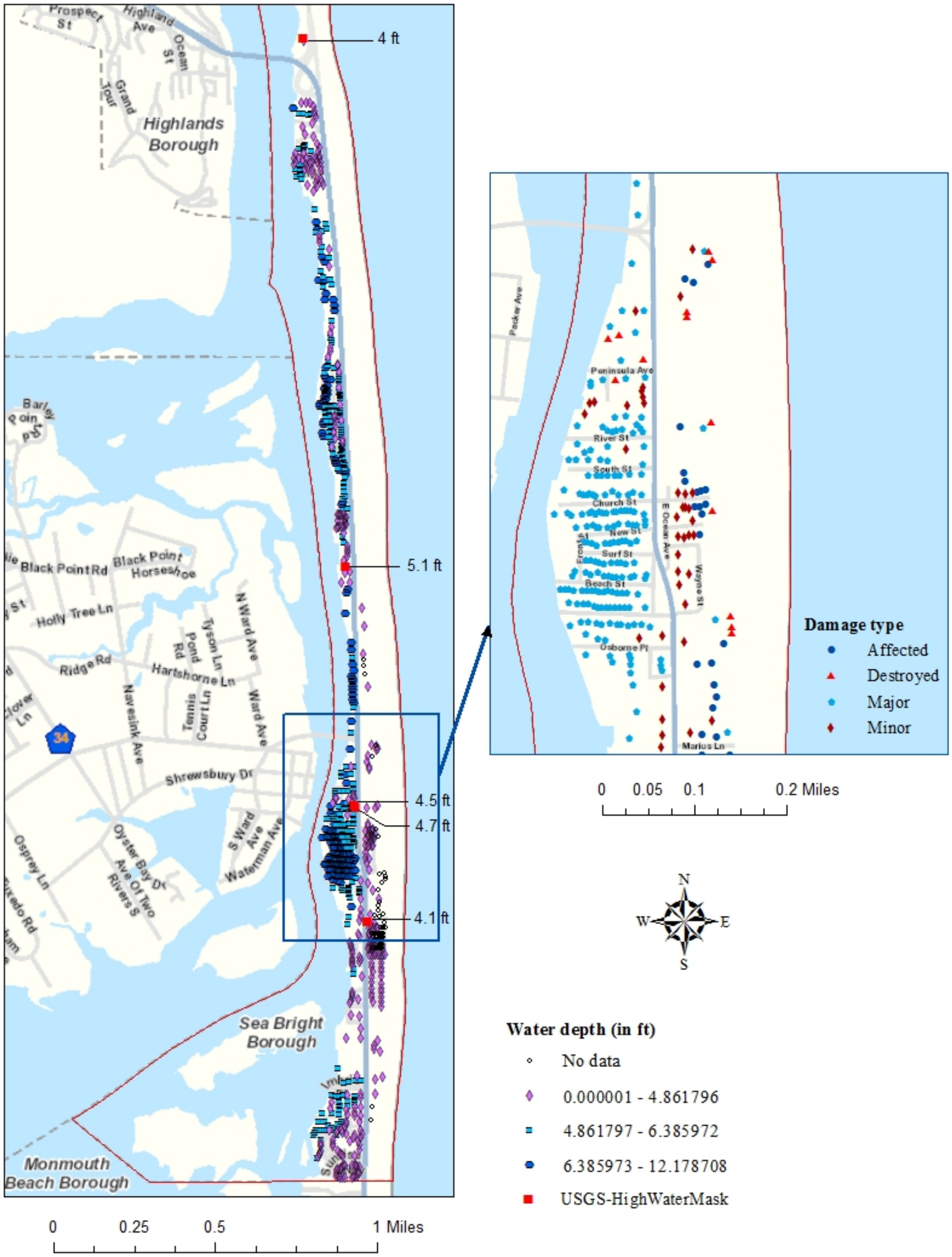

Figure 4: Image showing water depth in damaged structures with USGS high water mark data and inset view of damage in one part of Sea Bright.

Damage report from Questionnaire

The responses from the questionnaire survey have been geocoded to locate the position of the property within the study area. Knowing the location helps in analyzing data and comparison with other information from same or different sources. Accordingly, 180 responses among 303 were found to be within the study area, the remaining 123 addresses were found to be outside Sea Bright because their property in the study area is used mostly as second home or they choose to use this address for postal purposes. After having the spatially georeferenced position of the survey responses, the FEMA-MOTF data on damages and inundation was merged with the survey information following a georeferenced map and matching corresponding locations spatially. The data findings after analysis are discussed in the following sections.

In the questionnaire, the respondents were requested to categorize the damage to their home as no damage, not very extensive damage, somewhat extensive damage and very extensive damage. Table 4 shows the result of their responses.

Table 4: Damage to home from survey responses and FEMA-MOTF data on respective location.

Damage Level	**All Response from the survey**		**Response addresses located only in Sea Bright**		**Damage Level**	**FEMA-MOTF data corresponding the response in Sea Bright**	
	n	**%**	**N**	**%**		**n**	**%**
No Damage	20	6.69	7	3.94	Affected	22	12.22
Not Very Extensive	73	24.42	46	25.84	Minor	86	47.78
Somewhat Extensive	113	37.79	68	38.20	Major	69	38.33
Very Extensive	93	31.10	57	32.02	Destroyed	3	1.67
Total	299	100	178	100	Total	180	100
Missing	4		2				

The survey shows 93 to 96% (considering 180 and 303 responses) of the Sea Bright borough experienced damage to some level from not very extensive to very extensive damage. From response of 303 households, it is found that 68.89% of the total area have gone through extensive damage (includes both somewhat and very extensive damage) while considering identified response within the study area (i.e. of 180 responses) it is 70.22%. However, comparing the damage condition to the FEMA-MOTF, data shows 87.78% of the damaged area had experienced minor to complete destruction. Figure 5 shows spatially the result from survey responses and FEMA data with respect to damage condition perceived by the households and as assessed by FEMA plotted on a map of Sea Bright. Given different qualitative assessment of damage it is difficult to make a direct comparison of the survey data and the FEMA data.

Based on the damage estimates in survey responses, kernel density analysis is done in ArcGIS to create a continuous surface surrounding damage concentration. Here damage cost in dollars are the count or quantity to be spread across the landscape. Kernel calculates a magnitude per unit area using a kernel function to fit a smoothly tapered surface to each point or polyline. Figure 6 maps the result of such analysis. The analysis considered the 180 responses located in the study area, so the outcome is not very representative. The map highlights the area with more damage concentration based on people's perception. From this map it is clear that the south part of Sea Bright has more damage estimates than north part.

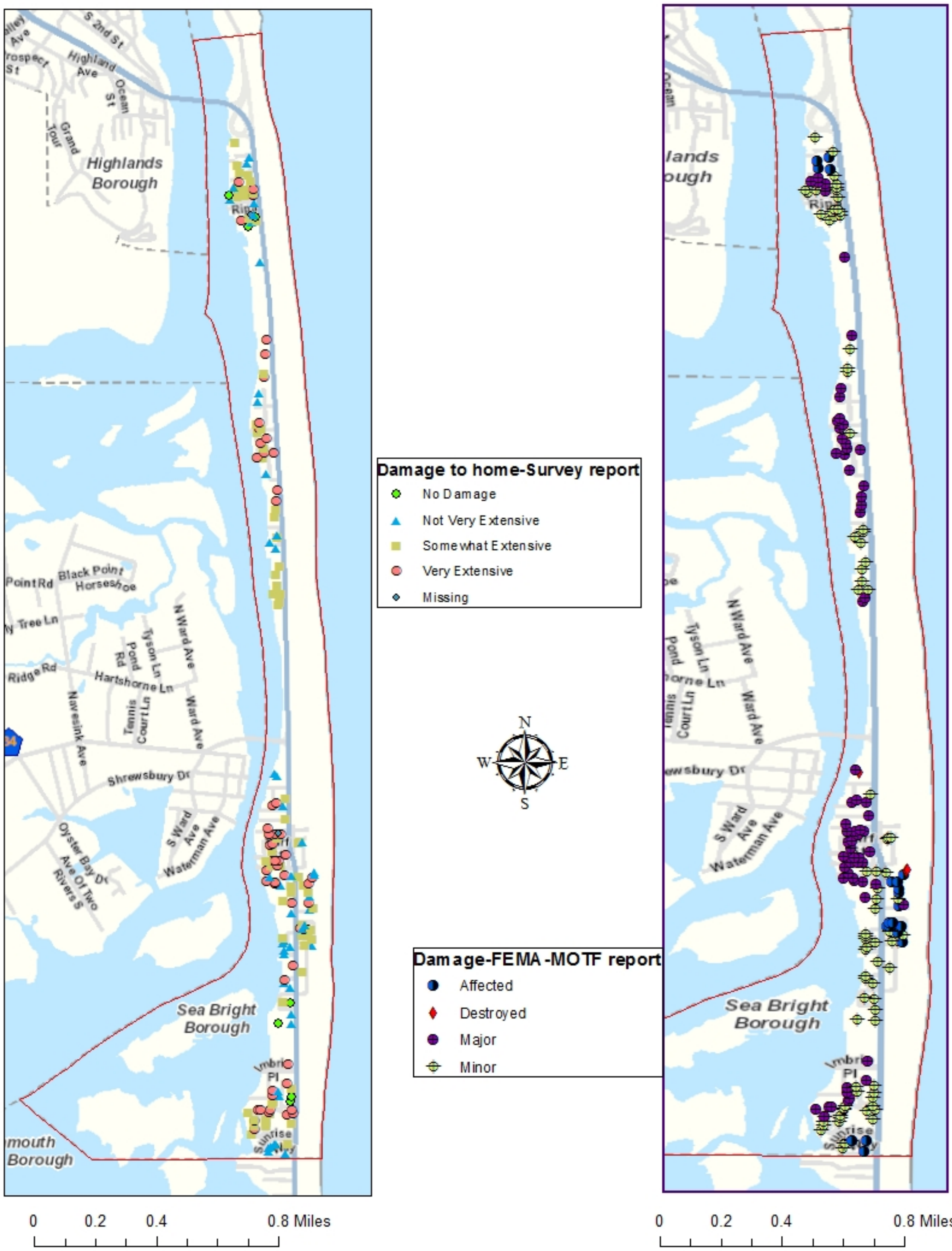

Figure 5: Damage condition recorded from questionnaire and FEMA-MOTF data.

