

Summary of Hurricane Maria NCST Investigation Progress

NCST Advisory Committee Meeting

September 9, 2025

Joseph Main
Lead Investigator

Maria Dillard
Associate Lead Investigator

NIST Hurricane Maria Investigation



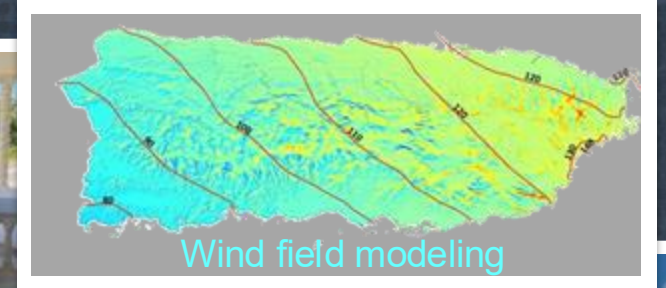
Event Impacts



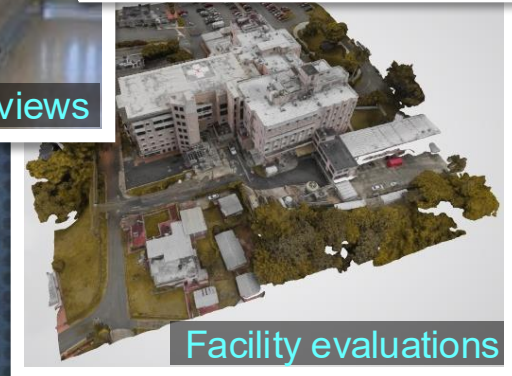
Failure of power & communications



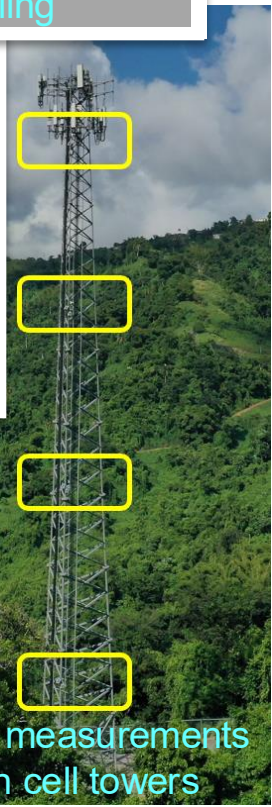
Surveys & interviews



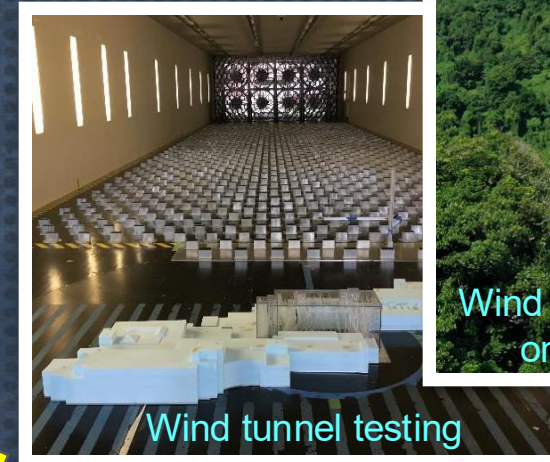
Wind field modeling



Facility evaluations



Wind measurements on cell towers



Wind tunnel testing

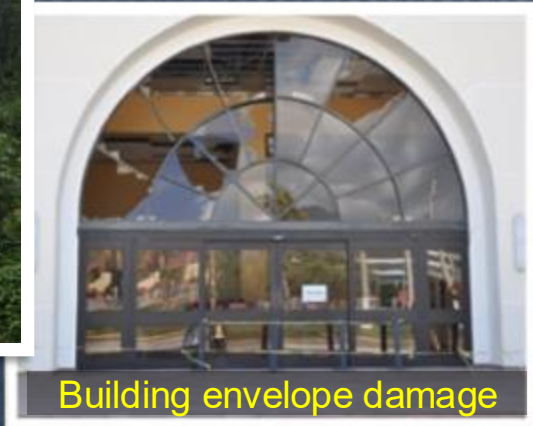
Recommendations



Landslides, road damage



Heavy rain and flooding



Building envelope damage



Rainwater intrusion in buildings

Investigation

1

Program Overview

4

Preliminary Findings

2

Investigation Timeline

5

Anticipated Impacts

3

Data Collection & Analysis

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

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

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.”*

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**



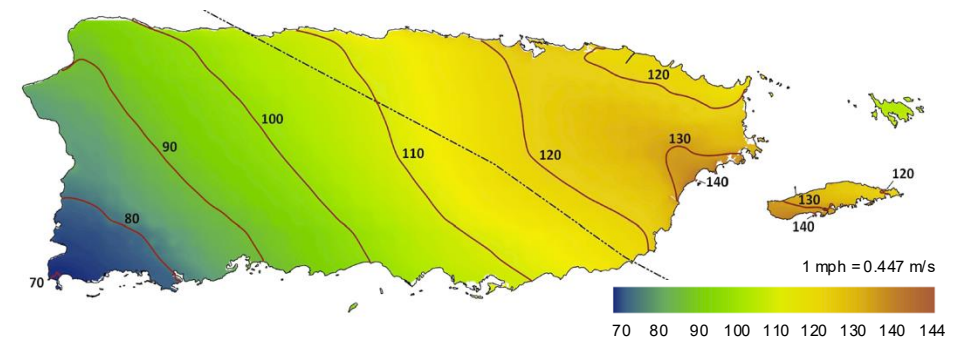
Credit: NOAA

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

Peak gust wind speed without topographic effects (mph)

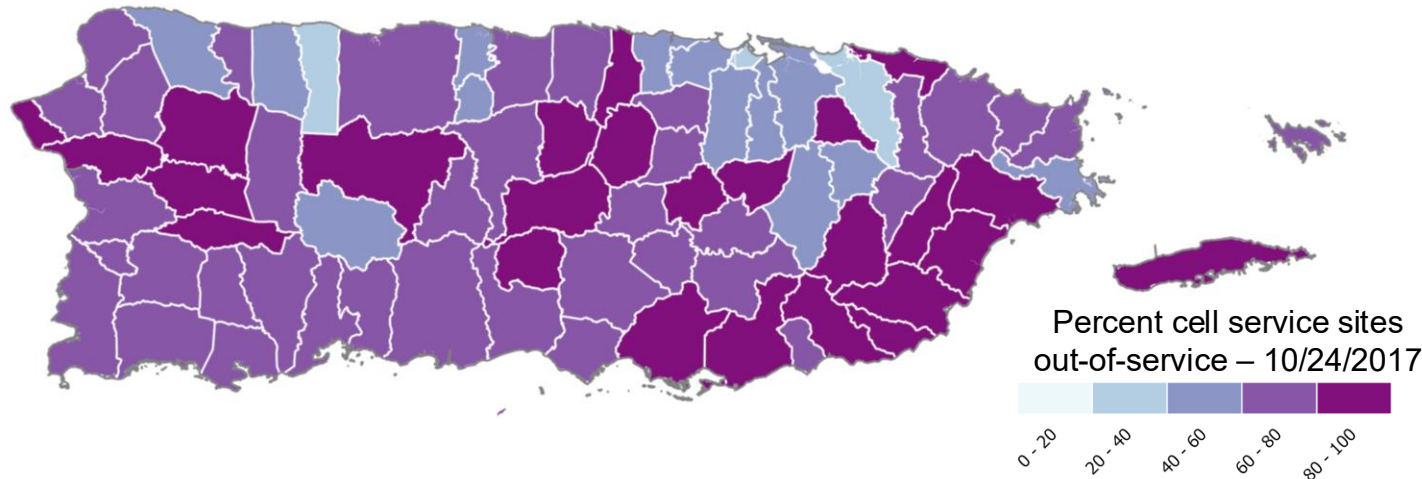


1 Impacts on Infrastructure and Recovery

- **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



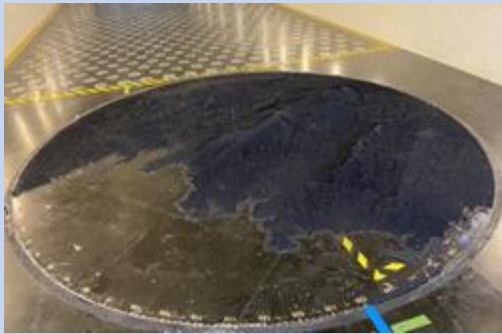
Wireless communications status at 1 month



