Flood Resilience Strategies for Cantera, Puerto Rico

An Interactive Qualifying Project proposal submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science

May 13th, 2020

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Abstract

With rising global temperatures increasing the severity of extreme storms and escalating flooding, improving the resilience of Cantera, Puerto Rico is critical. This report, prepared for La Compañía para el Desarrollo Integral de la Península de Cantera (CDIPC), assesses analogous case studies and conducts interviews and surveys with key informants to determine appropriate flood resilience strategies. We identified 67 strategies and based on cost, feasibility, and effectiveness, we recommend six flood resilience strategies. These recommendations include both structural and nonstructural projects the CDIPC should address to create a more resilient community in Cantera.

Acknowledgements

We would like to thank the following people and organizations for their support and contribution to the success of this project:

- Alfredo Pérez Zapata
- Alejandra Ramos Carmenatty
- Francisco Pérez Aguiló
- Alejandra Castrodad-Rodriguez
- Community of Cantera
- Professor Lauren Mathews
- Professor John-Michael Davis
- Professor Hektor Kashuri
- La Compañía para el Desarrollo Integral de la Península de Cantera and WPI for this project opportunity

Our team would like to extend a special thank you to our advisors John-Michael Davis and Hektor Kashuri for their encouragement and support during the transition to working remotely. We would also like to thank Alfredo Pérez Zapata and CDIPC for providing us with guidance and insight, as well as accommodating this remote project given the circumstances of COVID-19.

Authorship

Jacqueline Cardin, Justine Davids, Gracie Lodge-McIntire, and Reed Nowling all contributed to the research, writing, and editing of this report. The following is a breakdown of how the final proposal was produced:

Jacqueline Cardin contributed by writing the Introduction and the following sections: Strategies to Improve Resilience, Identifying Strategies from Case Studies, Analysis of Viable Strategies, as well as the Introduction to the Methodology and Results. She also led the interview with the representative from Atkins Global, collaborated on Appendix A: Interviewing Resilience Experts with Reed, and created the Title Clearance flier in Appendix E. Jacqueline worked alongside Justine to write the section Resource Policy and alongside Reed to discuss distribution in the Surveying and Interviewing Homeowners section.

Justine Davids wrote the sections Interviews: Organizations and Homeowners and sub-sections, Conclusion, Appendix B: Cantera Homeowner Survey, and Appendix D: Cantera Resident Interview Questions. She also led the interview with a community representative from Cantera. Justine worked alongside Reed to complete the Infrastructure of Puerto Rico section and organizing Appendix C: Supplemental Strategy Research, alongside Jacqueline with Resource Policy, and alongside Gracie on the Community Analysis.

Gracie Lodge-McIntire completed sections of Introduction to the Background, Effects on Climate Change, Methodology's Community Analysis, Result's Categorization of Strategies. Gracie collaborated with Justine on the Conclusion.

Reed Nowling wrote the sections on Resilience and Adaptive Capacity, Appendix A: Interviewing Resilience Experts, and Appendix F: Homeowner Survey Results. He also led the interview with the former Resilience Chief of Puerto Rico. Reed worked alongside Justine to write the section on Infrastructure of Puerto Rico and revise Appendix C: Supplemental Strategy Research.

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Executive Summary

Hurricane Maria was one of the most devastating natural disasters in recent history, costing an estimated $90 billion in damages in Puerto Rico (Pasch, 2019). Storms of this severity are expected to worsen due to climate change, and the damages are exponentially increasing due to the rise of urbanization (Berkowitz & Arnoldo, 2018). Due to these factors and the low economic status of the area, San Juan, Puerto Rico has been identified as extremely vulnerable to the effects of natural disasters.

Following Hurricane Maria, Puerto Rico unified people behind achievable and effective resilience projects; projects aimed to improve the “ability of a community exposed to hazards to resist, absorb, accommodate to and recover” (UNISDR, 2009). Lopez-Marrero, a researcher that studied two flood-prone communities in San Juan, found resilience to be affected by a vast range of determinants, from the typical structural designs to education and awareness (Lopez-Marrero, 2010). These can be identified as two general types of strategies to enhance resilience: structural and nonstructural. Whereas structural strategies directly protect the community from floodwater, nonstructural strategies give communities the ability to understand the risks associated with disasters and properly prepare for them, increasing the effectiveness of structural strategies. For these reasons, education and information outreach are often just as effective at increasing resilience, while remaining low in cost. Even though Puerto Rico has slowly been improving flood resilience, building sustainable and adaptable resilience projects in flood-prone areas like Cantera needs more focus.