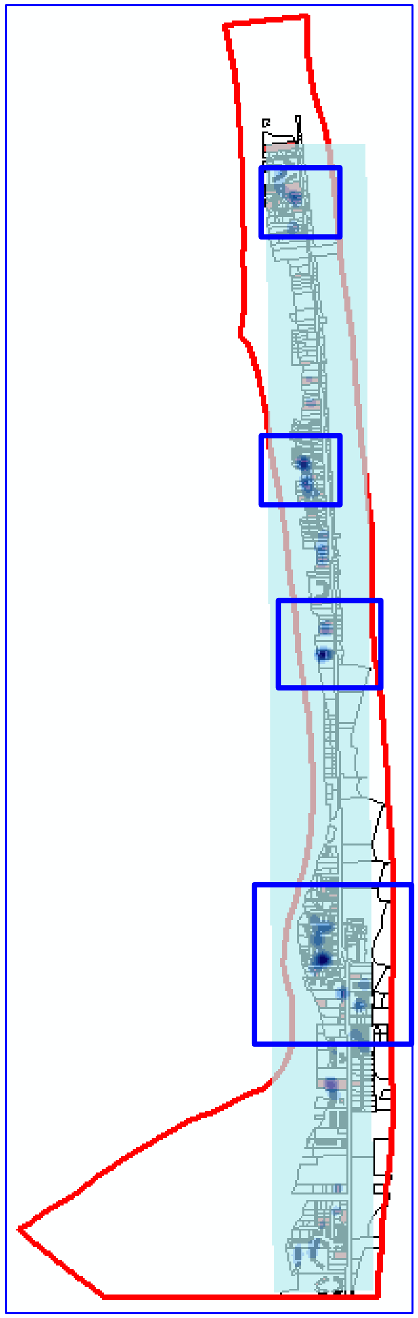

Figure 6: Findings from Kernel density analysis showing distribution of estimated damage from survey, scaling damage to the study area

Scaling damage to the study area

To explore the range and variability in the data on damage, the damage categories are scaled to create a picture of on an 'average' scenario for the whole study area. The values were chosen arbitrarily but based on the severity of the damage such as 'only affected' has a value of

1, ‘minor’ and ‘major’ damage have values of 2 and 3 respectively, where ‘destroyed’ is assigned the largest value 4. For each category of damage, the product of the number in that damage type with their value divided by the number of total damaged properties represents the impact of damage. These resulting values are then summed to find the average damage value for the study area.

The weighted value with the number of structures under specific damage criteria are listed in Table 5 in order to compute the weighted damage in each level and finally their weights are added to quantify the damage level of the overall community of Sea Bright. Damage data from FEMA-MOTF for the entire locality and for location of the survey responses within Sea Bright are shown in parallel in this table and the grand total of weighted damage values in both cases have found to be very close i.e. 0.241 and 0.229 respectively.

Table 5: Quantifying damaged property to estimate the damage level of the study area using FEMA data for whole area and survey responded location within study area.

Damage Type	**No of Damaged Property**		**Scale**	**Impact of damage = (No of Property with specific damage x Weight) / Total damaged property**	
	Survey location	**Entire borough**		**Survey location**	**Entire borough**
Affected	22	108	1	0.12	0.14
Minor	86	252	2	0.07	0.66
Major	69	381	3	1.15	1.51
Destroyed	3	18	4	0.96	0.09
Total	180	759		2.29	2.41

Next in Table 6 the weighted result considering the 279 responses (excluding no damage and missing data) from the questionnaire are summarized to determine the total weighted damage of the locality Sea Bright with the specific damage classification reported by the respondents. Here the weight of the damage has been readjusted as ‘not very extensive’ damage is weighted as 1, ‘somewhat extensive’ damage weights to 2.5 and ‘very extensive’ damage is given a weight of 4. The specific weighted value considering number of structures in each damage type is computed following the same computation rule in previous table. In this case the resulted average weighted value for the entire community has found to be 2.6.

Table 6: Quantifying damaged property to estimate the damage level of the study area using the total survey responses.

Damage Type	No of Damaged Property	Scale	Impact on properties
No Damage	20	0	0
Not Very Extensive	73	1	0.26
Somewhat Extensive	113	2.5	1.01
Very Extensive	93	4	1.33
Total	279 (excluding no damage)		2.6

The average value found from FEMA damage data for whole study area and from survey responses within the study area along with damage data from overall survey are shown schematically in Figure 7 with each of the estimates of damage plotted on a scale from 0 (no damage) to 4 (destroyed). From this diagram it is obvious that on average the whole community has experienced minor to major damage that was a significant factor in selecting Sea Bright as a study area for assessing recovery over time.

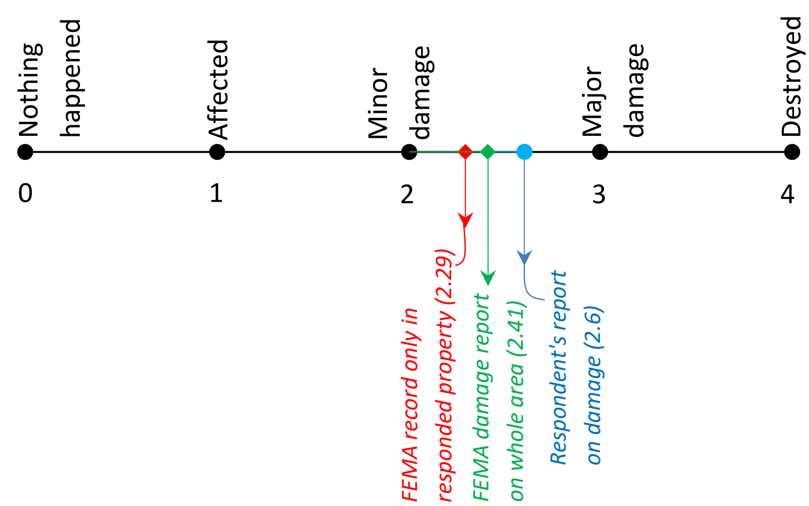

Figure 7: Schematic diagram showing the average damage from different data sources.

Visual interpretation from Aerial imagery

Open source, aerial images of the study area were found for four time frames: 1) before Hurricane Sandy image in 2010; 2) in 2012 the year Hurricane Sandy occurred; and 3) after Sandy impact in 2013 and 2014. The images of 4th July, 2010 and 30th July, 2013 are collected from publicly available National Agriculture Imagery Program (NAIP) imagery, downloaded from http://earthexplorer.usgs.gov/. The NAIP provides ortho imagery with 1-meter ground sample distance (GSD) and horizontal accuracy of +/- 6 meters to true ground.

The aerial image of 2012 was downloaded from the NOAA 'Hurricane Sandy: Rapid Response Imagery of the Surrounding Regions' data base (NOAA, 2012). The airborne digital imagery were acquired by the NOAA Remote Sensing Division from a nominal altitude of 7,500 feet, using a Trimble Digital Sensor System (DSS) with approximate ground sample distance (GSD) of 35 cm (1.14 feet) in each pixel (https://geodesy.noaa.gov/storm_archive/storms/sandy/docs/sandy_metadata.htm and https://geodesy.noaa.gov/storm_archive/storms/sandy/index.html). The images covering Sea Bright were captured on November 01, 2012 in Flight 1.

The study area image for 2014 is clipped from the large data set of Ortho-rectified mosaic tiles in raster format that was created at 0.35m ground sample distance (GSD) for each pixel by the NOAA's Coastal Mapping Program (CMP) for the NOAA Integrated Ocean and Coastal Mapping (IOCM) initiative in Hurricane Sandy coastal impacted areas. The high-resolution original images were acquired with Intergraph/Leica DMC Sensor Systems from January 01 to April 21, 2014 (NOAA, 2014). (http://coast.noaa.gov/dataviewer/ accessed on 5-10-2015).

These images are visually inspected to detect change and identify the locations with differential land use including man-made and natural features through overlaying them one above another in ArcGIS software and by swiping the target image over the base imagery, and identifying the changes. Figure 8 shows the full view of the study area with damaged building locations (shown in red) and natural dunes (shown in blue) in the image on the left. The inserts show highlights of a specific section where the images for buildings differed from the earlier image. This figure represents a large view and specific years, 2010, 2012, 2013 and 2014 showing the changing situation in the field. In the case of buildings, the difference could only be detected if the property was fully destroyed or demolished for rebuilding and after the space has been occupied again in the observed time interval.

