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Green Infrastructure Planning Framework for Loíza, Puerto Rico

Introduction

"Nature pervades the city, forging bonds between the city and the air, earth, water, and living organisms within and around it."[i] Anne Whiston Spirn discusses in her quote that natural systems are a part of every aspect of the world both environmentally and socially. This quote exemplifies how our team approached GI planning as we made sure to keep in mind how Green Infrastructure affects more than just planning for nature but also how it extends into the daily lives of residents. The methodology for Loíza, Puerto Rico's planning framework focuses on how Green Infrastructure planning practices can intersect with traditional planning methods in order to create a system that both serves the environmental needs of the region and the socio-economic needs of the residents of Loíza, PR when it comes to hazard mitigation and future planning endeavors. The framework incorporates four planning strategies (i.e., Natural Resource Protection, Critical Public/Private Facilities Policies, Property Acquisition Programs, Private/Public Sector Initiatives) that will allow for Loíza to utilize GI planning techniques in a comprehensive planning structure. For instance, this report will discuss the opportunities for GI planning in different plan types like transportation, health/wellbeing, land-use/zoning, etc. Ultimately this means that Loíza will be able to address both large-scale and small-scale projects that provide the municipality the ability to address different types of vulnerable settings such as Urban centers, Inland Open Space, and Coastal regions.

Defining Green Infrastructure

In order to understand how best to plan for Loíza it is important to establish a working definition of Green Infrastructure and how it applies to the daily life of people. Green Infrastructure is more than just a technical idea that refers to the design or restoration of natural systems and landscapes. Instead, Green Infrastructure can be described as the management of natural systems/landscapes which can provide economic, environmental and social services which promote safe sustainable processes that enhance natural as well as community resilience

and mitigates hazard risks. Specifically, this section will discuss how there are several main aspects to GI that informed this framework.

The first condition of Green Infrastructure is resilience and sustainable oriented design. From a technical standpoint current trends in green infrastructure planning outline how green infrastructure is, "the interconnected network of land and water that supports biodiversity and provides habitat for diverse communities of native flora and fauna at the regional scale."[ii] This definition provided by the in the Chicago Wilderness Green Infrastructure Vision highlights how green infrastructure is a tool to create conditions that are balanced. The creation of this balanced system means that for more urban conditions the focus is to create guidelines, projects, infrastructure and lifestyles that reflect a more synchronized relationship between people and natural ecosystems.

Restoration of Natural systems is another key area that needs to be considered thoroughly. For instance, FEMA discusses in their guidelines the concepts of "Living Shorelines" and "Waterfront Parks" that utilize environmental components to provide preventions to coastal erosion and mitigate other coastal hazards.[iii] These components need to be stabilizers for the environment, an example of which would be the mangroves located in Puerto Rico along the coast help to prevent coastal erosion and prevent flooding and other natural hazards. Restoring these systems means that nature can perform at its very best and thus there is less damage that will occur.

Another component of GI planning is the implementation of Nature Based Solutions. Defined by the International Union for Conservation of Nature, "Nature-based solutions are actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits."[1] This definition outlines that the goal for nature-based solutions is to incorporate Natural Systems planning into all forms of planning so as to better serve people by creating a more self-sustaining and biodiverse environment. An example of this in Loíza is how before deforestation in the region the mangroves and forests located along the coast and in the

[1] https://www.iucn.org/theme/nature-based-solutions

adjacent inland areas prevented other parts of the island from receiving more devastating damage from natural hazards like hurricanes, flooding, earthquakes and tsunamis. To respond a great example of Nature Based Solutions would be to begin work on replanting these areas and instituting planning practices that respect or even mimic the effects of these ecosystems in areas where it is impossible to completely return the environment back to a natural state.

The last major component of GI planning is Ecosystem Services looks at how the natural processes incorporate into the daily lives of people. Ecosystems Services is defined by four categories: provisioning services (raw materials, drinking water, etc.), regulating services (water purification, flood control, etc.), supporting services (nutrient cycling, habitat for flora/fauna, etc.), and cultural services (recreational, educational, etc.)[iv] In essence, these different categories examine how different aspects of the environment affect people, specifically by improving or servicing different communities, not only that, but ecosystem services describe how Green Infrastructure in any form can serve communities in different ways. This means that green streets, plazas, parks, bridges, and other projects can be educational or recreational spaces that also serve important functional purposes for both a community and the physical environment. A good example would be a park or greenspace. Typically, these spaces provide opportunities for reduction in both physical and societal issues and can promote positive health and social benefits by reducing air pollution, creating carbon sinks, making space for exercise, improving mental health, and other benefits.[v] For Loíza making sure that communities are able to get the benefits of Green Infrastructure planning is extremely important because it means that there can be a melding of built, social, and natural environments that create solutions which improve the lives of Loíza residents and assist with hazard mitigations to events like flooding, air pollution, etc.[vi]

In culmination, all of these components combined show that both large scale and small-scale projects need to be considered. In order to make a comprehensive GI structure that is successful it is important that while efforts to reforest occur there is also education and local efforts to improve public gathering spaces with things like permeable pavement. One, the reforestation is both long-term and requires regional contribution and control whereas the permeable pavement and education spaces would be more short term in completion and best controlled by local communities. In essence, our definition of Green Infrastructure helps to

dictate our approach to how we determined and created our framework, focusing on both Macro (large, regional scale) and Micro (small, local scale).

Physical and Social Vulnerability Analysis

Loíza is a coastal municipality of about 30,000 residents, many Afro-descended, located on Puerto Rico's northern Atlantic Coast to the east of the island's capital city, San Juan. Loíza has a low-lying terrain at a nearly uniform level, and it does not surpass 100 meters above the sea level. It is also situated in the flood plain of the largest river in Puerto Rico by volume, the Río Grande de Loíza. These geographic characteristics make Loíza prone to tropical storms and hurricanes, river floods, and coastal erosion. Meanwhile, this low-lying place also faces tremendous risk from earthquakes that can cause significant damage through tsunamis, ground shaking, liquefaction, and landslides. Details of the hazards, including their characteristics, historical precedents, effects, and priority levels are summarized in Table A1, and Coastal Erosion as well as Tropical Storm and Hurricane" are identified as Loíza's top two risks. In additional to major environmental challenges, Loíza has been long facing many social and economic issues, including economic disinvestment, historical marginalization, concentrated poverty, and inadequate infrastructure. The devastating effects of the 2017 Hurricanes Irma and María have reinforced these vulnerabilities in Loíza deeply, ravaging through the homes and livelihoods of many of its residents as well as a substantial amount of its key marine, coastal, freshwater, and forest ecosystem.

To better situate Loíza in the face of damages from future disasters, it is important to know a community's both physical vulnerability and social vulnerability, as these two aspects together determine how well a community gets through in a disaster. Physical vulnerability is related to the geographic characteristics of the places where human settlements are located or to the fragility of homes or infrastructure (summary in Table A2). Social vulnerability refers to a lack of economic, social, and political assets which need a historical context within which they can be explained, as such conditions do not occur suddenly, but rather, develop in an incremental manner over time (summary in Table A3).[vii]

This section addresses how historical climate/hazard trends, physical environments, and social conditions have shaped the susceptibility of Loíza to hazard exposure and hence help

identify 3 target areas in need of green infrastructure planning and policy focus. They are coastal, inland open space, and urban areas (Figure A2). The Municipality of Loíza is subdivided into 6 barrios (i.e., county subdivision), including Medianía Alta, Medianía Baja, Canóvanas, Torrecilla Alta, Torrecilla Baja, and Loíza Pueblo. On the neighborhood level, it is also divided into 10 census tracts (Figure A1). Breaking down the municipality level into the neighborhood level clarifies the examination of disparities within the city. Although the census tract boundaries are not exactly corresponding to the recognized community boundaries by the residents, they are used as the basic unit of this analysis because they most closely approximate the size of neighborhoods and match with the boundaries adopted for the major data source—American Community Survey by U.S. Census Bureau.

Coastal Area

Using tract-level American Community Survey 5-Year data of 2014-2018, both Social Vulnerability Index (SoVI) used in the 2021 Puerto Rico Mitigation Action Plan and CDC's Social Vulnerability Index (SVI) (Figure A4) cited in this section reveal that coastal communities, especially the tracts 1101.01, 1102, and 1103.01, have been the most vulnerable (i.e., with a score above 0.79 out of 1) in comparison to the rest of the city. Over 2015-2019, there were a total population of 13,461 people living in the coastal area, about 50 percent of at-risk population to the city living in or around the 1 percent annual chance flood zones. Coastal population tended to have larger non-White populations, much lower median household incomes (nearly half of the urban population's), higher poverty rate (over 50 percent) and unemployment rate (about 30 percent), and they were less likely to possess a car (over 20 percent).

Housing units considered "informal" are more common in rural, coastal communities; where residents often sell or inherit properties through informal agreements, subdivide land without completing the title process, occupy government owned land to build homes, or build a house without completing the construction permit process.[viii] Informality is another challenge faced by the coastal communities, as it prevents residents there from receiving federal aid for house repair and reconstruction and having controls over the surrounding natural environment and resources. Many critical public, private, and community facilities are concentrated along the coast. Yet the erosion in coastal areas has been threatening to these structures and infrastructures. The 2018 damage reduction proposal by the United States Army Corps of Engineers reports that

Hurricanes Irma and Maria exacerbated the erosion of the coast along Parcelas Suárez, one of the coastal neighborhoods of Loíza. The most threatened of the structures include a public school, a public community center, and a public road (Calle Punta Del Atlantico), as shown in Figure B1.

Inland Open Space

The Loíza River (Río Grande) and Herrera River irrigates the territory, the former comprising the largest watershed on the island. Extensive modifications to the hydrology of this watershed however have increased the region's natural predisposition to flooding. The major hydrologic system also includes the Piñones on the west of Torrecilla Baja and La Torrecilla Lagoons, the latter shared with the municipality of Carolina. The Piñones area is a sensitive, integrated ecological system of forests, mangroves, lagoons, and connecting streams and channels. It includes the Piñones Forest, official declared a "Natural Reserve" by the Department of Natural Resources, and covering an area of 2,525 acres.[ix] This ecological system is supposed to be the first line of defense to water-related hazards and produce health and economic benefits. Due to the damaging impacts of the 2017 Hurricanes and intense market economy resource exploitation, they are currently in urgent need of restoration.

Urban Center

Urban center consisted of the tracts 1103.03 and 1103.04 have the least vulnerability with a score less than 0.37 out of 1 according to the CDC's Social Vulnerability Index. Urban area is classified as a 0.2 percent-annual-chance flood zone; its building footprints are more structured, organized, and connected to the major roads and surrounding municipalities; its population are most educated and mostly White, and they have the smallest poverty rate (around 30 percent) and unemployment rate (10-20 percent) than other areas. Yet the urban population face a set of their unique challenges. Over 30 percent of residents are cost-burdened. Although in the city itself urban population's median income is the highest, an average of $26,388 is much lower than the median income of $62,000 in the mainland. It helps to solidify the fact that the municipality as a whole is dealing with higher amounts of poverty on average. Besides housing affordability, housing quality appears to be another concern to the urban population, as over 70 percent of them have lived in housing units over 30 years old, implying loosened, aged, and hence

vulnerable structures to hazards. Impermeable surfaces created by intensive human activity and development further lessen the urban center's endurance to rainwater runoff and flooding.

