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PUCP

Efectos de fallas Geotécnicas en Puerto Rico por el Huracán María

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Conferencia Patrocinada por la Maestría en Ingeniería Civil
Escuela de Posgrado, PUCP
OpenPUCP, Plaza San Miguel
Lima, Perú, 27 Mayo, 2019

AGENDA

- Eventos Extremos
- Misión NSF GEER.
- Ubicación, Descripción general de PR.
- El evento (Huracán María).
- Ejemplos de Daño Observado.
- Mecanismo Deslizamientos Inducidos por Lluvia.
- Resumen y Conclusiones.

NOTA A PARTICPANTES

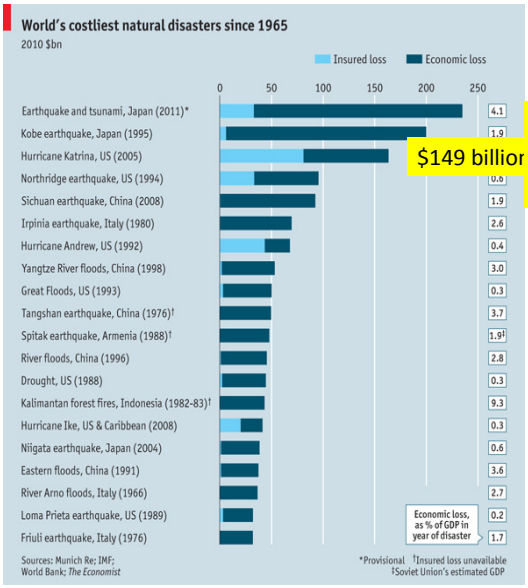
- La presentación es un archivo muy grande. Como el material presentado esta relacionado al informe final de la misión GEER se sugiere bajar informe final en la siguiente dirección:

http://www.geerassociation.org/

- Si no puede bajar este informe de la direccion arriba mencionada contactar a: mpando@uncc.edu

EVENTOS EXTREMOS

Natural Disaster: a trillion dollar business



$149 billion

Irma + Harvey ~ $200 billion
Maria ~ $139 billion
Florence - $170 billion

UNC CHARLOTTE EPIC

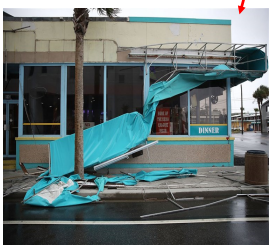
Escala Saffir-Simpson de Velocidades de Viento en Huracanes

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph 64-82 kt 119-153 km/h	**Very dangerous winds will produce some damage:** Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 83-95 kt 154-177 km/h	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3 (major)	111-129 mph 96-112 kt 178-208 km/h	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 113-136 kt 209-251 km/h	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or higher 137 kt or higher 252 km/h or higher	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

UNC CHARLOTTE EPIC

Extreme Hurricanes: Wind speed

Wind speed at Land
Michael – 155 ~~mph~~
Maria – 155 mph
Florence - 90 mph
Katrina – 120 mph



(Photo Credit: Internet)

Typical tropical storm: 39 to 74 mph
Hurricane: > 74 mph
Tornado wind speeds: 112 mph to 300 mph

Super typhoon Haiyan (Yolanda)

En Filipinas
Nov. 2013
Vel. Viento = 190 mph

(No se ha visto en EEUU)

(Photo Credit: Shenen Chen)

