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Development of Educational Modules to Assess Flood Risk and Mitigation Strategies for Coastal Communities

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Coastal Communities are exposed to multiple hazards including hurricanes, storm surges, waves, and riverine flash floods. This paper presents the outcome of a Basin-wide Flood Multi-hazard Risks module that was developed and offered as part of a collaboration between two research projects: the UPRM-DHS Coastal Resilience Center of Excellence (CRC) funded by the Department of Homeland Security and the Resilient Infrastructure and Sustainability Education Undergraduate Program (RISE-UP) funded by the National Science Foundation (NSF). The content was designed to give students an understanding of complex project management in coastal communities. The main learning objective was for students to be able to assess and recognize the actions that can be taken to improve resiliency in coastal communities. Students learned how to manage multi-hazard floods. Through knowledge gained by participating in lectures, discussions, and the development of case studies, students were able to assess flood risk and current mitigation strategies for coastal communities in Puerto Rico. The learning experience provided an overview of the history, needs, and challenges that coastal communities face regarding flood and coastal hazards. Through the case studies, students were able to appreciate and understand the risk exposure on the natural and built infrastructure, and the importance of always taking into consideration the social impact.

Keywords: educational modules, multi-hazards, floods

1. Introduction.

Floods constitute one of the most frequent and most impacting natural hazards on Earth, accounting for extreme impacts to the natural and built infrastructure. According to the World Bank, floods are one of the most common and severe disasters affecting the lives and livelihoods of people around the world. Floods often cause irreversible damage and suffering, especially in developing countries, where lower GDP affects the quality of infrastructure systems – including drainage and flood protection – and often are underdeveloped. While countries at all stages of development are at risk of flooding, the vast majority (89%) of people at risk of flooding worldwide live in low- and middle-income countries. Crucially, not only large, less frequent floods, but smaller, more frequent events can undermine years of poverty reduction and development gains [1].

According to the definition that the United Nations Office for Disaster Risk Reduction (UNDRR) postulates for a Multi-Hazard, the term may be interpreted as the particular circumstances where dangerous and unsafe events may unfold, whether they occur simultaneously, over time, or overlapped, taking into consideration the potential that interrelated effects may have [2]. UNDRR identifies the following categories: biological, environmental, geological, hydrometeorological and technological processes and phenomena. It is common to identify multi-hazards based on the interaction of various causes of natural phenomena, for example, the interaction of floods, winds, earthquakes, tsunamis, and others based on the previous classification [2]. However, for the purpose of this paper, the concept of multi-hazards refers to interaction of various categories of flooding events among themselves or with other phenomena as previously defined. These interactions can be by various mechanisms as triggering (when one event provokes another), influencing (when one changes the chances of the other to occur), or simultaneous (when one occurs independently of the other without influencing the occurring opportunity of the other). In all cases, there may be a cascading effect which can amplify the effects of each event alone. The World Health Organization (WHO) defines three types of floods, namely, flash floods, riverine floods, and coastal floods. However, floods can be further classified as riverine, urban, coastal, nuisance, waves, tsunami, storm surge, dam breaks, and other specific classifications. Each one has its own location, phenomenology, causes, and impacts. Their effects and impacts should be considered holistically [3].

The causes and impacts are broad and significant. Floods are multi-hazards and manifest their impacts in diverse ways. The projected climate change, the continuous urban and rural development, the uncontrolled basin-wide activities, including the upland and coastal communities amplifies and worsens the projected scenarios for the future. Flood management accounts for significant public and private resources, including state and federal regulations as alternatives to face flood impacts in the future. It is imperative and required to implement strategies to understand and be prepared to mitigate flood hazards in the future. Flood mitigation alternatives have focused gray, green, and hybrid alternatives. Likewise, they can also be classified as structural and non-structural alternatives. However, independently of the flood alternatives chosen as most appropriate to be applied to a specific case, formal and professional education and capacity building are required to address the sustainable and resilient mitigation of flood impacts in the future [4].