Calling Out Urgent Environmental Issues

Loíza, given its particular geographical position, is susceptible to three major natural hazards: coastal erosion, flooding, and hurricanes. The historic rate of erosion along the Loíza´s Piñoes beach road ranges from 0.5 to 2.3 meters[x] per year and have been observed and expected to increase in present and coming years as the rate of sea-level rise increases. Flooding events are very frequent, with a significant flood occurring every five years on average, and on average every 20 years an extreme flood event takes place. Referring to the flood zone classification map (Figure A3), one can find that the majority of the municipality is classified as flood zones subject to a 1-percent-annual-chance flood event according to the FEMA definition. The floodplain is generally flat and slopes gently from about 10 meters above mean sea level near P.R. Highway 3 to sea level at the shore.[xi] The coastal floodplain is bounded on the west by Torrecilla Lagoon, on the east by the divide between Río Grande de Loíza and Río Herrera, on the north by the Atlantic Ocean, and on the south by the P.R. Highway. Rio Herrera, Rio Epíritu Santo and the Blasina Stream coincide in the Rio Grande de Loíza and end at Boca de Cangrejos, Laguna San José, and the coasts of the city.[xii] This convergence of the major rivers and tributaries have created permanent susceptibility to flooding in the area. The zones of the most risks VE and AE are provided with base flood elevations as one means of protection. The damages due to the 2017 hurricanes Irma and Maria however showed that elevations were not enough. Both inland and coastal areas of the municipality were swamped with floodwaters and storm surges, and a series of areas of vegetation was damaged and polluted by mud and debris deposits. Simulation studies by NOAA have warned that one climate effect's augmentation, for example in current water level or hurricane category, will lead to one or more scales' increase in the expansion of hazard-prone regions. Under alarmingly increasing climate change effects, either coastal flooding or storm surge will not just be a beachfront problem; the risk would extend many miles into the inland and urban center from the immediate coastline in some areas (Figures B2-B4).

Calling Out Urgent Social Issues

Located about five miles east of Puerto Rico's capital city of San Juan, Loíza is adjacent to an increasingly expanding metropolitan region. Flanked by the highly industrialized municipalities of Carolina to the west as well as Canóvanas to the south, and the touristic Río Grande immediately to the east, however, Loíza is unlike its more developed neighbors. It is an economically and politically disadvantaged community, comprised mostly of minority population. A third of households are female-led; 17 percent of population are senior citizens; the largest demographic groups are identified as 38.7 percent of Black and 36.2 percent of the Other Race. The numerous rivers, streams, and channels that crisscross the municipality present challenges for the building and maintenance of roads that permit transit to and within Loíza. Despite the construction of elevated roads and modern bridges in the last quarter of the 20th century, many of Loíza's neighborhoods could still become dangerously inaccessible during the heavy rains of hurricane season (approximately from July to November).

Roads and rivers circle Loíza in a way that creates an impression of remoteness to the adjacent metropolitan and modern zone. This apparent seclusion, many believe, has prevented Loíza's population from mixing with the rest of Puerto Rico, but of course, it is not naturally formed. Figure A2 shows that Loíza is neither well connected internally or externally to the adjacent municipalities. The Puerto Rico Highway 3 extends to pass it leaving only one arterial road for the residents to get in and out. Vehicle ownership is hence critical to Loíza residents since major routes and public transit do not easily pass through the whole municipality due to its topographic characteristics, long-term disinvestment and low maintenance. Yet the currently low vehicle ownership especially in the coastal area cannot sustain this level of auto dependency. A seventh of the population does not have access to a car, and at least a quarter of the households do not have access to at least one smartphone, computer, or table. Meaning that both reaching these community members is more difficult and the hazards outlines previously are even more exacerbated because there are lower levels of mobility and fewer ways of disseminating emergency information.

Existing Plans Analysis and Integration

To understand how GI fits into the overall planning process for Loíza, the framework examines the ways that GI can fit into traditional plan types like Land-use/zoning plans, transportation plans, health/wellbeing plans, etc. Ultimately by looking at the ways that GI applies to different planning documents it will show that GI planning can occur across the board. In addition to examining how to plan with GI in different contexts this section will evaluate the current 2016 Loíza Hazard Mitigation plan. Following our understanding of both the vulnerabilities and definitions of Green Infrastructure our team was able to determine that the 2016 Hazard mitigation plan overall does not successfully include Green Infrastructure planning into the document.

Lessons from the 2016 Loíza Hazard Mitigation Plan

There are several important things to note about the 2016 Loíza Hazard Mitigation Plan. First the plan was designed to fit all of FEMA's guidelines, and therefore does take into consideration some aspects of green infrastructure planning. Second, while it fulfils requirements the plan lacks the following components: nature-based solutions, restoration of ecological systems, community participation and resiliency. Instead, the document was primarily focused on the repairing of damaged property and the costs associated with bolstering the community against future hazardous events. Tables A4 and A5 show the scoring system and the met criteria for the plan. In Table A4 the scoring system looks at several categories and addresses the different components of the plan asking the following questions: Does it address climate change? Is the community involved? Does it include social vulnerability? Does it build upon existing GI? Does it promote nature-based solutions? These questions focus on utilizing the definition of GI, then the scale has a 0-2pt rating system where 2 exceeds minimal requirement, 1 meets requirement and 0 does not meet minimum standards. Based upon this criterion set the Hazard Mitigation Plan only scored a 4.6/10. Meaning that more often than not the plan did not meet a full average standard (i.e., 5/10). Alternatively, Table A5 depicting the met criteria based upon FEMA guidelines shows that the plan meets most of the checklist criteria.

One thing this indicates is that the standard way of measuring (as seen in Table A5) does not always mean that one will end up with a plan that does not successfully address the issue it

needs to. Even in the case of this Hazard Mitigation Plan there was little involvement of the community however sections like the implementation portion of the plan discussed incorporating community feedback and education into the management of the plan. Also, the plan did not have all of the data it needed to adequately address different Hazard vulnerabilities but proceeded to make decisions even when no data was present for these particular sections like missing information for landslides but listing landslides as a high priority hazard. Finally, the plan did not discuss resilience/sustainability or nature-based solutions, there was one or two projects listed that included reforestation of mangroves, however most of the other projects outlined for the plan where focused on protecting damaged property, this means that while the plan was addressing hazards it was not looking for ways to reduce their effects in the long-term.

Comprehensive Integration of GI into Plans

Figure A6 and Table A6 show how Green Infrastructure can be incorporated on all fronts by leveraging its benefits into all facets of urban planning for Loíza. The combined strategy will provide a holistic framework to improve the quality of life of Loíza's residents. The following sections show examples of Green Infrastructure Projects that can serve the system well.

Land Use Plans: GI incorporated into land use plans will focus on protection and preservation of natural systems and critical ecosystems. Coastal zone management is intended to protect the shoreline through hard and soft engineering measures while discouraging residential development along the coast or in at-risk areas.

Transportation Plans: In addition to improving connectivity and creating evacuation routes for inland retreat, the transportation plans will also focus on the creation of GI links which connect GI hubs with one another.

Economic Development Plans: The plans will prioritize low-impact eco-tourism and other local green businesses. These businesses and local resources will be hedged against exploitative practices by predatory actors. The plans will ideally conform to the New Urban Agenda (UN-H) to provide “ensure sustainable and inclusive urban economies.”

Public Health Plans: GI planning in the public health plans will prioritize critical life-saving systems and triage during disasters as well as post-disaster recovery. The plans will seek

to promote the soft benefits of GI which increase mental health, water and air quality, and the overall quality of life.

Physical Infrastructure Development Plans: The primary goal of the physical infrastructure development plans is to achieve long-term climate adaptation. Low-impact development and nature-based engineering solutions such as rain gardens and permeable pavements are the primary vehicles of these plans.

Green Infrastructure Planning Strategies

A recommended GI planning framework should be based on scale (i.e., macro, micro) and location (i.e., coastal, inland open space, urban). Macro scale is matched with large, regional projects that focus on interconnected systems of natural areas, resources, and open spaces, and it requires long-term planning for the whole municipality and intergovernmental coordination. Micro scale is matched with small, localized projects that focus on tailored practices built into an individual site, neighborhood, or community, and it requires a high level of civil involvement.[xiii]The combination of these strategies ensures that the weaknesses of focusing on either Macro or Micro approaches would create. For instance, natural conservation or restoration programs that only come from a Macro-scale decision without neither an emphasis on community's perspectives nor community's input are very likely to cause environmental displacement. Whereas smaller scale projects (Micro) tend to be more cost burdening as it requires more time and efforts to implement. In other words, the municipality needs to spend the manhours working with the various communities and ensuring that they have the resources that they need.

How to Determine Planning Priorities

Following the 2-scale approach, we split 9 strategies[2] by scale (more details in Table A7) and created scoring categories to determine which strategies would be most beneficial and urgent

[2] Macro-scale strategies address Natural Resource Protection, Development Regulation and Land Use Management, Building Standards, Critical Public and Private Facilities Policies, and Incentive Tools. Micro-scale strategies address Public/Private Sector Initiatives, Financial Tools, Property Acquisition Programs, and Public Information and Awareness.

to prioritize based on both our vulnerability analysis of Loíza's current conditions and assessment of its 2016 mitigation plan. There are three of the scoring categories utilized across both Macro and Micro scales, because GI planning in both large-scale and small-scale contexts would have to (1) produce long-term lasting change, (2) ensure cost efficiency and spur economic growth, and (3) establish and repair natural systems. What the two scales differ fundamentally depends on the parties, stakeholders, and ways the municipality works—inter-agency participation/resources for Macro sale, and community engagement for Micro scale. For large-scale projects, the municipality would need to link its GI planning to a variety of plans, obtain funding, data, and resources, and receive technical expertise from external agencies. On the other hand, the major focus of a small-scale approach lies in community input as projects need to stem from the residents' vision and needs, be repeatable and replicable (so that they are not one-offs and eventually fail) and are also accessible enough.