The purpose of this project is to recommend strategies to mitigate flooding and increase disaster resilience in the community of Cantera in San Juan, Puerto Rico. To achieve this goal, our first objective was to identify potential strategies to mitigate flooding from analogous case studies. Our second objective was to determine Cantera’s needs and capabilities in relation to flood resilience to narrow down potential strategies. Lastly, our third objective was to present the CDIPC with a list of flood resilience strategies and an implementation guide to build resilience in Cantera. Cantera’s susceptibility to flooding and limited access to resources has locked them into a state of constant destruction with no way to recover from disasters. Without proper intervention, the people of this community will be unable to fully recover and protect themselves from the increasing threat of flooding.

Methods

To improve the resilience in Cantera, we needed to identify potential flood resilience strategies. We performed a literature review on analogous case studies of flood mitigation in similar coastal cities. We systematically searched scientific databases including Google Scholar, Science Direct, JSTOR, and WIT Press for studies that specifically discussed resilience or flood resilience strategies. We identified and analyzed 15 articles guided by the following questions: 1) What structural strategies mitigate flooding? 2) What nonstructural strategies improve adaptive capacity? 3) What factors affect the feasibility of implementation? 4) Who can implement these strategies, residents or larger organizations? 5) How does this strategy improve resilience?

We extracted 67 strategies from these 15 sources and compiled them into a spreadsheet. We were especially interested in green infrastructure projects because they are the most sustainable and recommended by the Environmental Protection Agency (EPA). Once the list of strategies was organized, we interviewed resilience experts and community members to exclude unreasonable strategies. Because of the current COVID-19 pandemic, travel restrictions prohibited our team from traveling to Puerto Rico. Thus, interviews were conducted over Zoom, a video conference platform. We asked resilience experts questions regarding the cost, ease of implementation and maintenance, and effectiveness of solutions (see Appendix A). We also interviewed the president of a community council in Cantera to gather more information on the smaller scale strategies and a homeowner's perspective (see Appendix D). A survey was posted on the CDIPC Facebook page to better assess the flood-related needs and perceptions of Cantera homeowners (see Appendix B). Based on these interviews, we made flood resilience recommendations and an implementation plan for the CDIPC.

Selected Strategies

The results of our methods produced six viable flood resilience strategies for Cantera. Given our limitations regarding long-distance communications and analysis, we were unable to tailor our strategies more specifically to the area. This resulted in an extensive list. Viability was discerned through a systematic analysis of cost, ease of implementation, ease of maintenance, and number of residents positively impacted. Through this method, we found the most viable structural strategies are: harvesting rainwater, bioswales and infiltration trenches, and an AquaDam. The most viable nonstructural strategies are: education and orientation, increased access to disaster resources, and adhering to construction and land development codes.

Harvesting rainwater on a residential level prevents large amounts of storm water from accumulating on the streets of Cantera. Bioswales, infiltration trenches, and AquaDams would also address this issue. These organization level structures collect water, keeping it away from neighborhoods. Bioswales and infiltration trenches use the natural or adjusted landscape to gradually release water. AquaDams instead fill with floodwater into a functioning floodwall. All were categorized as water collection, a subcategory of diversion, displaying the main concern of the community: overabundant water accumulation.

In order to thoroughly promote resilience, both structural and nonstructural strategies are necessary. Thus, we selected education and orientation. Education is a broad strategy, garnering its own category in our analysis. Within this category, we selected the following topics: evacuation plans and safe havens, access to resources, and, more specifically, the Title Clearance Program. All aforementioned topics are strategies we have deemed viable and necessary for resilience. Keeping the citizens informed eases the preparation and recovery processes. To encourage effective communication, we recommend these topics be shared through an orientation, that is, a public gathering of residents with the CDIPC or similar organization, a strategy deemed highly viable within our analysis.

Lastly, we recommend updating homes to adhere to current construction and land development codes. Most houses in Cantera are not up to code, making them vulnerable to the disastrous effects of flooding and hurricanes. By updating these homes, the people of Cantera would be safer.

