NIST Investigation Update

Hurricane Maria's Impacts on Puerto Rico

July 2025

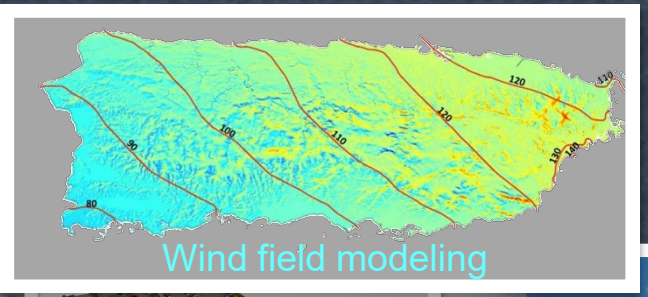
Joseph Main
Lead Investigator

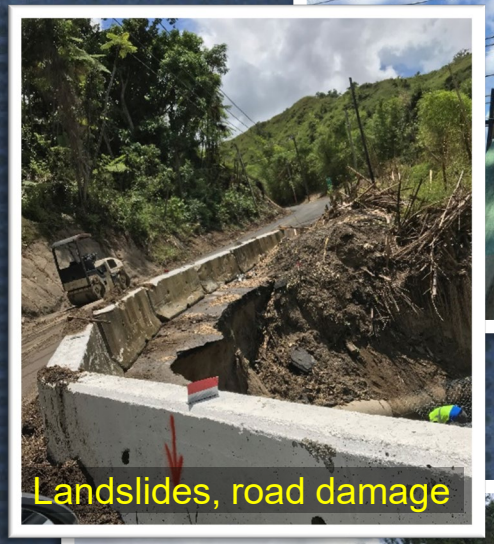
Maria Dillard
Associate Lead Investigator

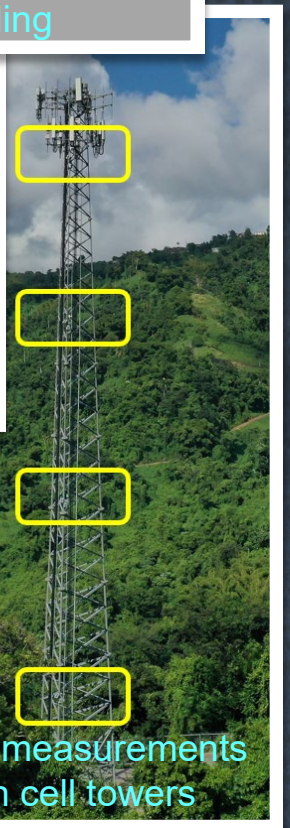
NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. DEPARTMENT OF COMMERCE

NIST Hurricane Maria Investigation

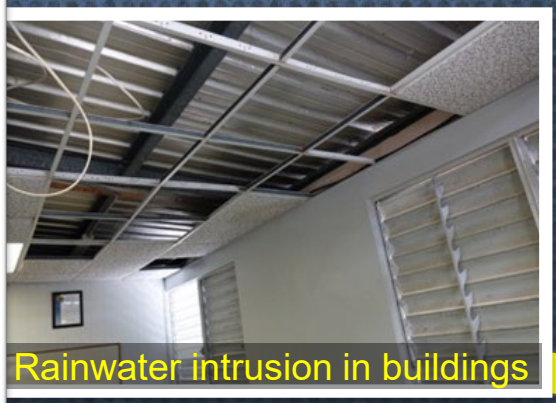
Event Impacts







Recommendations



Investigation

1 Program Overview

2 Investigation Timeline

3 Data Collection & Analysis

4 Preliminary Findings

5 Anticipated Impacts

NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
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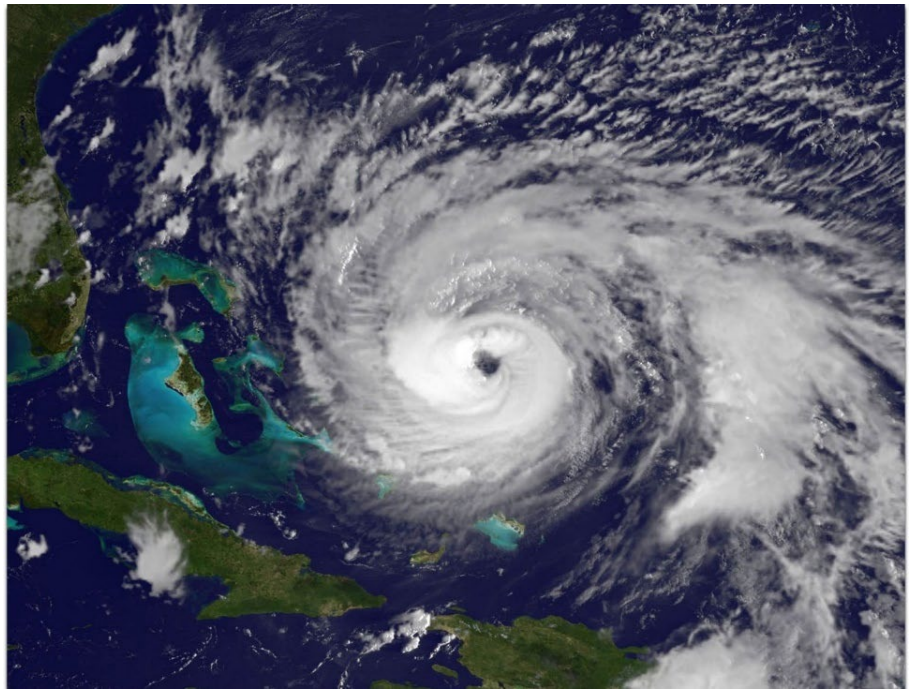
1 Program Overview

1 NIST Hurricane Maria Program

- **NIST is studying** Hurricane Maria's effects on Puerto Rico and subsequent recovery
- **Goal:** Recommend improved building codes, standards, and practices to help communities in Puerto Rico and across the U.S. to be more resilient
- Launched February 2018; authorized by:
  - National Construction Safety Team Act
  - National Windstorm Impact Reduction Act



Credit: NOAA

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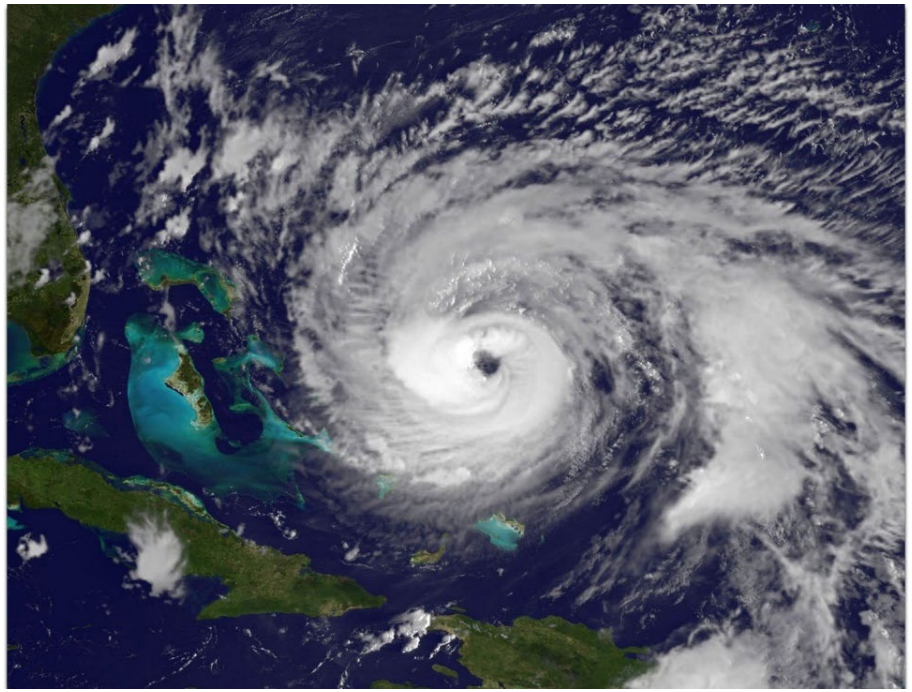

Credit: NOAA

NCST Act (Public Law 107-231): Authorizes NIST to establish investigative teams *"to assess building performance and emergency response and evacuation procedures in the wake of any building failure that has resulted in substantial loss of life or that posed significant potential of substantial loss of life."*

NIST Hurricane Maria Program

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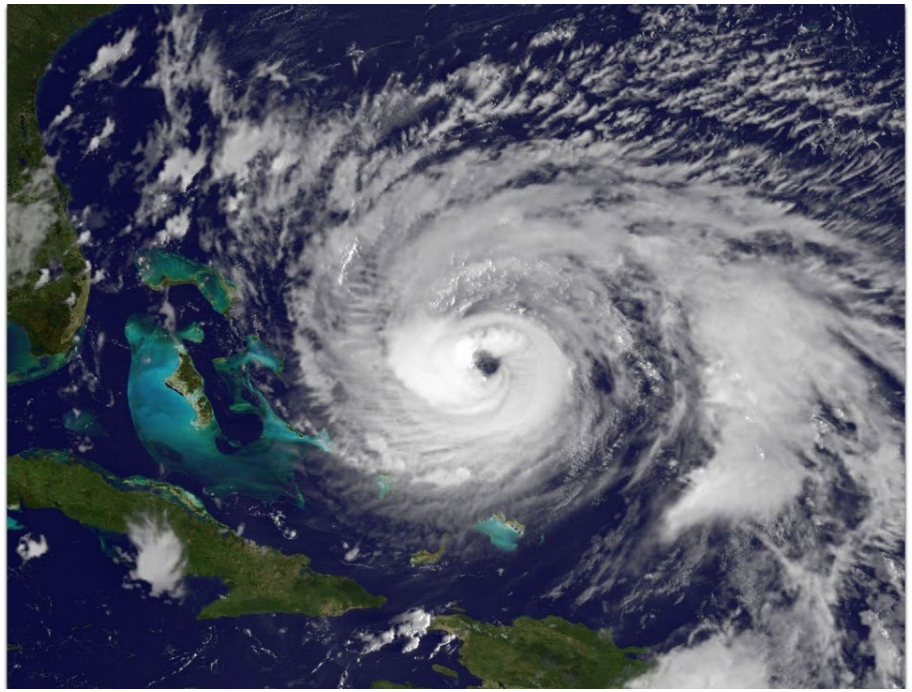
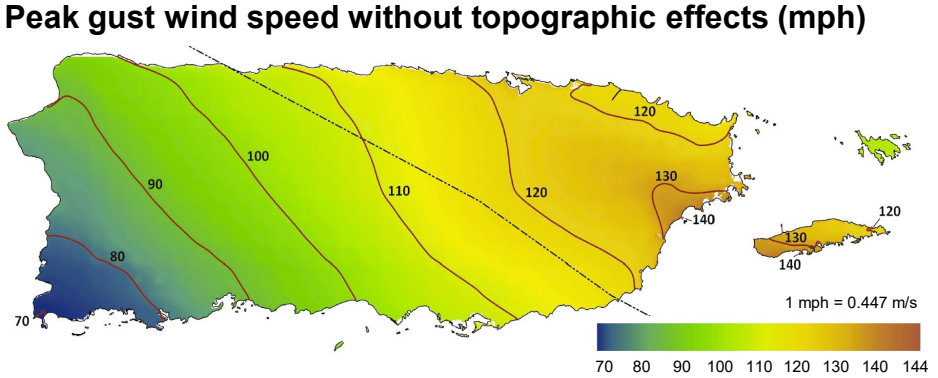


Credit: NOAA

NWIR Act (Public Law 114-52): Designates NIST as lead agency for National Windstorm Impact Reduction Program (NWIRP) and gives NIST responsibility for "*carrying out research and development to improve model building codes, voluntary standards, and best practices for the design, construction, and retrofit of buildings, structures, and lifelines*" with the purpose of achieving "*measurable reductions in the losses of life and property from windstorms*."