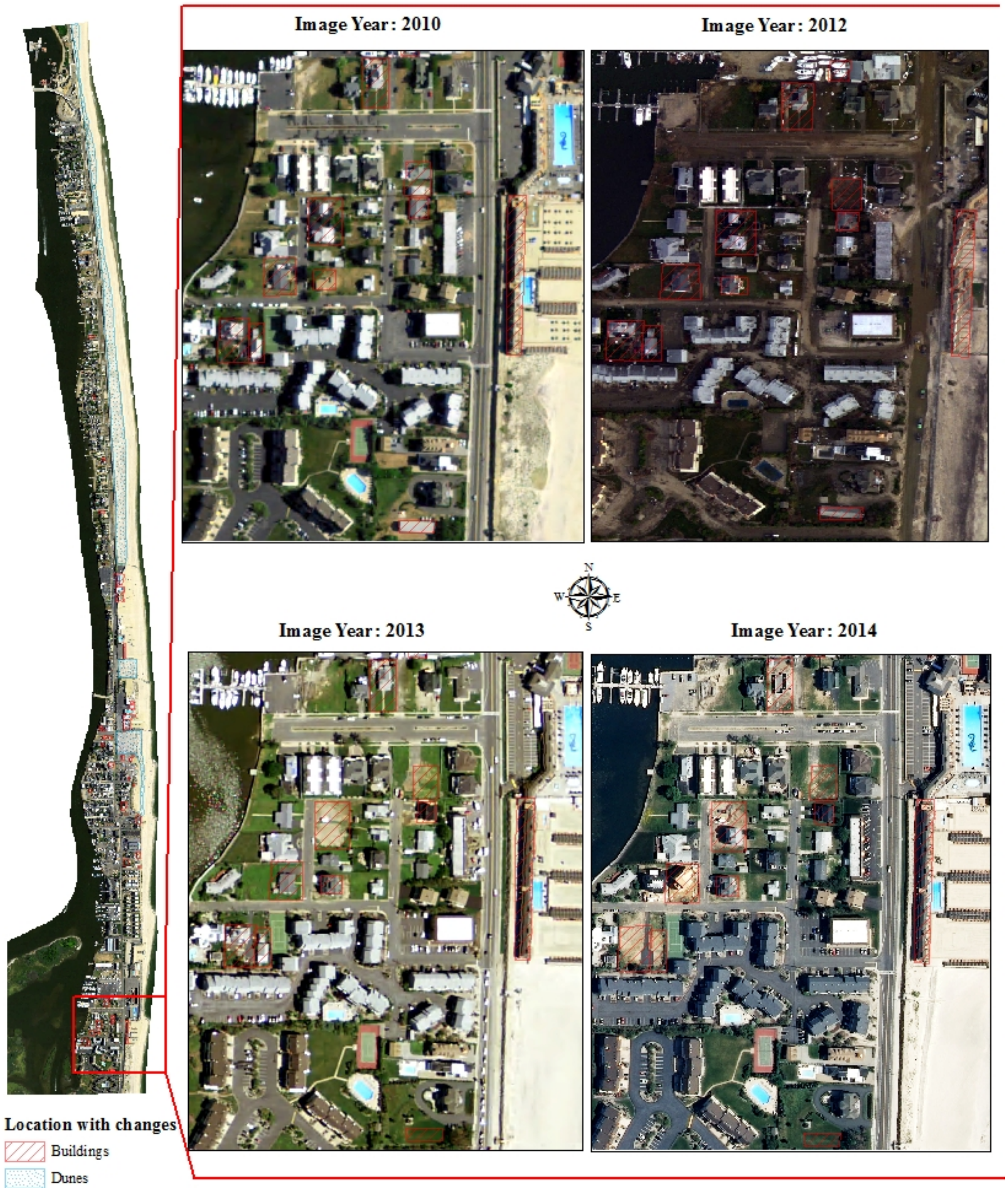

Figure 8: Visually identifiable changes in buildings (2010-2014) after Hurricane Sandy impact in 2012.

Figure 9, like Figure 8, shows the full view of the study area with damaged building locations (shown in red) and natural dunes (shown in blue) in the image on the left, and the insert images focus on the dunes. From imagery the change in natural features like continuation of sandy dunes can be identified clearly. In the case of the sandy dunes that protect Sea Bright naturally, it is found that in Hurricane Sandy the dunes had been damaged in several places, which had not been repaired until 2014. Figure 9 shows snap shots of the dunes in 2010, 2012, 2013 and 2014, capturing this situation.

Chronologically, comparing the building structures from site images, it is found that 48 points had some change. Among them, in Hurricane Sandy, 18 locations were destroyed fully, 18 had major damage, 9 had minor damage and 3 buildings were affected in that disaster. Up to 2013 there was little activity on the destroyed properties with only four properties rebuilt. This number increased to seven in 2014, and the rest were still vacant plots. In 2013 eight major damaged plots were found vacant where building structures existed earlier. This number increased to 16 with two of those previous vacant location had houses reconstructed in 2014. The minor damaged sites also experienced demolition, for example, in year 2014, seven of these locations were found to be unoccupied. Affected buildings are not an exception in this scenario where three such plots were bare land in 2014. The damage sites going through reconstruction, and demolition with their damage condition in Hurricane Sandy are shown in Figure 10. From this figure it can be concluded through visual observation that the south part of Sea Bright area was still going through the recovery process in 2014 considering the number of unoccupied plots and change in use patterns from previous.

Figure 9: Visually identifiable changes in dunes after Hurricane Sandy between 2010 and 2014.

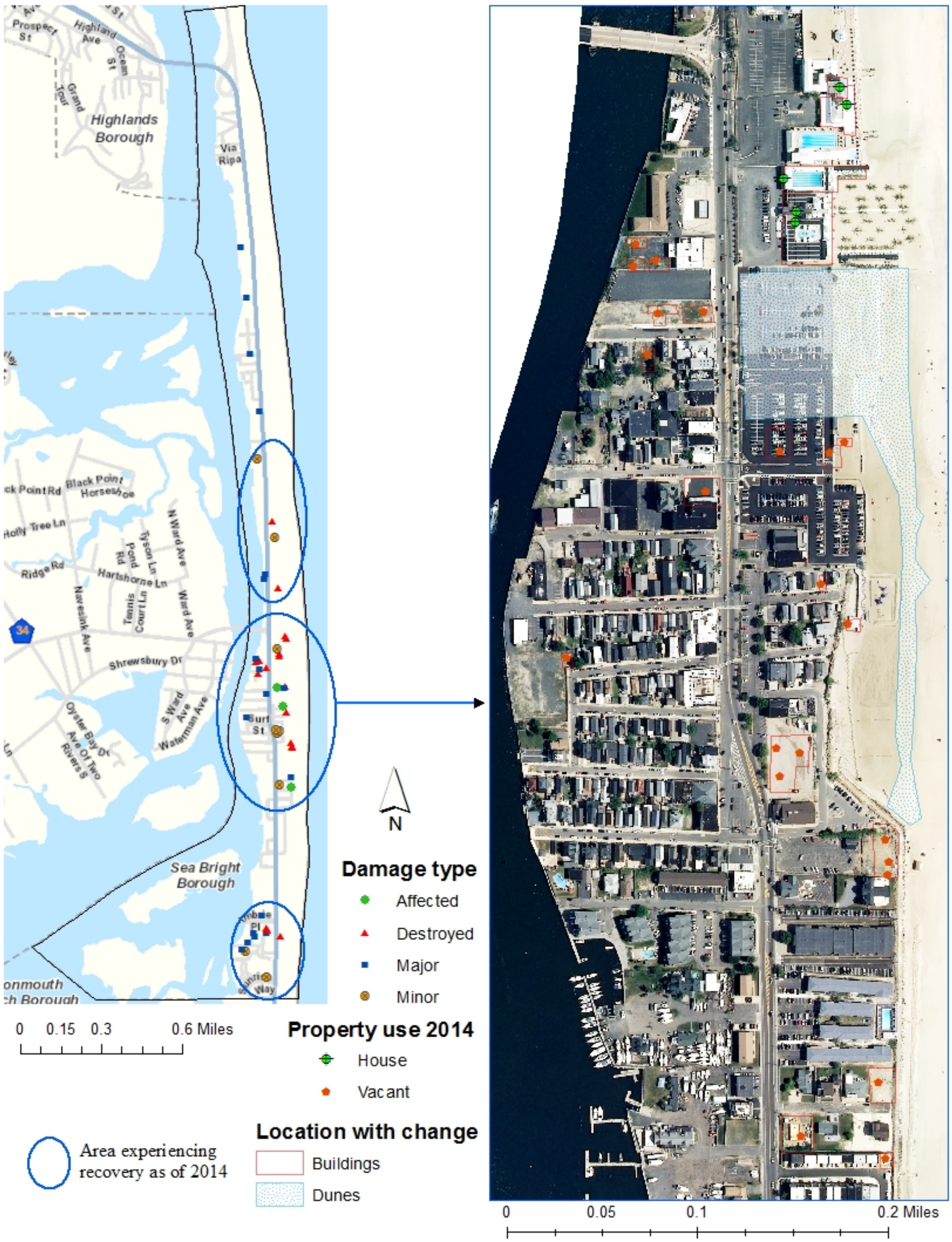

Figure 10: Location of 48 damage points that showed change in different time until 2014 after Hurricane Sandy, concentration identifies the area experiencing housing recovery.