Eventos Climáticos Extremos

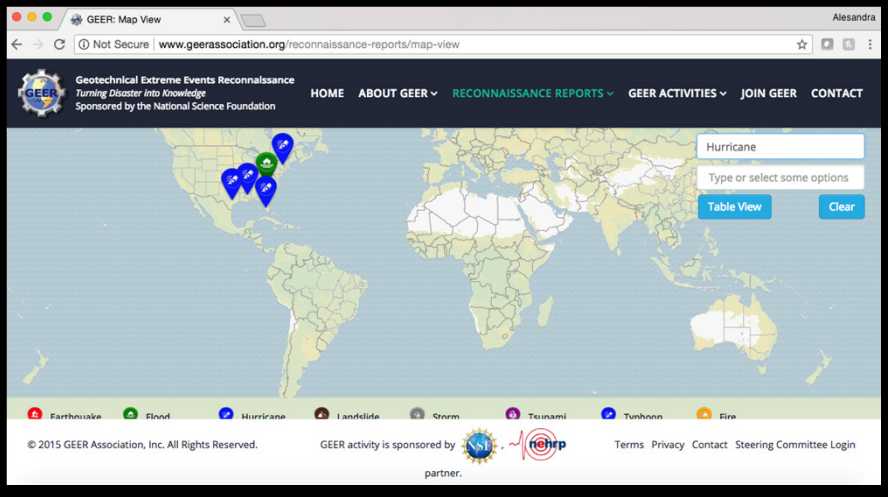
- Fuerzas Extraordinarias!
- Distintas amenazas/peligros:
  - Florence: Inundaciones,
  - Michael: Vientos y fuerzas asociadas.
- ***Multiple hazards***:
  - Marejada + inundaciones + viento + erosión + deslizamientos.
- Dependerá tipo de evento, región geográfica, geología, uso del terreno, etc.

MISIÓN NSF GEER

National Science Foundation GEER

- Geotechnical Extreme Events Reconnaissance (GEER) Association *"Turning Disaster into Knowledge"*
- http://www.geerassociation.org/

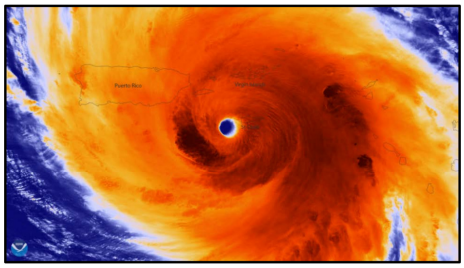
National ScienceFoundation GEER



MISION FUNDACION NACIONAL DE CIENCIAS
NSF GEER MISSION

GEOTECHNICAL IMPACTS OF HURRICANE MARIA IN PUERTO RICO

Event Date: September 20, 2017



by: Francisco Silva-Tulla (Leader), Miguel A. Pando (Co-Leader), Alejandro E. Soto, Alesandra Morales, Daniel Pradel, Gokhan Inci, Inthuorn Sasanakul, Juan R. Bernal, Robert Kayen, Stephen Hughes, Tiffany Adams, and Youngjin Park

Geotechnical Extreme Events Reconnaissance
Turning Disaster into Knowledge
Sponsored by the National Science Foundation

GEER Association Report No. GEER-057 June 29, 2018

Table 1-1: Summarizes the GEER team composition

First Name	Last Name	Team Role	Organization	Expertise	Home Base
Francisco	Silva-Tulla	Leader*	Consulting Civil Engineer	Geotechnical engineering, earth structures	MA
Miguel A.	Pando	Co-Leader*	University of North Carolina (NC), Charlotte	Geotechnical engineering	NC
Tiffany	Adams	Member*	AECOM	Geotechnical engineering	CO
Juan R.	Bernal Vera	Member*	University of PR, Mayagüez	Geotechnical engineering	PR
Luis Oscar	García	Member	GeoCim	Geotechnical engineering	PR
Carlos	García Echevarría	Member	GeoCim	Geotechnical engineering	PR
Stephen	Hughes	Member*	University of PR, Mayagüez	Geology of PR, unmanned aerial vehicle (UAV)	PR
Gokhan	Inci	Member*	Federal Emergency Management Agency (FEMA)	Civil engineer, FEMA National Dam Safety Program	Washington, DC
Robert	Kayen	Member*	USGS	Geometry determination, UAV, LiDAR	CA
Alesandra Cristina	Morales Velez	Member*	University of PR, Mayagüez	Geotechnical engineering	PR
Youngjin	Park	Member*	University of NC, Charlotte	Geotechnical engineering	NC
Daniel	Pradel	Member*	The Ohio State University	Geotechnical engineering	OH
Inthuorn	Sasanakul	Member*	University of South Carolina (SC)	Geotechnical engineering, erosion and scour	SC
Alex	Soto	Member*	GeoCim	Geology of PR, landslides	PR
José Miguel	Bermudez	Collaborator	Puerto Rico Electric Power Authority (PREPA), Dams and Irrigation Division	PR State Dam Safety Official	PR
Ruben	Estremera	Collaborator	PRASA	Dam safety	PR
Jaime	Lopez	Collaborator	PRASA	Dam Safety	PR
Aurelio	Mercado-Irizarry	Collaborator	University of PR, Mayagüez	Oceanography	PR