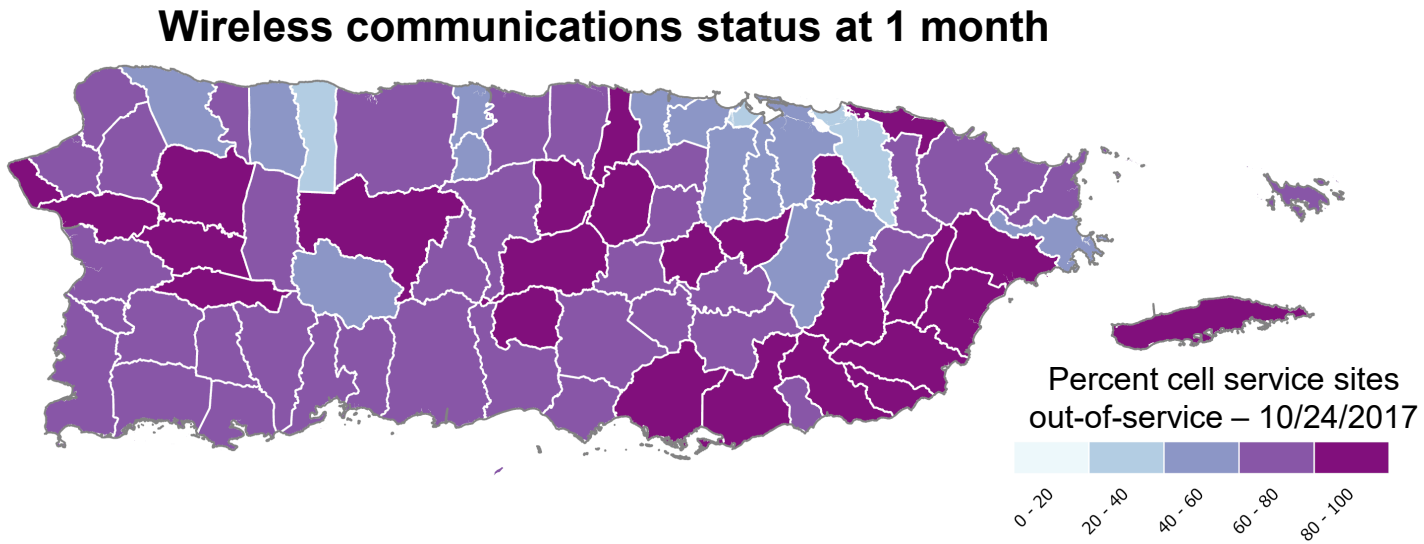
1 Hurricane Maria's Impacts on Puerto Rico

- **Hazard Exposure:** Strong Category 4 hurricane, peak gusts near 140 mph (greater with topographic speedup), over 30" rain, extensive flooding, landslides
- **Exposed Population:** Entire Commonwealth (~3.3M people)
- **Mortality:** Challenges attributing hurricane-related deaths; excess mortality est: 2,975
- **Engineered Buildings:** Extensive nonstructural damage, rainwater intrusion, loss of function
- **Emergency Response:** Challenges with rescues in flooded areas, complicated by loss of communications for extended periods



1 Impacts on Infrastructure and Recovery

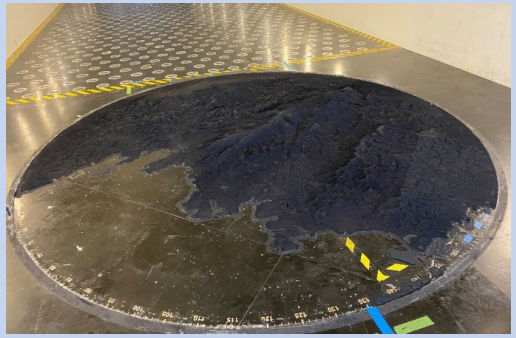
- **Infrastructure Systems:** Severe physical damage and complete/near complete loss of function for electrical and communications systems presented emergency response and recovery challenges
- **Education, Healthcare and Businesses:** Impacts on recovery due to power loss, non-structural building damage, generator failures, road closures



1 Hurricane Maria Projects

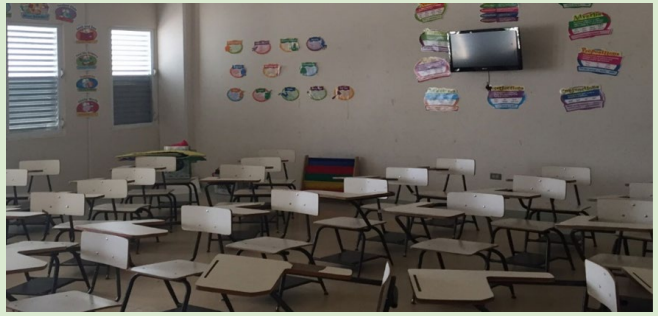
National Construction Safety Team (NCST) Technical Investigation

Hazard Characterization	Performance of Critical Buildings	Public Response to Emergency Communications	Morbidity & Mortality



National Windstorm Impact Reduction Program (NWIRP) Research Study

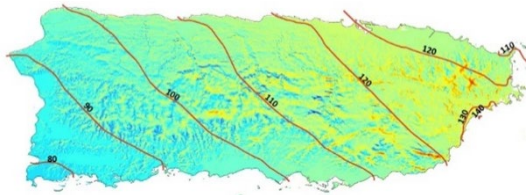
Recovery of Business & Supply Chains	Recovery of Social Functions	Impacts to & Recovery of Infrastructure Systems



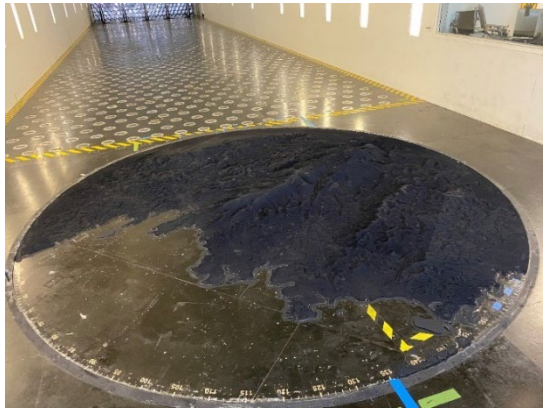
1 NIST Hurricane Maria Team

1 Supporting Contracts

Contract
Wind Field Modeling
Wind Tunnel Testing and Field Measurement of Winds
Engineering Services to Evaluate Critical Building Performance
Social Science Data Collection
Morbidity and Mortality Assessment



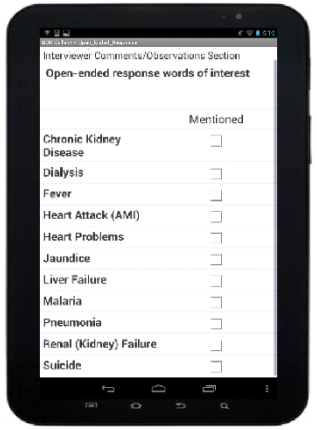
Applied Research Associates



University of Florida

Stantec Consulting

Horsley Witten Group



Source: Bernardo Hernández Prado

GW/UPR*

*George Washington University / University of Puerto Rico

1 Collaborating & Coordinating Agencies

Federal

Federal Emergency Management Agency
NOAA's National Weather Service
U.S. Army Corps of Engineers
U.S. Geological Survey
Small Business Administration
Dept of Health & Human Services

Puerto Rico

Depts of Education, Health, Housing, Transportation & Public Works, Economic Development & Commerce
PR Ports Authority, PR Energy and Power Authority
PR Aqueduct & Sewer Authority, Emergency Management
Central Office for Recovery, Reconstruction & Resiliency
Municipalities, universities, businesses, nonprofits
Governor's Federal Affairs Administration
Resident Commissioner's Office

Collaborate
Coordinate
Cooperate

NIST Engineering Laboratory

Disaster & Failure Studies Program
Community Resilience Group
Structures Group
Earthquake Engineering Group
Applied Economics Office
Data, Security, Technology Group

Other NIST Units

Public Affairs Office
Office of Chief Counsel
Congressional & Legislative Affairs
Program Coordination
Management & Organization
Acquisition & Agreements Mgt
Statistical Engineering Division of ITL
Research Protections

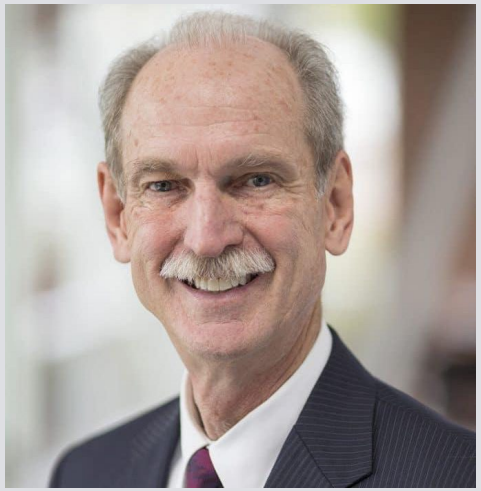
1 NCST Advisory Committee

www.nist.gov/disaster-failure-studies/national-construction-safety-team-ncst/advisory-committee-members

- Advises NIST on investigations under the NCST Act
- Reports annually to Congress to provide:
  - Evaluation of NCST activities
  - Assessment of implementation of recommendations

José Izquierdo-Encarnación (Chair)

Kimberly Shoaf

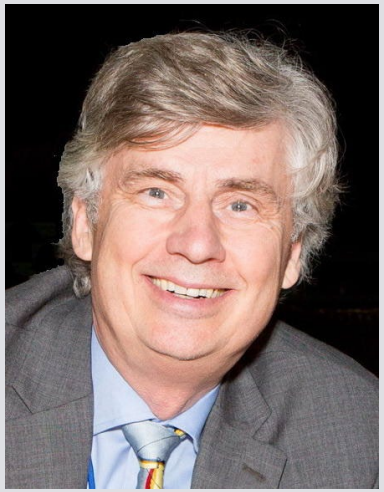


Donald Dusenberry

Lori Peek

Kurtis Gurley

Aspasia Zerva

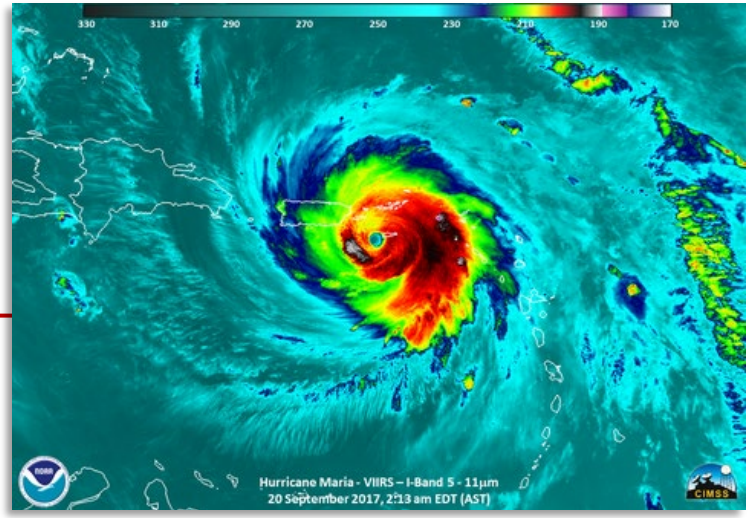


John Osteraas

2 Investigation Timeline

2 Investigation Timeline

Sep: Hurricane Maria made landfall in PR
Dec: Preliminary reconnaissance



2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

Feb: NCST Team established
May: Investigation plans presented to NCSTAC
Aug: Windshield survey across Puerto Rico