Recommendations for CDIPC

The viability of solutions for Cantera was decided based on feedback from a community representative as well as our literature review. We determined if strategies were initially viable based on cost, effectiveness, availability of materials, and implementation process. This process of elimination enabled us to put these results in parallel to our understanding of the needs of Cantera to recommend our top six viable strategies for homeowners and the CDIPC to implement. To achieve the greatest impact on resilience within Cantera, both structural and nonstructural solutions are needed. The most viable structural flooding solutions for Cantera homeowners was harvesting rainwater. This consists of a homeowner installing a 155-gallon barrel 10 feet above a house to create enough head pressure and attach a PVC pipe to water the garden or connect to toilet plumbing (Pérez, 2020). The most effective structural solutions for organizations to implement were bioswales, infiltration trenches, and AquaDams. Bioswales and infiltration trenches work to divert water away from homes, solving homeowners' problems with standing water. AquaDams are structures that, after filling with flood water, act as a flood wall to protect the area they surround. These solutions got a positive response from both the CDIPC and the community representative. In order to address other needs not fulfilled by structural strategies, we recommended nonstructural strategies. The top viable newly proposed nonstructural solutions organizations can implement in Cantera are: creating orientation and educational programs, increasing access to available recovery resources, and connecting outside organizations with the community to help implement existing construction and land development codes. These nonstructural solutions help to increase the awareness, overall education and access to resources which has been shown to improve resilience (Lopez- Marrero, 2010). When combined with structural solutions, these promote a significant impact on community resilience. Flooding within Cantera has greatly impacted the resident’s day to day life and furthering this research could help solve their problem. Solutions for flooding within Cantera address the growing need for flood resilience due to climate change and the potential of severe floods. The recommendations we have provided for the CDIPC should positively impact the residents of Cantera and inspire programs around resilience.

1. Introduction

Known locally as the “barriadas,” this former wasteland makes up about half of Cantera, Puerto Rico (Rojas, 1995). Cantera is a neighborhood of about 9,000 people that came to fruition when recurrent hurricane disasters paired with an uncontrollable increase in urbanization in the 1900s (Cantera Capitals, 2020). Today, Cantera is still a crowded and impoverished community located on a peninsula that spreads to the neighboring San José and Corozos lagoons (Ruiz-Marrero, 2000). Since these homes were built on unauthorized land generations ago, residents do not own the title to their land, which denied them disaster aid after Hurricanes Irma and Maria (How the Title Industry Can Help, 2018). A vicious cycle of natural disasters and insufficient resources has prevented this community from fully recovering.

Hurricane Maria was one of the most devastating natural disasters in recent history (Pasch, 2019). Extreme storms, like Maria, are expected to increase in severity and frequency due to increasing global temperatures, which results in thermal expansion causing sea levels to rise. This leads to a disastrous escalation of flooding in areas of poor run-off, such as Cantera (Jury, 2018). With these effects of climate change, improving Cantera’s flooding resilience is critical to create a safer community.

Resilience refers to a community’s stability and ability to cope with and adjust to a changing environment. Resilience strategies offer a community a greater tolerance threshold for flooding by providing flexibility in the area’s infrastructure in two ways: structural stability and adaptive capacity (Liao, 2012). Structural stability refers to physical flood protection, whereas adaptive capacity is essentially the social learning of flood protection, or behavior that is influenced by the environment (The Editors of Encyclopaedia Britannica). This helps create the foundation for effective strategies to improve community resilience. In recent years, adaptive capacity has been promoted as a more favorable framework for enhancing resilience because it promotes adaptability rather than the past strategy of flood resistance (Liao, 2012). In the past, Puerto Rico has focused solely on structural stability, but this framework is inflexible to the changing environment (López-Marrero & Tschakert, 2011). After years of repeated devastation from hurricanes and with ongoing susceptibility to flooding, Cantera needs new strategies to build sustainable and adaptable resilience to prevent future flooding damage.

The purpose of this project is to recommend a variety of flood resilience strategies to La Compañía para el Desarrollo Integral de la Península de Cantera (CDIPC), a government agency created to improve the living conditions in Cantera (Moscoso, 2018). These strategies include structural engineering projects that directly address flooding, and nonstructural strategies that will increase community awareness and understanding of flooding problems (Liao, 2012). A balance of these strategies is ideal, as they support each other and help strengthen the community in complementary ways.