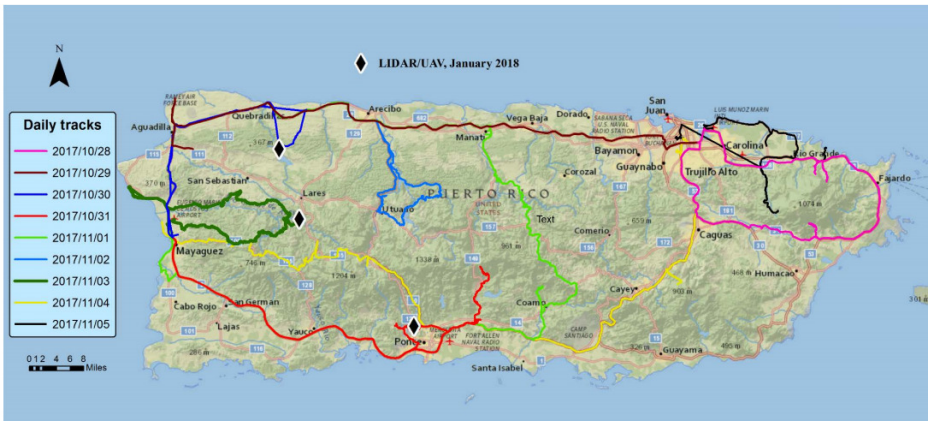
* Indicates report co-author

GEER Association Report No. GEER-057

NSF GEER Mission
10/31/17 – Guayabal Dam

Hurricane Maria GEER Team

Reconnaissance daily tracks



UBICACIÓN, DESCRIPCIÓN GENERAL DE PUERTO RICO

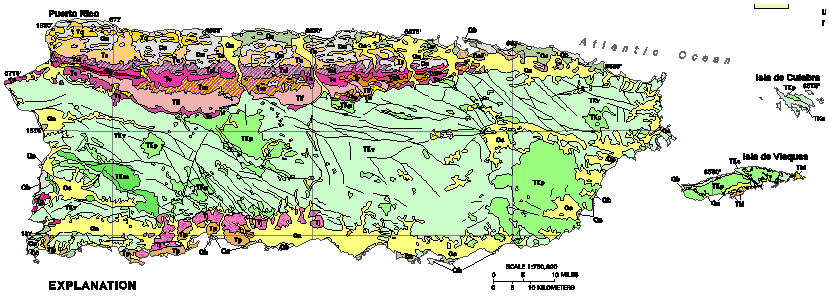
Background (Location)

Background (Puerto Rico)

Dimensions: 180 km x 65 km
Population ≈ 3.8 millions

Population densities:
PR: **325** p/km^2
US: 31 p/km^2
Mexico: 54.5 p/km^2
Canada: 3.3 p/km^2

Geology



EXPLANATION

Quaternary deposits
- Qa Alluvium
- Ql Landslide deposits
- Qb Beach deposits
- Qs Swamp and marsh deposits
- Qaf Artificial fill
- Qu Undifferentiated surficial deposits

Pliocene and Miocene rocks
- Tq Quebradillas Limestone
- Tp Ponce Limestone

Miocene rocks
- Ta Aymamón Limestone
- Tad Aguada (Los Puertos) Limestone
- Tg Guaniljibo Formation
- Tc Cibao Formation
- Tmv Montebello Limestone Member
- Tqa Quebrada Arenas Limestone Member (includes Miranda Sand Member
- Tr Río Indio Limestone Member (includes Almirante Sur Lentil
- Tcg Guajataca Member

