Impact of Climate Change in the Highway and Transportation Infrastructure Adjacent to the Coast in Urban Settings of Caribbean Countries

Benjamín Colucci Ríos
PhD, PE, PTOE, FITE, JD, API
Professor
University of Puerto Rico at Mayagüez

Alexander Molano Santiago
BSCE
Graduate Student
University of Puerto Rico at Mayagüez

Lessons Learned and Best Practices – Resilience of Coastal Infrastructure
Headquarters of the College of Engineers and Surveyors of Puerto Rico
San Juan, Puerto Rico • March 9, 2017
Good Morning!
“The benefit of this research is for the whole population. At the end of the day, the biggest issue isn’t going to be us, it’s going to be the public.”

Mr. José E. Sánchez, Director
U.S. Army Engineer Research and Development Center
Coastal and Hydraulic Laboratory
Coastal Transportation Infrastructure

a. PR-165, Toa Baja, PR
b. Barahona Railway, RD
c. Luis Muñoz Marín International Airport, Carolina, PR
d. Puerto Caucedo, Boca Chica, RD

e. Rincón Lighthouse, PR

Lessons Learned and Best Practices-Resilience of Coastal Infrastructure

a., b. y d.  https://www.panoramio.com
c.  https://blog.masslive.com
e.  https://s-media-cache-ak0.pinimg.com
Characteristics of Puerto Rico’s Highway Network

• 28,862 km, of which 454 km are freeways concentrated along the coast (200 km)
• Uniform density throughout territorial extension

Sources:
- Autoridad de Carreteras y Transportación de Puerto Rico
  http://geoserver.gis.pr.gov/geoserver/wfs?request=GetFeature&typeName=pr_geodata:g35_viales_carreteras_estatales_julio_2015&outputFormat=SHAPE-ZIP
Condition of bridges and pavements in Puerto Rico

• Condition of network pavements:
  • 80.4% “poor”
  • 16.7% “fair”
  • 2.9 % “good”


• Inventory: 2,304 bridges
  • Federal National Highway System: 780
  • Classed as deficient: 1,269
  • Functionally obsolete: 968
  • Structurally deficient: 301
Port Infrastructure of Puerto Rico

• **Total foreign trade of Puerto Rico in 2015**
  - **Exports:** $ 69,391 million
  - **Imports:** $ 43,233 million
  - **Net Balance:** $ 26,158 million

• *Port of San Juan* among **top 10 container seaports in the USA and territories**
  based on trade volume: 1,319,961 TEU (2014, +3.9% growth from previous year)

Sources: Apéndice Estadístico del Informe Económico al Gobernador y a la Asamblea Legislativa, Junta de Planificación
Characteristics of Dominican Republic’s Highway Network

- 9,872 km and undergoing rapid expansion
- Greatest density towards interior and south coast

Zona marítima in DR
Ley 305, May 29, 1968

• Sesenta (60) metros tierra adentro desde línea de pleamar (marea alta) ordinaria, incluyendo humedales costeros
Excepciones: turístico, utilidad pública

• Extensión lineal: 1612 km

http://www.jmarcano.com/mipais/geografia/costa.html
http://ojd.org.do/Normativas/INMOBILIARIA/Leyes/Ley%20Nv%20305,%20que%20modifica%20el%20articulo%2049%20de%20la
%20Ley%20No%201474,%20sobre%20Vias%20de%20Comunicación,%20de%20fecha%2022%20de%20febrero%20de%201938.pdf

Zona marítimo-terrestre in PR, 1886

• Espacio costanero de Puerto Rico
  • Definida por reflujo de olas donde sean sensibles (significativa) las mareas
  • Definida por mayores olas de los temporales (tormentas y huracanes) donde no sean sensibles las mareas

• Origen: Ley de Puertos de España, 1880
• Extensión lineal: 1,286 km
• Reglamento 4860, DRNA
Tidal Range in the Caribbean and its Relationship to Global Tidal Ranges

- Caribbean: 10 cm
- West Atlantic Ocean: 30 cm
- Context of Puerto Rico and Dominican Republic

Coastal Zone of Puerto Rico

- Strip located along the land-sea interface
- Definition: land strip located up to 1,000 meters inland and the sea strip located up to 3 leagues (16.66 km or 9 miles) from the high tide coastline
- Legal basis: Coastal Zone Management Act