LiDAR data findings

LiDAR data provides more detail and accurate data for any region. The U.S. Geological Survey (USGS) produced LiDAR point cloud data from remotely sensed, geographically referenced elevation measurements. They used second-generation Experimental Advanced Airborne Research Lidar (EAARL-B), a pulsed laser, in an aircraft to measure ground elevation, vegetation canopy, and coastal topography of the target area (USGS, 2014). The approximate travel speed and flight height was 55 meters per second and 300 meters respectively that resulted laser swath of approximately 240 meters with an average point spacing of 0.5 to 1.6 meters. Data acquisition dates were October 26, 2012 prior to Hurricane Sandy and on November 1, 2012 and November 5, 2012 just after landfall in New Jersey and the data published in 3 June, 2014. They initiated this project to produce accurate and highly detailed digital elevation maps serving the needs of researchers. (http://coast.noaa.gov/dataviewer/webfiles/metadata/2012_usgs_pre_sandy_nj_eaarlb_m3658_template.html; http://coast.noaa.gov/dataviewer/webfiles/metadata/2012_usgs_post_sandy_nj_eaarlb_m3657_template.html; Accessed May 2015) . The relevant data in geospatial data format (las for LiDAR multiple return points) is downloaded from free source of the NOAA Coast data (link: http://coast.noaa.gov/dataviewer/#) with UTM projection Zone 18N, horizontal datum 'NAD 1983' and vertical datum 'NAVD 1988' in unit meter. From the large data set only the information confining the geographic boundary of the study area has been segregated/separated for further analysis. In this subset of LiDAR data, the point spacing in the pre-sandy LiDAR data is 1.948 meters, number of points are 1,071,985 having a minimum elevation of -1.099 meter (Z min) and maximum elevation of 22.92 meter (Z max) where average elevation is 2.595 m and standard deviation 2.881 m. In post-sandy the number of points is 1,415,180 having point spacing of 1.711 meter with Z min -0.818 meter and Z max 24.85 meter where elevation average is 2.246 m and standard deviation 2.792 m. In general comparison the difference in maximum elevation increased approximately by 1.93 meter and the minimum elevation difference is reduced by 0.281 meter from pre to post sandy elevation change representing debris accumulation or loss of land over the study area.

The Quick Terrain Modeler (QTM) software is used to produce 2-meter resolution digital surface model (DSM) based on point spacing in pre and post scenario. Here two meter is chosen to have a good result as it is more than point spacing in both data sets, and all points are covered in surface creation. The surface models created from pre and post sandy elevation are used to find out the location with differential change in elevation identifying loss or gain in elevation as an indicator of damage or debris accumulation in the area. To determine this change, the analysis tool 'change detection map' in QTM software is used to create a continuous surface showing elevation difference. These maps are useful in visually identifying the areas with gain or loss in elevation due to impact of Hurricane Sandy. This type of LiDAR data analysis is effective in damage estimation of an area considering its physical properties. Figure 11 and Figure 12 respectively shows the visual interpretation from LiDAR data analysis of elevation change detection in pre and post Hurricane Sandy in natural dunes and building structures. Changes are color coded by from a low of -11 meters to a high of +16 meters.

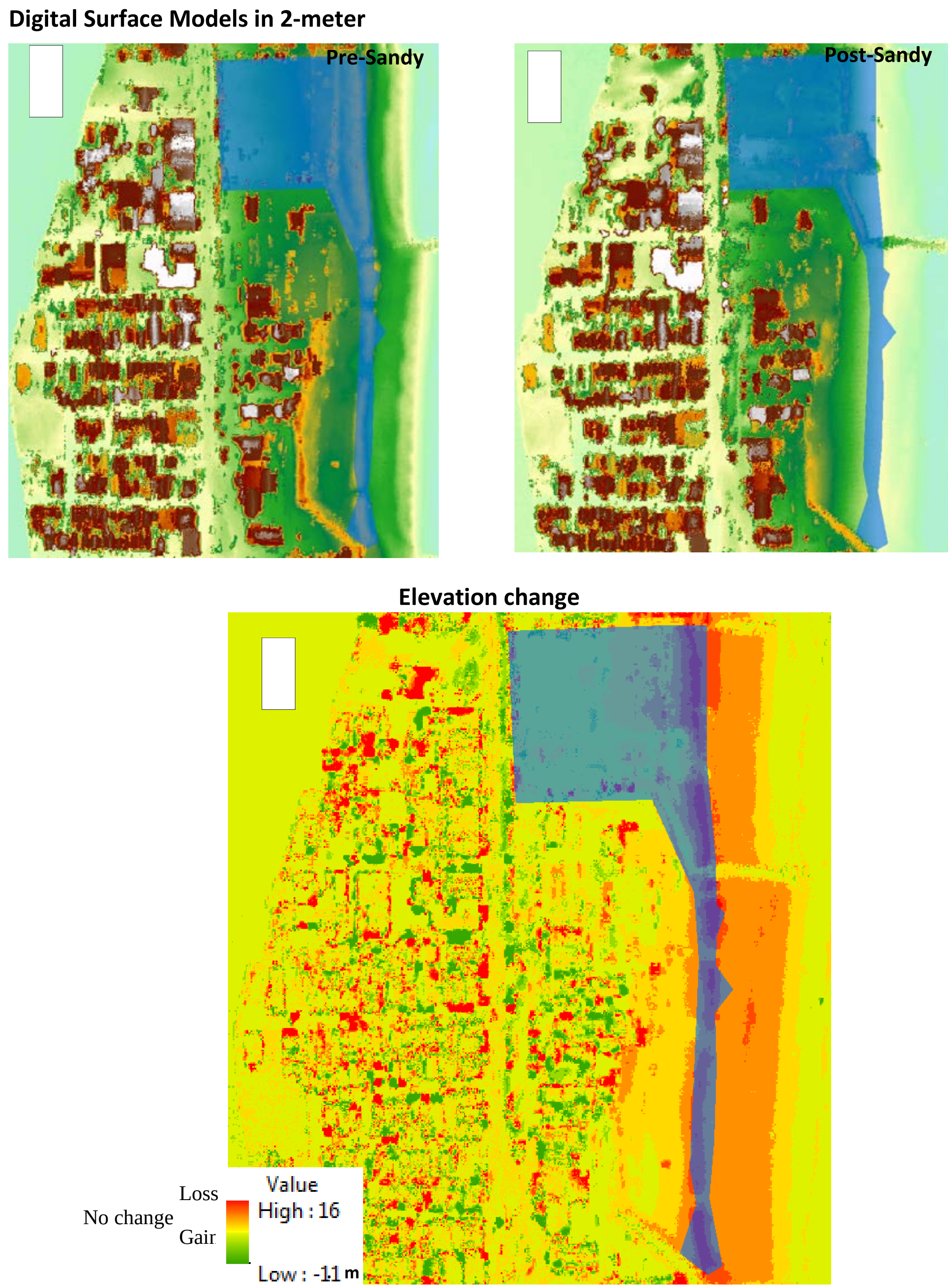

Figure 11: Change detection in dunes pre and post Sandy using LiDAR data.