The scoring results summarized by Table A4 conclude that "Natural Resource Protection" and "Critical Public and Private Facilities Policies" as the priorities for the Macro-scale strategies. Although "Development Regulation and Land Use Management" receives the same score of 9 out of 11 as "Natural Resource Protection", it is not selected for entailing tools that overlap those in the "Critical Public and Private Facilities Policies". We also recognized that building on existing ecological systems to promote nature-based solutions has the greater capacity of addressing a wide range of environmental challenges faced by Loíza. The Micro-scale Priorities are "Property Acquisition Programs" and "Private-Public Sector Initiatives." Both of them receive the maximum scores for "Community Engagement" and "Long-term Vision." This remarkable performance is closely aligned with our proposed objectives of the Micro-scale strategy to be community-driven and repeatable in a long term. These two strategies perform poorly on cost-efficiency, but because we recognized the urgent need of involving residents in the planning and decision-making process, we would like to push the municipality to have a direct and open discussion with the residents of what are the alternative possibilities beyond maintaining the status quo.

1. Natural Resource Protection

This strategy aims to protect and connect ecological hubs and vital ecosystems through green infrastructure programs so that a more resilient coastal and urban environment can be

created under ample natural barriers, such as wetlands, barrier islands, estuaries, dunes, and forests. The tools proposed for this strategy emphasize autonomy on data and analysis, restoration of existing, damaged ecological systems, tailored land-use guidelines and plans for different target areas, management of natural resources[3] and maintenance of their protective features, and effective enforcement of land-use guidelines and plans (Table A7). Given the underfunded and understaffed nature of the Municipality of Loíza, we call for strong, transparent collaboration and financial, technical support across different levels of government bodies to support this long-range, costly, and technically challenging strategy. Although at the first the strategy does not seem cost-efficient, its return on investment will be promising by reducing gray infrastructure costs, increasing land values, lessening energy consumption, and providing a catalyst for economic development.[xiv]

Mangroves, for example, can significantly reduce annual and catastrophic damages from storms and are a strong first line of defense for coastal communities, according to a study from researchers at UC Santa Cruz, the Nature Conservancy, and Risk Management Solutions Inc. They find that mangroves in Florida prevented $1.5 billion in direct flood damages and protected over half a million people during Hurricane Irma 2017, reducing damages by nearly 25 percent in counties with mangroves.[xv] This quantification of the effectiveness of mangroves in reducing flood risk to people and property helps Loíza identify where to invest cost effectively in habitat restoration and conservation in a long run, which is critical for building its coastal resilience. A scientific study supported by the Puerto Rico Department of Natural and Environmental Resources discovers that the mangroves at Piñones have been significantly impacted by the past hurricane events and suffered a mortality rate of 30 percent, but the entire understory appears to be recovering naturally, through seed germination and tree re-sprouting. Recommendations are to passively monitor and allow for natural regeneration.[xvi]

A famously successful example of this strategy in action is a partnering between a local non-profit organization in San Juan called the Corporación del Proyecto ENLACE del Caño

[3] Natural resource here is defined as components of interrelated systems working together to provide complementary and more-robust services and economic value. Examples are coastal resources, forests, and key species.

Martín Peña (ENLACE)[4], the Commonwealth of Puerto Rico, the Puerto Rico Department of Natural and Environmental Resources, and the U.S. Army Corps of Engineers. In 2016, the completed a feasibility study for the Caño Martín Peña Ecosystem Restoration Project (CMP-ERP) and aim to re-establish the tidal connection between the San Jose Lagoon and the San Juan Bay, and thus, the eastern and western sections of the San Juan Bay Estuary where Loíza is also part of it. This restoration would improve dissolved oxygen levels and salinity stratification, increase biodiversity by restoring fish habitat and benthic conditions, and improve the functional value of mangrove habitat within the estuary.[xvii] This project was initially planned back in 2007 when the Congress authorized $150 million through the Water Resources Act, conditioned the approval of this study.[xviii] This example highlights the need of an inter-agency partnership and a community-based, participatory process operated throughout this partnership. A larger network with directory information for groups, experts, or organizations that could provide aid, resources, and technical assistance would be helpful for a small, overburdened municipality to determine priorities, mobilize expertise, and delegate tasks. About 9 years have been waited since the initial allocation of funding in 2007 until the final delivery of the feasibility study, mirroring the similarly long waiting process currently happened to Loíza for the funding, assistance, and actions to be done for disaster recovery after 2017. Community members hence have to be involved in a partnership to hold different parties accountable for their responsibilities. It is also important to support on-the-ground organizations that can facilitate the conversation between residents and organizations and directly serve the immediate needs of the community. Based on this example, another opportunity for Loíza is that similar studies can be and should be conducted in order to better direct the local restoration effort. A walkthrough of the recommended suitability analysis is provided in the next action and it emphasizes the concept of asset mapping to educate the value of the living environment, to involve residents in identifying the needs, and offered guidance about natural resource protection.

[4] The ENLACE Corporation is a public corporation created by law to coordinate and implement public policies regarding the rehabilitation of the Martín Peña channel ("Caño Martín Peña") and to promote the urban, social, and economic development of its eight adjacent communities.

2. Critical Public and Private Facilities Policies

This strategy works to address Public and Private Facilities as they are often located in physically vulnerable areas of Loíza. The tools for this strategy focus around setting up guidelines that can assist in the building, adaption or mitigation of buildings in order to prevent damage and loss of the facility infrastructure due to hazardous events. Other tools focus on requiring certain amounts of GI that allow for greenspaces, permeable pavement, certain materials etc. That provide protection and integrate the building better into the natural systems of Loíza. In Table A8, this strategy and "Development Regulation and Land Use Management" scored the same (9/11), it was determined that some of the strategies that were outlined in the other strategy also overlapped with some of the strategies in this strategy. Therefore, when we compared dissimilar tools to each other we found that this category better addressed the issues in Loíza (as these facilities are important to keep the function of the municipality running).

The standards set by this strategy would seek to, when possible, have newer projects built in areas with lower amounts of physical vulnerability (while recognizing that there are several established urban centers in the municipality that are located in more vulnerable areas). In order for this strategy to properly be implemented it has a long-time frame, as a result the strategy requires the use of inter-agency resources. This is also helpful as often facilities like schools, hospitals, fire stations, etc., are expensive to build and upgrade. Therefore, this strategy recognizes that by focusing on an inter-agency regional approach resources can be drawn into the municipality and there can be additional expertise added by other agencies that could assist with the mitigation of these municipal resources.

An example of this strategy in action is the partnering of FEMA with the Polytechnic University of Puerto Rico (UPPR) and the municipality of Loíza to establish a newly built Emergency Operations Center. This project began back in June of 2020 and the focus was for FEMA to aid the university and municipality both financially and assist with preserving the goals of the community,[xix] In this project the UPPR students worked with the community and municipality of Loíza to develop the concept and design. The plan itself tries to incorporate green planning practices (like the addition of photovoltaic panels and cisterns) that work to utilize natural processes in case of power grid failures while also creating a cleaner method of collecting energy.[xx] This example shows the power of the inter-disciplinary need for many of

these facilities. Like the new Emergency Operations Center, these facilities often need many hands working on it to find the best solution. In addition, the inter-agency cooperation allowed in this case for FEMA to help incorporate island wide initiatives into the project so that while the project is catered to Loíza specifically, it also addresses the overarching concerns of all Puerto Rico.[xxi] It is important that when working on projects that the expertise and information provided by other organizations allows for Loíza to both develop its own toolsets but also have access and help incorporating and drawing inspiration from other frameworks and methodologies that will make these projects more dynamic.

3. Property Acquisition Programs

This strategy works to assist different neighborhoods and communities in the municipality to acquire land. In Loíza, several of the coastal urban areas are more informal in nature and thus there is the possibility that many residents are therefore more insecure. In order to combat this, the Property Acquisition Programs strategy will focus on creating initiatives for community land trusts, programs for neighborhoods and communities to purchase land for public use like parks and plazas and encourage a Delegated Management Model. It is important not only for residents to own the land they occupy but also have a reasonable control of the communal and natural resources within the municipality.

Allowing the community control means that it could prevent unwanted development, allow for the community to be given more stakeholder power and incorporate more grassroots ideas into GI and Municipal planning practices. It also means that communities then can keep safe natural resources that could otherwise be sold or developed therefore resources remain accessible to the people for generations to come. The informal nature of Loíza in addition to promoting ownership and other opportunities for communities to have more control, this strategy acknowledges that informal residents often have a more difficult time receiving funding and assistance for GI planning initiatives and thus are more vulnerable and could have higher amounts of environmental displacement in the event of a natural hazard event.

A great example of a project in Puerto Rico that is currently running is Casa Pueblo. The non-profit located in Adjuntas, Puerto Rico began in 1980 as a community led initiative to prevent the mining of natural resources that would have caused both irrevocable environmental

and social damage to the region. After succeeding at preventing the mining of the surrounding natural resources the organization established a learning center that works to implement green infrastructure projects and educate the community about natural processes and greener ways of living.[xxii] This project is a great example of a community driven group that works to assist the community. For instance, they are working on projects to install solar panels, create urban gardens, preserve their forest reserves and other interesting endeavors. Assisting Loíza neighborhoods with this type of community engagement would mean that the residents could help greatly influence how their communities grow, incorporate, and build green infrastructure. It would mean creating education and economic programs that can assist residents with multiple facets of their lives and help to raise up the community and make it more resilient to future displacements due to hazards or environment.

4. Private-Public Sector Initiatives

In addition to working with the community on Property Acquisition, this strategy works to create community driven programs that work on education and participation of the community in the GI programs. The strategy also looks to try and incorporate the community into the planning processes. This strategy has many tools that can assist with these processes. For instance, in Table A_ the tools mentioned describe partnering with schools, religious centers and other community gathering institutions to set up educational and interactive programs.

The strategy also looks to make sure that there are regulations that require community input and participation in planning processes so that concerns and issues are presented and incorporated into the final plans. This way the community ensures that the needs that most affect their ability to remain resilient are addressed. The incorporation of the community into these processes also allows for the collection of more data and information that can better allow planners to understand the physical and specific conditions between neighborhoods to better understand how hazards like hurricanes, tsunamis, coastal erosion, etc., affect the municipality as a whole. This strategy could also utilize a suitability analysis model that can help the municipality identify more vulnerable areas based on socio-economic factors which can determine where targeted and immediate efforts should be directed. One of the reasons that our group incorporated local community members like religious, community and education leaders is that these local residents are able to assist in this process of connecting the municipality to the

residents and also, they are adept at gathering community members together and initiating community outreach programs.

The Scuba Dogs Society located in Puerto Rico, and a non-profit organization established in 1993, works to help restore and fix natural systems. Currently there are several projects that the organization has worked on including a coastal initiative that occurred in Loíza to clean up marine waste (I.e., pollution along the beach and waterfront).[xxiii] The project was conceived after the non-profit received a grant through NOAA that enabled the organization to assist Loíza with its clean up by educating and training volunteer community members on proper disposal and collection of Marine Waste.[xxiv] The project ran from 2015 to 2017 and eventually removed in all of the locations (including Loíza) 10 metric tons of debris and 600 volunteers ended up working around 2,400 hours.[xxv] The benefit to this type of program is that it allows for the community to be trained to perform the task at hand and also gain education and knowledge about the natural processes that are at risk. Having projects like this means that residents of Loíza and become experts on their environment and then can both continue the practices themselves and create a larger sense of ownership over their community. While this project only had a portion implemented in Loíza, if scaled up to the entire Loíza municipality it could mean that marine waste could be removed, and more mangroves could be then planted along the coast protecting the region from negative environmental effects. Not to mention that this type of project implemented at a larger scale could create cleaner beaches that would be more usable for the community.