Relevant Data of the Coast of Puerto Rico

- Zona costanera (superficie terrestre): 953.9Km² (1 Km)
- Aguas territoriales: 13,154.5 Km² (9 mn)
- Línea de costa: 1286 kilómetros
- Número de playas: ~1,220
- Frente marino ocupado: 24%
- Municipios costeros: 44
- Población municipios costeros: 2,317,189 (61%)
- Aeropuertos: 10
- Puertos: 12
- 200 kilómetros de carreteras primarias
- 1,738 kilómetros de infraestructura sanitaria
- Complejos de generación eléctrica: 7
- Plantas de tratamiento de aguas usadas: 13
- Parques industriales: 81
- Áreas terrestres protegidas: 16% (CLCC)
- Áreas marinas protegidas: 27.19%

= 10.5% of Puerto Rico land area

Credits: Ernesto Díaz, Department of Natural and Environmental Resources
Maritza Barreto, University of Puerto Rico at Río Piedras
Comparison of Coastal Demographics (0-10 m above sea level) of PR and DR at the Latin America and Caribbean Region

**Puerto Rico**
- 0.70M / 3.57 M inhabitants (7th)
- 726.7 inh/km² (7th)
- 17.2% of population (14th)

**Dominican Republic**
- 0.45M / 10.6 M inhabitants (9th)
- 253.5 inh/km² (9th)
- 6.1% of population (29th)

Source: GRUMP-CIESIN
Economic Activities Dependent on Coastal Transportation Infrastructure

- Import and Export of Merchandise → PR and DR are in islands
- Tourism
  - Cruise ships
  - International passengers
  - Sports and aquatic recreation
- Military defense
- Communication with adjacent islands
- Food (imports, fishing)
- Everyday land-based transportation → coastal roads and highways

Source: http://www.fortaleza.pr.gov/sites/default/files/CRUCEROS%206.jpg
Natural Threats Associated to Climate Change Impacting Coastal Zones of PR and RD

A. Sea Level Rise

B. Storm Surge and waves

C. Lower River Flooding

D. Saltwater Intrusion in Aquifers and Structures

E. Ocean Acidification

A. Credits: Dr. Aurelio Mercado, Sea Grant Puerto Rico
B. http://ecoexploratorio.org
C. http://rec-end.gfrcdn.net
D. http://www.recursosaguapuertorico.com
E. https://cdn.shopify.com
Probable Sea Level Rise Scenarios for 2100 at La Puntilla (San Juan) and Isla Magueyes (Lajas)

Likely scenarios for La Puntilla:
- Low: 0.18 m
- Medium: 0.49 m
- High: 1.50 m

Likely scenarios for Isla Magüeyes:
- Low: 0.15 m
- Medium: 0.46 m
- High: 1.46 m

Source: Puerto Rico’s State of the Climate 2010-2013, United States Army Corp of Engineers
Sea Level Rise Scenario of 1.5m at San Juan and Ponce

- **San Juan**
  - Port of San Juan (cruise ships) = completely flooded
  - Bridges to Old San Juan = potentially unusable
  - Highway PR-165 adjacent to sea
  - Cataño ferry terminal unusable
  - Puerto Nuevo = disconnected from highway network due to Kennedy Ave. flooding
  - PR-26 permanently flooded
  - Luis Muñoz Marín Airport = north runway unusable
  - Mercedita Airport exposed to minor cyclonic events (storms, category 1)
  - PR-Z adjacent to sea at Ponce
  - Port of Ponce unusable
  - PR-52 adjacent to sea

- **Ponce**
  - Guayanilla bay with all ports flooded
  - LNG terminal at Peñuelas unusable

Source: https://coast.noaa.gov/slr/
Sea Level Rise Scenario of 1.5m at Mayagüez and Arecibo

Mayagüez port exposed to minor cyclonic events (storms, category 1)

PR-102 may end up uncommunicated with minor cyclonic events (storms, category 1)

Port of Arecibo may remain uncommunicated

Great Arecibo river levees adjacent to sea

Lery Jurabe Pol Airport adjacent to coast

Source: https://coast.noaa.gov/slr/
Storm Surge Effects at Vega Baja, Puerto Rico

Note: direct cause was not a hurricane

Source: Google Earth
Exposure of **Puerto Rico** Port Infrastructure to Storm Surge

- 45% (5/11) of airports located at 1 km coastal zone.
- Total of 12 seaports at **coastal zone**.
- Considering category 5 hurricane **storm surge** adds:
  - Nery Jurabe Pol Airport (Arecibo)
  - Mercedita Airport (Ponce)