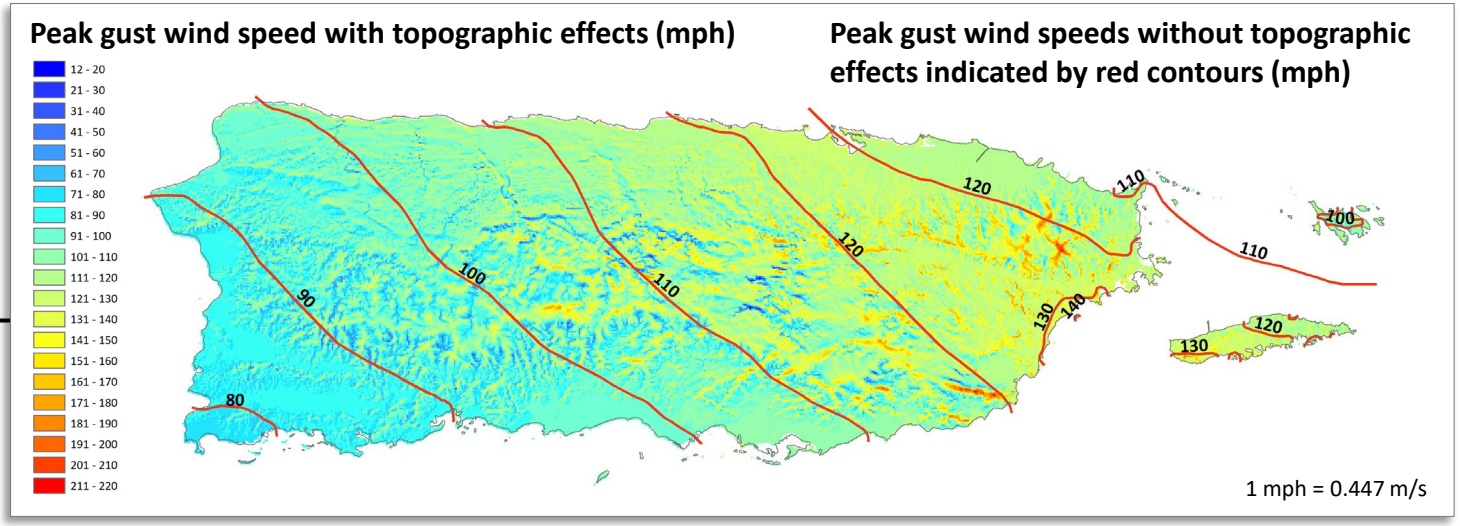
2 Investigation Timeline

Feb-May: ARA and UF contracts awarded for wind hazard characterization

Jul: Initial wind-field model developed

Oct-Nov: Stakeholder outreach in PR

Dec: Earthquake swarm began

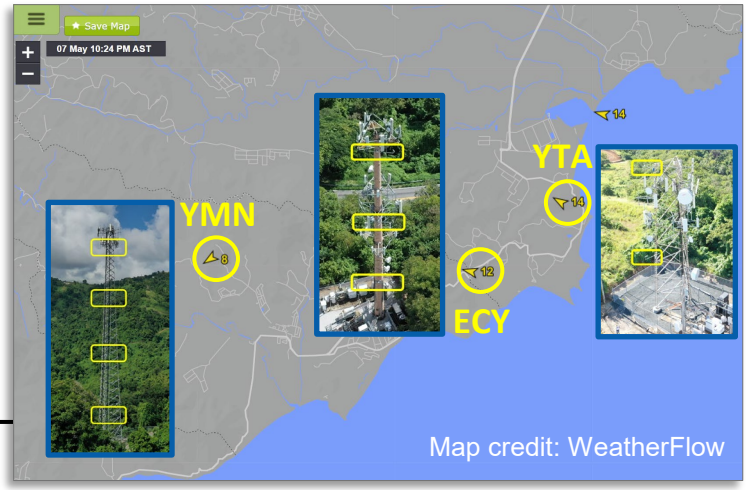


2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

Jan-Jul: HW, Stantec, GW contracts awarded for data collection in Puerto Rico

Mar: Start of COVID-19 lockdown

Oct: Anemometers installed on cell towers in Yabucoa



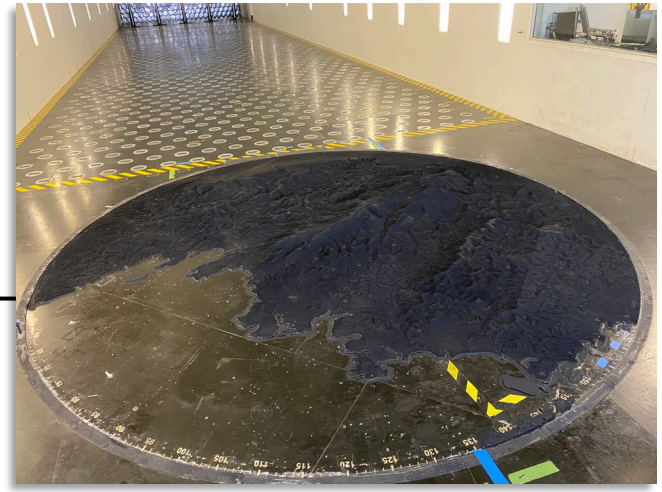
2 Investigation Timeline

Jan: Progress Report published

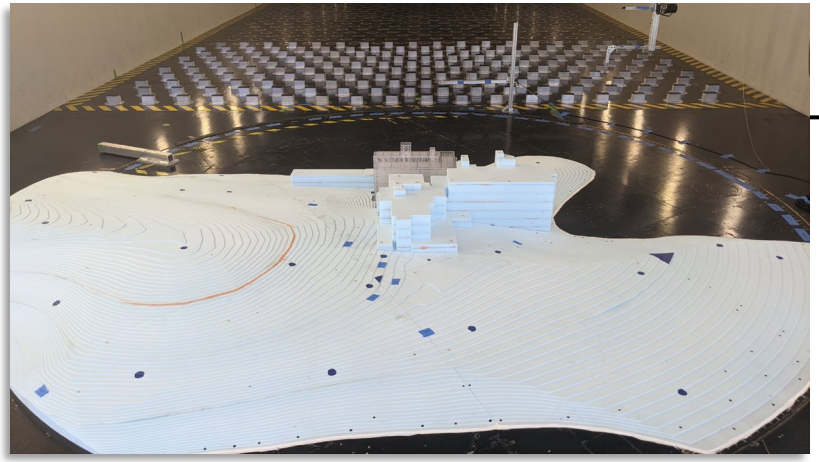
Feb: Drone photogrammetry of selected hospitals

Mar: Wind tunnel testing of topographic models

Jul: Emergency information provider interviews



2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026



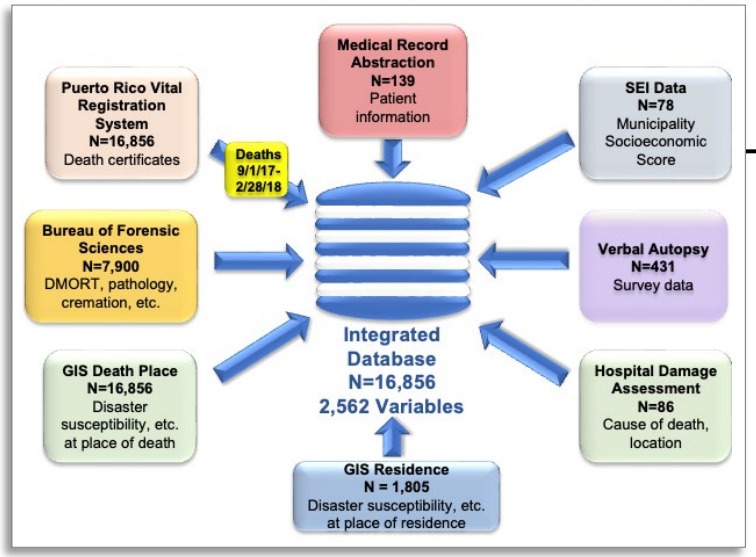
May: Business surveys

Jun: Wind tunnel testing of selected hospitals

Sep: Hurricane Fiona impacts PR

Sep-Nov: Next of kin interviews; **household surveys and interviews on emergency communications**

2 Investigation Timeline

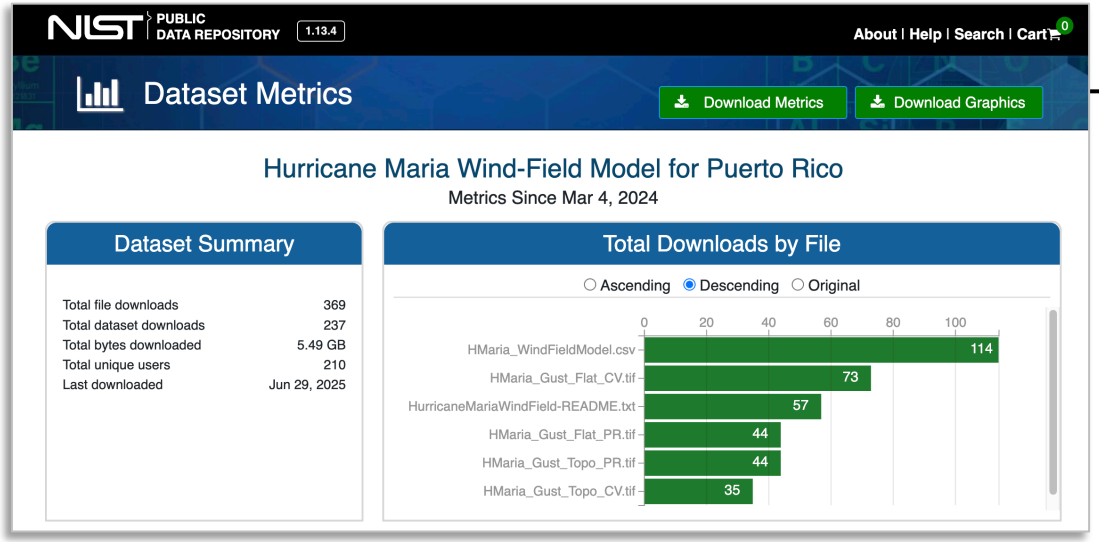


- **Mar: Integrated mortality database completed**

  Apr-Jul: School and hospital surveys, hospital functionality interviews, hospital and shelter building evaluations, shipping and transport interviews completed

  Sep: NCST data collection completed

2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026



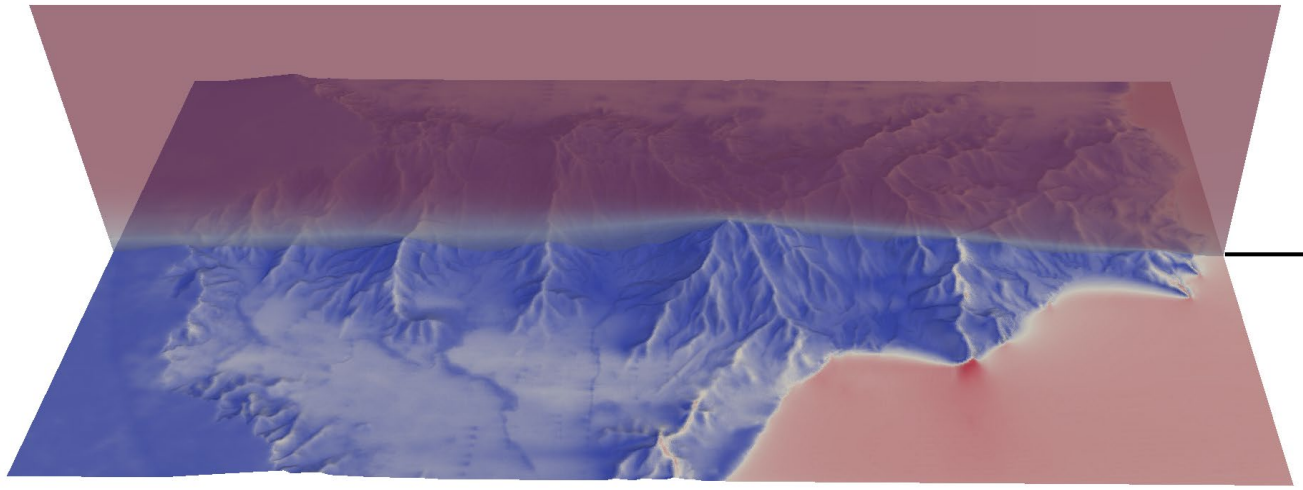
- **Mar: Wind field model dataset published**

  Mar-Jul: Contractor draft reports delivered for various data collection efforts

  Aug: Tropical Storm Ernesto impacts PR

  Nov: NWIRP data collection completed

2 Investigation Timeline



Feb: Refinement of findings across projects

Jun: Integration of wind-field model with wind tunnel data to evaluate wind loads on buildings

Jun: CFD simulations on effects of topography and forest canopy on winds

Jul: Project reports in review

Sep: NCSTAC Meeting (planned)

2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026

Anticipated:
Investigation results released

3

Data Collection & Analysis

3 Disclaimers

⚠ IMPORTANT: ALL DATA AND ANALYSES ARE PRELIMINARY

- This presentation describes preliminary data gathered to date as well as preliminary analyses of these data. These are subject to change.
- Once all data are finalized and analyzed, they will inform a broader understanding of Hurricane Maria's effects on Puerto Rico and subsequent recovery – and NIST's findings and recommendations.
- This presentation does not constitute NIST findings or recommendations.
- All survey and interview data collection included a consent process that specifies the allowable uses of data and protections of respondents.
- Copyrighted content (such as photographs) in this presentation is used with permission; reproduction, redistribution or reuse may require copyright holder permission, including for content with anonymous attribution/credit.

NCST Data Collection: Completed Sep 2023

Hazard Characterization

- Wind Tunnel Testing of Topographic Models ✓
- Meteorological Data for Wind Field Model ✓
- Field Measurements of Winds on Cell Towers (2 years) ✓
- Data on rainfall, storm surge, flooding and landslides ✓

Public Response to Emergency Communications

- Information Provider Interviews ✓
- Household Surveys ✓
- Public Messages for Qualitative Content Analysis ✓
- Household Interviews ✓

Performance of Critical Buildings

Facility Evaluations: 5 hospitals, 5 shelters

- Phase 1: Document collection & review ✓
- Phase 2: Site visits & interviews ✓

- Wind Tunnel Testing of Two Hospitals ✓

Morbidity & Mortality

- Verbal Autopsy and Social Environmental Survey ✓
- Integrated Database of Deaths in Puerto Rico ✓
- Medical Records and Hospital Functions Review ✓
- Spatial and Temporal Data for Analysis of Deaths ✓

3 NWIRP Data Collection: Completed Nov 2024

Recovery of Social Functions

- Wave 1 School and Hospital Surveys ✓
- Wave 2 School and Hospital Surveys ✓
- Interviews with School and Hospital Administrators ✓

Recovery of Business and Supply Chains

- Interviews of Shipping and Transportation Representatives ✓
- Surveys of Small and Medium-Sized Manufacturers and Retail/Service Businesses ✓