The Island continues to present more catastrophic settings from overdeveloped and exposed urban and rural communities, more vulnerable zones (flood prone, weak soils and landslides, hurricane wind exposure), highly concentrated and poorly planned urban communities, stressful tradeoff between urban development and natural ecosystems development and conservation, extreme economic development constraints and suboptimal first responders resources (e.g. funding, equipment, capabilities, training, and others) make the Island's educational settings most challenging. All these settings are available for firsthand assessment and evaluation from the educational and research perspective. Puerto Rico will be in a continuous development process focusing on providing a more resilient community and infrastructure to families, and individuals [4].

This paper focuses on two educational initiatives: the UPRM-DHS Coastal Resilience Center of Excellence (CRC) funded by the Department of Homeland Security (DHS), and the Resilient Infrastructure and Sustainability Education Undergraduate Program (RISE-UP) funded by the Hispanic Serving Institution (HSI) division of the National Science Foundation (NSF). Both initiatives share the common goal of building capacity to improve infrastructure resiliency in the face of future natural events. The projects developed flood-related modules but the depth of knowledge that students were expected to have after they completed the modules varied significantly. RISE-UP aimed to sensitize and inform students about flood hazards through a 3-hour long lecture and a case study assignment embedded into a 3-credit hour course that covered a wide variety of topics. UPRM-DHS CRC offered a 3-credit hour (45 contact hours) course titled "Managing Riverine and Coastal Floods for Resilient Communities". Students enrolled in the CRC course completed an in-depth analysis of the challenges faced in a coastal community in western Puerto Rico and proposed solutions to mitigate the impact of flooding.

2. RISE-UP Project

The Resilient Infrastructure and Sustainability Education – Undergraduate Program (RISE-UP) is a collaborative project funded by the HIS division of The National Science Foundation. The program's goal is to develop an interdisciplinary curriculum among three campuses at The University of Puerto Rico. The new curricular endeavor prepares students to design infrastructure that can withstand the impact of natural events.[5]. One of the program’s broader impacts is to benefit society by developing and enhancing awareness of engineers, surveyors, and environmental designers to issues related to resiliency and sustainability, encompassing multiple dimensions of these issues that affect the island of Puerto Rico.

From the very beginning of RISE-UP and through the course “Fundamentals of Integrated Practice for Resilient and Sustainable Infrastructure” students are faced with a session that addresses the implications of natural disasters on the design and construction of infrastructures. Aspects that are included in the class include topics regarding interdisciplinary problem solving and human factors that must be addressed from the perspectives of all involved disciplines. One specific module is entirely devoted to the topic of hydraulics of natural systems in Puerto Rico, and the impact that human interventions have on the performance of those natural systems, and then complemented it with case studies involving specific situations as is explained in the sections below.

2.1 “Basin-wide Flood Multi-hazard Risks” Lecture

The 3-hour long “Basin-wide Flood Multi-hazard Risks” lecture introduced flood disaster risk in Puerto Rico. It discussed flood prone areas focusing on areas impacted by flood multi-hazard. The students were able to witness evidence of flood hazard impacts and the challenges and solutions that are implemented at existing locations in Puerto Rico and beyond. The lecture also included an explanation of the basin-wide concept when dealing with floods. Flood hazard mapping and examples of flood risks to the built infrastructure were covered.

2.3 Case Studies to Sensitize and Inform Students

After the lecture, students were divided into groups and tasked to develop case studies with the goal of sensitizing and informing them about flood hazards in a coastal community. Students were divided into six teams of five students each. Each team was comprised of students from the three participating campuses which ensured that students at different stages of their undergraduate degrees and students who are pursuing bachelor’s degrees in environmental design (architecture) and engineering would work together towards the common goal. The teams were required to use a case study approach to study the impact of floods in urban areas of Puerto Rico, focusing on cases of floods generated by atmospheric events.

The teams were tasked with selecting and defining the characteristics of the problems to be studied. To encourage discussion and brainstorming among teammates, the instructors provided examples of approaches in which students could focus on. For example, students were given the option to focus on a specific event associated with floods, they could also focus on how flooding affects a specific structure, or on the actions of a particular community in dealing with a flood event.