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



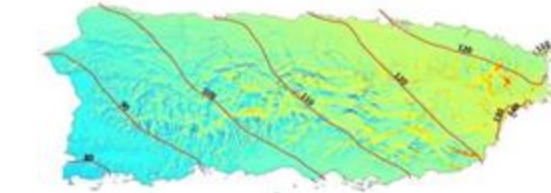
1 NIST Hurricane Maria Team



1 Supporting Contracts

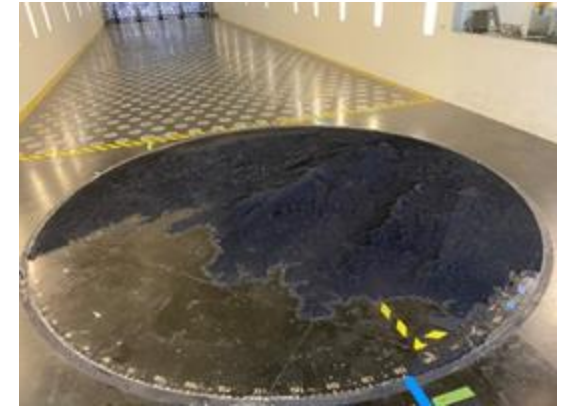
Contract

Wind Field Modeling



Applied Research Associates

Wind Tunnel Testing and Field Measurement of Winds



University of Florida

Engineering Services to Evaluate Critical Building Performance



Stantec Consulting

Social Science Data Collection



Horsley Witten Group

Morbidity and Mortality Assessment



Source: Bernardo Hernández Prado

GW/UPR*

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



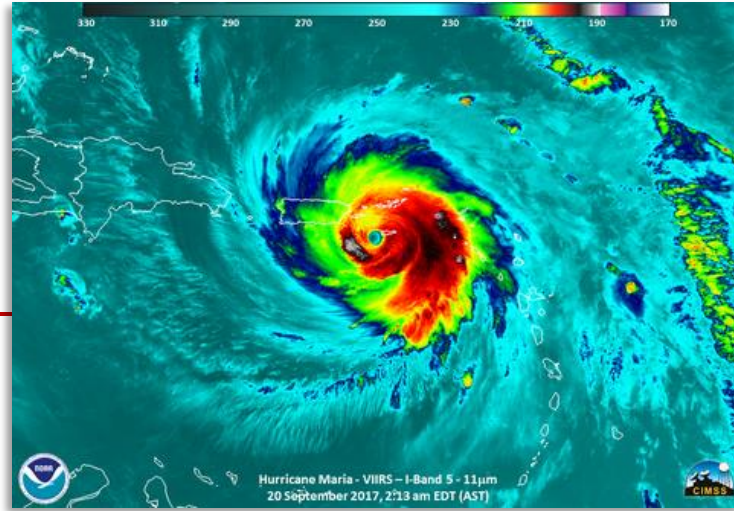
2

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

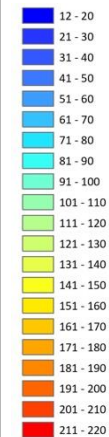
Feb-May: ARA and UF contracts awarded for wind hazard characterization

Jul: Initial wind-field model developed

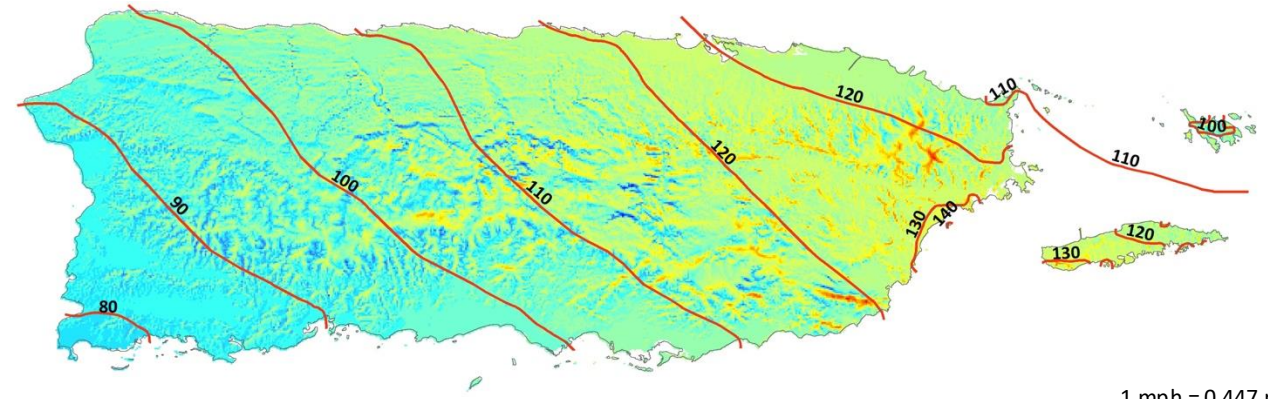
Oct-Nov: Stakeholder outreach in PR

Dec: Earthquake swarm began

Peak gust wind speed with topographic effects (mph)



Peak gust wind speeds without topographic effects indicated by red contours (mph)



2017

2018

2019

2020

2021

2022

2023

2024

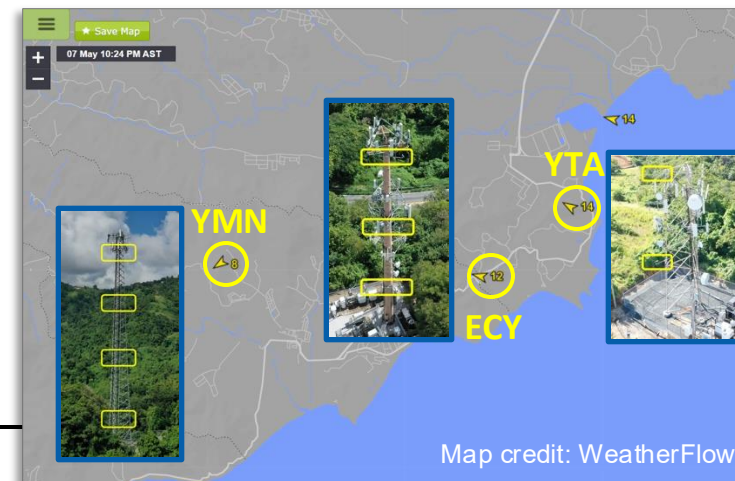
2025

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

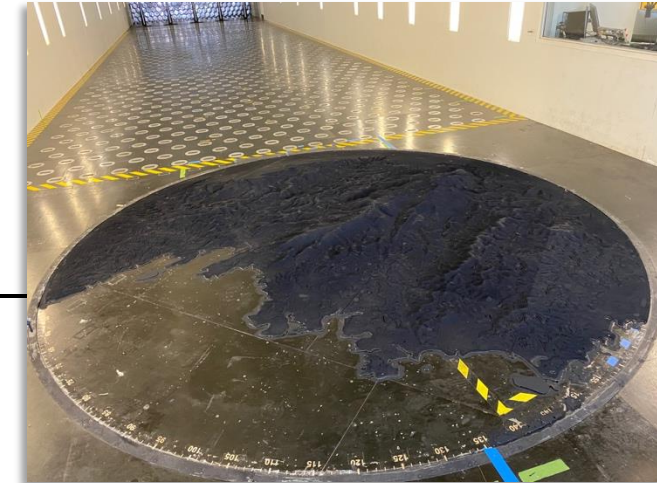


Jan: Progress Report published

● **Feb:** Drone photogrammetry of selected hospitals

Mar: Wind tunnel testing of topographic models ●

Jul: Emergency information provider interviews



2017

2018

2019

2020

2021

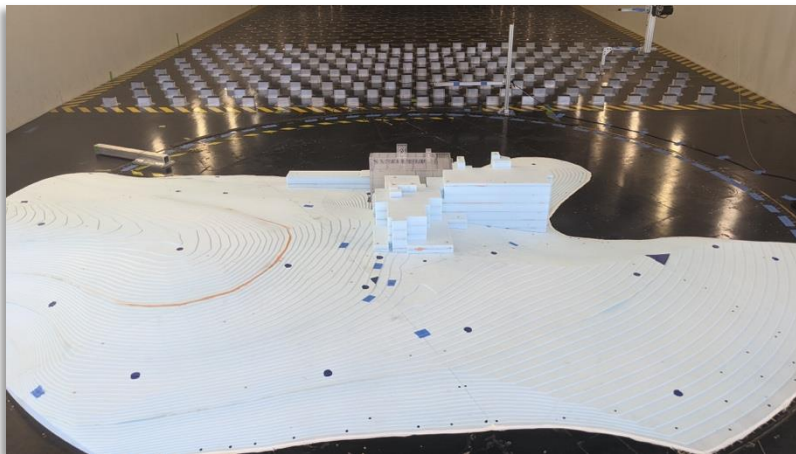
2022

2023

2024

2025

2026



May: Business surveys

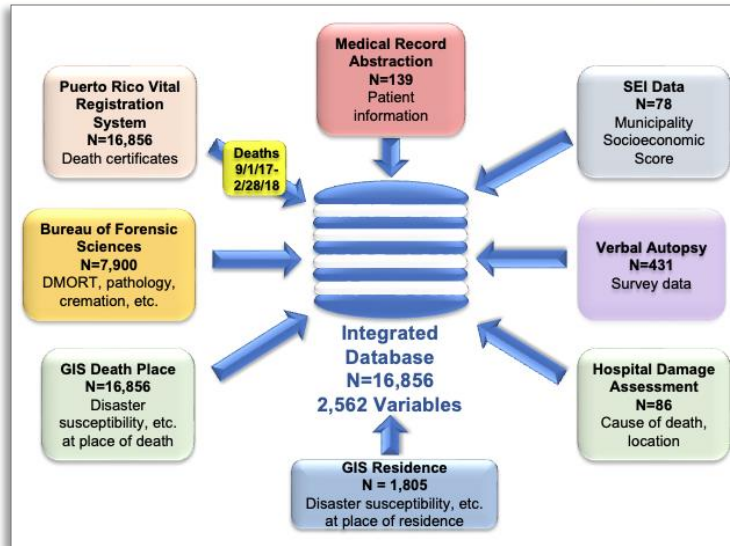
● **Jun:** Wind tunnel testing of selected hospitals