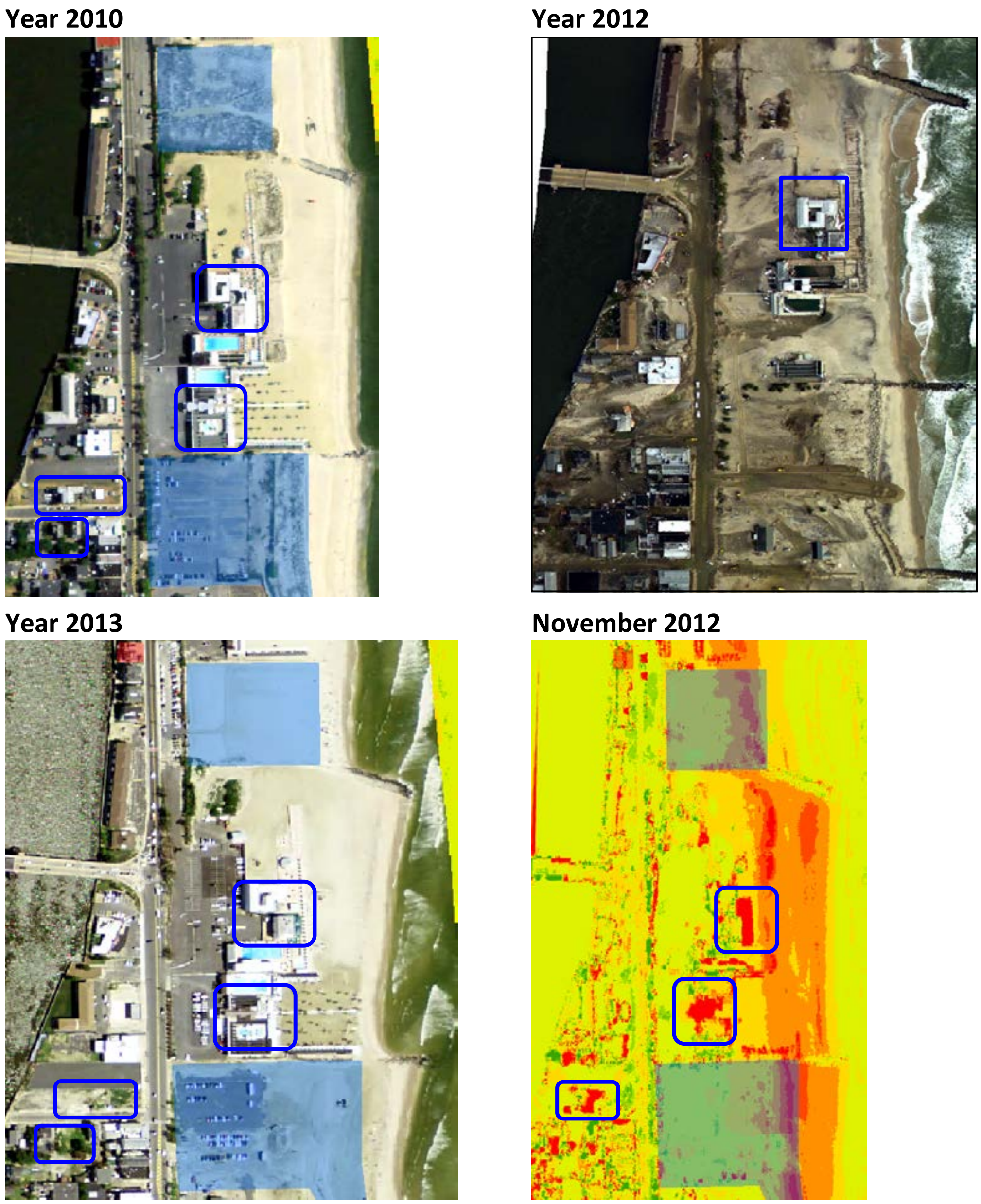

Figure 12: Change detection in building structures in pre and post Hurricane Sandy using LiDAR data.

Recovery Process

The recovery progress considers the changes in the number of damaged household properties. The main source of information to delineate progress is survey response on ‘status of repair completed or not’. If the repair has been completed, it has been counted as complete recovery with respect to structural damage. The change in the status of destroyed properties in

Hurricane Sandy could be studied for different time interval through visually noting the land use in those location from satellite images in Google Earth. The satellite images are available through April 2014. Also, the properties with major or minor damage or affected in Hurricane Sandy that have been rebuilt after being demolished or are found to be demolished prior rebuilding can be identified by observing the images in different times.

Property status comparing survey data and FEMA damage data

The repair status of the buildings in the survey as of August, 2014 compared to the initial damage reported by FEMA is shown in Table 7.

Table 7: FEMA damage data (DMG_COMBO) with property status in August, 2014.

FEMA damage record	Number of buildings damaged	From survey result			
		Repair complete	%	Repair not complete	%
Affected	22	15	68%	7	32%
Minor	86	62	72%	24	28%
Major	69	34	49%	35	51%
Destroyed	3	1	33%	2	67%
Total	180	112	62%	68	38%

In the study area, based on responses from addresses located within Sea Bright, 62% of the total damaged area has recovered considering repair of the building, and 38% of the area are in the process of recovery. Among the affected properties, 68% have reported 'repair complete', still 32% are in the process of recovery. Significant improvement has found in minor damaged properties where 72% have repair completed. The major damaged sites along with the destroyed plots are experiencing slow recovery. As of August, 2014, data shows 51% of major damaged sites with 67% of the destroyed structures are still in the process of repair, two years after Hurricane Sandy.

According to the damage category reported in the survey, the recovery progress is shown in Table 8. To compare the recovery progress in damage sites, the sites with 'no damage' recorded (20 responses) was excluded from the count.

Table 8: Damage to home as reported from survey of residents.

Extensive damage to home	**Repair complete**		**Repair not complete**		**Total damage**	
	n	**%**	**n**	**%**	**n**	**%**
Not Very Extensive	44	60.27	29	39.73	73	100
Somewhat Extensive	90	79.65	23	20.35	113	100
Very Extensive	52	56	41	44	93	100
Missing status	2	50	2	50	4	100
Total	188	66.43	95	33.57	283	100

In the damaged area 66.43% have completed repair as shown in Table 8, while from FEMA damage category and response of household survey shows 68% area under 'repair complete' and considered full recovered. The values are close enough to suggest consistency in the results found in different ways. Significant progress in recovery with respect to repair completion happened in 'somewhat extensive damage' part as reported in response from the survey i.e. 79.65% of that damaged area. In comparison 44% of very extensive damage part are in process of recovery as reported in summer 2014 survey.

Figure 13 shows the spatial distribution of survey result on 'repair completion' with location where repair is still needed. From the map it is apparent that there are no patterns in the progress of recovery based on location. Recovery has a mixed pattern throughout the borough. So, it cannot be said definitely which part had fully recovered or had more recovery. In one block if some damaged properties have completed repair, others are waiting for repairing the damage.

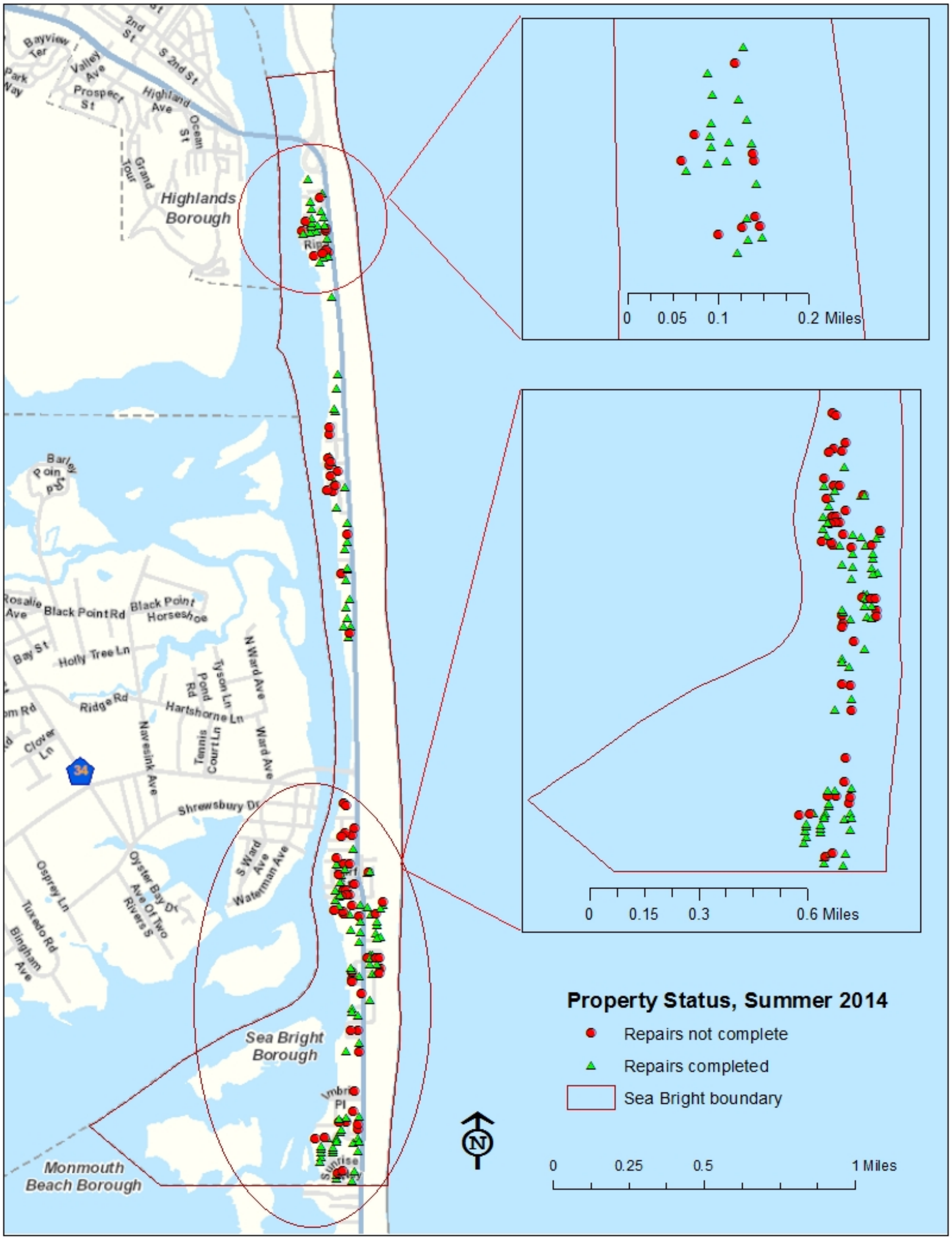

Figure 13: Recovery level of the study area based on repair status of the damaged buildings.