 Sources: Autoridad de Puertos, Junta de Planificación, CARICOOS, “Innovación en la Infraestructura Civil en Transportación y Transporte Público en el Siglo 21” (B. Colucci)

March 9, 2017

Lessons Learned and Best Practices-Resilience of Coastal Infrastructure
Exposure of Airport and Seaport Infrastructure of the Dominican Republic

71% of 14 airports of Dominican Republic are within 1 km of coastal zone


Google Earth

69% (9/13) of Dominican Republic seaports located along Caribbean Sea coast

Sources:
http://www.apordom.gob.do/sistema-portuario.html
Infrastructure Prone to Corrosion Damage

• Vulnerable transportation infrastructure
  • Docks
  • Highway bridges
  • Rigid pavements in highways and runways
  • Navigation aid buildings (lighthouses, air traffic control towers)

• Other vulnerable components
  • Retaining walls
  • Levees
  • Storm drain grates and channels

Sources:
https://c6.staticflickr.com/9/8226/8590114813_cbc64abc37_b.jpg
“Challenges of Electrical Tests for Chloride Permeability in Concrete”, A. Molano
Ocean Acidification is a Driver of Coral Reef Damage

Source: World Resources Institute
Adaptation Strategies

A. Emergency Plans
B. Hard Engineering
C. Planned Retreat
D. Green Engineering
E. Use of Technology

Supported by information and efficient resource use

A. http://uconn-today.universityofconn.netdna-cdn.com
B. https://classconnection.s3.amazonaws.com
C. https://sites.google.com
D. http://www.climatetechwiki.org
E. http://www.ssesb.com
A. Alternative Emergency Management Practices

A. Unmanned Aerial Vehicles (UAVs or ‘drones’)

B. Evacuation Route Access Management

C. Multimodal Evacuation Plans

TRR 2532:
“Unmanned Aircraft Systems used for Disaster Management”
“Multimodal Evacuation Simulation and Scenario Analysis in Dense Urban Area: Philadelphia, Pennsylvania, Case Study”
“Selecting Four-Leg Intersections for Crossing Eliminations in Evacuations”
“Hurricane Evacuation Route Choice of Major Bridges in Miami, Florida”

Images:
A. John Fischer in LinkedIn
B. FastAnswers.com
C. The Decatur Daily
B. Hard Engineering

A. Permanent barriers

B. Deployable barriers

C. Structure retrofitting and/or re-design

C. Planned Relocation

A. Redefined coastal zone

B. Formation of protected coastal areas

C. Inland relocation

Credits: A. Ruperto Chaparro, Sea Grant  B. cienciapr.org  C. Ernesto Arroyo, DRNA
D. Green Engineering

A. Wetland Restoration

B. Artificial Reefs

C. Beach Nourishment

Credits: (A, B) Ernesto Díaz, Department of Natural and Environmental Resources; C. Ruperto Chaparro, Sea Grant
E. Use of Technology

A. Instrumented pavements

B. Real Time Alert Systems

C. Geographic Information Systems (GIS)

D. Data mining for evacuation response

Credits:
A. “Remote Pavement Weather Sensing and applications for the Transportation Industry” Surface Systems Inc., Research Gate;
B. Revisión de inundaciones históricas en Puerto Rico”, José M. Rodriguez, PE, USGS.
C. Washington DOT http://wsdot.maps.arcgis.com/
D. TRR 2599 “Using Big Data to Study Resilience of Taxi and Subway Trips for Hurricanes Sandy and Irene”
EDC-4 Initiatives Related to Resilience and Climate Change

Collaborative Hydraulics

Road Weather Management

Advanced Traffic Signal Performance Measures

Integration of NEPA and Permitting

Using data to improve Traffic Incident Management

Sources: https://www.fhwa.dot.gov/innovation/everydaycounts/edc_4/, El Nuevo Día
Deployment of Resilience Practices at State DOTs

NCHRP Project 20-117: Joint Project of NCHRP, AASHTO, USDOT and National Research Council

Intended outcomes

◦ Tools and guidelines for transportation resilience
◦ National Summit and peer Exchange for transportation resilience

Source: http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4208
Examples of State DOT initiatives

A. Washington DOT Community Planning Portal
   A. http://wsdot.maps.arcgis.com/home/webmap/viewer.html?webmap=927b5daaa7f4434db4b312364489544d

B. GIS for Flood Impact Mitigation, Florida
   B. : GIS For Decision Support and Public Policy Making (book)

C. Caltrans Resilience Metrics for Transportation Planning