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

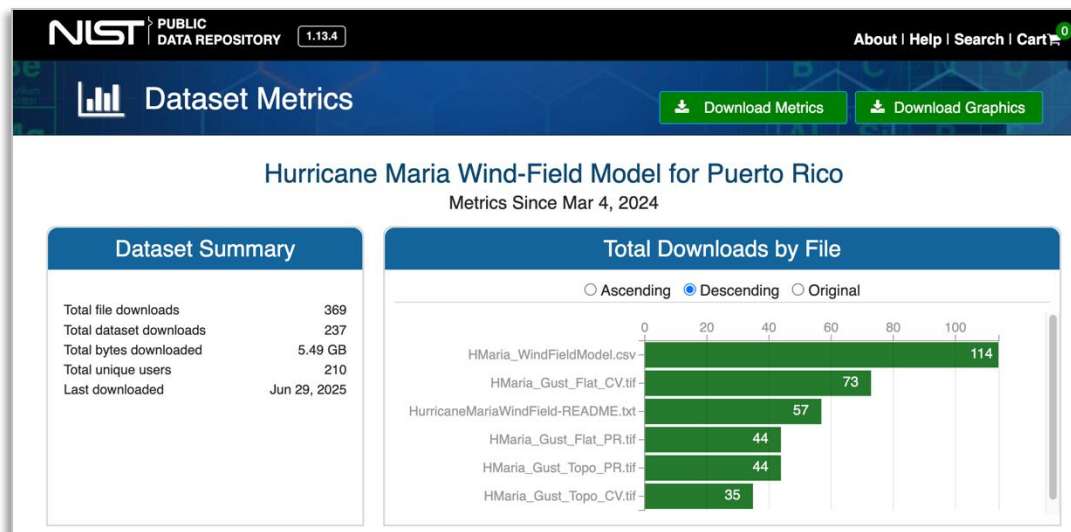
2022

2023

2024

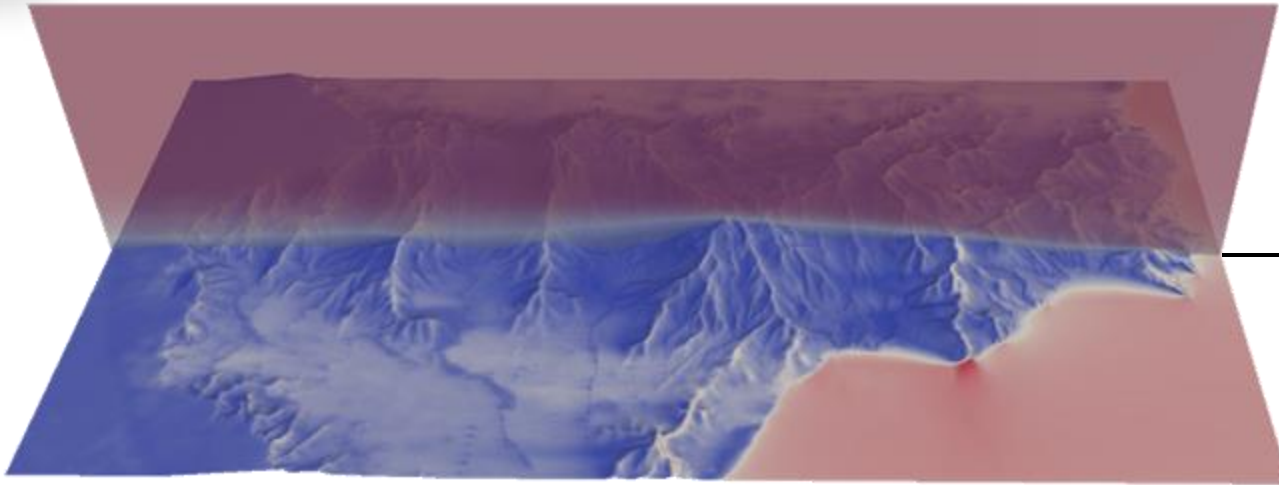
2025

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; Public update released
- Sep:** NCSTAC Meeting

2017

2018

2019

2020

2021

2022

2023

2024

2025

2026

NIST Shares Preliminary Findings From Hurricane Maria Investigation

July 14, 2025

NIST Hurricane Maria Program | Technical Update (July 2025)

NIST HURRICANE MARIA INVESTIGATION

TECHNICAL UPDATE
JULY 2025

The National Institute of Standards and Technology (NIST) has released a video update and press release on its study of Hurricane Maria's impacts on Puerto Rico.

MEDIA CONTACT

Brian Gutierrez
brian.gutierrez@nist.gov

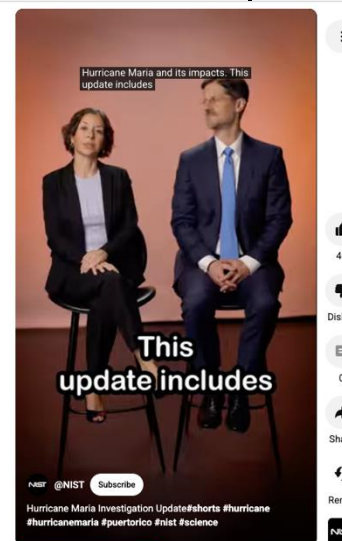
ORGANIZATIONS

Engineering Laboratory
Engineering Laboratory Office
Disaster Impact Reduction Office

RELATED LINKS

NIST's Hurricane Maria Program

NIST's Investigations of Structural Disasters: What We Do and Why They Can Take Years to Complete



Anticipated:
Investigation results released



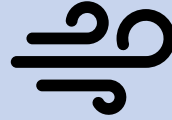
3

Data Collection & Analysis

⚠ 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. Uncertainty estimates will be included in NIST reports.
- 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.

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



Recovery of Social Functions

Created by Matthias Hartmann
from Noun Project

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



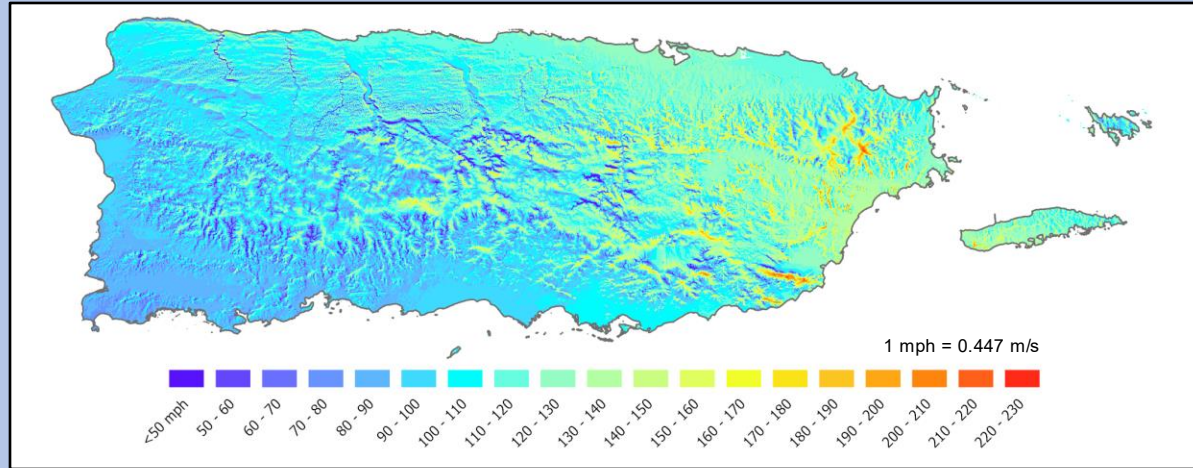
Transportation Incident
Database



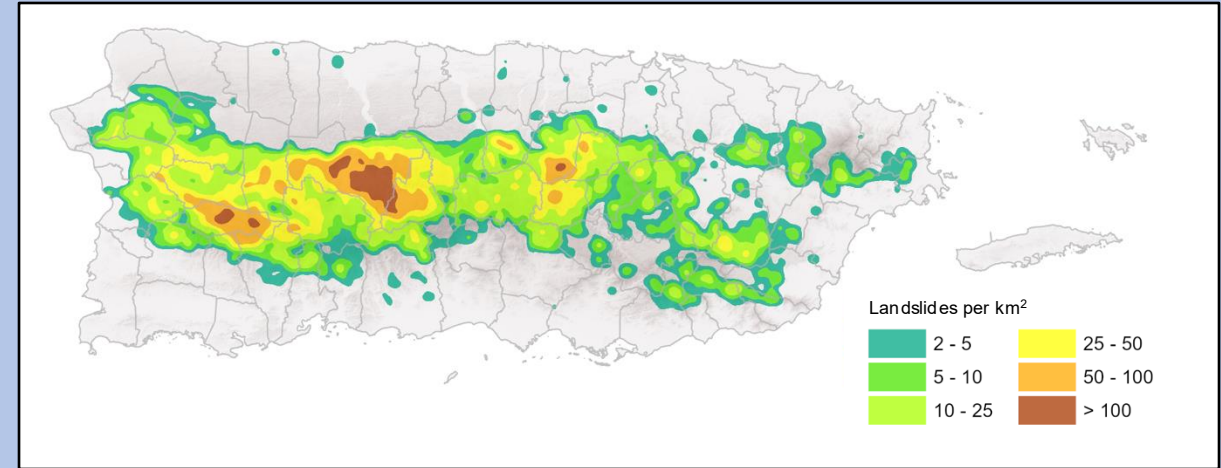
What were the hazards, and how severe were they across Puerto Rico?