From the survey it is found that three of the major damaged (FEMA-record) properties are still abandoned where two experienced inundation. These properties are owner-occupied single-family houses, all have flood insurance, and as of August, 2014 they have not repaired yet. One of them will be rebuilt and is scheduled for repair. None of them was or will be demolished though the properties are not in good condition and faced very extensive damage as reported in the survey. Although this does not provide a quantitative assessment of recovery, a review of the survey responses (see Greer 2015 and McNeil et al., 2016 for a review of the survey methodology) provide some insight into the challenges in recovery, such as the statement of a property owner who was 'not sure' of the property status stated:

> We moved 4 times in 5 months. Spent the 1st week after the storm in same 2 sets of clothing. Overpaid for a rental large enough for a family, when we finally found a rental. The insurance process wasn't difficult, just depressing. We had a structural engineer report to the insurance company that we had major structural damage under our home, only to have them deny that part of the claim. They said my policy didn't cover the damage caused by "moisture". It was a flood, not moisture! We then hired a public adjuster who wrote a massive report on his findings. He said we are covered for the damage we had and escalated the findings up to FEMA. They also denied it. It was $26k worth of damage. Our last resort was to hire a lawyer who would take 40% of that money. We called a lawyer, but haven't done much else with it. So now we are working on RREM grant. We were told not to start the project or we could be disqualified for the grant. Bottom line - it's been a mess from day one. All of it. I'm tired. My family living in a rental, our home sits rotting. The start of our project is nowhere in sight. I can't take another form to fill out or denial or having to prove we were victims of this storm. We run out of rental assistance Sept 1st and I am scared. We can't afford our rental, plus our home mortgage, taxes, insurances, and bills

Recovery of destroyed property assessed from aerial and satellite imagery

The recovery of destroyed properties could be verified by visual inspection of sequential images in google earth. The georeferenced location of destroyed plots have been imported in google earth and their status was checked in available time series after Hurricane hit in October, 2012 until April, 2014. Figure 14 shows a time series (November 1, 2012, November 3, 2012, November 5 2012, April 25, 2013, December 6 2013, and April 24 2014) of snap shots of a destroyed part of Sea Bright. In the upper left is the Shrewsbury river bridge that provides a landmark. The corresponding location is seen in each image. The images can be used to find the location with or without development to assess the recovery process of these type of damaged properties.

Comparing the recovery among the damaged properties it has been found that the destroyed properties are experiencing slow recovery; although this observation is based on a small sample only one destroyed plot out of three reported in the survey had completed repair. While from the satellite images from Google Earth in different time periods, the images show that up to April 24, 2014, seven plots out of 18 destroyed plots are in use (i.e. 38.89%), the remaining are vacant with no use. Figure 15 shows the trend line with monotonically increasing percentage of recovery progress over total destroyed structures considering the use of the land and also bars shows the decreasing number of plots vacant after being destroyed in Hurricane Sandy over time.

Scaling recovery in the study area

The completion of the property repairs is given the same values as Table 5, Table 6 and Figure 5 to assess the average recovery for the entire community. In this case the number of respondents who have not completed repair has been quantified and the number is multiplied with the value of the specific damage category and then divided by the total number of damage structures to find out the impact in each damage group. All of the values are summed to give the average damage value for the whole study area. Table 9 shows the result from FEMA damage category of the responses located within Sea Bright and the cumulative value for the area is 0.93, so it is very close to 'affected'.

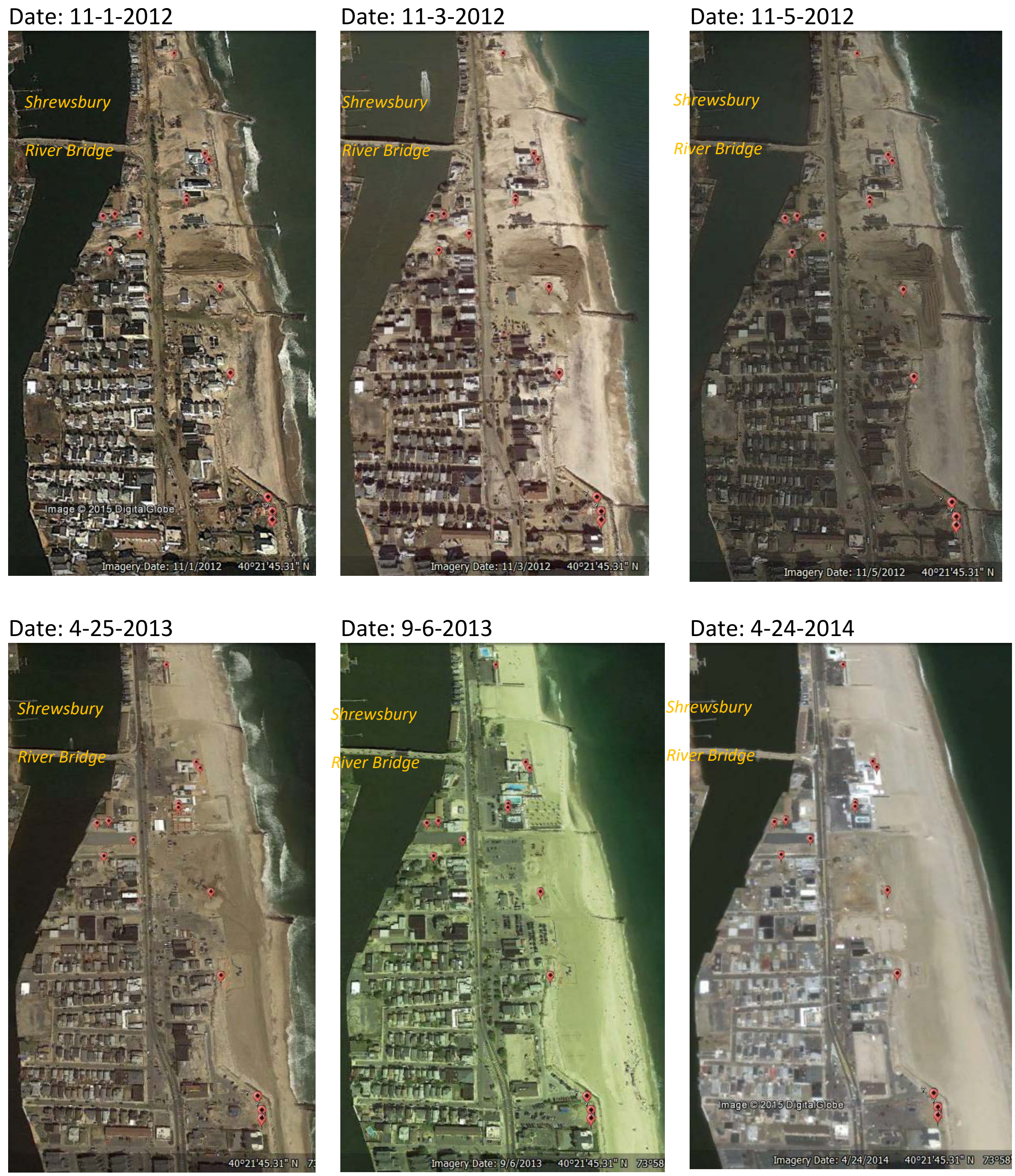

Figure 14: Google Earth images in several time to visually detect land use changes in destroyed plots.

The value according to the damage category specified by the residents who responded in the questionnaire is shown in Table 10. Here also the result shows very close proximity to 'not very extensive damage' of the entire community.

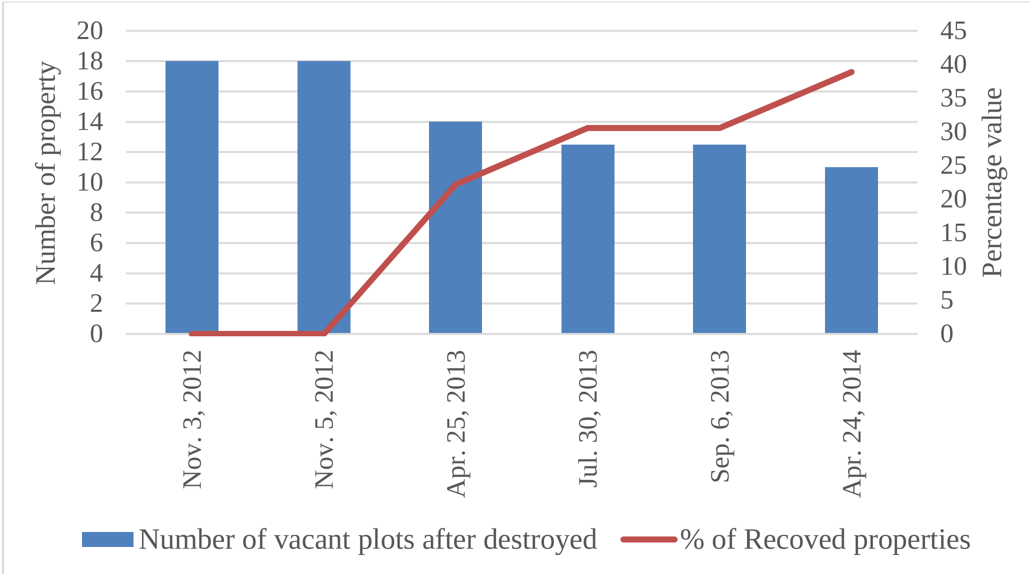

Figure 15: Recovery progress (%) of the destroyed property with their status (vacant) in different time period in Sea Bright after Hurricane Sandy.

Table 9: Quantifying repair of the damaged property to estimate the recovery level of the study area.

FEMA damage record	**No of Damaged property**	**Repair not complete**	**Scale**	**Value of properties = (No of Property still need repair with specific damage x Weight) / Total damaged property**
Affected	22	7	1	0.04
Minor	86	24	2	0.27
Major	69	35	3	0.58
Destroyed	3	2	4	0.04
Total	180	68		0.93

Table 10: Value recovery considering the repairing and damage recorded in August 2014 questionnaire.