Laying Out Stakeholders and Community Resources

A recommended GI planning process of both Macro- and Micro scales demands a whole community approach in order to ensure comprehensive and individualized strategies developed for each of the three target areas (e.g., coastal, inland open space, and urban) based on a community's given needs. FEMA defines "whole community as a means by which residents, emergency management practitioners, organizational and community leaders, and government officials can collectively understand and assess the needs of their respective communities and determine the best ways to organize and strengthen their assets, capacities, and interests."[xxvi] Table A9 provides in details the relevant actors and stakeholders on both Macro- (e.g., federal, island-wide, and local governmental bodies) and Micro- (e.g., community-based organizations,

private companies) scales and identifies their responsibilities respectively according to the four proposed priority strategies as mentioned above.

Walkthrough of Planning Tools

1. Plan Scoring to Better Integrate Green Infrastructure Planning Framework

Green Infrastructure planning has the potential to be incorporated into different components of a comprehensive planning framework (i.e., land use, transportation, economic development, public health, physical infrastructure) for the purpose of hazard mitigation. Based on the lessons from the 2016 Loíza Hazard Mitigation Plan addressed above, we recommend the municipality to continue utilizing and developing our plan scoring methodologies when making future plans. A plan is usually required to have sections, including Vision, Planning Process, Fact Basis, Goals and Objectives, Interorganizational Coordination, Policies and Coordination, and Implementation Plan. Due to GI encompassing both physical and social solutions/orientations, the recommended scoring includes subcategory criteria asking the following questions to each of the required sections in a plan: (1) Does it address climate change? (2) Is the community involved? (2) Does it include social vulnerability? (3) Does it build upon existing GI? (4) Does it promote nature-based solutions? These questions focus on utilizing the definition of GI; then the scale has a 0-2pt rating system where 2 exceeds minimal requirement, 1 meets requirement and 0 does not meet minimum standards. For the examination of each plan, a scale from 0-2pt is applied to each section of the plan by subcategory criteria which at maximum would be received an overall score out of 10. This methodology was developed so that zero would indicate if the plan failed to meet minimum standards (i.e., including something to "check a box") or if it was considered to be non-existent in the first place and that a 1 would be meeting minimum standards and a 2 would be exceeding those standards and be more on par with what we would want from a plan in the first place.

2. Suitability Analysis for Developing Green Infrastructure Programs

Suitability Analysis is a procedural technique used to assess the ability of a system to meet the needs of stakeholders and users. A suitability analysis augmented by GIS mapping essentially depicts the best location for a specified purpose. Suitability analysis can also be used to map vulnerability to potential hazards, such as floods, sea level rise, earthquakes, biological

contamination, and also crime.[xxvii] This process can also be used to locate advantageous sites for activity hubs and commercial centers. In a disaster management context of Puerto Rico, suitability analysis can be incorporated to map the following: Potential Hazard Sites, At-risk/vulnerable communities, Green Infrastructure Hubs and Links, Natural Ecosystems to be preserved.

Figure A5 as an example serves to depict the process involved in mapping vulnerability in terms of population density, floodplains, and the locations of critical ecosystems. A similar process can be carried out to identify sites which provide ecosystem services and thus, could be prioritized for preservation. Suitability analysis can be incorporated into land use plans and physical infrastructure development plans to identify potential sites for development and other critical ecosystems to be avoid any construction altogether. This process is also useful for transportation plans as it can assist in laying out non-intrusive road networks and also establish blue and green links which connect Green Infrastructure hubs. The suitability analysis can also potentially be used to situate mangrove coverage along the coastline for shoreline protection.

Conclusion

The plan for Loíza is to adapt to climate change in a way that advances the interests and aspirations of the local community. The community must achieve resiliency to maintain normal function in the face of future challenges, and for the long term strive to adapt to the changing climate by having flexible social and infrastructural templates. Green Infrastructure can serve this ambition as it allows planners to synchronize the built environment with the surrounding natural systems in a non-intrusive manner with promising return on investment and produce a series of social, public health, and economic benefits. Effective GI planning strategies as outlined in the report combined with powerful tools as plan scoring, suitability analysis, and asset mapping can lay the groundwork for a robust comprehensive plan that builds upon and further develop the existing valuable ecological systems in Loíza. Furthermore, GI planning can be incorporated into traditional plans for land use, transportation, infrastructure development, healthcare, and economic development to better align with the long-term climate goals. This can be achieved by tailoring the existing plans to fit the GI planning strategies directed towards disaster preparedness and post-disaster recovery.