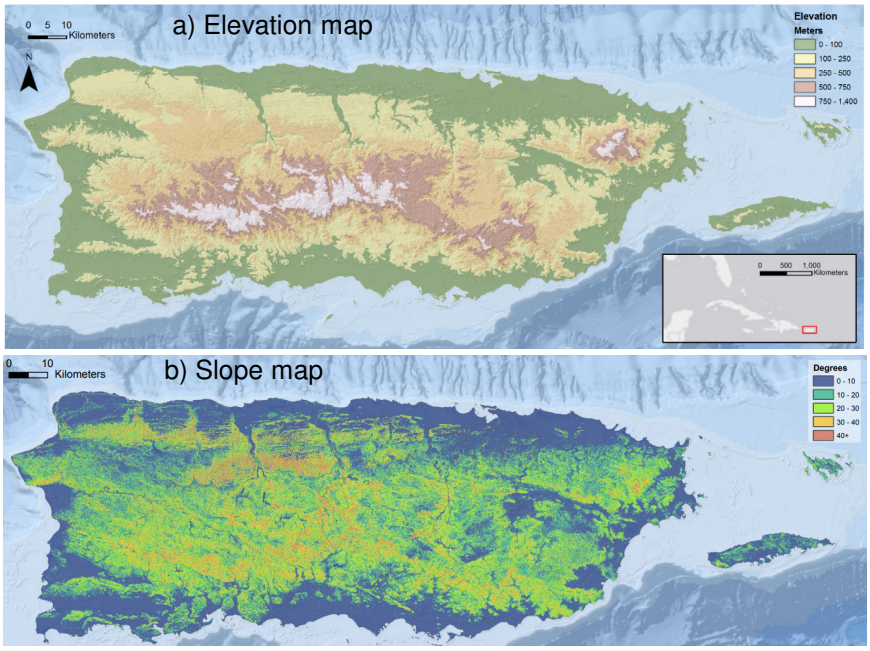
Miocene and Oligocene deposits
- Tmc Mucarabones Sand
- Tj Juana Díaz Formation
- Tlf Lares Formation
- Ts San Sebastián Formation

Eocene, Paleocene, and Cretaceous rocks
- TKv Volcanic and sedimentary rocks
- TKp Plutonic rocks (Mostly quartz diorite and granodiorite
- TKm Metamorphic (serpentinite), sedimentary, and igneous rocks

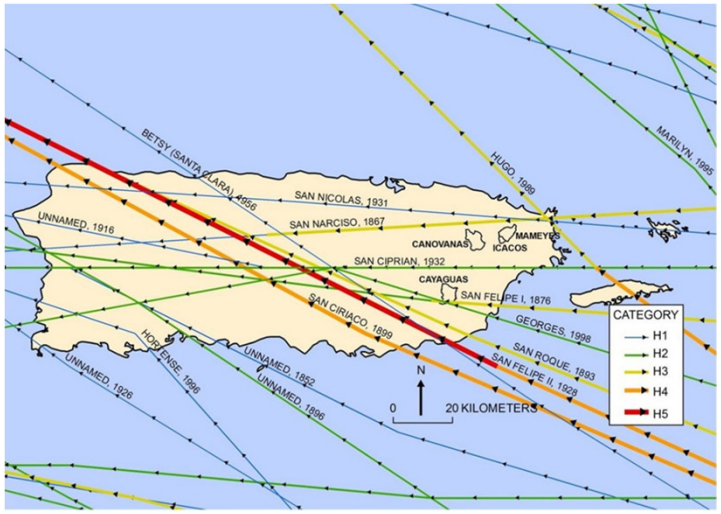
Fault

Modified from:
Briggs, R.P., and Akers, J.P., 1965, Hydrogeologic map of Puerto Rico and adjacent islands: U.S. Geological Survey Hydrologic Investigations Atlas HA-197, scale 1:240,000, 1 sheet
Monroe, W.H., 1980, Geology of the middle Tertiary formations of Puerto Rico: U.S. Geological Survey Professional Paper 953, 93 p.
R.D. Krushensky, written commun., 1993.
Base modified from U. S. Geological Survey digital data.