Extensive damage to home	**No of Damaged property**	**Repair not complete**	**Scale**	**Impact**
Not very Extensive	73	29	1	0.104
Somewhat Extensive	113	23	2.5	0.206
Very Extensive	93	41	4	0.588
Total	279	109		0.898

Figure 16 shows schematically the position of the weighted recovery level considering FEMA damage category and survey responses classification of damage. The responses related to repair completed or repair not completed has been weighted to find out the status of the area as a whole. It is seen from the weighted result in Figure 16 that whole area is very close to 'affected'. It is assumed that when the value reaches '0' it can be said that the recovery is done for the moment considering the structural damage in the area.

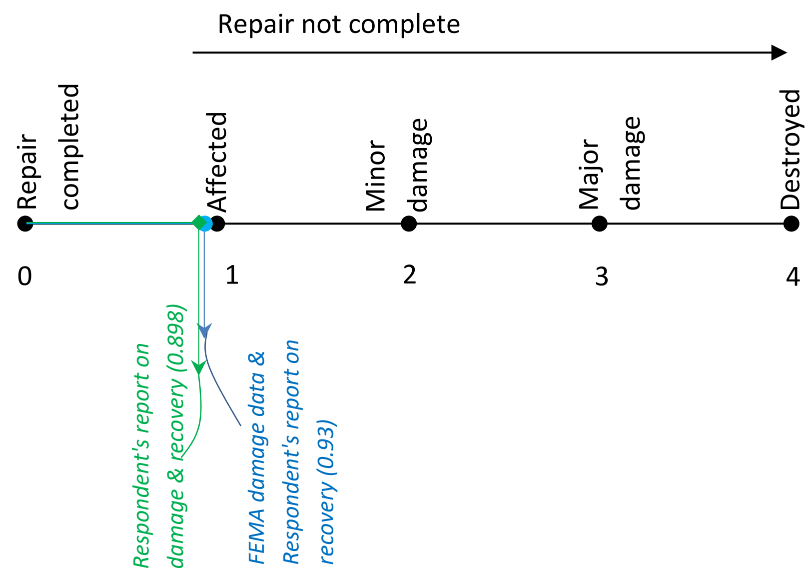

Figure 16: Schematic diagram showing the weighted recovery from different data sources

This analysis was repeated using the results of the December 2015 survey as shown in Table 11. Given the consistency between this measure and the alternative measures shown in Figure 7 and Figure 16, the analysis suggests that the survey data is a reasonable representation of recovery. Data on percentage damaged homes rebuilt or repaired are shown in Table 12 and plotted in Figure 17. The trajectory show that the rate of recovery has slowed after June 2014.

Table 11: Value recovery considering the repairing and damage recorded in December 2015 questionnaire.

Extensive damage to home	**No of Damaged property**	**Repair not complete**	**Scale**	**Impact**
Not very Extensive	41	2	1	0.014
Somewhat Extensive	53	8	2.5	0.142
Very Extensive	47	4	4	0.113
Total	141	14		0.270

Table 12: Recovery Timeline

Date	% of Damaged Homes Repaired or Rebuilt
Nov-12	0
Aug-14	60.9
Dec-15	90.1

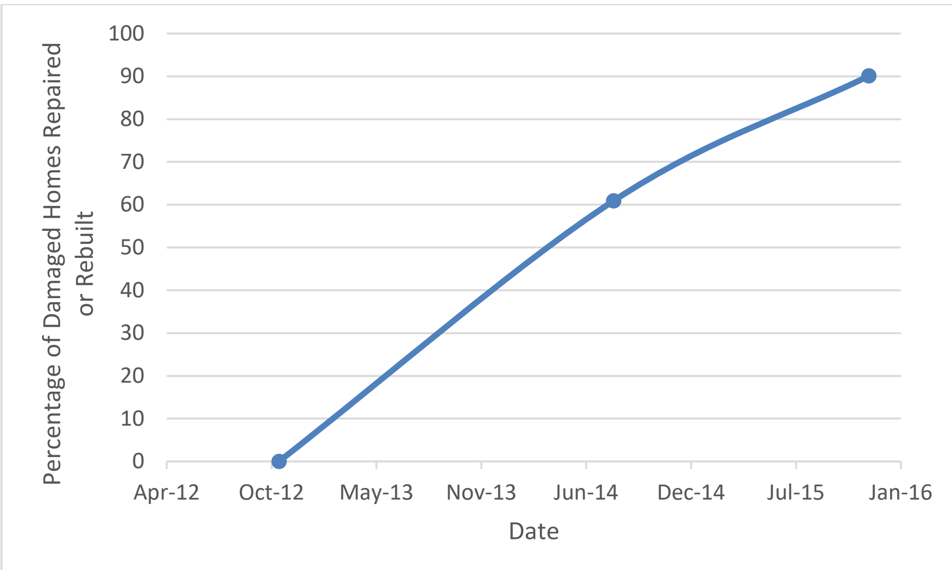

Figure 17: Recovery Trajectory

Discussion

This section summarizes the major findings from analysis presented in the above subsections. From data analysis it is found that the results are almost identical whether only 180 responses with postal address within Sea Bright are considered or all of the responses related to Hurricane Sandy are counted. Also, the FEMA-MOTF data are consistent with the results found from survey data. The findings show the entire locality of Sea Bright has gone through minor to major damage as seen from average damage score based on a scale for specific damage categories. However, considering the weighted value of recovery, the present condition of the area in 2014 is found to be in 'affected' level based on FEMA damage data and survey responses on repair. While comparing this value with respondent's damage category, the recovery of the study area is in 'not very extensive' damage level. One more step will move the community to full recovery considering the structural damage and repair completion. The survey data gives good results but the response size is small. It would have been better if more responses were obtained.

In contrast, the visual interpretation of satellite and airborne imagery shows very slow recovery progress in the completely destroyed plots. Only 39% of the destroyed sites have recovered regarding redevelopment of the property up to April, 2014. Therefore, the more severe the damage, the more challenging is the recovery. Again, many of the major damaged plots and some of minor damaged and affected plots show as rebuilt starting approximately from mid-year of 2013 and such scenario is increasing significantly as identified by visual inspection of images. This indicates that the recovery process is going on and the recovery level of a community can be changed depending on the future condition of the area. The south part shows more damage as found using kernel density analysis of damage cost and also shows slower recovery than the north part of Sea Bright as found through analyzing data till 2014. So, it is important to capture the time line in estimating the recovery level.

It is tough to handle a number of different types of data with several dimensions. The study struggled a lot in data management and processing before running analysis. LiDAR data needs intense processing before use. For the time being only the surface model is created using LiDAR data to identify damage in loss or gain through change detection in elevation.

Finally, it is learned from this research that assessing recovery is a difficult task to do considering the different kinds of data with different measurement units, such as households versus structures.

CONCLUSIONS

There has been limited research and literature that defines the demand for transportation assets and connects this concept to data reflecting recovery after a disaster. The term recovery embraces many dimensions including the physical, social, economic, natural, cultural aspects of the impacted region along with the psychological recovery of the affected people. Targeted research can be done on each aspect of recovery, but even detailed study can cover a small part within the major sectors. This research contributes to the field of disaster recovery by considering the patters of damage and recovery of physical housing properties in a disaster affected area.

The research presents a data driven conceptual framework for assessment of post disaster damage and housing recovery and shows an example of how damage and recovery can be measured within a specific geographic boundary. Several dynamic data sets, ranging from a mail-based survey of residents to geospatial information, are used to fulfill the objective of assessing long term housing recovery over time. Combinations of data from different sources results in a more comprehensive assessment of damages and recovery over time.

Recovery progress can be tracked over time starting just after the disaster impacts an area. The study develops a standard methodology, or standard format, to be followed in tracking the progress of housing recovery. Time series analysis of an area incorporating several types of information from different data sources is most challenging but comes up with more effective results in analysis. These multilayered data sets add complexity to the analysis. Therefore, it is difficult to manage the different patterns, and resolutions of data from different sources and unite them to generate new knowledge using appropriate methods and techniques in data processing and analysis drawn from remote sensing, image processing, and geospatial data analysis.

In this research four main types of data have been compiled and compared to understand the housing recovery over time. The data mapping followed the same projection system to ensure overlying and comparing data to each other represented the same location in the ArcGIS software. From the large data set of FEMA-MOTF Hurricane Sandy impact data the subset for Sea Bright area was separated. Similarly, in the case of the LiDAR data and aerial images the part of study area was extracted following its geographic boundary. The mail survey data processing consumed more time to geocode and locate the respective response location in the field, incorporating the information from the resident's response and merge these data with geospatial information for further interpretation. In the case of the LiDAR data the status of the point clouds with point spacing, x, y, z values with maximum, minimum and averages were checked to determine the resolution to create surface models representing pre and post Sandy conditions. A trial and error method was applied to find out the most representative outcomes with 1m, 2m and 3m resolution digital surface models. Later the minus tool in ArcGIS and change detection tool in Quick Terrain Modeler was used to identify damaged areas having loss or gain in elevation due to Hurricane Sandy impact. For visual interpretation of aerial images with the same projection in different time periods, it took more time to focus and concentrate carefully with zooming in as much as possible until it gets distorted and thus finding out the areas with land use change and then digitize those locations. Finally using several data from different times, the research identifies the location on maps where damage happened. It also compares the condition of the site in subsequent time periods to outline the area going through the process of recovery and map the progress of recovery. Locations experiencing slow or rapid recovery can be identified and mapped.