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Appendix A

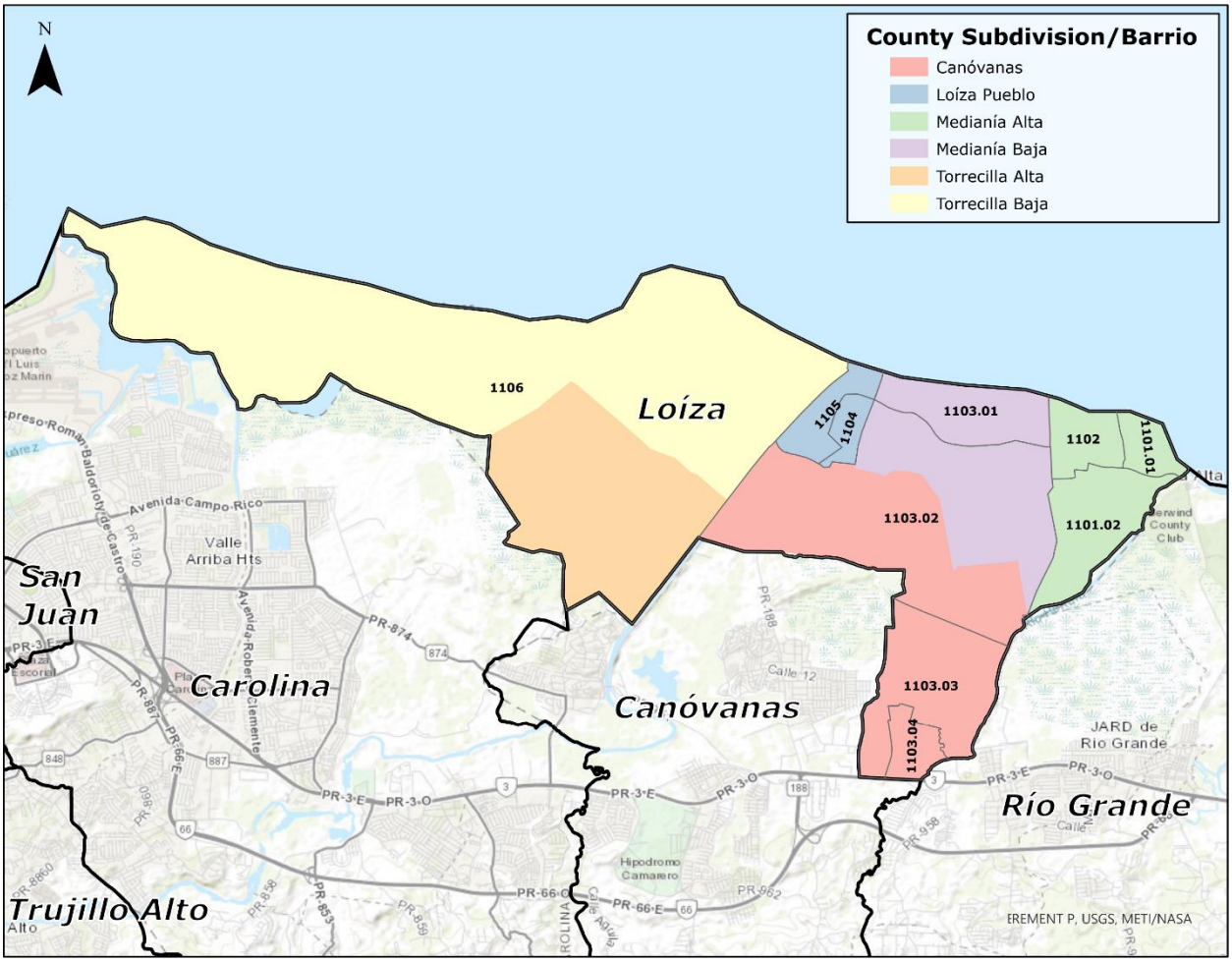


Figure A1. Loíza is divided into 6 barrios or 10 census tracts

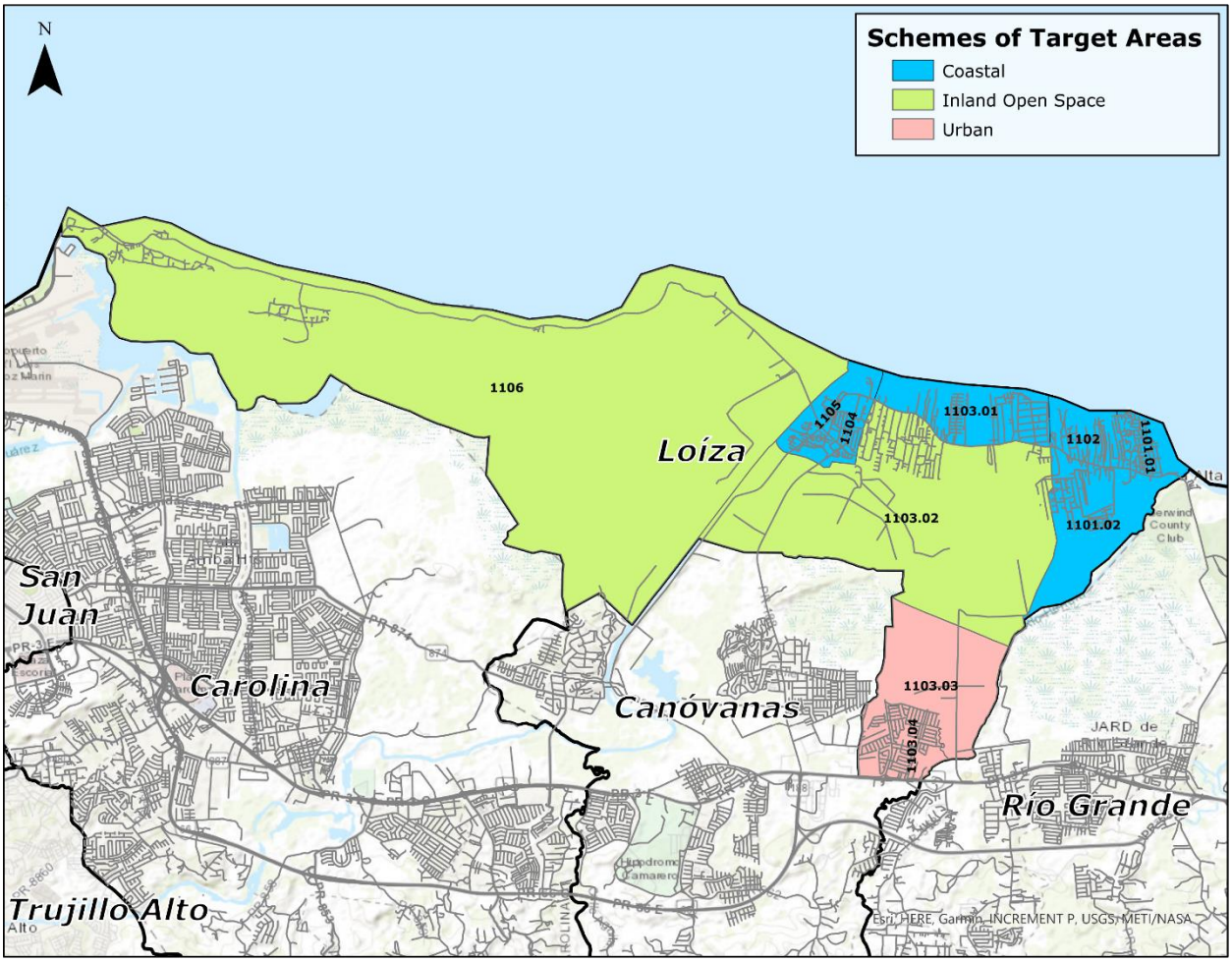
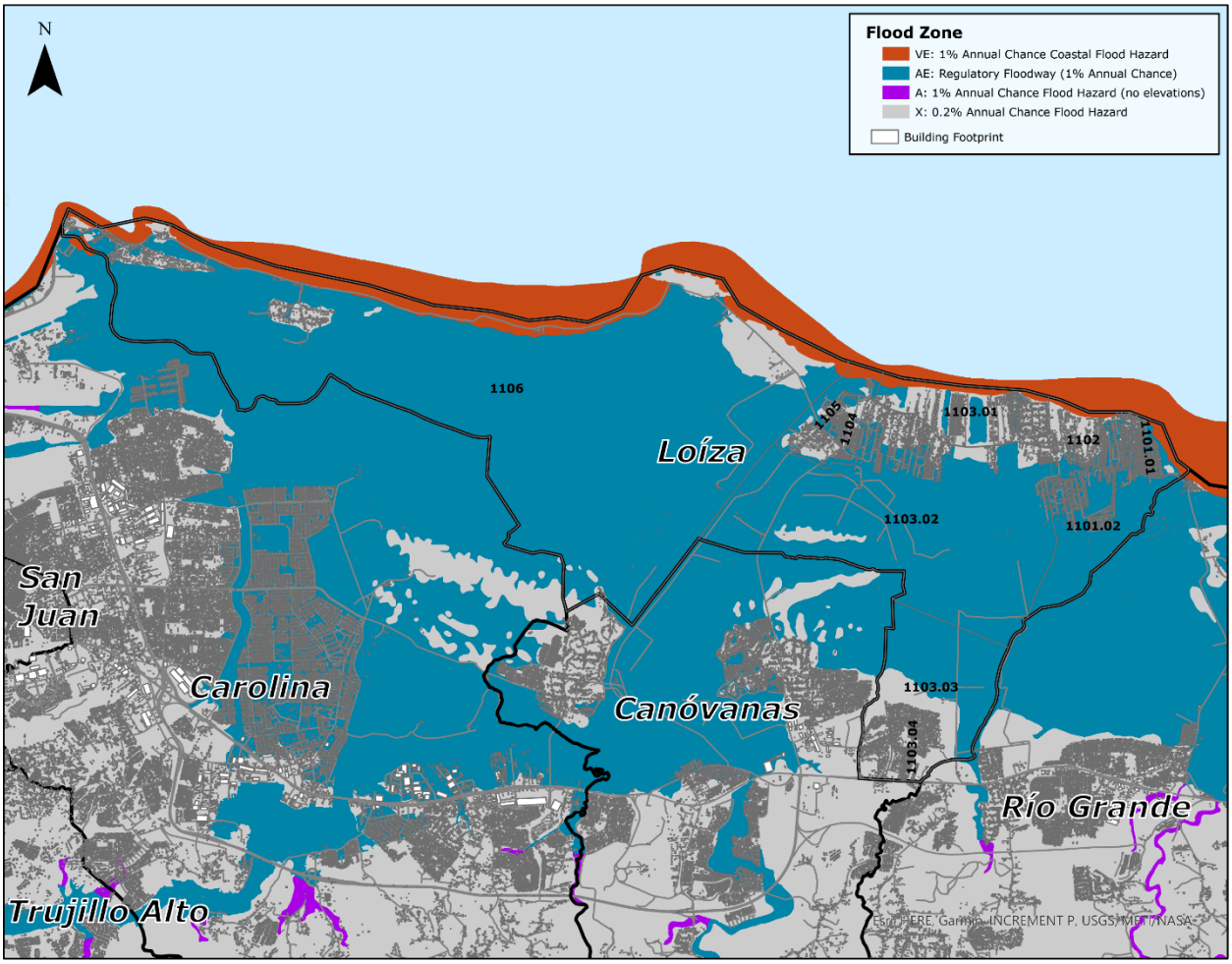


Figure A2. Green Infrastructure Planning in Loíza should address 3 target areas accordingly



Creator: Mengqi (Archie) Chen
Data Sources: FEMA Flood Map Service Center, 2018

0 0.5 1 2 Miles

Figure A3. Flood Zone Classification of Loíza

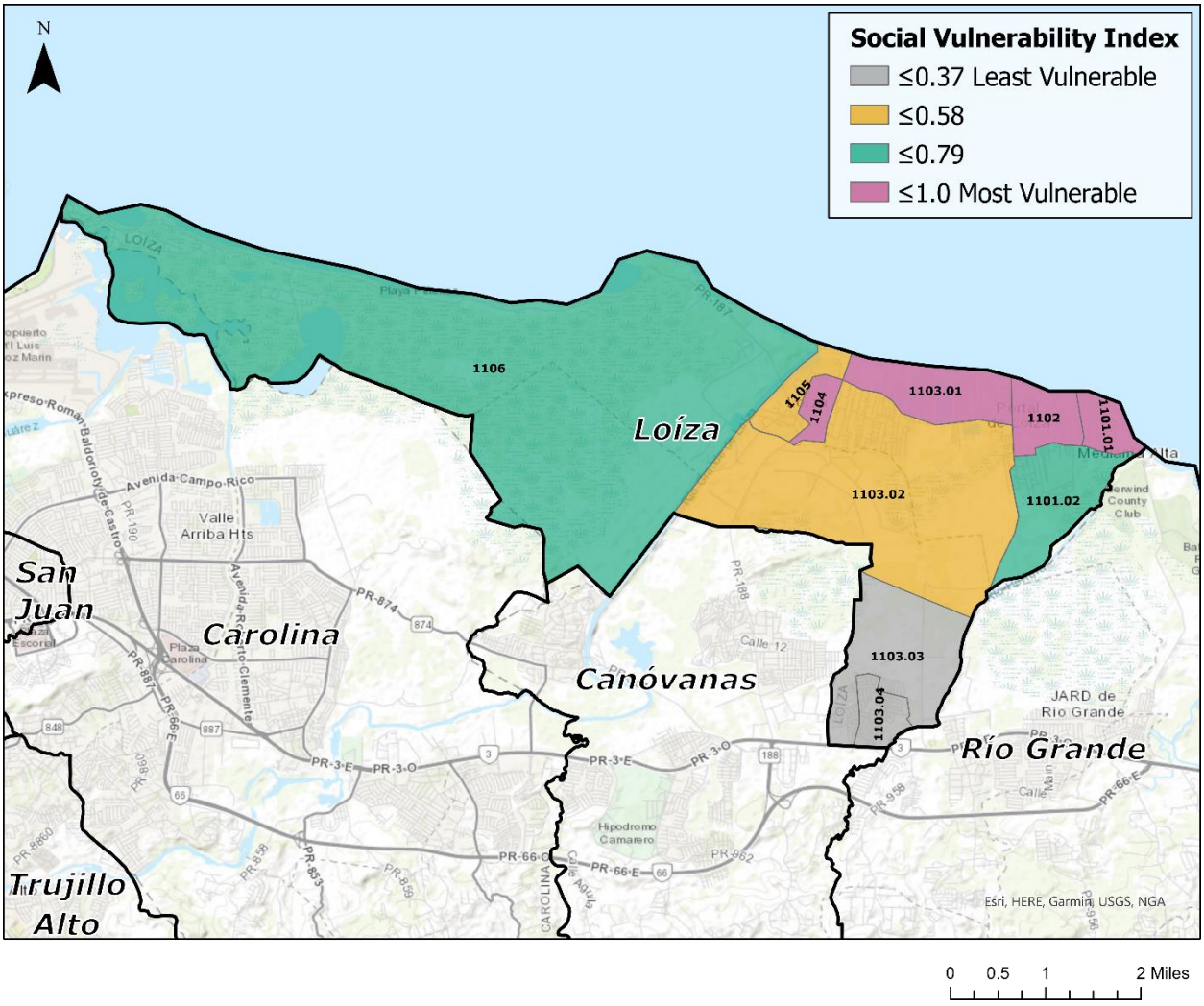
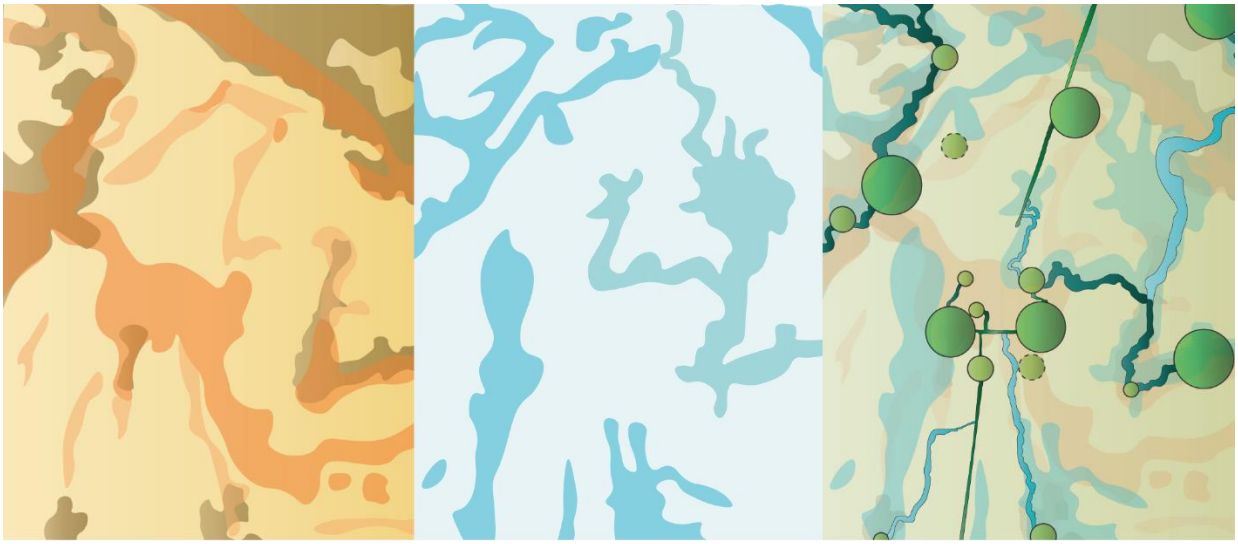