Hazard Characterization

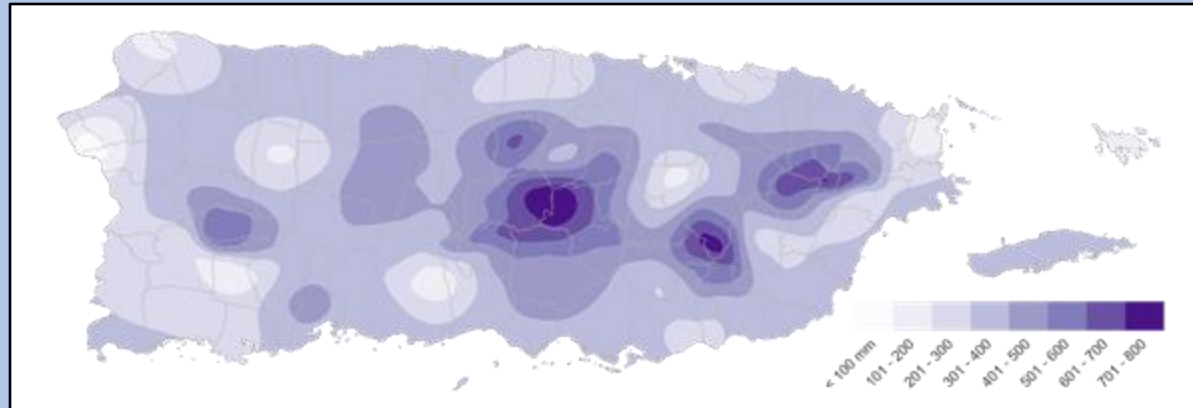
Peak gust wind speed with topographic effects (NIST wind-field model)



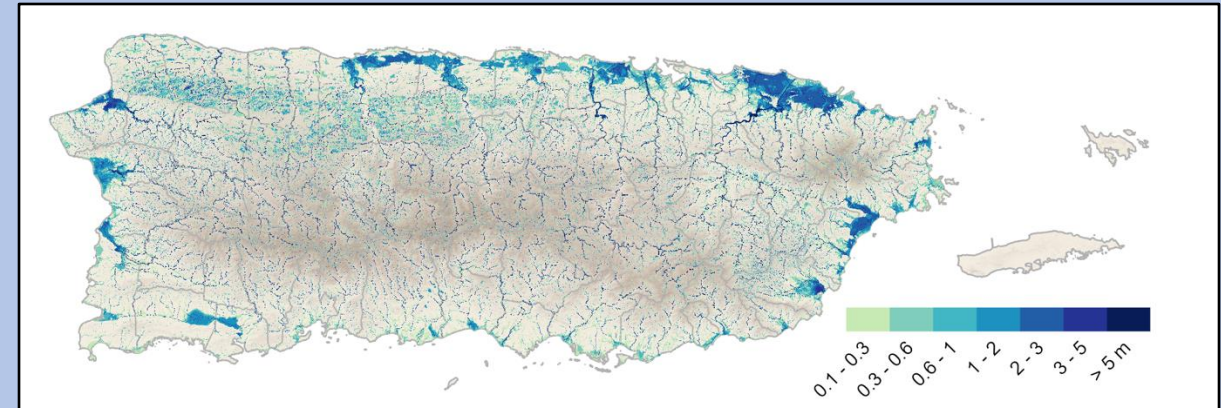
Landslide density (Data source: USGS)



Storm total rainfall (NIST Gaussian process model)



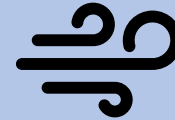
Flood depth (Bristol University modeling)



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

Hazard Characterization

Linking Hazard Exposure with Survey Data



Landslide density

Flood depth

Peak wind speed

Total rainfall



Created by Adrian Coquet from the Noun Project

1500+ Household Surveys
On public response to emergency communications



Created by iStockphoto from the Noun Project

450+ Business Surveys
On hurricane impacts and recovery



Created by Adrian Coquet from the Noun Project

275+ School Surveys
On recovery of social functions



Created by Adrian Coquet from the Noun Project

15+ Hospital Surveys
On recovery of social functions

What communications did the public receive about protective actions?

Emergency Communications

NOAA Weather Radio Messages

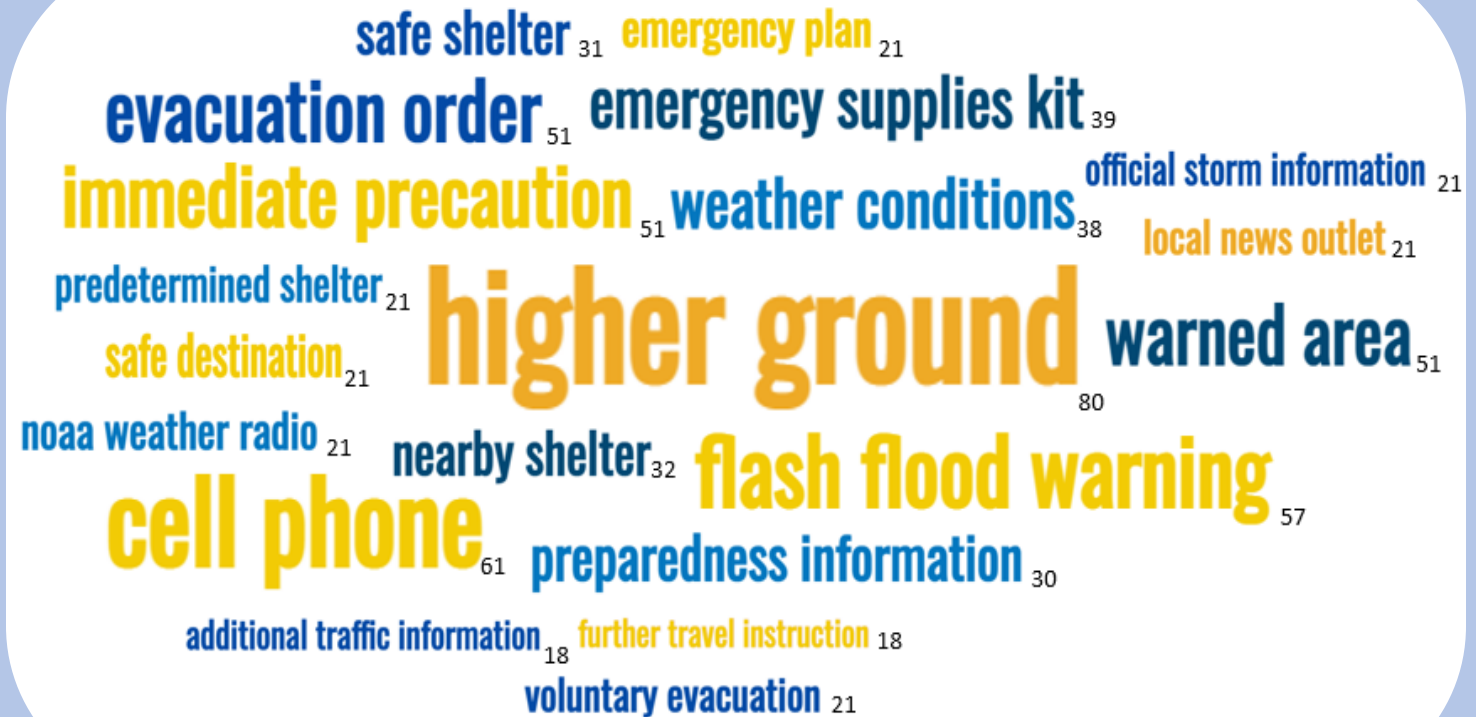
Move to higher ground due to flood risk

Charge cell phone and use sparingly

Follow locally-issued evacuation orders

Prepare emergency supplies kit

Phrases used for preparedness instruction:



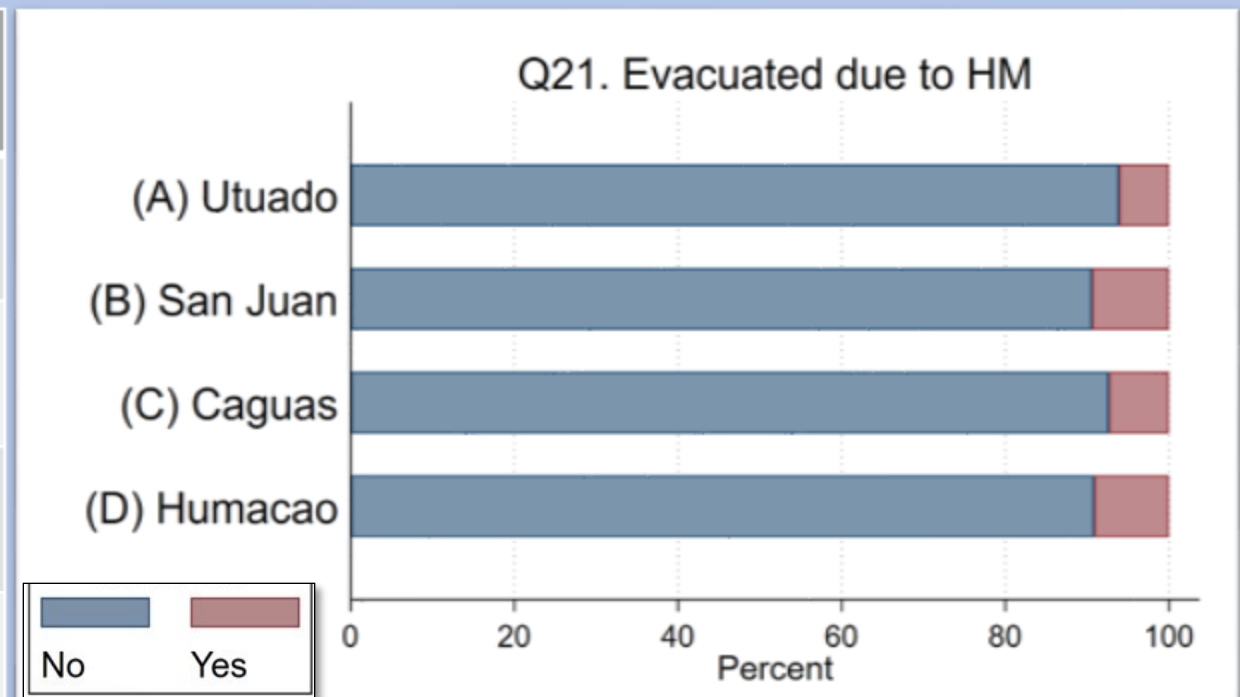
Emergency Communications

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%



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.

Created by Matthias Hartmann from Noun Project

Recovery of Social Functions

Hospital survey results:

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

Created by Adrian Coquet from the Noun Project

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.

Created by Kantor Tegakari from Noun Project

Critical Buildings

Hospital personnel interviews:

Created by Adrian Coquet from the Noun Project

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

Critical Buildings

Hospital personnel interviews:

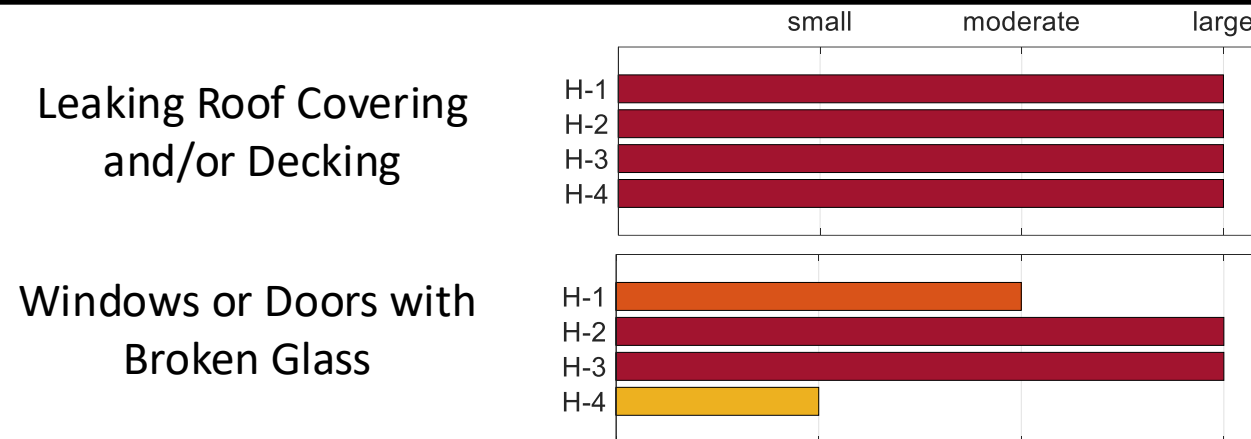
- All 5 hospitals experienced significant rainwater intrusion
- Most prevalent sources of rainwater intrusion:
 - Leaking roof covering and/or decking
 - Windows or doors with broken glass
 - Damaged or dislodged rooftop equipment



Created by Adrian Cooper from the House Project

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



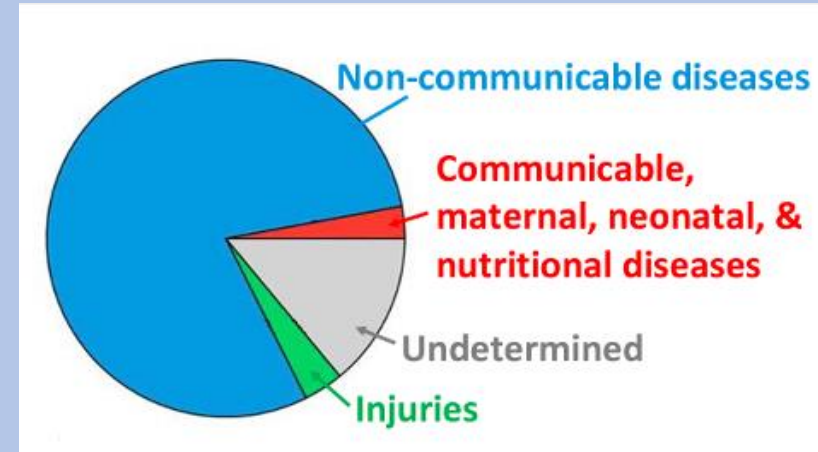
Damaged/Dislodged Rooftop Equipment



Morbidity and Mortality

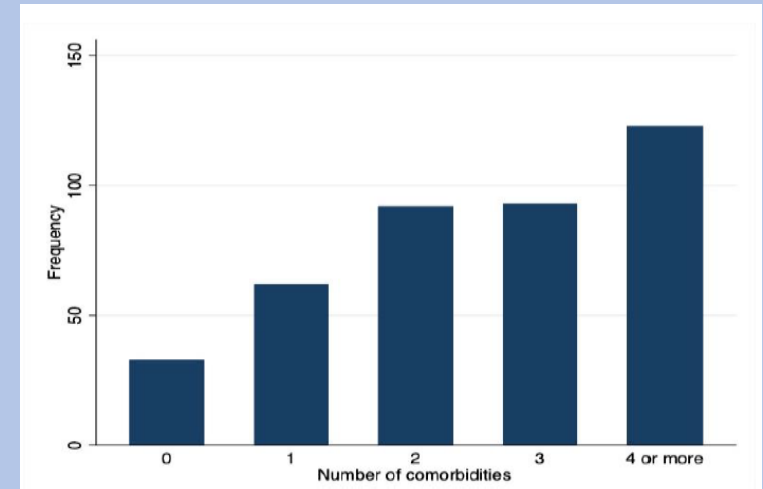
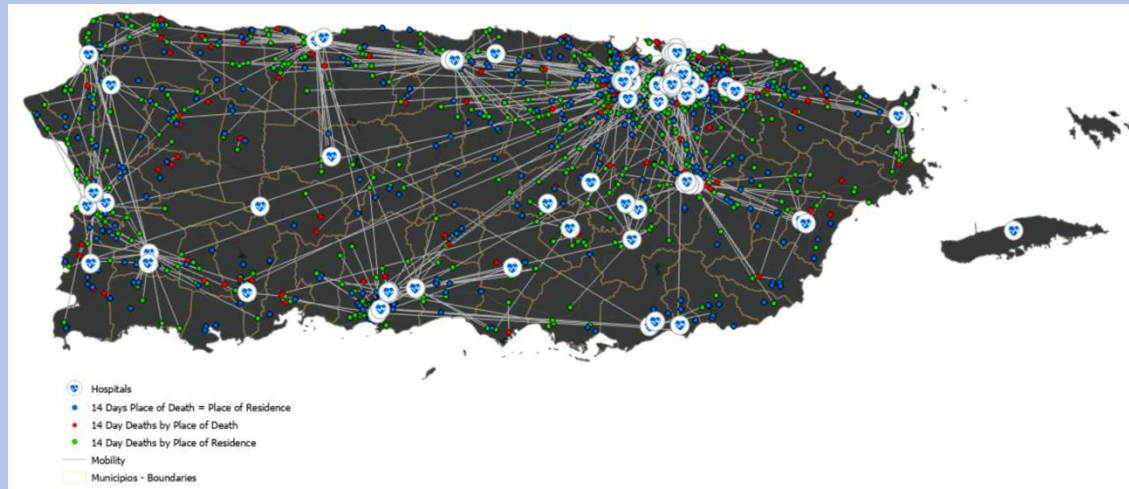
Verbal autopsy survey results:

- 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.



Created by Kantor Tegawan
Biotek Nippon Project

What were the impacts of damage on hospital functionality?