To create this list of recommendations, we first identified and evaluated 67 flood resilience strategies by examining case studies from around the world. Some of these case studies included other areas of Puerto Rico, like Mansión del Sapo and Maternillo (López Marrero, 2008). Second, we investigated local characteristics and identified community needs. Surveys and an interview with a Cantera resident enabled us to prioritize strategies based on those needs as well as to adapt flood resilience strategies to Cantera. Third, we excluded strategies and refined our flood resilience recommendation list by consulting the CDIPC and two other flood resilience experts. These steps produced a prioritized list of recommendations for the CDIPC to improve flood resilience in Cantera. While the recommendations specifically cater to Cantera, similar methods and strategies can be applied to other coastal communities affected by flooding and climate change worldwide.

2. Background

Severe storms are expected to worsen due to climate change (Berkowitz & Arnoldo, 2018). This reduces flood protection in Cantera by limiting access to resources and the area's exceedingly low elevation. Following Hurricane Maria, people unified behind resilience projects to reduce vulnerability in the area. These projects are beginning to address gaps with access to resources and flood mitigation, but more strategies could make a considerable impact within the community of Cantera.

2.1. Effects of Climate Change

Climate change is a significant issue all around the world. The world temperature is rising, Australia and California experienced traumatic wildfires, the Caribbean islands received intense hurricanes and thousands of earthquakes rocked Puerto Rico. On September 20, 2017, Puerto Rico experienced record-breaking levels of wind, rainfall, flooding, and damage from Hurricane Maria. It dropped, on average, 30 % more rain than the previous record and 66 % more rain than Hurricane Georges, the former largest and costliest storm to ever hit the island (Hersher, 2019). This escalation in severity is associated with the effects of climate change. With warmer air and ocean water, "a storm of Maria's magnitude is nearly five times more likely to occur" (Hersher, 2019).

Additionally, sea level rise impacts the coastal Puerto Rican communities. These higher sea levels cause increased vulnerability to coastal communities. This issue is related to polar ice melt and the expanding of water in the warmer oceans, a result of the increase in global temperature. Starting in 1955, the sea level was rising 0.175 centimeters a year (Jury, 2018). While this isn't desired, it is little cause for concern. Unfortunately, starting in 2005, this rate has more than quadrupled to 0.725 centimeters per year, and the sea level is predicted to rise more than 0.3 meters by 2050 (Jury, 2018). This escalation is constantly increasing the threat of flooding and the difficulty of recovery for coastal communities.

These coastal communities are still rebuilding from past hurricanes. Irma swept through island communities and the United States in September of 2017 (New Times Staff, 2017). Due to its extreme wind, heavy rain, and high surf, Hurricane Irma caused 47 direct deaths in the Caribbean Islands and southeastern U.S. The term 'direct' refers to those who drowned in a storm surge, rough seas, rip currents, and freshwater floods, flooding and water-related forces being the most prevalent. This does not include those who lost their lives to disease, slow medical response, or other indirect causes. The sea rose by approximately 11 feet and traveled nearly 1.2 miles inland in some areas. Waves were observed to reach over 26 feet high. The cost in property damage in the United States alone added up to approximately $50 billion (Cangialosi, 2018).

Two weeks later, Hurricane Maria caused significant damage through Dominica, St. Croix, and Puerto Rico. On top of 31 direct deaths, Dominica suffered damage costs upwards of $1.31 billion. St. Croix, one of the U.S. Virgin Islands, received devastating rainfall, causing significant flooding and mudslides. Puerto Rico was severely hit with storm surge and wave effects. There was extensive damage to buildings, homes, and roads. River flooding reached unprecedented levels: La Plata River flooded the entire alluvial valley requiring hundreds of families to be rescued from rooftops. And, 80% of utility poles and all transmission lines were knocked down, causing a power outage to nearly all Puerto Rican residents (Pasch, 2019).

Hurricane Maria severely affected Puerto Rico and the U.S. Virgin Islands. Storm surge, rainfall, flooding, and powerful winds wrought an estimated $90 billion in damages. This storm was "by far the most destructive hurricane to hit Puerto Rico in modern times," as the previous costliest hurricane caused approximately $5 billion of damage in 1998 (Pasch, 2019). By the end of 2017, about three months later, approximately half of Puerto Rico was still without power. The following month, electricity had been restored to only 65% of the island (Pasch, 2019). Additionally, one of Puerto Rico's main weather monitoring radars was destroyed by winds upward of 160 mph. Both the radome and 30-foot wide radar dish went missing (Belles, 2017). This is a significant and dangerous issue, as these weather monitoring systems directly contribute to hazardous weather forecasts.