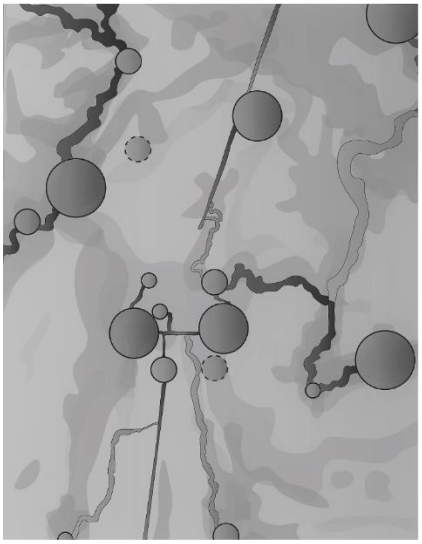
Figure A4. CDC Social Vulnerability Index of Loíza at Tract Levels, 2018



Indicator 1
"Population Density"

Indicator 2
"Flood Plains"

Indicator 3
"Critical Ecosystems"



Output
"Vulnerability Map"

Figure A5. Example of Composite Suitability Analysis Consisted of Multiple Factors

Figure A6. Green Infrastructure Planning on All Fronts:
How GI is Integrated into Different Components of a Comprehensive Plan

Table A1. Summary of Natural Hazard Challenges to Loíza

Sources: U.S. Geological Survey; US Army Corps of Engineers, 2018; Government of Puerto Rico, 2021; Volcano Discovery, 2021

What Hazards Are You Exposed To?	What Are the Hazard Characteristics?	Historical Precedents	Hazard Effects	Priority Level
Coastal Erosion	The process by which local sea-level rise, strong wave action, and coastal flooding wear down or carry away rocks, soils, and/or sands along the coast	Long-term, ongoing; Further exacerbated by impacts from the 2017 Hurricanes Irma and María	Permanent loss of property and land; Weakened infrastructure foundations; Loosened construction debris	High
Earthquake	Violent tremors induced by seismic activity of tectonic plates; Can potentially trigger landslides, tsunamis, and volcanic activity	Forty-five earthquakes with a magnitude of 4 or above over the last 50 years	Destruction of public utilities; Damage to the built and natural structures; Exacerbated impact on people with underlying health issues; Stressed allocation of local resources and need for triage	Medium
Flooding (particularly riverine and coastal)	Inundation of normally dry areas due to increased water levels in an established watercourse; Commonly associated with low pressure weather systems, including tropical storms and hurricanes	The largest known flood to occur on the Río Grande de Loíza was on August 4, 1945 with a discharge of 2,410 cubic meters per second (cms); Other notable floods for the river occurred on September 6, 1960; August 4, 1961; and October 9, 1970	Incapacitation of public utilities; Damage to physical infrastructure Migration influx until water levels recede	Medium
Tropical Storm and Hurricane	Intense tropical weather systems with maximum sustained winds greater than 74 mph causing devastating physical and social impacts; Usually accompanied by high tides, storm surge, gales, and heavy rains that can bring about landslides and flooding	Six Category 4 or above Hurricanes over the last 100 years: San Felipe II (1928), San Ciprián (1932), Hugo (1989), Georges (1998), Irma (2017), María (2017)	Destruction of built and natural structures; Disruption of services weeks/months; Damage and loss of human life; Strain on social and human capital; Psychological impact and panic-driven decision making; Long-term negative economic impacts	High

Tsunami	Displacement of a large volume of water causing a rapid and sweeping inundation across the land; Primarily caused by earthquakes, volcanic activity, or underwater explosions	1867 Virgin Islands tsunami gave a maximum wave height of more than 7 meters (23 feet); A magnitude 7.5 earthquake in 1918 caused a tsunami which reached 6 feet and killed at least 91 people in northwestern Puerto Rico;	Destruction of built and natural structures; High death toll; Devastating impact on local economies; Inland migration influx until water levels recede	Medium

Table A2. Summary of Physical Vulnerability Analysis
Sources: NOAA, FEMA, U.S. Army Corps of Engineers

Structures	**Groups Affected**	**Who's Responsible If Affected?**	**Need Investment?**
Residential housing along the coast and in the inland areas (tract 1103.04)	Homeowners, renters	PR Departamento de la Vivienda, Homeowners	Yes. Over 70% of housing units in tracts 1104, 1105, and 1103.04 are over 30 years old. More developed inland areas also have a large coverage of impermeable surfaces, and hence require interventions to fortify existing structures for long-term resilience.
Businesses along the coast (particularly in tracts 1104, 1105)	Auto shops, Restaurants, Convenience stores, Gas stations, Hotels	PR Departamento de Desarrollo Económico y Comercio, Businesses owners	Yes. Residents have been cut off historically cut off from the major transport network. Local businesses need to be maintained to provide daily necessities. Since many of them are located along the coast, shoreline protection is necessary.
Religious institutions and community-based organizations along the coast (particularly in tracts 1104, 1105)	Churches, Community gathering places	Religious and community leaders	Yes. These institutions are valuable social capital and can help mobilize residents and educate them to engage in GI initiatives.
Critical Infrastructure	**Groups Affected**	**Who's Responsible If Affected?**	**Need Investment?**
Public roads	Drivers, pedestrians	PR Departamento de Transportación y Obras Públicas, City staff	Yes. Hurricanes Irma and Maria made landfall along with erosion created immediate damages to the roads.

			Emergency shoreline protection is needed to prevent the road from further failing due to the continued and exacerbated erosion made worse by the storm events.
Educational institutions along the coast (particularly in tracts 1104, 1105)	Elementary schools, Middle schools, teachers, families	School boards	Yes. Schools can act as one of the stations for education outreach out green infrastructure initiatives.
Public facilities along the coast (particularly in tracts 1104, 1105)	Airports, Bus stops, Water Pumping stations, Water plants, Police stations, Energy stations	Departamento de Transportación y Obras Públicas, City staff, Business owners	Yes. Adequate transportation services provide residents access to employment, education, medical services, and other necessities of daily life, as well as opportunities to escape during an emergency. Also, the municipality has been disconnected from the power supply networks very often during past storm events.
Natural Infrastructure	**Groups Affected**	**Who's Responsible If Affected?**	**Need Investment?**
Beaches, Dunes, Fish and wildlife habitats	Fisherman, Tourism-related industries, Residents, Wildlife	PR Departamento De Recursos Naturales Y Ambientales, City staff	Yes. Without shoreline protection, erosion will continue to reduce the available land, beaches, and foraging/nesting habitat.
Freshwater sources	Residents, Business owners	PR Departamento De Recursos Naturales Y Ambientales, City staff, Business owners	Yes. Otherwise, turbid water quality conditions will continue due to the ongoing erosion and storm event impacts.
Wetlands and large stands of trees bordering bodies of water Wetlands	Residents, Wildlife	PR Departamento De Recursos Naturales Y Ambientales, City staff	Yes. Wetlands can be utilized to manage rainwater runoff.
Coral reefs	Residents, Wildlife	PR Departamento De Recursos Naturales Y Ambientales, City staff	Yes. Reefs are unique ecosystems of plants, animals, and their associated geological framework. They are also of great economic importance. Increasing sea level rise can disrupt all aspects of reef morphology—colony size and shape, cross-reef relief, surface rugosity, and so forth.

Table A3. Summary of Social Vulnerability Analysis
Sources: U.S. Census Bureau ACS 5-Year 2015-2019

Factors	**2019 ACS 5-Year Data For Loíza**	**Overview**
Household Structure *US Household size: 2.52/US Family Size 3.14	Average Size: 3.02 Average Size (Owned Home): 2.94 Average Size (Rented): 3.2 Average Family Size: 3.65 % Households Cost Burdened: 22.53% (Owned: 22.4%, Rented: 22.85%)	The family and household size are larger than US averages. Around a quarter of the population is cost-burdened
Socio Economic Status *US Median Income: $62,843/ Puerto Rico Median Income: $20,539	Median Household Income: $17,852 Per Capita Income: $9,335 Poverty Rate: 48.22% % (households) receiving public assistance: 4.75% % (households) receiving cash assistance: 51.48%	The average income trend for Loíza is lower for both the US and Puerto Rico. Also, over half of Loíza's population needs assistance to make ends meet.
Gender	Average Size of Household (Female Head): 3.86 Average Size of Household (Male Head): 3.71 Percent of Female Head Households: 31.66% Sex Ratio (Males Per 100 Females): 87.1	Around a third of the households have female heads and the household sizes tend to be larger in female-run households than male-run households.
Race and Ethnicity	Race: (White – 24.3%, Black – 38.7%, Other – 36.2%. Two or More – 0.4%) Ethnicity: (Hispanic or Latino – 99.7%, Not Hispanic or Latino – 0.3%)	Loíza's population is predominately comprised of minority racial backgrounds and (because it is PR) is almost 100% Hispanic/Latino
Age *US Median Age: 38.1/ Age Dependency Ratio: 53.28%	Median Age: 40.2 Years (M:38.9, F:40.9) Age Dependency Ratio: 61.3 (Old Age: 27.4, Child: 33.9)	Loíza has both an older population and has a higher dependency ratio than the USA averages.
Tenure	Rent: 29.5% Own: 70.5% Has a Computer/Smartphone: 6,297	Loíza is mostly comprised of an owner population and around a quarter of the population does not have access to a computer and about a seventh of the population has access to a car.