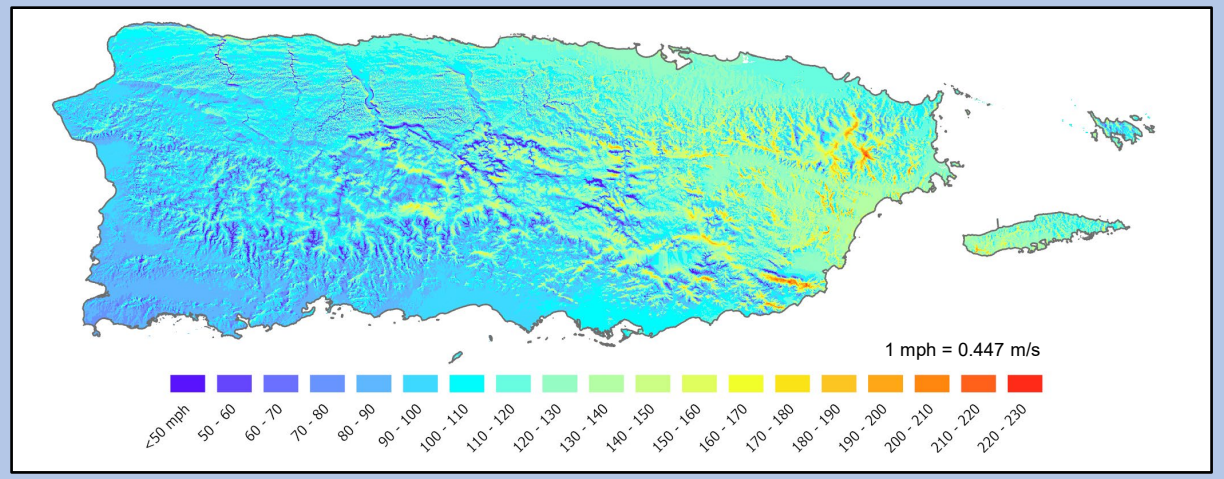
Impacts to and Recovery of Infrastructure Systems

- Satellite Remote-Sensing Data on Tree Canopy Cover ✓
- Structured Interviews on Infrastructure Dependencies ✓
- Aerial Imagery of Cell Towers ✓
- Transportation Incident Database ✓

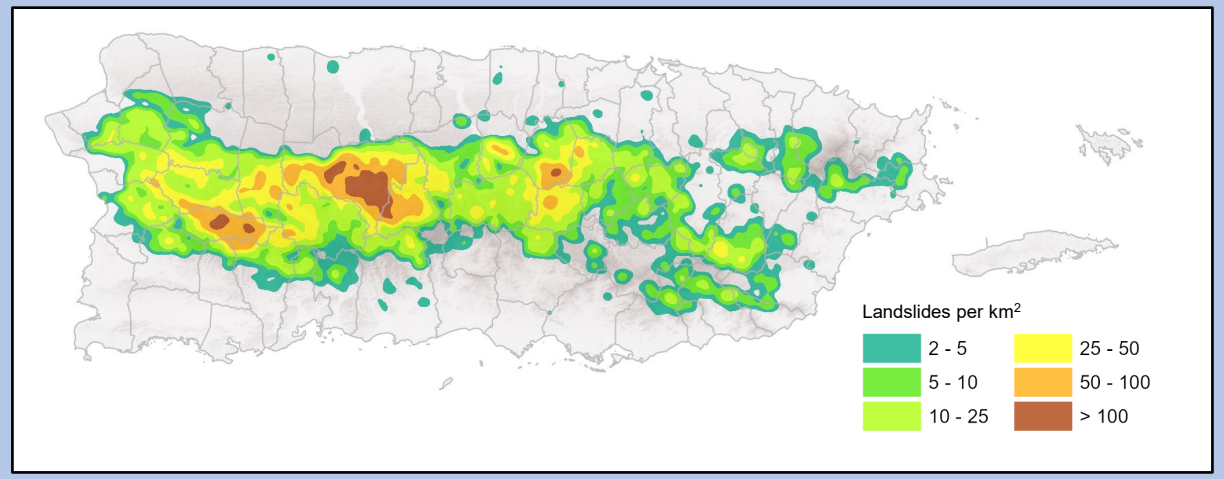
3 What were the hazards, and how severe were they across Puerto Rico?

Hazard Characterization

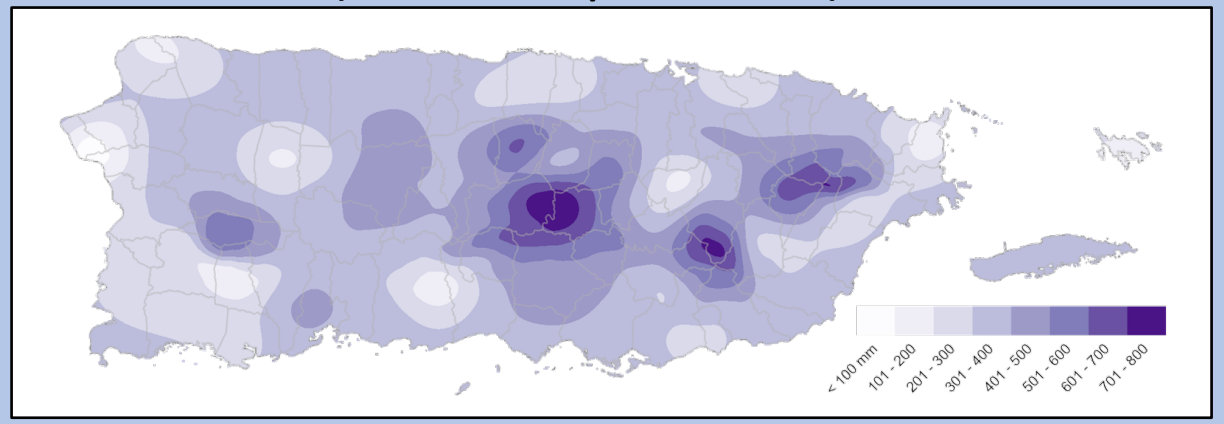
Peak gust wind speed with topographic effects (NIST wind-field model)



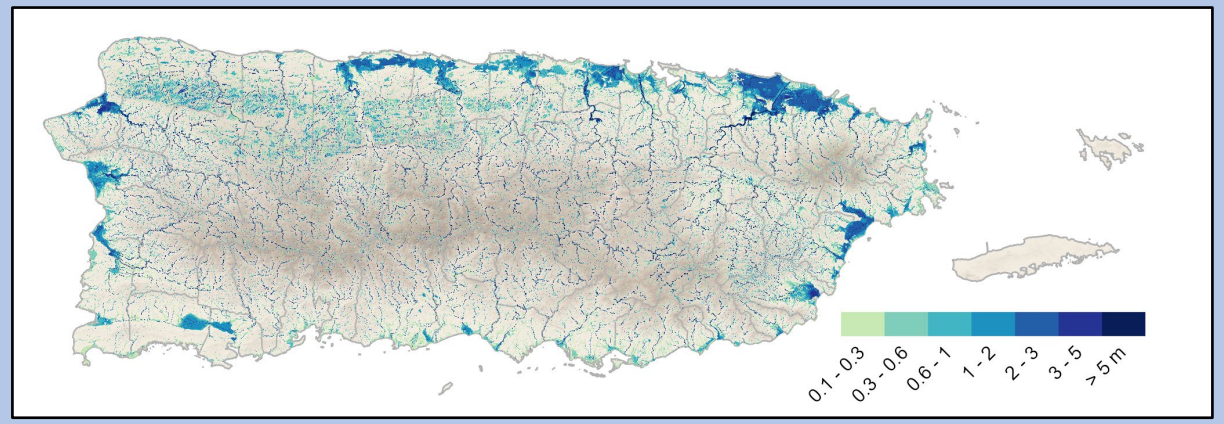
Landslide density (Data source: USGS)



Storm total rainfall (NIST Gaussian process model)



Flood depth (Bristol University modeling)

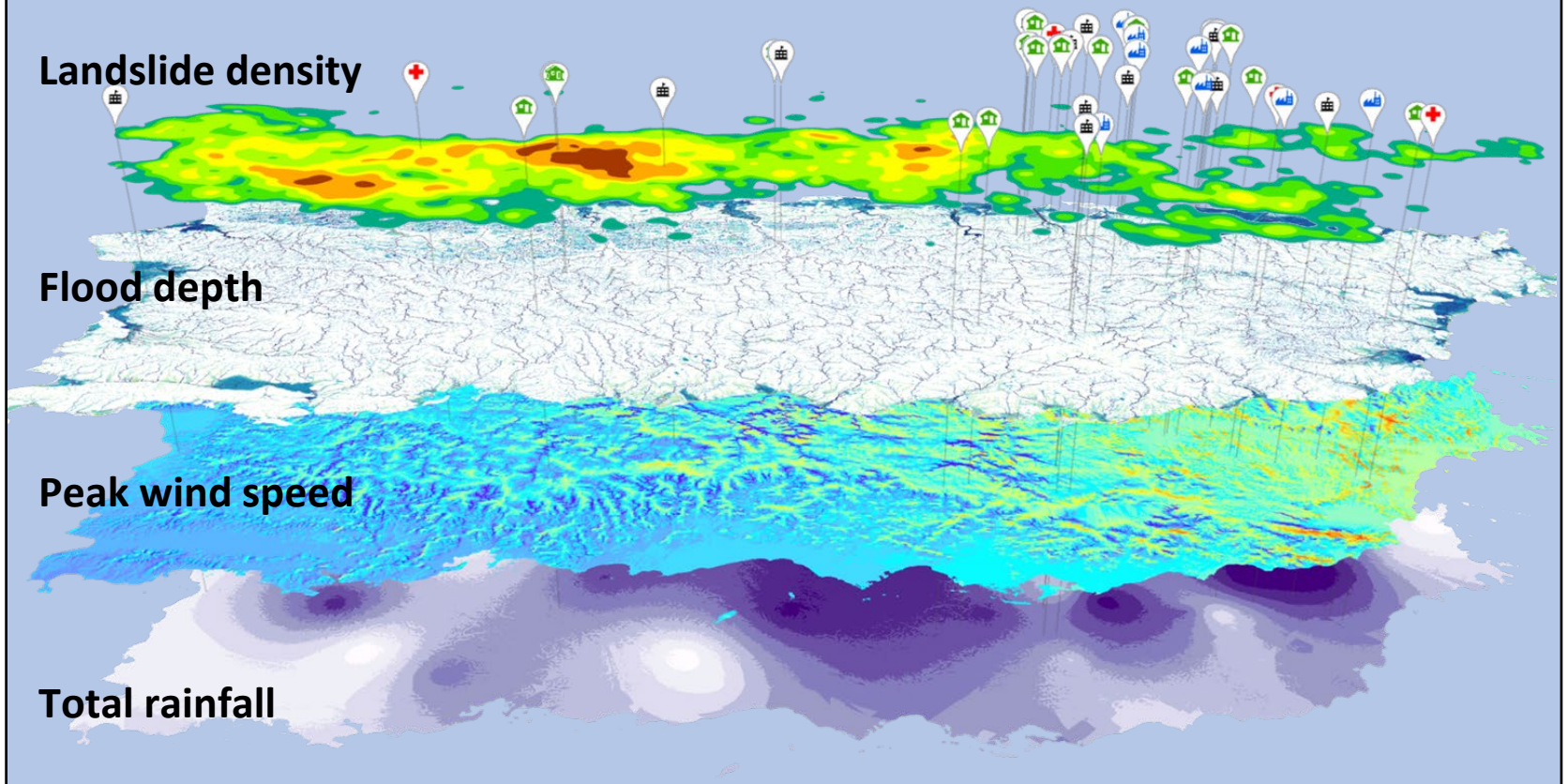


PRELIMINARY ANALYSIS

3 What was the hazard exposure for households, businesses, schools, and hospitals?

Hazard Characterization

Linking Hazard Exposure with Survey Data



1500+ Household Surveys
On public response to emergency communications

450+ Business Surveys
On hurricane impacts and recovery

275+ School Surveys
On recovery of social functions

15+ Hospital Surveys
On recovery of social functions

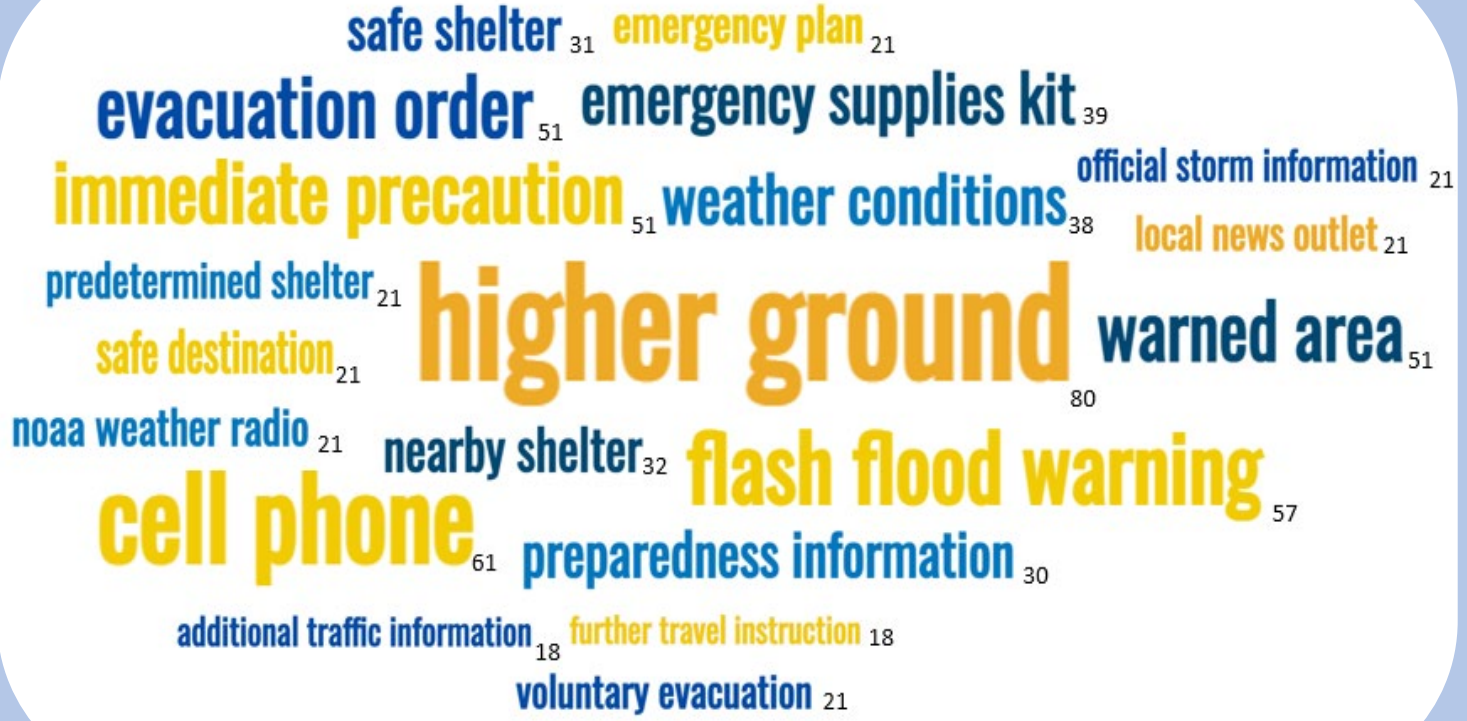
3 What communications did the public receive about protective actions?