In the months following Hurricane Maria, a story ran on PBS NewsHour about the devastating social effects on Puerto Ricans. It featured a protest in San Juan that broke out in response to a study that stated around 4,600 residents died due to indirect effects of the storm. A significant portion were seniors that died due to delayed medical attention. Those with diabetes, on dialysis, suffering from strokes, dementia, and other diseases did not get the care they needed. In this same story, it was revealed that the suicide rate across the island increased by 29%. Unfortunately, for people aged 65 - 69, the rate more than doubled, and for those 75 - 79 the rate tripled. People's livelihoods were destroyed, and Medicaid did not reach those who needed it (Varney, 2018).

The death toll grew in the dark months without power. The official number was 64, but many questioned the reality of the statement because of the clear severity of the storm. After further examination, and a recount at the command of Governor Resello, the number changed to an overwhelming 2,975 people as of February 2018 (Andrade, 2018).

There was a growing movement in Puerto Rico urging the government to be more transparent about the recovery strategy and resource disbursement following the catastrophe of Hurricane Maria. Mabel Román Padró, a leader in the small community of Cantera in the municipality of San Juan, urged Congress to translate a report about the recovery strategy to Spanish, the island's native language (Florido, 2018). In Cantera, most Puerto Ricans are not fluent in English, and Román Padró said by not translating the document to Spanish "the government is limiting our access to this information and impeding our ability to participate in the recovery" (Florido, 2018). Now, more than ever, Puerto Ricans, especially in working-class areas like Cantera, are taking action into their own hands to become more involved in the direction of the current Puerto Rican administration and their own recovery. The area of Cantera and its disaster resilience will be the point of focus in this research project.

2.2. Resilience and Adaptive Capacity in Puerto Rico

With the rise of urbanization in the 20th century came the increasing need for protection against the escalating severity of natural disasters. Through the 100 Resilient Cities initiative, the Rockefeller Foundation found over 50% of today's population live in cities, and this will rise to 75% by mid-century (Berkowitz & Arnoldo, 2018). With the prevalence of highly populated cities, and their continued growth, exponentially more people are at risk of catastrophe without proper prevention and recovery strategies.

San Juan, Puerto Rico has been identified as extremely vulnerable to the effects of natural disasters due to the low economic status of many areas and the high population density. Within San Juan, many communities are built on unstable land or land deemed unprotected from natural disasters (Rojas, 1995). An economic boom in Puerto Rico in the early 1900s caused these urban centers to rapidly develop in flood-prone areas to keep up with the industrialization along the coast of San Juan (Rojas, 1995). However, in the 1970s, Puerto Rico saw a sharp decline in its economy leading to a collapse of these economic centers (Rojas, 1995). Many of these communities have not recovered from this economic decline, with Alejandra Castrodad-Rodriguez, the Former Chief Resilience Officer of Puerto Rico, saying "we're entering our 15th year of a recession this year and [there are] no signs that's going to get better anytime soon". This has trapped the people of San Juan in a constant cycle of adversity and setbacks.

After Hurricane Maria's devastation, Puerto Rico launched the Resilient Puerto Rico Advisory Commission in 2017 with the goal of unifying the Puerto Rican people behind achievable and effective resilience projects (Resilient Puerto Rico, 2018). Their leading projects include increasing land ownership among residents, establishing backup energy systems for critical infrastructure emergency services, and implementing funds to protect the micro and small business infrastructure, which provides over 80% of Puerto Rico's employment (Resilient Puerto Rico, 2018).

These projects aim to improve Puerto Rican communities' "resilience" to disasters. Resilience was a term coined nearly half a century ago from the ecological sciences to define species with unstable populations, yet still seemingly persist (Holling, 1973). Disaster resilience is defined differently by various experts, but ultimately the consensus is "The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions" (UNISDR, 2009). For the purpose of our project, resilience is the ability of a city or area to maintain stability and recover from increasingly severe weather before, during, and after such disasters.

Due to the United States' control of most Puerto Rican disaster policies, Puerto Rico has had a strong focus on engineering projects to prevent loss of life and expedite recovery (López-Marrero & Tschakert, 2011). Currently, there is an ongoing project in Puerto Rico to improve the drainage of El Caño Martín Peña, a canal south of Cantera. The goal of this project is to improve the shape of the canal to allow for better drainage, revegetate around the canal to slow inundation of it, and install culverts with control gates and collection areas to divert water during a storm. Although structural projects such as this have shown success in reducing the mortality of flooding disasters, the small economies of Puerto Rico still suffer greatly due to high levels of property destruction and dislocation still present (López-Marrero & Tschakert, 2011). Though the resilience of San Juan has been slowly improving, little focus has been placed on improving the adaptive capacity, the ability of a community to adapt to destruction wrought from natural disasters.