An important criterion that students were asked to keep in mind when selecting the case study approach was why the case was relevant to study. The following questions were provided to assist students in assessing the relevance of their chosen topic: Can we learn something about what happened? What to do or what not to do in future atmospheric events? How can we prepare from the perspective of our disciplinary areas to tackle this or similar problems? Is there an important success / failure story that deserves to be recorded as a lesson learned for future events? Table 1 and figure 1 show the titles and locations of the case studies that students selected.

Table 1: Case Study Titles and Locations

Title	**Location**
Ocean Park Drowns	San Juan, PR
Beach at Crossroads	San Juan, PR
Murky Waters at Caño Martin Peña	San Juan, PR
Coastal erosion Impacted by Gabions	Toa Baja, PR
General Student Parking - An Unsolved Controversy	Mayagüez, PR
Mayagüez Terrace is Paralyzed	Mayagüez, PR

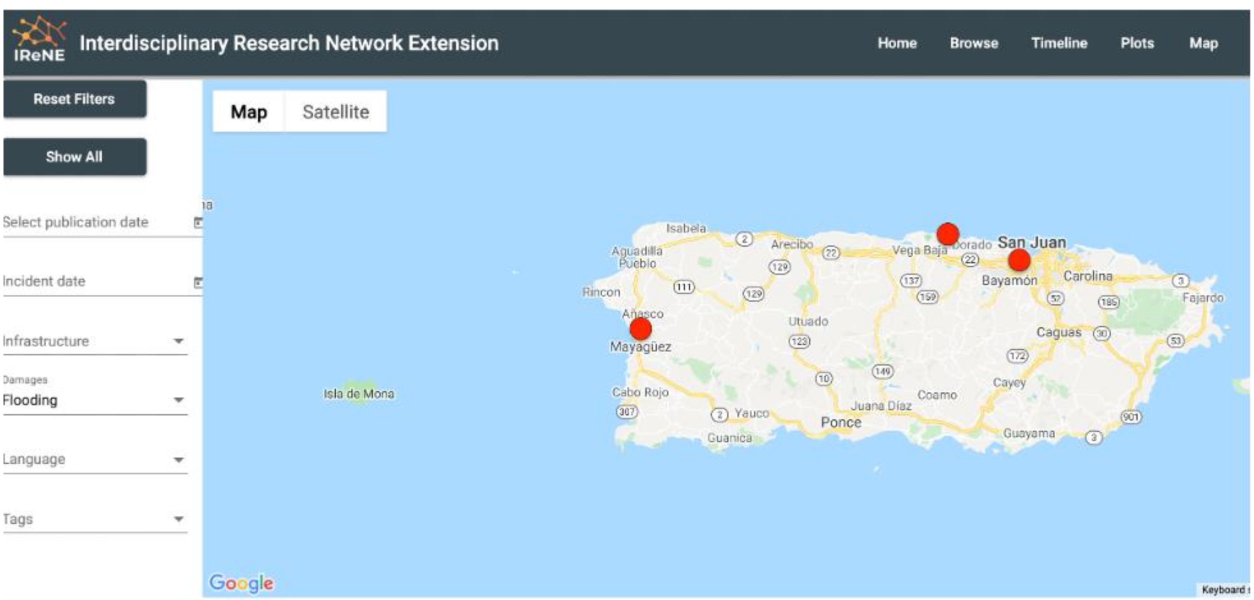

Figure 1: Case Study Database

3. CRC Project

The CRC main goals are to educate the community by transferring state of practice knowledge to stakeholders (students, faculty, professionals, first responders, and workforce) through formal (curriculum, internships, student projects, undergraduate research) and informal (workshops, seminars, lectures, short courses, webinars) learning experiences. It serves as a vehicle to engage the community, with emphasis on the academic community, as a whole, to understand and learn its members' roles and responsibilities in providing resilient infrastructure systems to affected communities. The project helps the community understand better stages for hazard prevention, preparedness, response, recovery, and mitigation. The focus is to understand the natural phenomenology, the engineering methodologies to address the level of risk the infrastructure is exposed to, the engineering methodologies and technology to analyze and predict the level of resistance and vulnerability that the infrastructure and community is exposed to, the sustainable and resilient alternatives available at the state of practice or state of art to cope with communities' risks and vulnerabilities. It helps motivate students, faculty, professionals, and community leaders and create pipelines of students and professionals into resilient infrastructure careers (CRI) and practice. A graphical representation of the resilience cycle is presented in figure 2. Students were introduced to various components of the resilience cycle which helps develop a broader perspective to assess flood hazards.

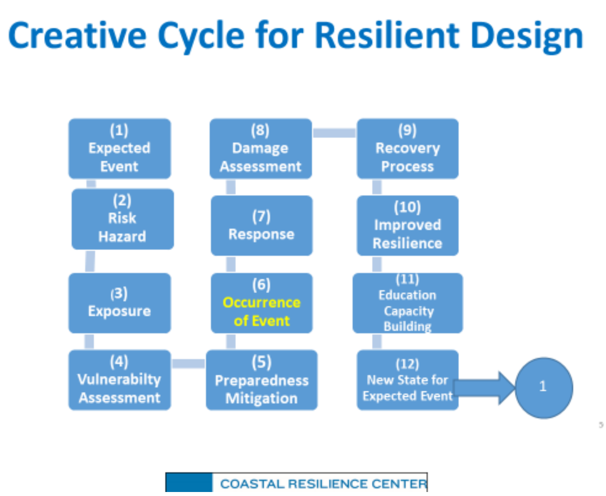

Figure 2. Creative Cycle for Resilient Design [4]