Emergency Communications

NOAA Weather Radio Messages

- Move to **higher ground** due to flood risk
- Charge **cell phone** and use sparingly
- Follow locally-issued **evacuation orders**
- Prepare **emergency supplies kit**

Phrases used for preparedness instruction:



PRELIMINARY ANALYSIS

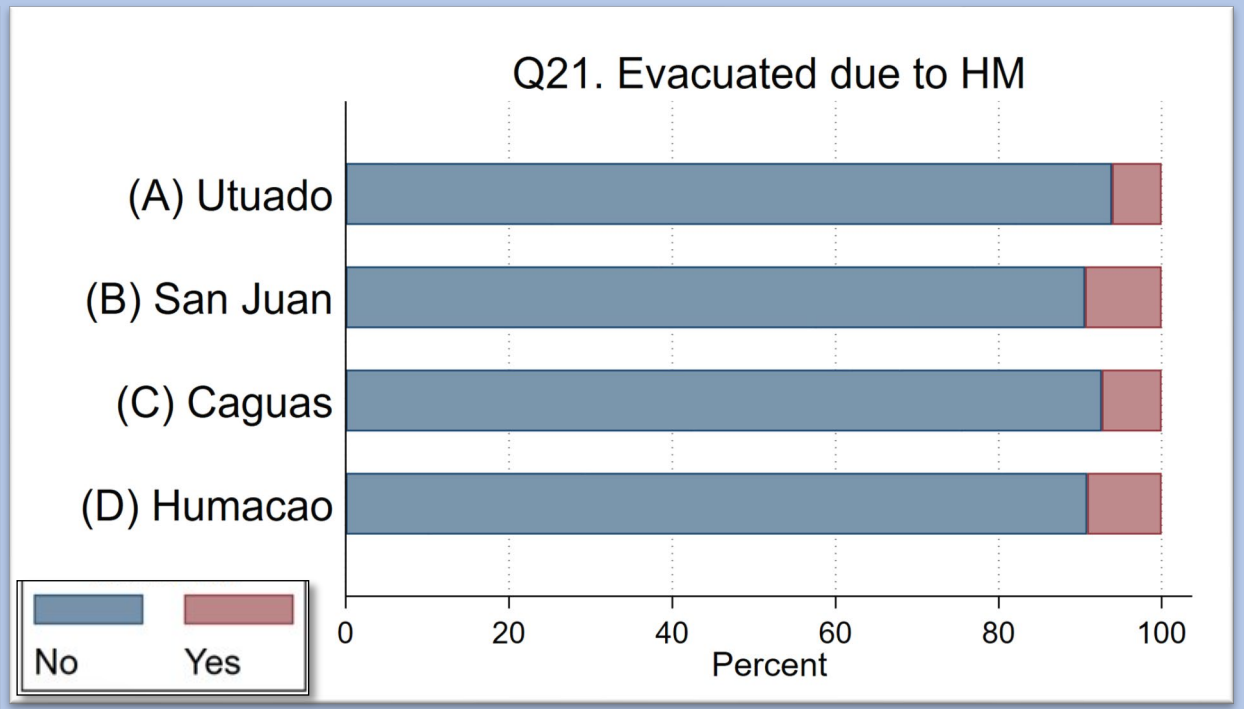
3 What protective actions were taken by the public?

Emergency Communications

Household survey results:

- Most Puerto Ricans did not evacuate for Hurricane Maria.
- 4 or more protective actions were taken by 58% of the population.
- Approximately 3% of the population did not take any protective actions.

High Ranking Actions Taken before Hurricanes Irma and Maria	%
Set aside food, water, medicine, or other supplies	93%
Talked with others about hurricane preparation	70%
Made a plan for evacuation (such as where to go)	42%
Had insurance coverage for a natural hazard (any)	34%



PRELIMINARY ANALYSIS

3 What preparedness actions were taken by hospitals, schools, and shelters?

Recovery of Social Functions

School survey results:

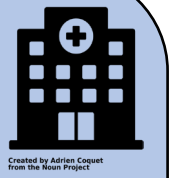
- 82% of schools in the sample had an emergency plan in place for natural hazard events such as hurricanes.

Recovery of Social Functions

Hospital survey results:

- 100% of hospitals in the sample had an emergency plan in place for natural hazard events.

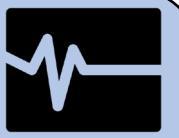
Critical Buildings



Shelter personnel interviews:

- None (n=5) of the facility POCs had access to Shelters Operations Plans.

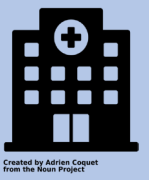
Morbidity and Mortality



Hospital personnel interviews:

- Ahead of the 2017 hurricane season, all 6 hospitals interviewed had developed emergency plans; implementation of these plans varied.

Critical Buildings



Hospital personnel interviews:

Protection Actions for Hospitals	# of Hospitals
Deployed storm shutters	5 of 5
Cleared roof drains	5 of 5
Anchored rooftop equipment	4 of 5
Placed sandbags for flood protection	3 of 5

PRELIMINARY ANALYSIS

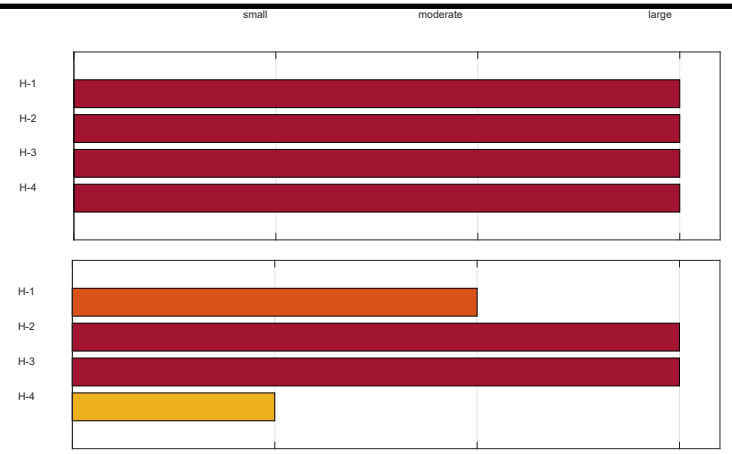
3 What was the damage to critical buildings?

Critical Buildings

Hospital personnel interviews:

- All 5 hospitals experienced significant rainwater intrusion
- Most prevalent sources of rainwater intrusion:
  - **Leaking roof covering and/or decking**
  - **Windows or doors with broken glass**
  - **Damaged or dislodged rooftop equipment**

Source of Rainwater Entry	Amount of Rainwater Intrusion



(H-5 experienced riverine flooding; staff could not identify sources of rainwater intrusion.)

Damaged Roof Covering

Windows with Broken Glass

Damaged/Dislodged Rooftop Equipment

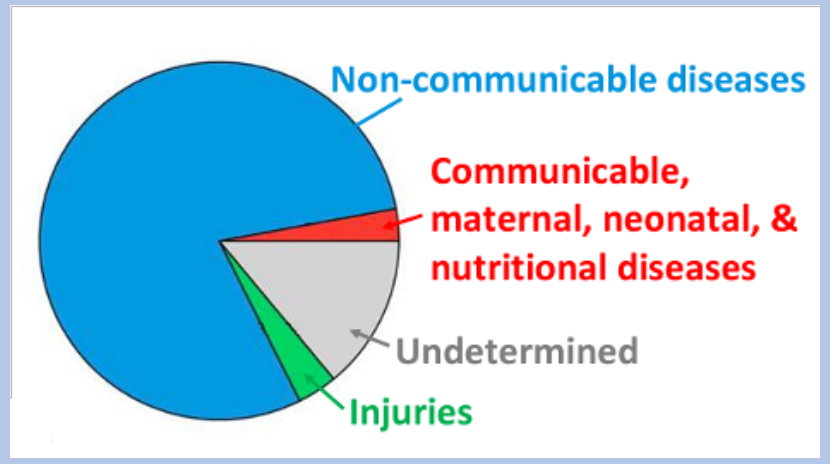
PRELIMINARY ANALYSIS

3 When, where, and why did people die?

Morbidity and Mortality

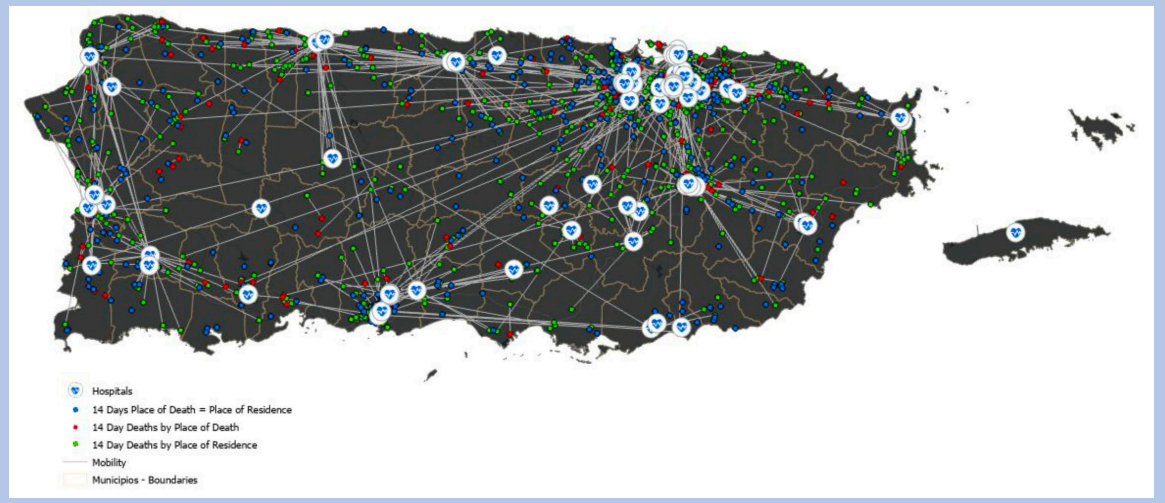
Verbal autopsy survey results:

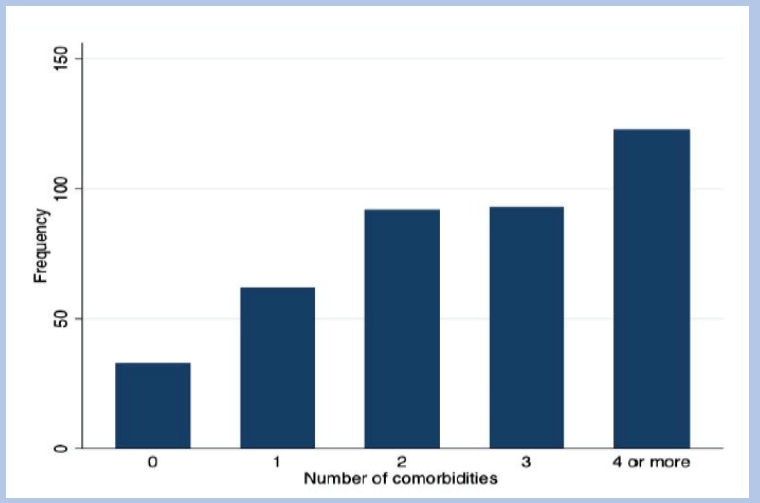
- 410 interviews were conducted with next-of-kin informants.
- Of these deaths, only about 1/10 occurred the day of landfall; the rest occurred in the 14 days after landfall.
- The majority of deaths were not caused by storm-related injuries; most of the deceased had 2 or more comorbidities.