	No Computer/Smartphone: 2,211 % No Car: 14.74%	
Urban/Rural	Majority in Urban Areas *estimated from previous Decennial Census Tables (2010, 2000, etc.)	This rings true as there is one large urban area in Loíza with the largest portion of the population
Special Needs	Percent Disabled: 19.04% Percent Disabled Over 65: 51.66	About 1 fifth of the total Loíza population identifies with having a disability (potential possibility this number is actually larger)
Employment status *US Unemployment rate: 4.9%	Unemployment Rate: 24.78% Percent Not in Labor-force: 50.97% Percent No Insurance: 9.28%	Loíza has a significantly larger unemployment rate compared to the same survey for the US

Table A4. Plan Quality Assessment for Loíza's Natural Hazard Mitigation Plan, 2016

Dimension / Question	**Does it address climate change?**	**Is community involved?**	**Does it include social vulnerability?**	**Does it build upon existing GI?**	**Does it promote nature-based solutions?**	**Overall Plan Quality Score**
Vision	1	1	1	0	0	3
Planning Process	1	1	1	1	1	5
Fact Basis	2	0	2	1	0	5
Goals & Objectives	1	1	1	0	0	3
Interorganizational Coordination	2	1	0	2	0	5
Policies & Coordination	1	0	1	1	1	4
Implementation Plan	1	2	1	2	1	7
Mean Score	1.3	.9	1	1	.4	4.6/10

Note: The overall plan quality score for each dimension is on a 10-point scale and consists of the sum of its scores on all 5 questions. Each of the 5 questions is graded range from 0 to 2. 0 refers to not included at all; 1 refers to where meets minimal requirements and standards; 2 refers to where exceeds the minimal requirements and standards.

Table A5. The Plan Review Crosswalk

Topic	Element-Related Questions	Scoring System
Prerequisite		
Adoption by the local governing body	Has the local governing body adopted the plan? Is supporting documentation, such as a resolution, included?	Met The plan has been adopted by the Municipality of Loíza, to be maintained in compliance with the Stafford Act (Amended, 2000)
Multi-jurisdictional plan adoption	Does the plan indicate the specific jurisdictions represented in the plan? For each jurisdiction, has the local governing body adopted the plan? Is supporting documentation, such as a resolution, included for each participating jurisdiction?	Met Six specified administrative divisions: Canovanas Loíza Pueblo Mediania Alta Mediania Baja Torrecilla Alta Torrecilla Baja
Multi-jurisdictional planning participation	Does the plan describe how each jurisdiction participated in the plan's development?	Met Appendix E: List of Polled Families and Questionnaires
Planning Process		
Documentation of the planning process	Does the plan provide a narrative description of how the plan was prepared? Does the plan indicate who was involved in the current planning process? Does the plan indicate how the public was involved? Was there an opportunity for neighboring communities, agencies, businesses, academia, nonprofits, and other interested parties to be involved in the planning process? Does the planning process describe the review and incorporation, if appropriate, of existing plans, studies, reports, and technical information?	Met Section 3.4: Review of Existing Legislation, Plans and Reports
Risk Assessment		

Identifying hazards	Does the plan provide a description of the type of all natural hazards that can affect the jurisdiction?	Met 4.2 Identification of Hazards
Profiling hazards	Does the risk assessment identify the location of each natural hazard addressed in the plan? Does the risk assessment identify the extent of each hazard addressed in the plan? Does the plan provide information on previous occurrences of each hazard addressed in the plan? Does the plan include the provability of future events for each hazard addressed in the plan?	Met 4.3 Profile of Hazards
Assessing vulnerability	Does the plan include an overall summary description of the jurisdiction's vulnerability to each hazard? Does the plan address the impact of each hazard on the jurisdiction?	Met Probability-based analysis to assess frequency of disasters
Assessing vulnerability by identifying structures	Does the plan describe vulnerability in terms of the types and numbers of existing buildings, infrastructure, and critical facilities located in the identified hazard areas? Does the plan describe vulnerability in terms of the types and numbers of future buildings, infrastructure, and critical facilities located in the identified hazard areas?	Met 4.6 Inventory of Assets
Assessing vulnerability by estimating potential losses	Does the plan present an overview and analysis of the potential losses to the identified vulnerable structures? Does the plan describe the method used to prepare the estimate?	Met 4.7 Loss Estimates
Assessing vulnerability by analyzing development trends	Does the plan describe land uses and development trends?	Needs improvement
Multi-jurisdictional risk assessment	Does the plan include a risk assessment for each participating jurisdiction as needed to reflect unique or varied risks?	Needs improvement
Mitigation Strategy		
Local hazard mitigation goals	Does the plan provide a description of mitigation goals to reduce or avoid long-term vulnerabilities to the identified hazards?	Met 5.1 Mitigation Strategy
Identification and analysis of mitigation actions	Does the plan identify and analyze a comprehensive range of specific mitigation actions and projects for each hazard? Do the identified actions and projects	Met 5.2 Mitigation Action Plan

	address reduce the effects of hazards on new buildings and infrastructure? Do the identified actions and projects address reducing the effects of hazards on existing buildings and infrastructure?	
Implementation of mitigation actions	Does the mitigation strategy include how the actions are prioritized? Does the mitigation strategy address how the actions will be implemented and administered? Does the prioritization process include an emphasis on the use of a cost–benefit review to maximize benefits?	Met (All conditions included)
Multi-jurisdictional mitigation actions	Does the plan include at least one identifiable action item for each jurisdiction requesting FEMA approval of the plan?	Met
Plan Maintenance Process		
Monitoring, evaluating, and updating the plan	Does the plan describe the method and schedule for monitoring the plan? Does the plan describe the method and schedule for evaluating the plan? Does the plan describe the method and schedule for updating the plan?	Met 6.2 Monitoring
Incorporation into existing planning mechanisms	Does the plan identify other local planning mechanisms available for incorporating the requirements of the mitigation plan? Does the plan include a process by which the local government will incorporate the requirements in other plans when appropriate?	Met 6.7 Implementation through Existing Planning Mechanisms
Continued public involvement	Does the plan explain how continued public participation will be obtained?	Met (Participation mechanisms in place)
Federal Emergency Management Agency (FEMA). State Multi-Hazard Mitigation Planning Guidance (Mitigation Planning "Blue Book"). Washington, DC: Author, January 2008.		

Table A6. Types of Plans and their Hazard Mitigation and GI Applications

Types of Plans	General Purpose	Hazard Mitigation and Climate Change Considerations	Green Infrastructure Planning Techniques
Land-use Plans	Protect and preserve natural systems and sites with special value to local communities. Land-use plans zone economic development and residential areas away from at-risk areas to minimize loss of life and livelihoods to natural disasters	Coastal zone management to be carried out rigorously to hedge against the hazards posed by natural disasters. Longitudinal sections of land could be allocated for hard and soft engineering measures across the coastline.	Creating zones so that micro ecosystems can be better preserved through more specific planning.
Transportation Plans	Improve connectivity through road, pedestrian, transit, and other non-conventional modes of transport.	Emergency access routes to be planned beforehand; routes enabling rapid inland migration during cyclones, storm surges, or flooding must be a high priority[4].	Preserving roads against erosion. Promoting transportation planning in non-essential vegetative areas.
Economic Development Plans	Conform to the New Urban Agenda (UN-H) to provide "ensure sustainable and inclusive urban economies". Governments can achieve economic sustainability "by leveraging the agglomeration benefits of well-planned urbanization, including high productivity, competitiveness, and innovation."	Promote the development of major economic activity hubs and residential zones away from coastal zones. Ensure protection of local natural resources from exploitation by predatory actors Incorporate DRNA tools and guidelines into the economic development plans.	Promote green businesses Incentives to discourage environmentally damaging activities
Public Health Plans	Maintain a robust Medicaid plan with sound program integrity. Establish healthcare infrastructure and systems to provide comprehensive coverage in terms of expertise and specialties.	The Puerto Rico Medicaid plan can be reviewed for disaster preparedness and historical inefficiencies can be addressed retroactively. The overall health plans could be boosted in the capacity for triage and critical lifesaving systems deployed during and after natural disasters. Secure the plan with fraud prevention mechanisms to prevent additional stress on the system during times of crisis.	Incorporating parks to promote physical and mental health, improve water quality

Physical Infrastructure Development Plans	Improve existing utilities catering to water, power, and waste management. Promote inclusive, efficient, and sustainable urban development (UN-H).	Green Infrastructure (GI) funding mechanisms are required to ensure the protection of vulnerable groups. The possibility of climate gentrification should be considered while planning and implementing GI (Anguelovski, 2019[5]). Infrastructure must be resilient to short-term environmental challenges and be able to quickly reorient itself to maintain normal function in the face of adversity. Boosting the physical infrastructure should be a means to achieve long-term climate adaptation.	Rainwater management (e.g., rain gardens, green roofs, permeable pavement) Low-impact development

Table A7. Nonstructural Hazard Mitigation and Adaptation Strategies and Policies

Strategy	**Goals**	**Tools**
Macro Scale		
Building standards	Incorporate and enforce building codes designed to promote climate-resilient infrastructure	Establish building standards that meet FEMA Building Codes for: Earthquake Building Codes High-Wind Building Codes Multi-Hazard Building Codes Utilize the FEMA Substantial Damage Estimator Tool[5] to determine vulnerable buildings and plan for their updating. Create building standards for different building types: Schools, Religious, Community/Public, Houses, etc. Implementation of coastal setbacks

[5] https://www.fema.gov/emergency-managers/risk-management/building-science

Critical Public and Private Facilities Policies	Create clear guidelines on the location of public/private facilities to avoid areas at most risk for hazards.	Enforce Open Space determinations with programs/guidelines for the dedication of lands to the creation of parks, GI projects, land conservation, and other adequate uses Setting design standards that promote GI mitigation practices in vulnerable areas. Set requirements for mitigation infrastructure in both public and private sectors regardless of location in vulnerable areas (i.e., using certain materials, promoting permeable pavements, green roofs, etc.) Initiate GI programs geared towards rebuilding the coastline of Loíza (i.e., mangroves, rebuilding of natural vegetation, anti-corrosion methods of planning, etc.)
Development regulation and land use management	Zoning codes to push residential development away from coastal zones Incentivize relocation to safer zones	Establish special overlay districts to provide additional provisions to at-risk zones. Utilize incentive tools (as described in Strategy #5) to encourage sustainable development away from coastal flood zones Create regional zones to customize mitigation planning: Coastal, Infill, and Urban Adopt protected areas as designated and amend zoning laws/regulations to harmonize existing uses within the boundaries of the protected and in their immediate surroundings
Incentive tools	Encourage landowners and developers to preserve the physical environment and avoid destructive development activities in environmentally sensitive and hazardous areas Reduce future flood risk and cost	Training and capacity-building program to promote green businesses Tax incentives or public funding to relocate businesses or facilities out of hazard areas Environmental Quality Incentives Program[6]