The project provides students and faculty, professionals, homeland security personnel, and affected citizens with capabilities to assess the effects of natural hazards on infrastructure, the conditions of existing structures, and rehabilitation alternatives to mitigate future damage and potential risks. The educational content focuses on pre-incidents, incidents, and post-incidents. The courses deal with estimates of causes and effects of multi-hazard events, namely: multi-hazard floods (riverine, urban, nuisance, floodplain and coastal, storm surge, ocean waves, earthquake effects, tsunami loads, and intense winds).

This paper focuses on multi-hazards floods. Courses are alternatively offered in the form of conferences, workshops, and lectures. Lecturers and experts from CRC, U.S. Army Corps of Engineers' ERDC, FEMA, and other partners are invited to participate. State of practice technology is a priority, e.g., FEMA P-646 publication for tsunami load estimates. The National Infrastructure Protection Plan and state infrastructure protection programs and plans are addressed. Advances in the field by partner investigators regarding flood, wave, earthquake and tsunami, and hurricane wind effects are the source of material for the course. Being a small and fully developed island, Puerto Rico offers the ideal setting to assess lessons learned of the effect of natural hazards on built and natural infrastructure including housing, commercial, industrial, institutional, transportation, communication systems, and others. Most recently, Hurricane Irma and María experiences on the devastation over Puerto Rico provided a unique, although catastrophic, opportunity for acquiring data and providing lessons learned which have been incorporated in our curriculum contents and guidelines for best practices. Other more localized extreme events continue to provide new lessons, data, and opportunities to study the spatial and temporal influences on the cascading effects of flood multi-hazards. The principal investigators continue participating in various working teams, forums, and meetings addressing building a resilient community in Puerto Rico for the future [6].

3.1 "Managing Riverine and Coastal Floods for Resilient Communities"

This course has been designed to give students an understanding of complex project management in coastal communities. The course includes lectures, discussions, and case studies of actual complex coastal community projects. Students conduct an in-depth case study of a coastal community impacted by floods. Students learned how to manage riverine and coastal floods that impact coastal communities and identify resilient solutions. The fundamentals of a five-dimensional project management model to manage complexity were presented followed by an analysis of the typical sources of complexity in coastal projects. The basin-wide approach is presented for acknowledging and learning diverse factors, such as spatial and temporal rainfall characteristics, basin hydrography, topography, geology, urban development, and natural and built infrastructure that affect a basin response to extreme rainfall events that create riverine, nuisance and urban floods. The course project is designed to reinforce the material covered during the lectures. Table 2 shows the course outline and contact hour distribution.