Geospatial analysis of death records:

- More than 1/2 of deaths in the first 14 days occurred after patients were admitted to hospitals.





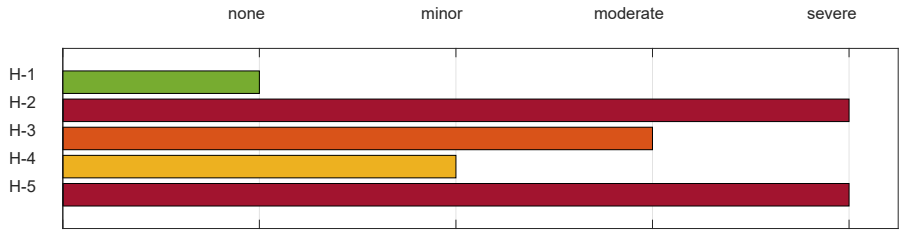
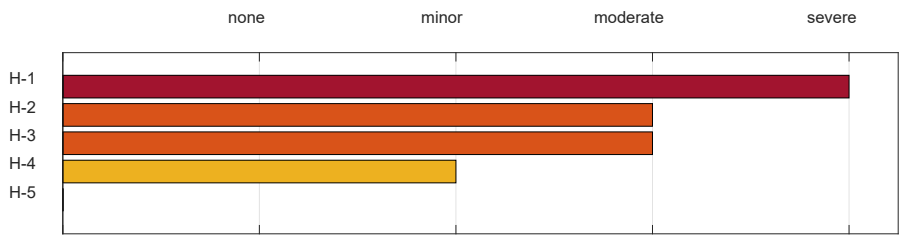
PRELIMINARY ANALYSIS

3 What were the impacts of damage on hospital functionality?

Critical Buildings

Hospital personnel interviews:

- 4 of the 5 hospitals reported loss of function for elevators, making it challenging to move patients when required
- Water intrusion caused damage to electrical/mechanical systems, interior finishes, and contents, which impacted hospital functionality:

Contributing Factor	Severity of Impact on Functionality
Damage to Electrical/ Mechanical Systems	
Damage to Interior Finishes and Contents	

Morbidity and Mortality

Hospital personnel interviews:

Patient movement was very difficult for four of the hospitals because they had problems with their elevators, due to limited electric power generator capacity, flooding in the elevator machine room, or due to a fire causing temporary loss of electrical power.

H-10: The major infrastructure problem was the breakage of a door on the roof, which caused the elevator machine room to flood, causing the elevators to stop working.

Verbal autopsy survey results:

The verbal autopsy interview revealed that those who died in hospitals encountered hospital disruptions that included power outages, loss of air-conditioning, rainwater entering the building, and water leaking through the ceiling.

PRELIMINARY ANALYSIS

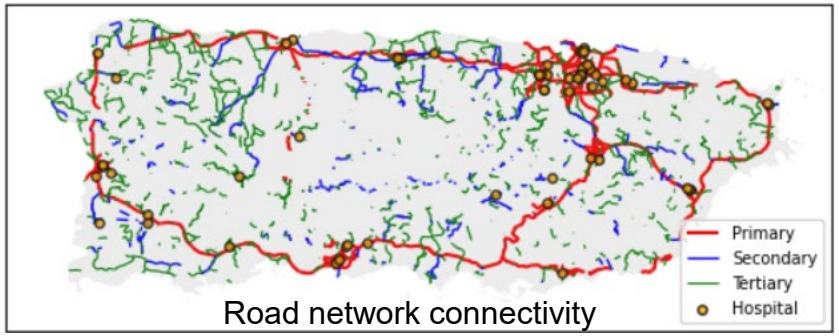
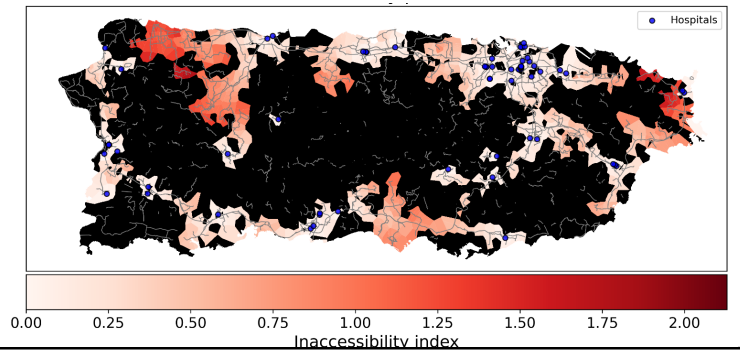
3 What were the impacts to infrastructure service and what was the recovery timeline?

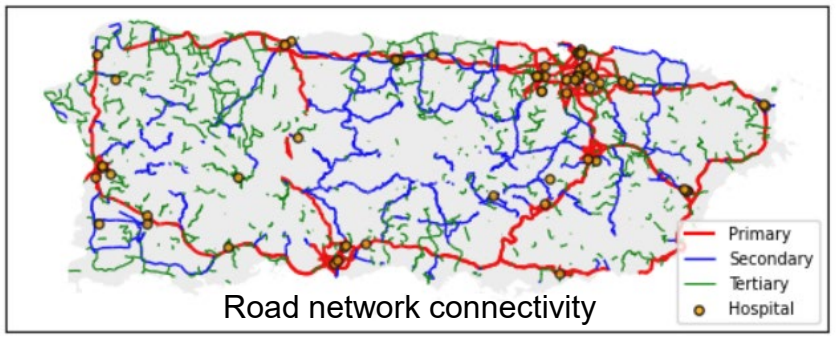
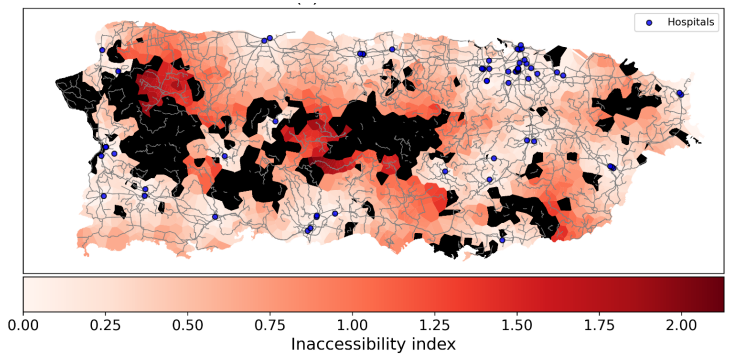
Recovery of Infrastructure

Network Modeling:

Network disruptions are simulated by breaking road segments based on recorded transportation impacts from PR DTOP data; then connectivity and hospital access are recalculated.

- Hospital access is equated with connectivity to hospitals; we assume 0% of roads were disrupted before Hurr. Maria
- "Poor" hospital access here is ***inaccessibility index*** greater than 1 (an index of 1 is a travel time of 1 h in ideal conditions)

Immediately after Hurricane Maria			• 30% of road segments disrupted
			• 54% have poor to no access
			  • No (51%)
			  • Poor (2.7%)

1 month after Hurricane Maria			• 20% of road segments disrupted
			• 16% have poor to no access
			  • No (12%)
			  • Poor (4.4%)

PRELIMINARY ANALYSIS

3 What backup utilities were available for schools and shelters?

Recovery of Social Functions

School survey results:

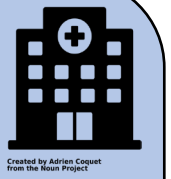
- 95.3% of schools lost power
- Average days without power for schools in the sample is 102.2 (SD=74.7)

Backup Infrastructure Services	% Had	% Used
Electrical Power	22.0%	27.8%
Water/Sewer	43.7%	31.4%
Landline Telephone	15.2%	18.8%
Internet/ IT	7.9%	10.1%

SC34374: *"… we had to emphasize to students that they needed to bring their water because, after a hurricane, the water, or when there is no running water for a while, then the water is not safe."*

Critical Buildings

Shelter personnel interviews:



Power: All 5 shelters lost external power;
4/5 shelters had emergency power generators

Water: All 5 shelters had cisterns;
4/5 shelters had issues with potable water supply

Shelter	Had Generator	Used	Worked as Intended	Issue
1	Yes	Yes	Yes	-
2	Yes	Yes	Yes	challenge obtaining fuel
3	No	-	-	-
4	Yes	Yes	No	malfunctioning part
5	Yes	Yes	Yes*	water intrusion damaged component

**Generator failed around same time shelter was closed.*

PRELIMINARY ANALYSIS

3 What backup utilities were available for hospitals?

Morbidity and Mortality

Hospital personnel interviews:

Created by Kantor Tegalsari from Noun Project

- 4 of 6 hospitals reported a redundant electric power generator system with capacity to supply the facility's electricity needs during the 2 weeks after Hurricane Maria's landfall.
- However, power generators of 2 of the 4 hospitals with backup power were not able to provide the amount of electricity needed.
- This impacted patient movement via elevators, among other functions.

H-4: There was concern over the possibility that the power generators, which had been operating for many days, might fail or break down, and that the power supply would be interrupted, affecting the medical care of patients connected to medical equipment.

Recovery of Social Functions

Hospital survey results:

Created by Matthias Hartmann from Noun Project

H154: *"There was an electrical issue caused by the river water because, when it got flooded...the pumps were submerged under water, something we didn't expect either, and we lost power. ...we had neither electricity nor running water."*

Backup Infrastructure Services	% Had	% Used
Electrical Power	100.0%	87.5%
Water/Sewer	87.5%	56.2%
Landline Telephone	56.2%	37.5%
Internet/ IT	50.0%	37.5%
Oxygen	93.8%	50.0%

PRELIMINARY ANALYSIS

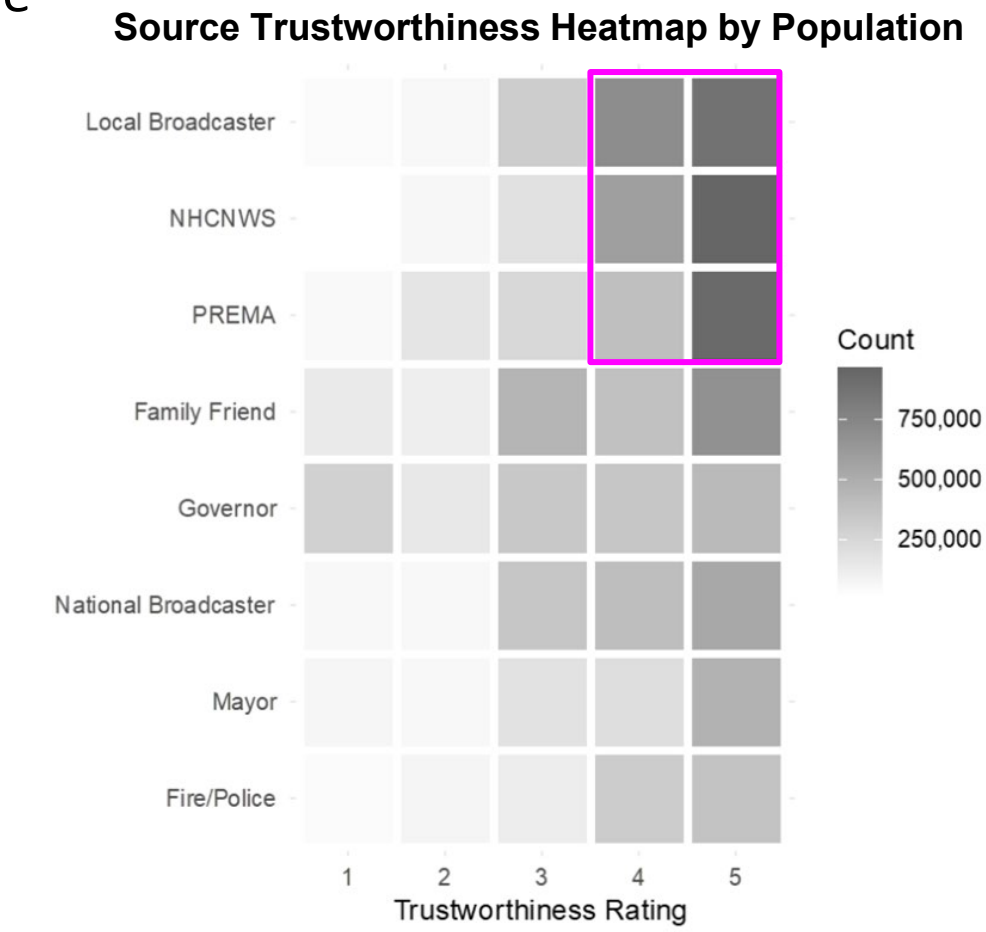
4 Preliminary Findings

Preliminary Findings

Pre-Storm Emergency Communications & Protective Actions

Access to pre-storm messages from multiple sources via multiple channels contributed to broad public understanding of the anticipated hazards associated with Hurricane Maria.