Topography



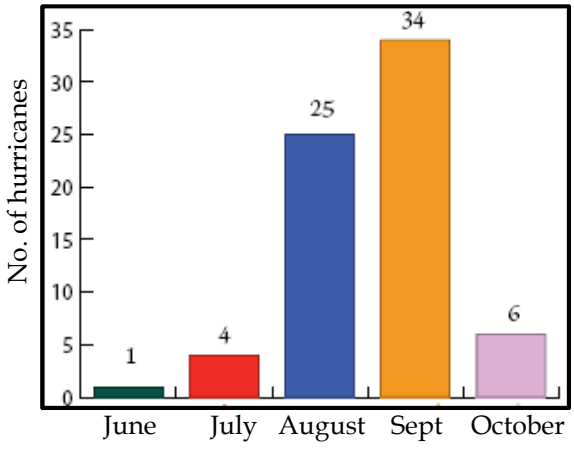
Background - Path of historical hurricanes that have impacted Puerto Rico



[Source: https://www.usgs.gov/media/images/puerto-rico-hurricanes-map] [USGS, 2018]

Severe Hurricanes (Seasonal Distribution)

(Period 1508 to 1997)



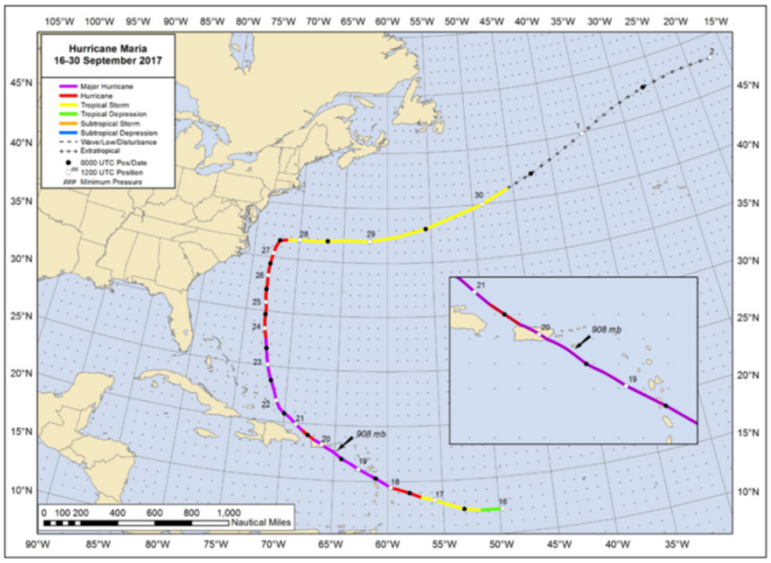
Note: Only hurricanes with wind speeds ≥ 60mph
(Adapted from Boose et al. 2004)

EL EVENTO (HURACÁN MARÍA).

Hurricane Maria (20 Sept./17)

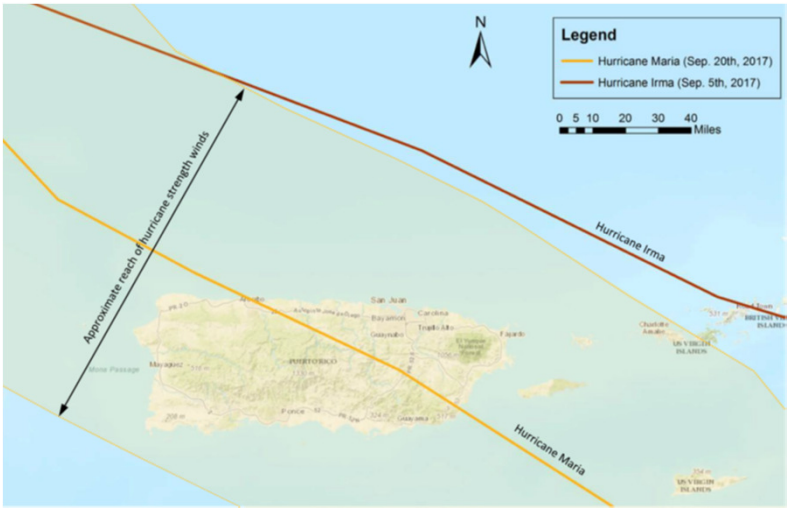
- Landfall SE town of Yabucoa as a powerful Category 4 storm at 6:15 am Wednesday, 20 Sept. 2017.
- Moved diagonally across the island with sustained winds of 155 mph (~250 kph), exit near Arecibo about 3 pm, 20 Sept. 2017.
- 48-hr average rainfall intensity between 5.8 to 11.6 mm/hr.
- Worst storm to hit PR in over 80 years.
- Arrived only two weeks after Hurricane Irma that passed just north of the island causing heavy rains throughout the island leaving about 1 million residents without power.
- Scale of Maria's destruction was devastating:
  - ≈ $95 billion in damages (Moody's Analytics, 28 Sept. 2018),
  - Electricity was cut off to 100% of the island,
  - Access to clean water and food became limited for most residents,
  - Number of fatalities attributed to Hurricane Maria: 4,645 fatalities (Kishore et al. 2018 in the New England Journal of Medicine).