Table 2. Course Outline and Contact Hours

Topics	**Contact Hours**
Introduction and Overview	1
Complex Project Management Fundamentals	2
Riverine and Coastal Floods Multi-hazards	2
Basin and Urban Drainage Systems and Infrastructure	2
Midterm Project Report and Presentation	2
Flood Control Alternatives: Structural and Non- structural	2
Low Impact Development and Green Flood Control Infrastructure	2
Final Project Report and Presentation	2
Independent Project Teamwork	30
TOTAL	45

3.3 In-Depth Case Study: Assessing Flood Risk and Mitigation Strategies for a Coastal Community near the Guanajibo River, Puerto Rico

Through knowledge gained by participating in lectures, discussions, and a site visit, students were able to assess multi-hazard flood risk and current mitigation strategies for the Guanajibo river floodplain with emphasis at the San José and Guanajibo Homes Communities in Mayagüez, Puerto Rico. Due to their locations within the Guanajibo river floodplain with neighboring wetlands, at the ocean front with sensitive coastal ecology in a seismic area, the community is exposed to multiple flood hazards, namely, flash floods, urban floods, coastal floods, and tsunamis which were addressed. The site visit consisted of several site stops to provide a broad appreciation of the multi-hazard complex flood project. Students and faculty also had the opportunity to interview resident leaders who presented and helped assess the social perspective of flood risks and vulnerabilities of the communities.

The first stop was an oversight of the lower Guanajibo river floodplain and coastal line. This allowed students to appreciate the magnitude and scale of the potential flood extent. The second stop was to a bridge located on road PR-102 over the Guanajibo River that is in the principal route the San José and Guanajibo Homes communities have for evacuation to higher lands in the eventuality a tsunami or a flash flood occur. The bridge presents multiple challenges such as aging, lack of maintenance, limited flow capacity, low bridge clearance prone to debris clogging, exposure to pier scouring and erosion in part of the bridge, and excessive sand and debris accumulation in the rest of the bridge. The third stop was at a new bridge built on the same road with up-to-date design standards and a resilient standard of practice. Students had the opportunity to appreciate the contrast of this bridge with the previous bridge at visited on the second stop.

The last stop was to visit the Guanajibo Homes and San José housing communities, which were built based on the 1950's codes and regulations. This communities are located within the floodway zone and the FEMA flood regulatory map. During the visit, a community leader provided an overview and graphical documentation of the history, needs, and challenges that the community faces regarding flood and coastal hazards. Through the site visit, the team were able to appreciate and understand the risk exposure of the natural and built infrastructure, and the importance of always taking into consideration the social impact [7].

At these four stops students had the opportunity of observing the state of risk due to inappropriate and under designed storm sewers which allows for localized urban flooding. They also appreciated the extent of the riverine flood and compared historical floodmarks, the regulatory FEMA floodplain, and their interaction with the FEMA coastal flood hazard zone. They had the opportunity to appreciate the community multi-hazard flood exposure with the reference of the NOAA Flood Exposure Mapper [8] and walk through the sites acknowledging flood levels indicated by flood maps.

The NOAA risk map shown in figure 3 illustrates that a category 5 hurricane will cause Guanajibo and San José Homes residents to be stranded by flooding caused by storm surge.