- Three information sources on hurricane risks and protective actions were reported most commonly (by >67% of the population) and were considered the most trustworthy.
  - National Hurricane Center (NHC) and National Weather Service (NWS): *Authoritative scientific information provided the basis for subsequent messaging and instructions on protective actions*
  - Local broadcasters: *Additional customization of messages contributed to the public understanding of the anticipated severity of the storm's impacts*
  - Puerto Rico Emergency Management Agency (PREMA)
- A significant portion of the Puerto Rican public (84% of adults) had experience with previous hurricanes and was largely familiar with the threats.



PRELIMINARY ANALYSIS

Preliminary Findings
Hazard Exposure

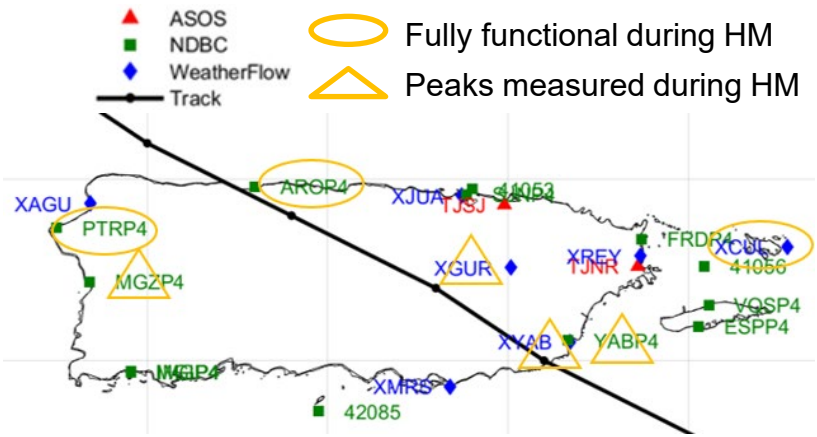
Failure of weather measurement systems posed significant challenges in quantifying Hurricane Maria's hazard exposure across Puerto Rico, both during the event and in post-storm assessments. Modeling was used to interpolate winds and rainfall from measurements deemed reliable. However, the limited availability of reliable data increased the uncertainty in the model results and increased the likelihood that some of the highest hazard intensities were not captured.

Wind measurements:

- 15 of 22 stations failed to measure the maximum wind speeds.
- Of the 7 that captured the highest speeds, 4 eventually failed, leaving only 3 that were fully functional throughout the storm.

Rain measurements:

- Many rain gauges (25 of 48 USGS gauges) and the Doppler weather radar failed during the hurricane.
- A few extreme rainfall measurements were rejected as invalid after review by NWS and USGS due to measurement challenges.



Location of wind measurements

Failure of Doppler weather radar

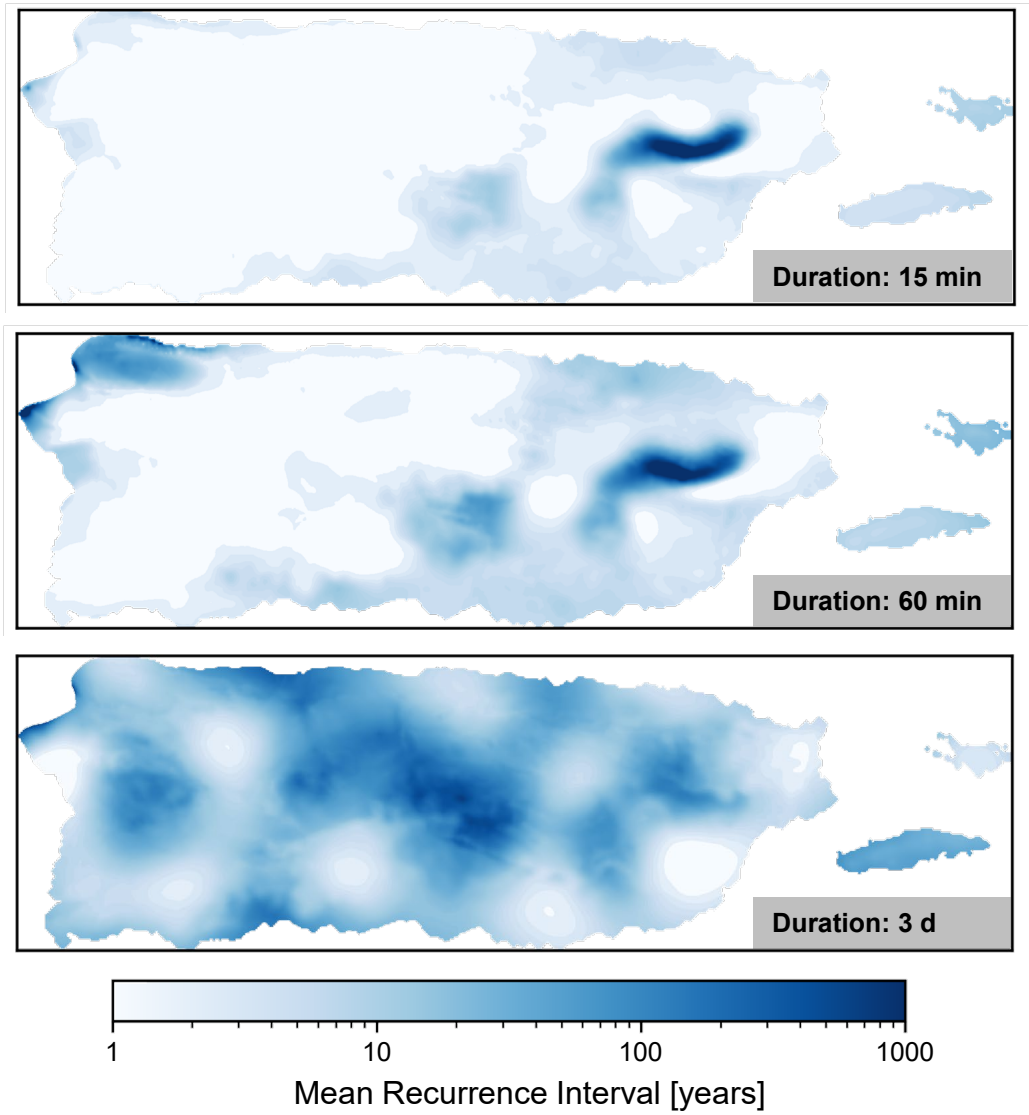
PRELIMINARY ANALYSIS

Preliminary Findings

Hazard Exposure

Based on analysis of reliable rain gauge measurements, the rainfall experienced during Hurricane Maria was extreme from a historical perspective. Mean Recurrence Intervals (MRIs) exceeded 700 years for the storm total rainfall and exceeded 1000 years for hourly and 15-minute rainfall accumulations.

- The spatial distribution and intensity of rainfall accumulation was significantly influenced by Puerto Rico's mountainous topography.
- MRIs exceeding 1000 years for the hourly and 15-minute rainfall intensities were concentrated in a relatively small region in the vicinity of the El Yunque tropical rainforest in the Sierra de Luquillo mountains.
- For most of Puerto Rico, storm total rainfall was more extreme from a historical perspective than the rainfall intensity over shorter durations of 1 hour or less.

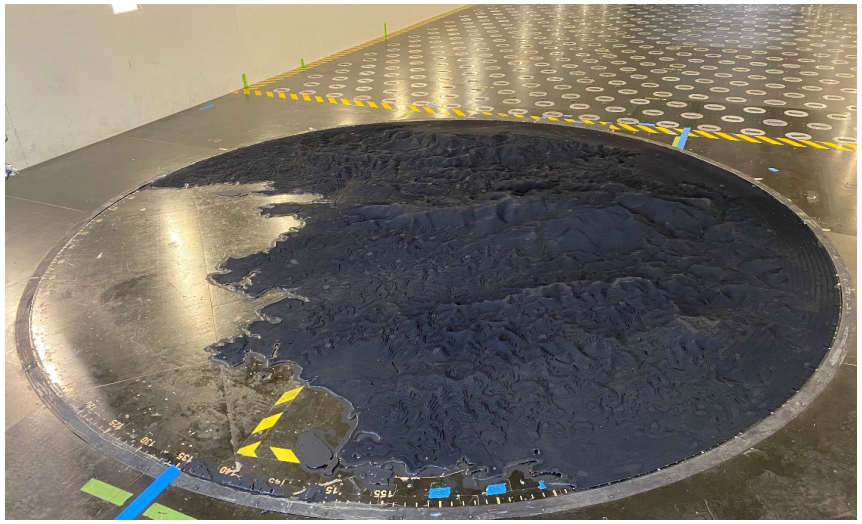


PRELIMINARY ANALYSIS

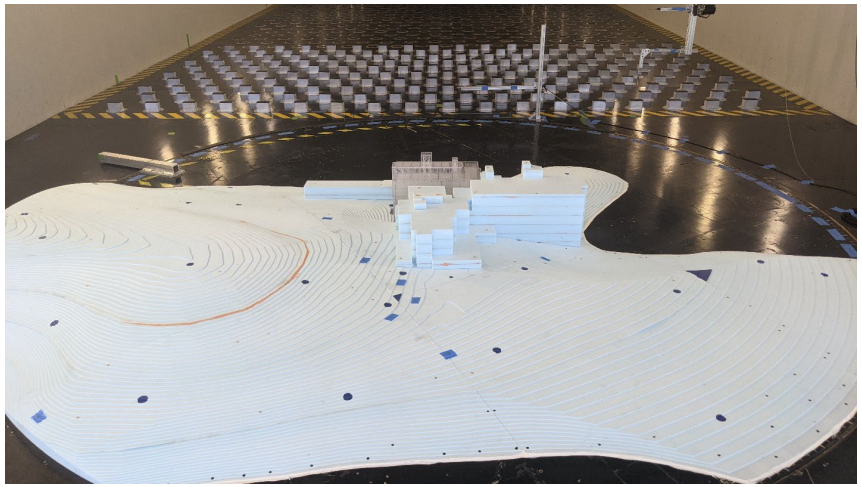
Preliminary Findings
Hazard Exposure

Puerto Rico's mountainous topography led to significantly increased wind speeds at some locations, resulting in substantially increased wind loads on buildings, communication towers, and other structures relative to winds over flat terrain.

- For Hospital Bella Vista in Mayagüez, wind tunnel testing indicated topographic speedup by as much as 36% at the site with increases of more than 80% in resulting pressures and forces on building elements.
- Based on the NIST Hurricane Maria wind-field model, estimated peak gust* wind speeds at the site of the damaged Doppler weather radar reached as high as 178 mph: 48% greater than the estimated peak gust* speed of 120 mph over flat terrain.



Mayagüez Topographic Model



Hospital Bella Vista Building Model

PRELIMINARY ANALYSIS

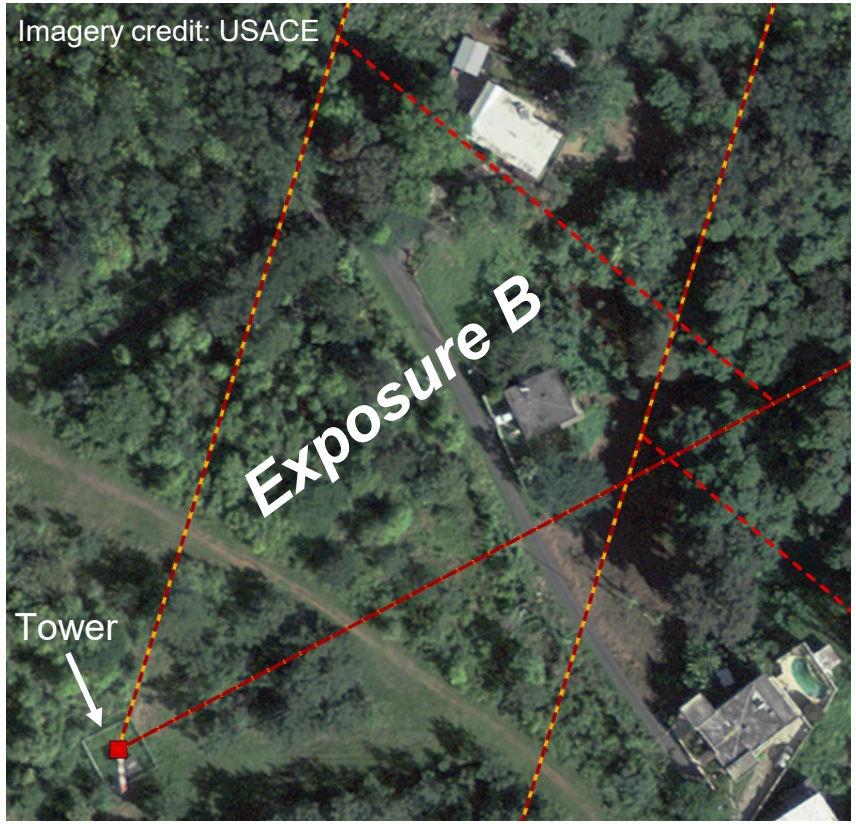
*Gust wind speeds correspond to a 3-second averaging time