Extended Path of Maria (9/16/17 to 10/02/17) (Landfall in PR September 20, 2017)



[USGS, 2018]

Paths of Hurricanes Irma and Maria with respect to Puerto Rico

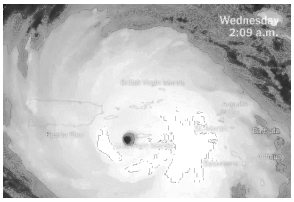


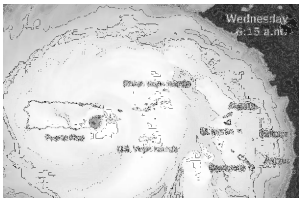
(adapted from Feng et al., 2018)

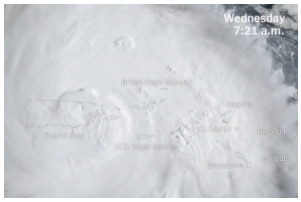
Maria:

- Category 5 (Saffir-Simpson wind scale) before PR
- Landfall as Category 4 at Yabucoa at 6:15 am on 9/20/17.

Images of Maria from Space







Landfall as Category 4
Yabucoa at 6:15 am, 9/20/17

Source: NASA

EJEMPLOS DE DAÑO OBSERVADO.

SE REFIERE AL PARTICIPANTE AL INFORME GEER

RESUMEN Y CONCLUSIONES.

Resumen y Conclusiones

- María: Evento Extraordinario! Demanda de carga muy alta (Viento >140 mph (>224 kph); Lluvia; Erosión).
- Múltiples Peligros/Amenazas:
  - Marejada+ inundaciones+ viento+ erosión + deslizamientos.
- Lluvia antecedente del Huracán Irma aumento vulnerabilidad!
  - Lluvia de Irma saturó laderas, reducción de resistencia al corte;
  - facilitó desprendimiento de arboles y vegetación.
  - Aumento efectos de deslizamientos, cantidad (frecuencia, distribución geográfica).
  - Aumento erosión superficial.
  - Frente de saturación más profundo, desprendimiento de arboles, facilito y aumento cantidad de flujo de escombros,
  - Daño a torres de transmisión, postes de electricidad, daño red eléctrica.
- Aguas debajo de deslizamientos:
  - Los inmensos volúmenes de escombros (suelo, lodo, arboles, escombros), crearon obstrucción de desagües, drenajes, alcantarillas, puentes. Esto resulto en fallas de varios puentes, y colapso de varias carreteras.

Resumen y Conclusiones

- Las fallas geotécnicas observadas en PR después del huracán María resaltaron la importancia que las lluvias antecedente s tienen en deslizamientos y flujo de detritos durante eventos extremos como huracanes y tormentas (El Niño/La Niña).
- Los efectos producidos por el Huracán María en los efectos que podemos esperar en topografía montañosa con suelos residuales en estado inicial no saturado (Cohesión aparente).
- La comunidad ingenieril debe adaptar y mejorar practicas der diseño y construcción para aumentar la resiliencia de la infraestructura y las *"lifelines"*.
- Debemos mejorar nuestra habilidad para estimar volúmenes de flujo de detritos, velocidad, trayectorias, para poder incorporar y diseñar medidas de mitigación (mejores torres de transmisión, postes eléctricos, cuencas de captación de residuos/escombros, etc.) para así reducir efectos negativos en estos eventos extremos.

MUCHAS GRACIAS POR SU ATENCIÓN

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