The results can help concerned organizations to focus more on specific locations and plan to help the residents to speed up recovery. More attention should be given to those areas experiencing slow recovery, so that the victims can have more support in improving their condition. The findings from this study can also help policy makers to focus more on the areas with differential progress in reconstruction, rebuilding, and repairing of houses and take necessary actions to overcome the problem associated with the situation. This may include accelerating infrastructure repair.

Images are used for visual analysis of damage in the area. These images also help decision makers understand the situation in the field without physically travelling the site. Using the geospatial technologies, the framework developed in this thesis and available information, the decision makers can identify the damaged sites and locations where something is going wrong, or where the process is facing slow progress, or where recovery has completed. Armed with such tools and information, they can revise plans considering existing situation and also pre-plan the recovery work.

Challenges

Like many research studies the available data and resources presented some limitations to the research. To better understand the applicability of the results of this research, this section reviews some of these limitations which include the following:

- The lack of formal definitions of damage and recovery
- The small sample size
- Ambiguities in the survey questions and responses
- Missing or unavailable data, and
- A focus on quantitative data rather than qualitative information.

The literature on disaster recovery lacks specific criteria or guidelines to define a state or position or condition in the impacted area, as well as its residents, that can be used to declare the area as recovered from the past disaster. Also, there is no universal measurement scale to declare an area to be fully recovered. In this study, considering the physical structures and housing condition, when the damaged property returns back in previous status after repair is completed or the destroyed property is occupied again, it is assumed that the property has recovered. Many other factors could be considered in modeling housing recovery. Here the survey responses from residents is the main input to assess the level of recovery. That is, if the respondent said repair is completed then that property is considered to be recovered.

In Sea Bright, only 180 responses with their postal addresses in Sea Bright could be located through geocoding. Other responses are from the same locality but could not be geocoded because the mail addresses were located outside the area. While geocoding some addresses did not match the exact location, for example, the residence was placed on a road or outside the boundary line for the township, so an approximate location within a nearby plot is assumed for those points. Thus, in case of visual representation of the scenario in GIS maps only the responses (180) from identified locations are used for further analysis using geospatial technologies. Furthermore, the responses (303) to the mail-based survey is very small compared with the overall number of houses in Sea Bright. Again, there are also some inconsistencies in the survey responses, for example, four respondents said no damage to their house but later they reported repair complete or repair not complete. If there is no damage there should not be any response regarding the question of repair completion. Similarly, the question asking the respondents to classify the level of damage to their homes was ambiguous. There was no specific guidance given respondents to define unique response categories: not very extensive, somewhat extensive and very extensive damage. So, the result depends on people's perception on how much damage they feel Hurricane Sandy caused to their homes.

Data limitations also hindered the time series analysis in many ways. For example, the building permit data is important for effective measurement of housing recovery and in combination of remote sensing analysis, it can show a more complete picture of recovery. While New Jersey has a standard building permit format and the data is intended to be publicly available, building permits for Sea Bright Hurricane Sandy were not available for use in this study. In the case of the LiDAR data, the LiDAR data collected immediately after Hurricane Sandy in 2012 is the only publicly available data. More recent data, is not accessible and achievable for free. If recent LiDAR data as well as that for the time between now and Hurricane Sandy could be assembled that could provide more detailed information to make comparisons and assess changes over time. In addition, the LiDAR data downloaded from NOAA are unclassified and includes only first return points with elevation data. It could not be used intensively for analysis as classified data can produce more details related to the study. Though LiDAR data and remote sensing images are a rich source of data these data require intense processing to produce useful outputs.

Sea Bright is a very small borough. The borough covers two census blocks that are merged in one census tract with other areas. Therefore, significant demographic information was not available to be used in parallel with the damage and recovery scenarios to better understand the findings from this research.

The research demonstrates several methods for tracking the quantitative assessment of housing recovery that in turn are important for tracking and justifying investments in transportation infrastructure. In practice, transportation planning and analysis occurs at a regional level, encompassing more than just one or two municipalities. This study only examined one very small area.

Furthermore, the research covered a limited time period. There are further opportunities to develop time series analysis with more recent data to both understand how to leverage this data and document the recovery process.

Summary

This research developed a comprehensive assessment of post disaster housing recovery that reflects changes over time. The measure used data from FEMA, a mail-based survey of households, aerial images and LiDAR data to assess recovery from Hurricane Sandy in Sea Bright, New Jersey. Data was geocoded to reflect the specific locations. Using the geocoded data, GIS analysis was used to present maps and summary data.

Throughout Sea Bright the “average damage status” immediately after Sandy was found to be between minor and major damage based on a qualitative scale of not affected, slightly affected, minor damage, major damage, and destroyed. Using the survey data from August 2014, the “average damage status” is slightly affected suggesting significant recovery. The survey data from December 2015 show further recovery. However, further analysis suggested that the rate of recovery of destroyed properties is not as great. Spatial analysis of the data suggested that there are no discernible differences in recovery rates throughout the borough. Interestingly the latest aerial imagery of 2014 shows some affected and major or minor damaged plots started rebuilding after two and half years of the event. It represents that the areas are still recovering concerning the physical features.

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Appendix A. COMMUNITY PROFILE

The following is the community profile of the study area, Sea Bright Borough, NJ according to Census 2010, American Community Survey 2011.

Population:

Total Population: 1,412; Male: 729 (51.63%); Female: 683 (48.37%)

Housing Status:

Total Housing Unit: 1,211

Occupied: 792 (65.40%)

Owner-occupied: 433 (35.76%)

Households with individuals under 18: 106 (8.75%)

Vacant: 419 (34.60%)

Vacant for rent: 67 (5.53%)

Vacant for sale: 12 (0.99%)

a) Population by Age:

Age group	Number	Percent
Under 18	160	11.33
18 & over	1,252	88.67
20 – 24	58	4.11
25 – 34	212	15.01
35 – 49	361	25.57
50 – 64	400	28.33
65 & over	205	14.52

b) Population by Race:

Race	Number	Percent
White	1,335	94.55
African American	11	0.78
Asian	32	2.27
American Indian and Alaska Naïve	0	0
Native Hawaiian and Pacific Islander	0	0
Other	21	1.49
Identified by two or more	13	0.92

c) Educational Attainment:

Education	Number	Percent
Less than 9th grade	10	0.90
9th to 12th grade, no diploma	7	0.60
High school graduate (includes equivalency)	182	16.50
Some college, no degree	245	22.30
Associate's degree	69	6.30
Bachelor's degree	386	35.10
Graduate or professional degree	202	18.30
Total	1,101	100

d) Income:

Median household income*: 78,550; Mean household income*: 139,847

Household Income*	Number	Percent
Less than $10,000	6	1.80
$10,000 to $14,999	4	1.20
$15,000 to $24,999	14	4.30
$25,000 to $34,999	11	3.40
$35,000 to $49,999	24	7.40
$50,000 to $74,999	27	8.30
$75,000 to $99,999	96	29.50
$100,000 to $149,999	36	11.10
$150,000 to $199,999	30	9.20
$200,000 or more	77	23.70
Total	325	99.90

* Data from American Community Survey 2011

Income in 2011 inflation-adjusted dollars

Due to size constraints, a census tract was not used for Sea Bright Borough, NJ.

Appendix B. FEMA-MOTF Damage Criteria

Detail criteria of damage classification used in FEMA-MOTF data (FEMA-MOTF, 2014 p.5):

FEMA DAMAGE CLASSIFICATION		VISIBLE IMAGERY BASED CLASSIFICATION				INUNDATION ASSESSMENTS
DAMAGE LEVEL	OBSERVED DAMAGE	Roof Covering	Roof Diaphragm	Collapsed Walls	Other Consideration	
Affected	Generally superficial damage to solid structures (loss of tiles or roof shingles); some mobile homes and light structures damaged or displaced	Up to 20%	None	None	Gutters and/or awning; loss of vinyl or metal siding	Field Verified Flood Depth (or Storm Surge): > 0 to 2 feet relative to the ground surface at structure. Depth damage relationships may vary based on building or foundation type, as well as duration or velocity of flood event.
Minor	Solid structures sustain exterior damage (e.g., missing roofs or roof segments); some mobile homes and light structures are destroyed, many are damaged or displaced.	>20%	Up to 20%	None	Collapse of chimney; garage doors collapse inward; failure of porch or carport Mobile homes could be partially off foundation	Field Verified Flood Depth (or Storm Surge): 2 to 5 feet relative to the ground surface at structure. Depth damage relationships may vary based on building or foundation type, as well as duration or velocity of flood event.
Major	Wind: Some solid structures are destroyed; most sustain exterior and interior damage (roofs missing, interior walls exposed); most mobile homes and light structures are destroyed		> 20%	Some exterior walls are collapsed.	Mobile home could be completely off foundation – if appears to be repairable.	Field Verified Flood Depth: Greater than 5 feet, modeling observed, relative to the ground surface at structure, and not high-rise construction. Depth damage relationships may vary based on building or foundation type, as well as duration or velocity of flood event.
	Storm Surge: Extensive structural damage and/or partial collapse due to surge effects. Partial collapse of exterior bearing walls.			Some exterior walls are collapsed.		Major is the general category where the onset of Substantial Damage (>50% of building value) as defined by the national Flood Insurance Program (NFIP) may occur.

Destroyed	Wind: Most solid and all light or mobile home structures destroyed.			Majority of the exterior walls are collapsed.		
	Storm Surge: The structure has been completely destroyed or washed away by surge effects.			Majority of the exterior walls are collapsed.		