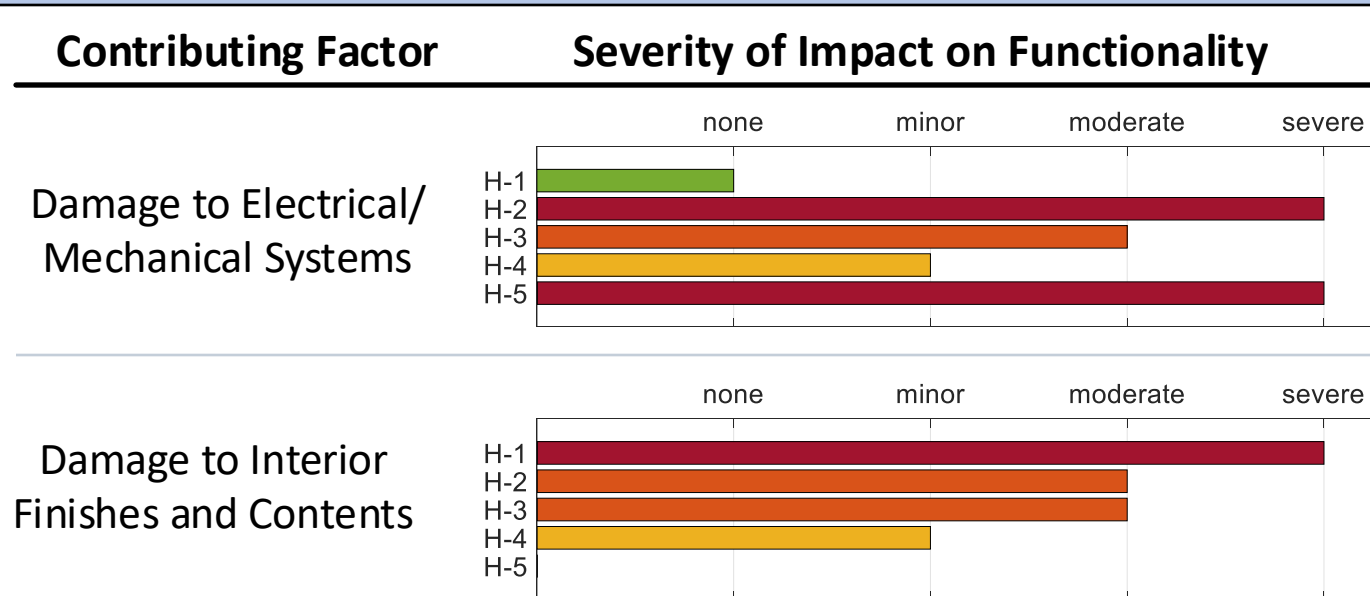
Critical Buildings

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:



Created by Adrien Coquet from the Noun Project



Morbidity and Mortality

Hospital personnel interviews:



Created by Vector Tradition from Noun Project

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.

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

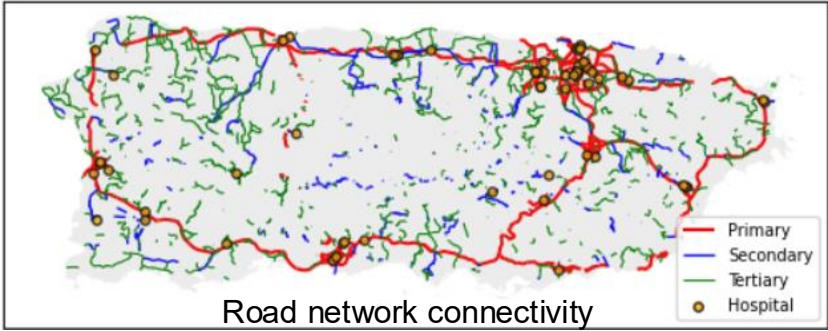
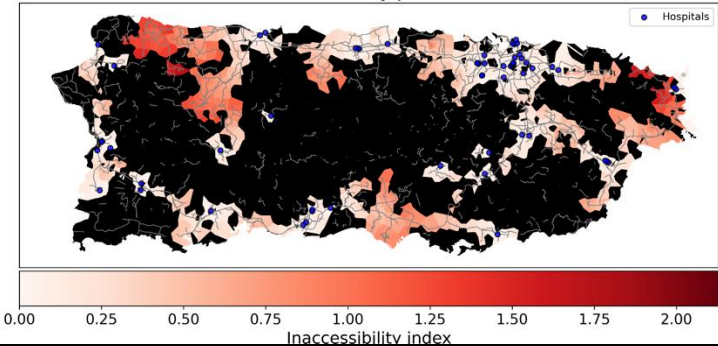
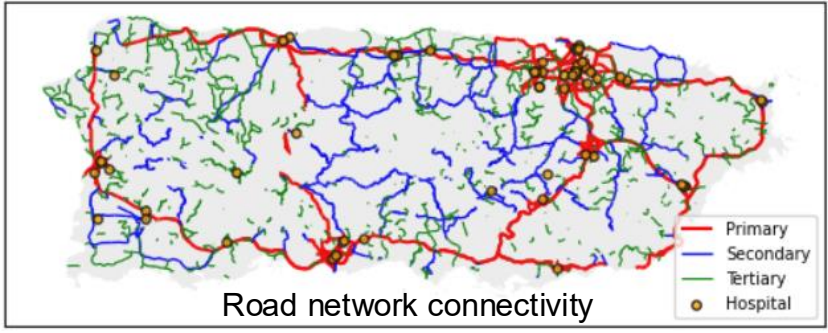
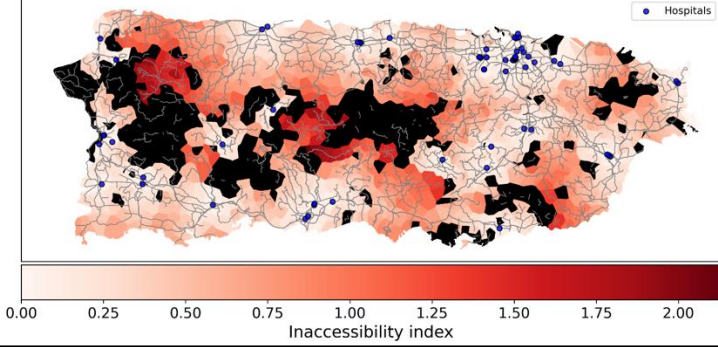
Recovery of Infrastructure

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



Immediately after Hurricane Maria	 Road network connectivity	 Inaccessibility index	• 30% of road segments disrupted • 54% have poor to no access • No (51%) • Poor (2.7%)
1 month after Hurricane Maria	 Road network connectivity	 Inaccessibility index	• 20% of road segments disrupted • 16% have poor to no access • No (12%) • Poor (4.4%)

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)


Created by Matthias Hartmann from Noun Project

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."

PRELIMINARY ANALYSIS

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


Created by Adrien Coquet from the Noun Project

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.

Morbidity and Mortality

Hospital personnel interviews:



Created by Karlos 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%

4

Preliminary Findings

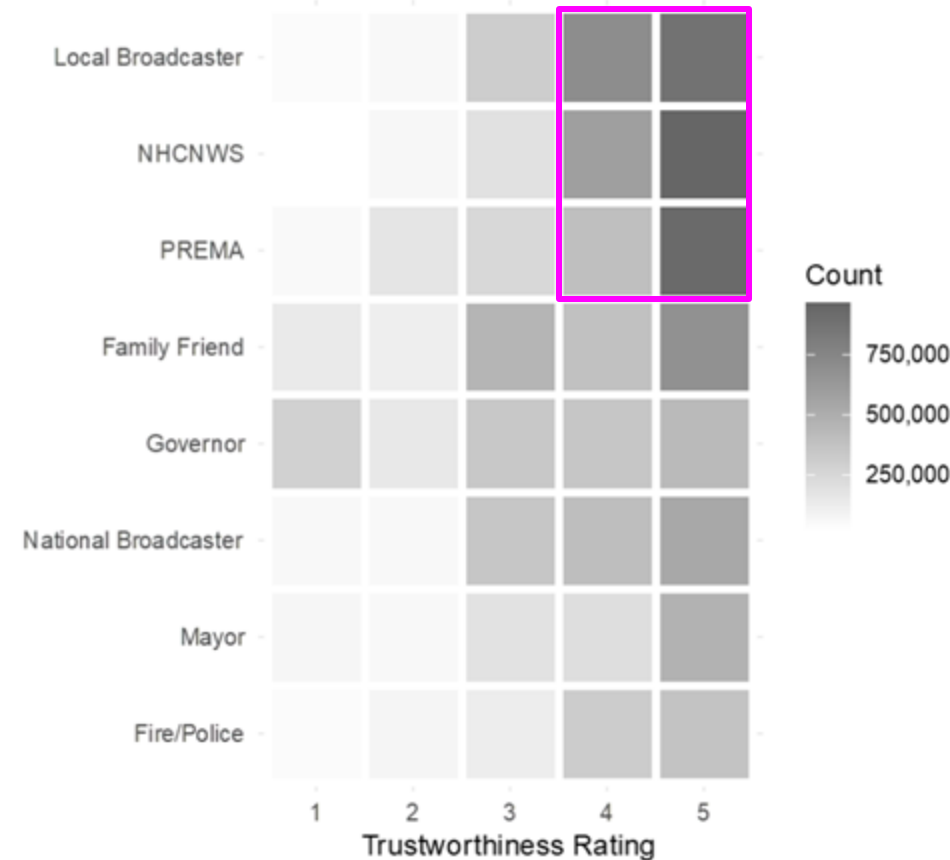
4 Preliminary Findings

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.