[6] https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip/

		Impact fees to cover public costs Restoration tax credits Fines on environmentally damaging activities Sell of transfer of development rights on properties to another non-hazardous area Funding designation towards the provision of low-income housing Participation in the National Flood Insurance Program (NFIP) and/or FEMA Community Rating System (CRS)
Natural resource protection	Protect ecological hubs and vital ecosystems Promote green infrastructure systems Establish links to connect hubs to create a sustainable and non-intrusive urban environment)	Incorporate suitability analysis to identify critical ecological hubs and nature trails. Develop programs for the creation and restoration of reefs (e.g., coral, oyster), barrier islands, dunes, beaches, wetlands, and forests Establish Regional Zones with individual environment guidelines Develop comprehensive watershed plans using integrated water resources management to promote the sustainable use of water resources Revise and effectively implement the municipality land use plan
Micro Scale		
Financial Tools	Partner with communities to create programs that promote GI planning and economic opportunity. Create more opportunities for communities by mitigating costs for GI mitigation.	Give tax incentives for residents and developers who implement GI planning techniques on their property. Develop programs that assist Loíza residents who do not have the funds to implement GI for their homes or property. Create programs in public spaces that promote communal economic interests associated with GI (i.e., integrate economic opportunities into farmers markets, community gardens, etc.)
Private-Public Sector Initiatives	Partner with communities to create GI education and participation programs. Promote community involvement in creating mitigation strategies.	Assist communities in mitigation planning by providing and collecting data and incorporating individual communities into the overarching regional plan. Implement a suitability analysis to assist the planning

		department with prioritizing communities with the larger number of vulnerabilities first. Promote community land trusts Partner with schools, community centers, and religious institutions to implement education programs that assist residents of the community with learning and interacting with local GI. Setting up community meetings and events in neighborhoods to gather local information about concerns and issues regarding hazard mitigation Set up regulations for hazard mitigation planning that promote community input (i.e., require a certain number of meetings at different times and locations, require public input at beginning of planning process, etc.)
Property acquisition programs	Acquire property for local community's and public's benefit and use Build upon existing green infrastructure and ecosystems to enhance resilience	Community Land Trust (CLT) to help communities own the lands permanently for promoting GI practices, ensuring housing affordability, and creating/securing public spaces Delegated Management Model[7] to allow communities to preserve the ecosystems and restrain environmentally damaging activities Collectively held rights in a resource system (e.g., forest, wetland, reef, mangrove) for preservation and restoration
Public information and awareness	Deliver coordinated, prompt, reliable, actionable, and accessible information to the whole community regarding any threat or hazard, as well as the actions being taken, and the assistance being made available (with an emphasis on promoting nature-based solutions)	Public education seminars, workshops, and other activities on hazard mitigation practices, nature-based solutions, and recognition of ecosystem values and services Training or information campaign, in general, to promote and prepare residents for green jobs and volunteering restoration works

[7] The state and/or local government maintains ownership of the resources and delegates management to local groups for a specific period of time, with the possibility of renewal.

		Informal science education and data collection to engage communities in understanding the living environment, climate change effects, and the resulting risks Training sessions for staff members to utilize data for analysis and decision-making

Table A8. Green Infrastructure Planning Strategy Prioritization Scoring Results

Strategy	**Categories**				**Score**
Macro	Inter-agency Participation/Resource (Transparency, Funding, Technical Assistance)	Economic benefit (Cost efficiency, Return on Investment)	Time Frame Short - X Medium - XX Long Term - XXX	Nature Restoration/Preservation (Utilizing Known Systems, Protecting from Further Physical Damage, Data Collection/Usage)	Total
Natural Resource Protection	XXX	X *Not cost-efficient; Requires coordination, labor, and time	XXX	XX *Data access would be an issue	9/11
Development Regulation and Land Use Management	XX *Transparency is not guaranteed but needed	X *Not cost-efficient; Requires intensive coordination	XXX	XXX	9/11
Building Standards	XX *Proposals do not seem to well match with existing federal funding opportunities	XX	XX *Medium frame for implementation though with a long-term vision through reinforcement, amendments, and updates	XX *Data access would be an issue	8/11
Critical Public and Private Facilities Policies	XXX	X *Not cost-efficient; Demand reliable funds	XXX	XXX	10/11

		and labor maintenance			
Incentive tools	XXX	XX	XX *Medium frame for implementation though with a long-term vision through maintenance and renewal	X *Does not directly utilize existing ecosystems; Data access would be an issue	8/11
Micro	Community Engagement (Locally Driven, Repeatable, Accessible)	Economic benefit (Cost Efficiency, promoting local development)	Time Frame Short - X Medium - XX Long - XXX	Nature Restoration/Preservation (Creating Community Benefits, Protecting from Further Physical Damage, Data Collection/Usage)	Total
Public/Private Sector Initiatives	XXX	X *Not Cost Efficient, Requires Large Time Commitment/Man-Hours	XXX	XX *Does not guarantee protection from future Physical Damage	9/11
Financial Tools	XX *This is not as Locally Driven as it would require more assistance from the municipality	X *Not Cost Efficient, Requires Large Time Commitment/Man-Hours	XX *Medium Frame as it is about incentivizing immediate projects and residents would need to continue to update homes/Property over time.	XX *Does not have a Data Usage Component	7/11
Property Acquisition Programs	XXX	X *Not cost-efficient as it requires the purchasing of land by the community	XXX	XXX	10/11
Public Information and Awareness	XX *Not locally driven (it is about municipality educating public on initiatives on their end)	X *Not Cost Efficient, Requires Large Time Commitment/Man-Hours	XXX	XX *Does not protect inherently against future damage as the point is to prepare and educate not implement	8/10

Table A9. Relevant Actors and Stakeholders and Their Responsibilities

Stakeholder	Natural Resource Protection	Critical Public and Private Facilities Policies	Property Acquisition Programs	Private-Public Sector Initiatives
Macro-Scale				
FEMA	X			X
HUD			X	X
U.S. Army Corps of Engineers	X	X		
PR Planning Board	X	X	X	X
Central Office of Recovery, Reconstruction, and Resiliency (COR3)	X			X
PR Department of Natural and Environmental Resources	X	X		
PR Department of Transportation and Public Works	X	X		
PR Department of Housing	X		X	
PR National Flood Insurance Program	X	X		
Municipality of Loíza	X	X	X	X
Micro-Scale				
People's Council, Residents	X		X	X
Community-based, or Non-Profit Organizations, e.g., Corporación Piñones Se Integra (COPI) (community-based organization for cultural and ecotourism services) Foundation for Puerto Rico (non-profit organization for economic development) Taller Salud (female-led non-profit organization)	X		X	X
Local Schools			X	X
Local Churches				X
Teachers' Unitions/Networks				X

Debris Management Companies				X
Water, Sewer, Electricity Utility Companies				X
Construction Companies				X
Center for Coastal Conservation at the University of Puerto Rico	X	X		X

Appendix B

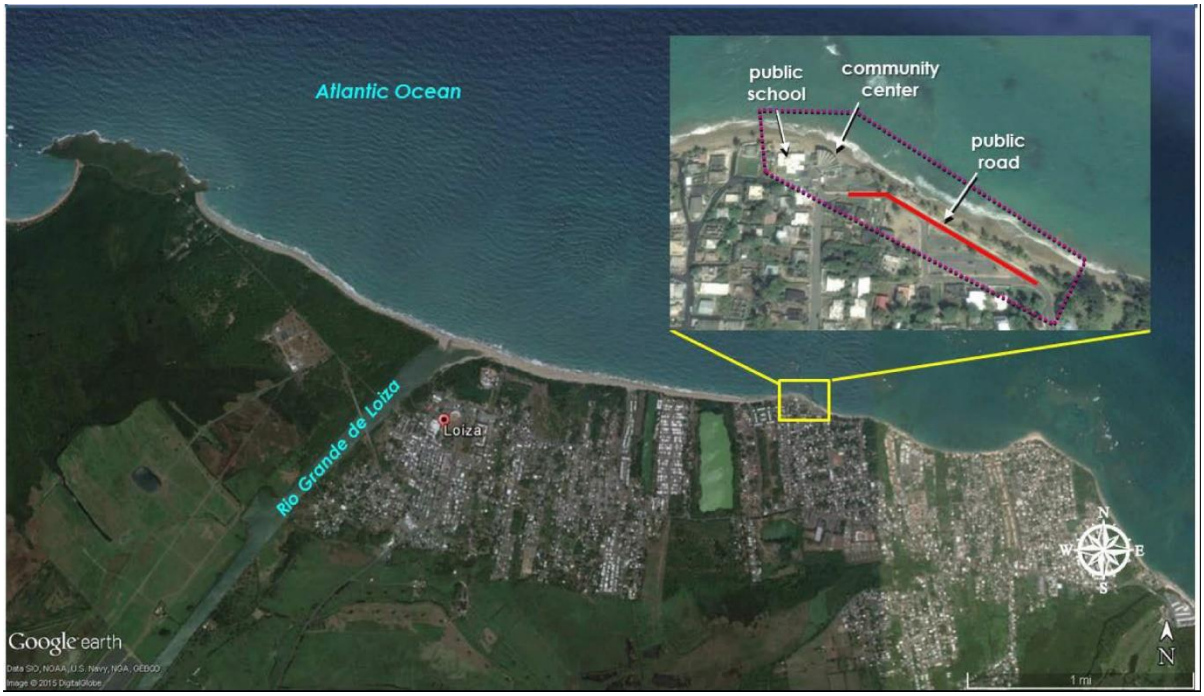


Figure B1. Structures at Risk of Erosion
Sources: U.S. Army Corps of Engineers, 2018, p. 3

Figures B2-B4
Sea Level Rise Simulation of Loíza
Sources: *coast.noaa.gov/slr/*

Current Mean higher high water (MHHW)

If MHHW rises 1 feet

If MHHW rises 3 feet

FOOTNOTES

[i] Spirn,1984, p. xi
[ii] Chicago Wilderness Green Infrastructure Vision, 2004
[iii] Fema, 2020
[iv] Cole et al., 2017
[v] Brooks, E., Davoudi, S., 2016
[vi] Tyler, 2016
[vii] Munoz Maldonado, 2001, pp. 41-42
[viii] Talbot et al., 2019, p. 2
[ix] Munoz Maldonado, 2001, p.59; Castro-Prieto et al., 2019
[x] Bush et al., 1995, p. 132
[xi] Munoz Maldonado, 2001, p.55
[xii] Ibid., p.58
[xiii] FEMA, 2020, p. 5
[xiv] Rouse & Bunster-Ossa, 2013, p. 22
[xv] Narayan et al., 2019, p. 2
[xvi] Branoff, 2018, p. 22
[xvii] USACE, Jacksonville District, 2016, p. v
[xviii] *U.S. Army Corps of Engineers Has the Studies to Environmentally Restore Caño Martín Peña in a Limbo*, 2015
[xix]https://www.fema.gov/press-release/20210318/fema-collaborates-public-and-private-entities-benefit-municipality-Loíza
[xx]https://www.fema.gov/press-release/20210318/fema-collaborates-public-and-private-entities-benefit-municipality-Loíza
[xxi] https://www.fema.gov/press-release/20210318/fema-collaborates-public-and-private-entities-benefit-municipality-Loíza
[xxii] Casa Pueblo, 2020
[xxiii] Scuba Dogs Society, 2020
[xxiv] NOAA, 2015
[xxv] NOAA, 2020
[xxvi] FEMA, 2011, p. 3
[xxvii] Hopkins, 1977