Preliminary Findings
Hazard Exposure

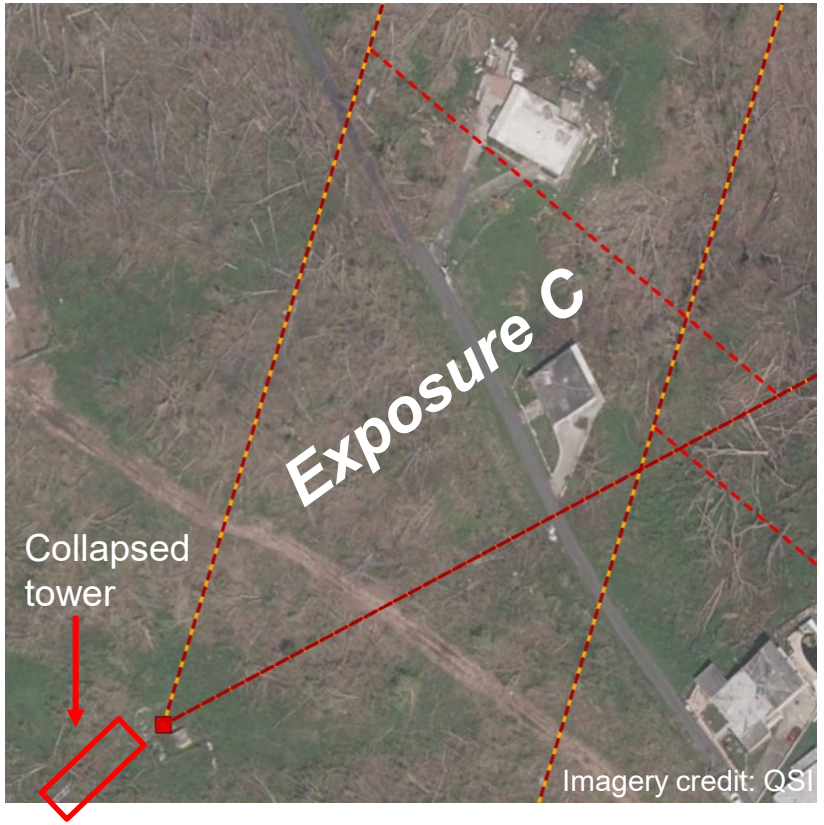
Hurricane winds caused extensive damage to trees, especially along mountain ridges where topographic effects were significant. Damaged trees resulted in other disruptions:

- Damage to power lines,
- Blockage of roads, including critical infrastructure-owned access roads, and
- Reduction in shielding of structures, resulting in increased wind loads.

Tree damage changed the wind exposure category from B (suburban) to C (open country) for ~25% of communication towers evaluated



Before Hurricane Maria

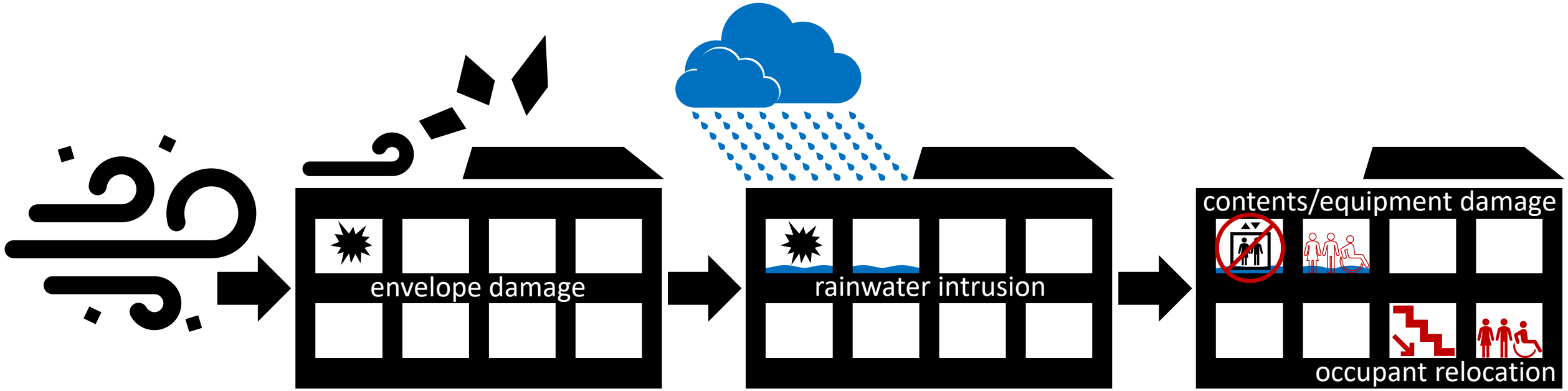


After Hurricane Maria

PRELIMINARY ANALYSIS

Preliminary Findings
Building Damage & Impacts on Function

Hurricane winds and wind-borne debris caused extensive damage to building envelopes (roof covering, windows/doors, and rooftop equipment), allowing significant rainwater intrusion, which damaged contents and equipment and forced the relocation of occupants.



PRELIMINARY ANALYSIS

Preliminary Findings
Protective Actions & Sheltering

Refuge areas in designated shelter facilities preserved life safety, successfully protecting occupants from hurricane winds and wind-borne debris. However, occupants were exposed to other hazards and significant operational challenges were encountered in these facilities:

- Refuge areas were affected by rainwater intrusion and flooding, especially accessible ground-floor refuge areas, requiring relocation of occupants.
- Lack of air conditioning (due to damage and or loss of power) exposed occupants to high heat and humidity and contributed to mold/mildew growth (following water intrusion).
- Shelter facilities generally had higher occupancies than expected and were used far longer than intended.
- Multiple groups were involved in managing shelters; a lack of clear roles and responsibilities exacerbated shelter operational challenges.

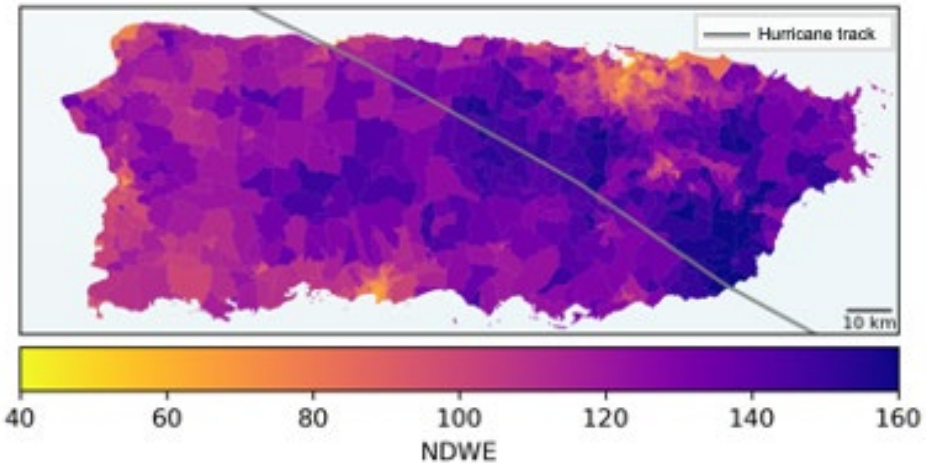
PRELIMINARY ANALYSIS

Preliminary Findings
Infrastructure Dependencies & Recovery

Complex interdependencies between disrupted infrastructure systems (especially communications, power, and roads) greatly delayed the recovery of infrastructure services following Hurricane Maria. The delayed restoration of these services affected recovery of critical social and economic functions in communities:

- Infrastructure operators ranked disruptions in availability of temporary power sources, fuel, and maintenance and repair services, as well as lack of communications, as key factors in slowed infrastructure service recovery.
- Prolonged electrical power disruption was a factor in recovery of social functions performed by schools and hospitals. In particular, the odds of advancing in the restoration of primary education and healthcare services were decreased by the number of days without power.
- Industry representatives identified disruptions in transportation and shipping as having delayed distribution of essential supplies and created cascading effects that hindered long-term business recovery.

Average number of days without electricity

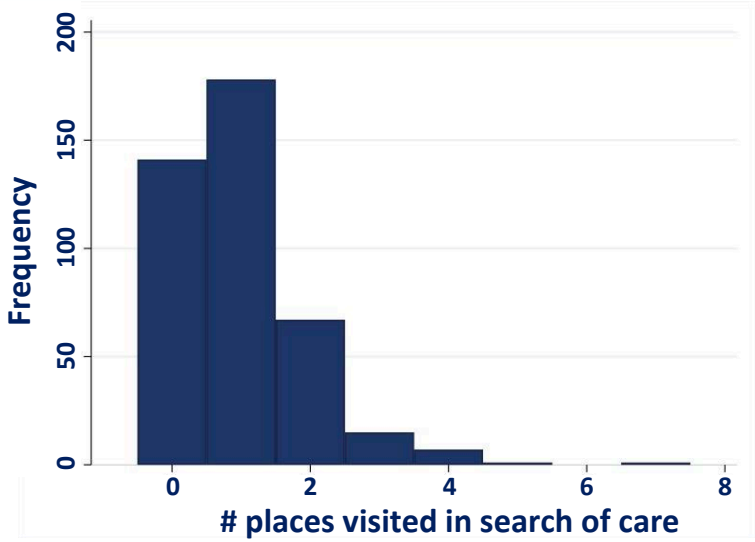


PRELIMINARY ANALYSIS

Preliminary Findings
Hospital Accessibility & Functionality

Patients who sought medical care following Hurricane Maria encountered significant challenges:

- Transportation network disruption following Hurricane Maria greatly limited access to hospitals for more than half of the population.
- Many sought medical care at multiple places (as many as 7).
- Most patients arrived at the hospital in poor condition: their condition may have deteriorated at home or while seeking care.
- Upon arriving at hospitals, most reported disruptions in services. (Only 10% reported no disruptions.)
- Backup power systems at many hospitals did not power AC systems or elevators.
    - Patients and staff were exposed to high heat and humidity.
    - Relocating patients was difficult (e.g., when required due to flooding).



Disruptions next-of-kin informants noticed where deceased was hospitalized	%
Power outage	96
A/C (ventilation) not functioning	71
A flood from rising water entered building	21
Rainwater entered building during the storm	30
Water leaked through the ceiling	23
Interruption of water service	19
Not enough staff	57
Not enough medical equipment	41
Medical gases (oxygen) were not available	15

PRELIMINARY ANALYSIS

Preliminary Findings
Preparedness & Recovery

Businesses, schools, and hospitals that took specific measures to prepare before Hurricane Maria were able to resume operations more quickly afterward. Preparedness measures and resilience investments that statistically improved recovery outcomes included:

- ***Businesses***: pre-established emergency plans, diversified suppliers, and backup power sources
- ***Schools and hospitals***: emergency plans, designated risk mitigation funds, and backup power

PRELIMINARY ANALYSIS

Preliminary Findings
Financial Assistance & Recovery

Financial assistance was a determinant of recovery progress for businesses, schools, and hospitals:

- Prolonged need for financial assistance is statistically related to slower recovery of businesses and business functions.
- Schools and hospitals that did not receive financial assistance within 18 months had statistically lower repair progress than those who received assistance.

PRELIMINARY ANALYSIS

5 Anticipated Impacts

5 Reports and Recommendations

- NIST intends to publish reports describing its analysis, findings, and recommendations, including:
  - draft reports for public comment and
  - final reports addressing public comments.
- Recommendations are expected to include specific improvements to building codes, standards, and practices based on the findings, as well as research to help prevent future building failures, improve emergency communications, and reduce loss of life.
- NIST has a statutory responsibility to promote implementation of recommendations from its NCST investigations.
- Through the development and promotion of measurements, standards, and technology, NIST is committed to making buildings, infrastructure, and communities more resilient to hurricanes and other hazard events in Puerto Rico and across the United States.

5 Potential Topics for Recommendations

Recommendations from the Hurricane Maria Program are anticipated to result in improvements in the following areas:

- Robust measurement systems for wind, rainfall, and flooding during extreme events to inform design criteria for future events
- Standard provisions to account for topographic effects on wind loads for design of buildings and other structures
- Design standards for storm shelters and selection criteria for best-available refuge areas
- Performance-based design criteria and methods for hospitals and other critical facilities to enable continued operation during and after hurricane events:
  - Enhanced design and detailing of building enclosures to resist intrusion of wind-driven rain
  - Standby generators for continued operation of elevators and air-conditioning systems
- Guidance on recording post-event incidents impacting networked infrastructure systems for prioritization of recovery activities
- Standards for attribution of disaster-related deaths

Acknowledgments

To all those in Puerto Rico who responded to the data collection requests and shared knowledge, experiences, and lessons learned, including:

- Households
- Families and loved ones of those who lost their lives
- Emergency information providers
- Business owners and managers
- Shipping and transport operators
- Hospital administrators and staff
- School administrators and staff
- Shelter operators
- Infrastructure operators

To all those impacted by Hurricane Maria.

To our dedicated team, including:

- NCST Members
- Technical Staff
- NIST Associates
- Institutional Support
- Contractors

To our many partners in Puerto Rico who have supported our data collection efforts.

NIST's Hurricane Maria Investigation

NIST HM Information

https://www.nist.gov/hurricane-maria

Public Meeting Videos

https://www.nist.gov/disaster-failure-studies/national-construction-safety-team-ncst/advisory-committee-meetings

NIST DFS Portal

https://www.nist.gov/disaster-failure-studies/data-submission-portal