Source Trustworthiness Heatmap by Population



4 Preliminary Findings

Hazard Exposure

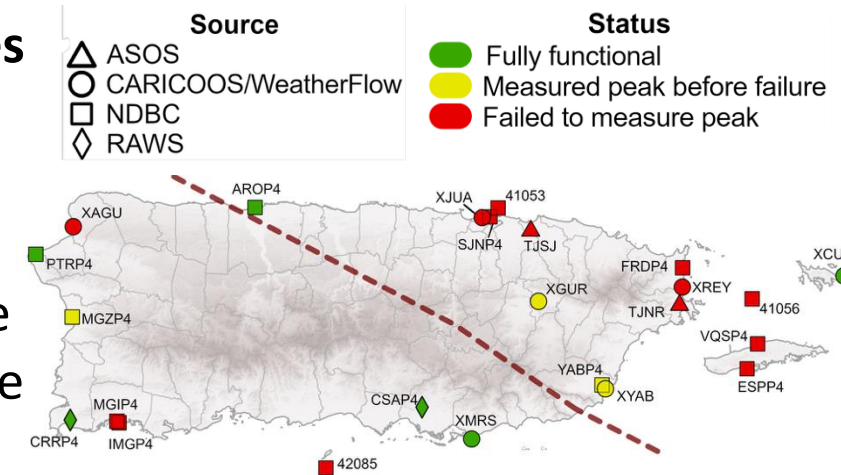
Failure of weather measurement systems posed significant challenges in quantifying Hurricane Maria's hazard exposure across Puerto Rico, both during the event and in post-storm assessments. Modeling was used to interpolate winds and rainfall from measurements deemed reliable. However, the limited availability 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:

- 14 of 24 stations failed to measure the maximum wind speeds.
- Of the 10 that captured the highest speeds, 4 eventually failed, leaving only 6 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



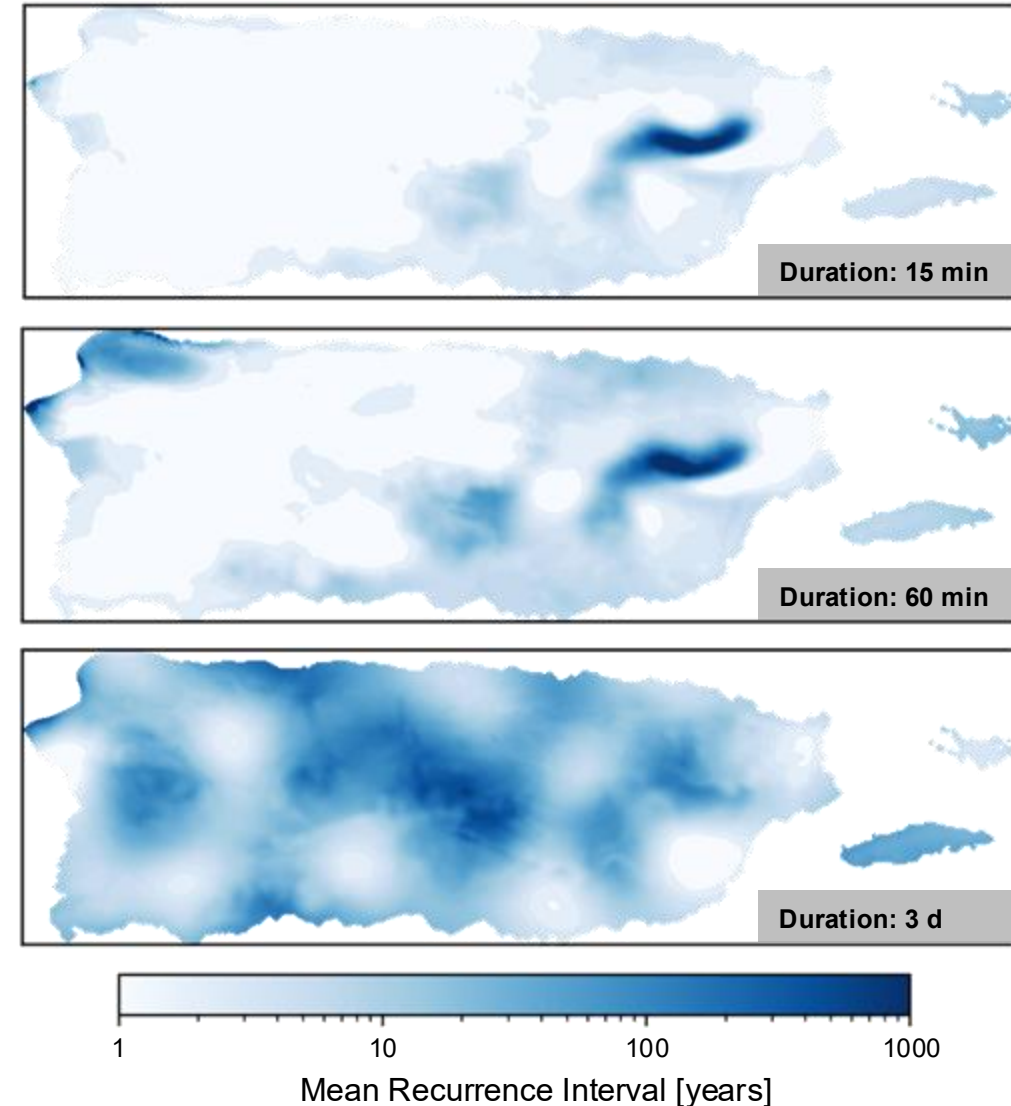
Failure of Doppler weather radar

4 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.

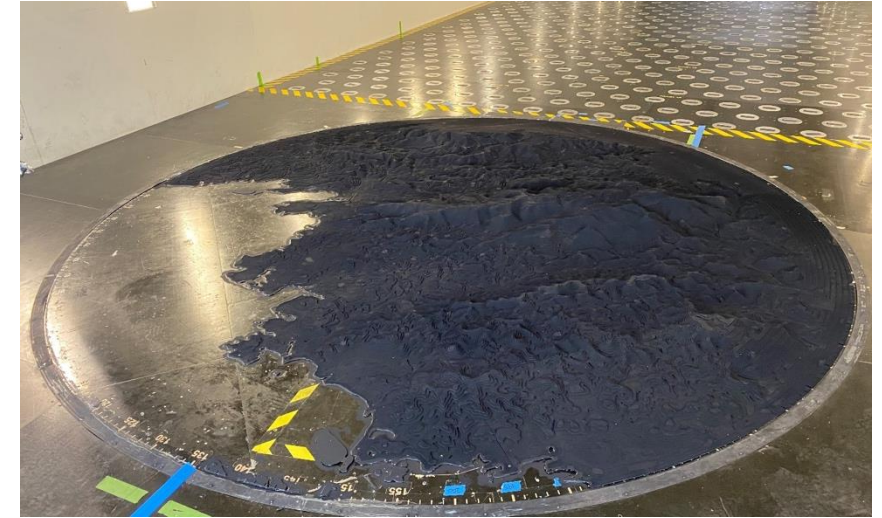


4 Preliminary Findings

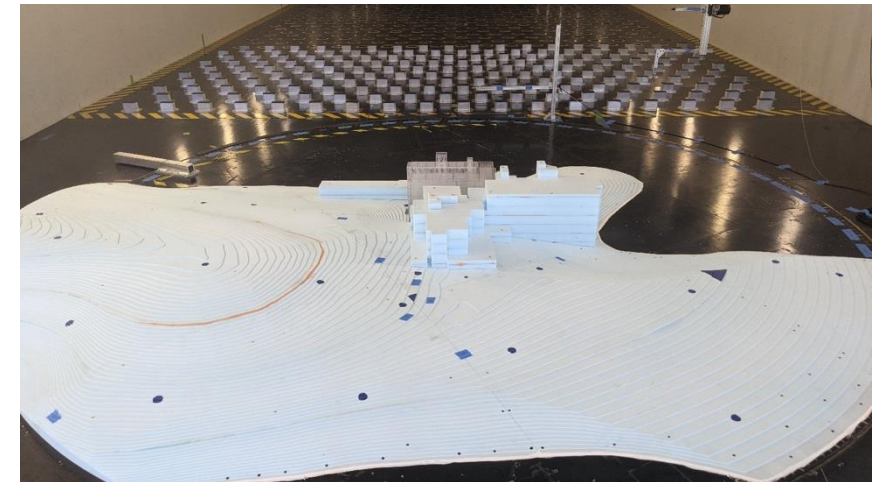
Hazard Exposure

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

4 Preliminary Findings

Hazard Exposure

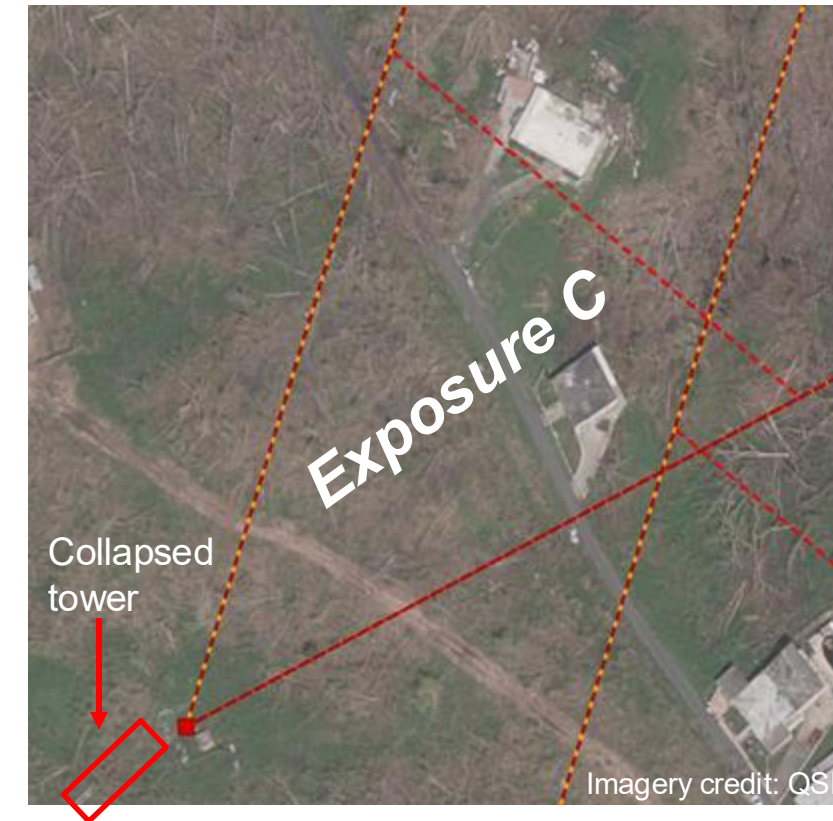
Hurricane winds caused extensive damage to trees, especially along mountain ridges where topographic effects were significant. Damaged trees resulted in other disruptions:

- 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

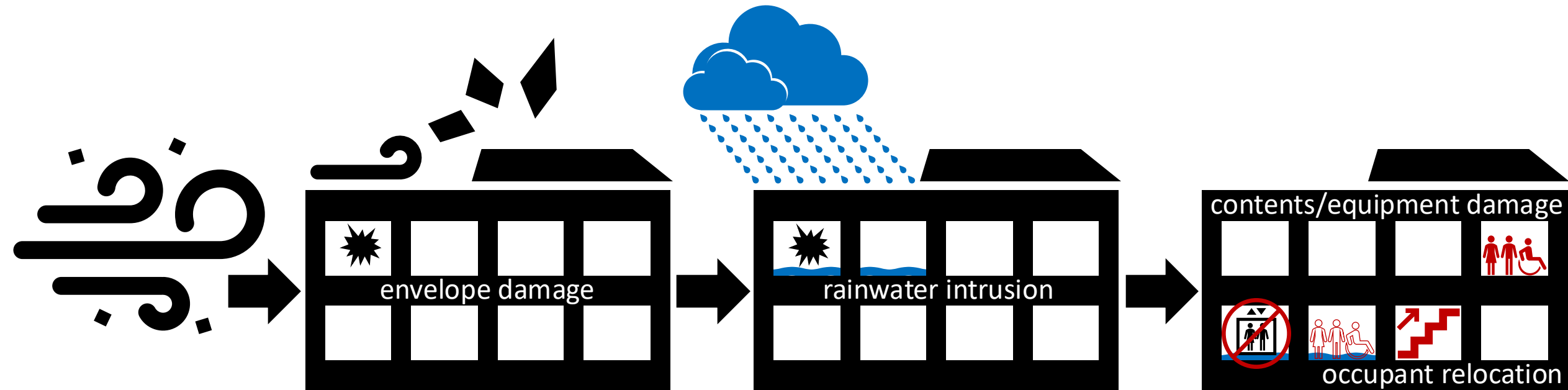


Before Hurricane Maria



After Hurricane Maria

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.



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:

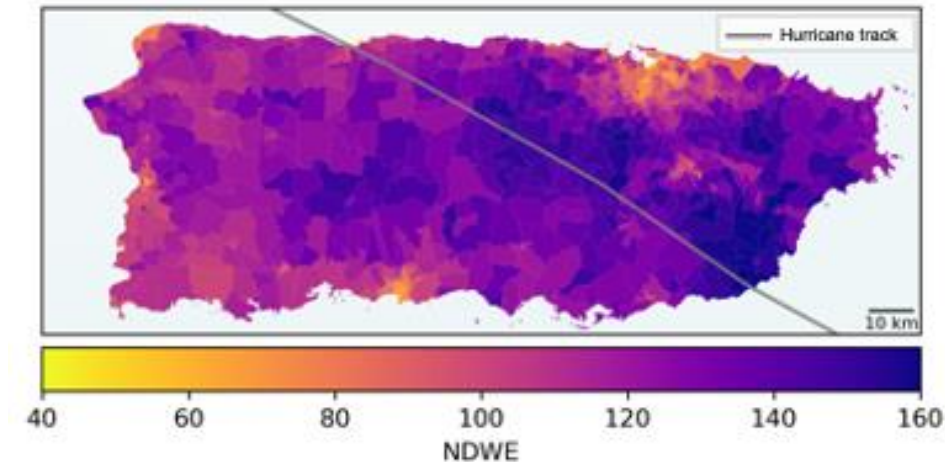
- Refuge areas were affected by rainwater intrusion and flooding, especially accessible ground-floor refuge areas, requiring relocation of occupants.
- Lack of air conditioning (due to damage and or loss of power) exposed occupants to high heat and humidity and contributed to mold/mildew growth (following 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.



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:

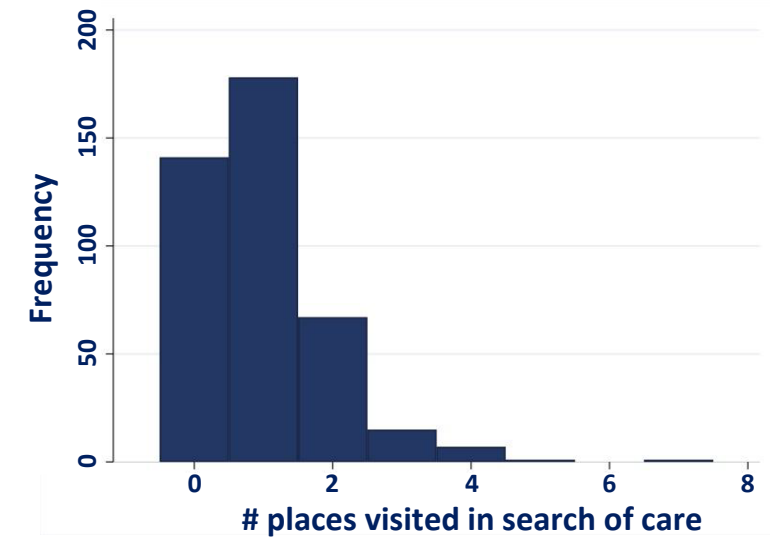
- Infrastructure operators ranked disruptions in availability of temporary power sources, fuel, and maintenance and repair services, as well as lack of communications, as key factors in slowed infrastructure service recovery.
- Prolonged electrical power disruption was a factor in recovery of social 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



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

- Transportation network disruption following Hurricane Maria is estimated to have 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

4 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



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.



5

Anticipated Impacts

- 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.

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:

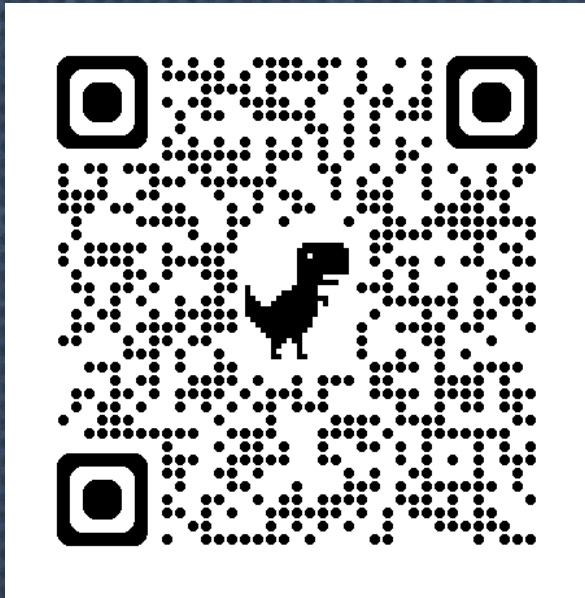
- NCST Members
- Technical Staff
- NIST Associates
- Institutional Support
- Contractors

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

NIST's Hurricane Maria Investigation

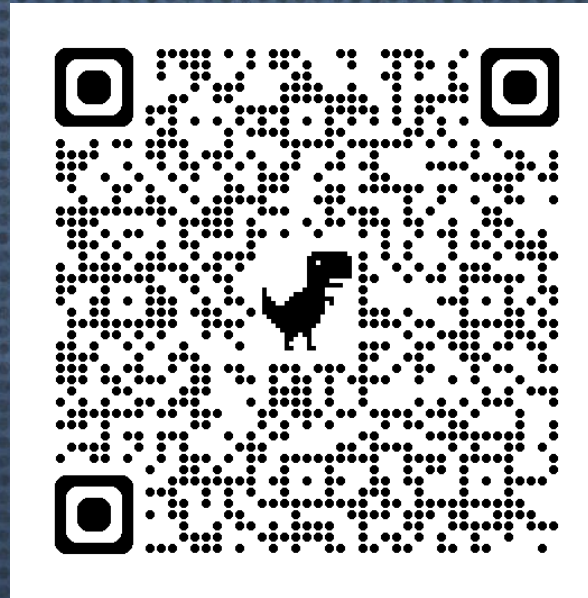
NIST HM Information

<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>