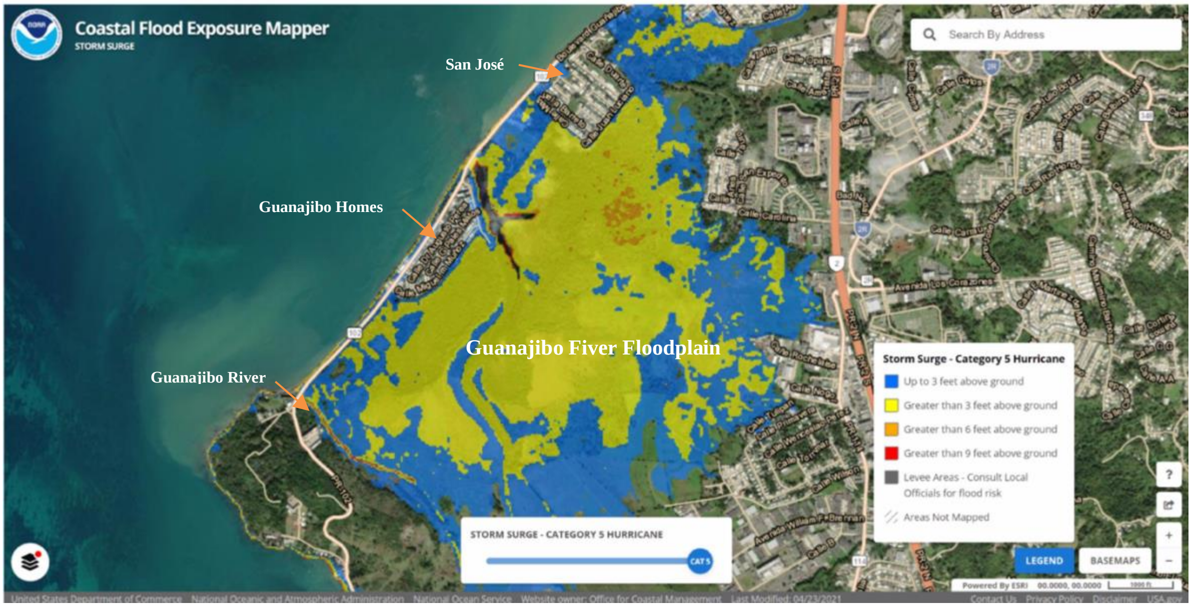

Figure 3. Category 5 Hurricane Flood Exposure Map as shown by NOAA [8]

The expected climate change in Puerto Rico shows uncertain projected scenarios. However, The Puerto Rico Climate Change Council, The Environmental Protection Agency, and Rodrigues, M. have studied the climate change expectations for Puerto Rico in the future [9], [10], [11]. An increase in sea water levels and in rainfall event intensity will most likely impact these and other communities on the Island in the future. Students were also able to assess the impact of the sea water rise at the visited communities using NOAA tools [8]. Figure 4 presents sea water rise scenario maps for (a) 3 feet and (b) 6 feet where it is evident that the coastal communities will be affected by the projected flood extension.

(a) (b)

Figure 4. Expected Sea Water Rise Scenarios maps for (a) 3 feet and (b) 6 feet [8].

Through infrastructure maps at classrooms, and later by field reconnaissance, students were able to assess the built and natural infrastructure exposed and vulnerable to various flood events, including historical and regulatory flood events. Typical exposed built infrastructure are power lines, communications, houses and housing buildings, commercial buildings, transportation facilities, sport facilities, water and wastewater, and all others typical in a coastal community. The natural systems are a bay, seashore, dunes, coral reefs, wetlands and mangroves, and other coastal ecological values.

Finally, students were able to identify and recommend potential flood mitigation alternatives including structural and non-structural alternatives, and grey and green infrastructure. They also presented their findings at the Coastal Resilience Center 2021 Annual Meeting [7]. This experience motivated various students participating in the course to continue taking courses, participating in internships, and engaging in the CRC and the RISE-UP activities.

4. Conclusions.

In both the 3-contact hour lecture and the 45-contact hour course, students learned various components of the resilience cycle applied to multi-hazard flood events. As it can be expected, the main difference between the two interventions is the depth of knowledge that students acquired. In the RISE-UP 3 contact-hour lecture, students were sensitized and informed about flood hazards. In the CRC 45 contact-hour students learned the most relevant components of the phenomenology, dynamics, and interaction of multiple flood hazards and were able to apply them to propose a solution for a coastal community. Both initiatives served as effective active activities to motivate students to engage and pursue further experiences to improve resilience of vulnerable communities.

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