Gallopín (2006) found "resilience" and "adaptive capacity" are frequently combined or one is a subset of the other; however, they cover distinct aspects of disaster mitigation and recovery. Adaptive capacity covers two main parts: the capacity of a system to cope with perturbations in the environment and potentially benefit from them, and the capacity to continually change its environment for its benefit (Gallopín, 2006). Adaptive capacity focuses more on a system's capacity to cope with changing environments and adapt to those changes, whereas resilience has a stronger focus on maintaining stability. Both terms are critical for protecting growing urban population centers against the dangerous effects of climate change.

Lopez-Marrero (2010) discussed adaptive capacity applied to natural disasters and found many variables influence a region or city's adaptive capacity (see Table 1). She goes on to describe how improving adaptive capacity in a region can involve simply changing the perceived danger of natural disasters as well as creating new relief connections to improve the quality, quantity, and readiness of recovery supplies. Thus, adaptive capacity also encompasses a community's access to resources necessary to adapt to adverse conditions and the ability to mobilize those resources (Nelson, Adger & Brown, 2007). Utilizing the two-pronged approach of physical and social strategies, cities can determine where the risk is and then what strategies they can and should implement.

Determinant	Description/Examples
Natural resources	The resources present in the physical environment (e.g. land, mangrove, raw materials) and/or the services they provide that are useful for adaptation.
Material resources and technology	The infrastructure (e.g. transport, drainage systems, housing) and the production equipment and materials available for adaptation; along with technological systems (e.g. communications systems, protective structures) available for adaptation.
Economic resources	The economic, financial resources people have (e.g. earned income, savings, credit, pensions, remittances, transfer from the state) and that are available for adaptation.
Human resources	The skills, knowledge, and awareness (e.g. of adaptation options, the nature and evolution of hazards), experience, ability to work, and good health that enable people to pursue adaptive strategies.
Social resources	The social resources (e.g. informal-horizontal networks, social mobilization, collective actions, and relations of trust, reciprocity, and exchange) upon which people can draw for adaptation.
Institutions	The availability of critical institutions that promote and support adaptive strategies, along with the way they operate and are structured (e.g. transparent decision-making, institutional requirements).
Political resources	Power, right, development of political capabilities or claims people can make on the state, institutions, or those more powerful than they are.
Perception/cognition	The different views of nature people have, perceptions of hazards (e.g. likelihood of occurrence and potential damage), perceived effectiveness of past adaptive actions, perceived alternatives and perceived capacity to undertake them or act upon hazard exposure.

Table 1. Determinants of Adaptive Capacity (Lopez-Marrero, 2010)

2.2.1. Strategies to Improve Resilience in Puerto Rico

The determinants from Table 1 influence the success of flood resilience strategies used within the area. There are two general types of strategies to enhance resilience, differentiated by their approach. Structural solutions are engineering projects that reconstruct landscapes in a community to divert flooding (Tyrrell, 2019), whereas nonstructural strategies reference the ecological dynamics between the community and surrounding environment (Liao, 2012). While structural strategies directly protect the community from floodwater, nonstructural strategies protect against flooding by increasing community resilience through awareness, preparation, and finally, recovery. Nonstructural strategies require a deeper understanding of the community, and they often greatly increase the effectiveness of structural strategies. For example, the nonstructural strategy of teaching residents realistic risk perception compels a community to continually employ flood resilience strategies (López Marrero, 2008). A majority of residents felt their current mitigation strategies were sufficient for protecting themselves even though they have become inundated by floods multiple times over the past 40 years (Lopez-Marrero, 2008). Lopez-Marrero found residents had short memories for disastrous flooding events and often felt secure after a few years, even without changing their strategies. She found increasing risk perception was one of the most effective and feasible solutions to help these communities during her study of coastal communities in Puerto Rico. This shows how each strategy symbiotically improves resilience, as they aim to strengthen the community in different ways. Nonstructural strategies have been neglected in the past, but they offer a more appropriate framework for both flood management and urban resilience because they recognize the need for flexibility and adaptability in a changing environment (Liao 2012).

An effective flood resilience strategy, either structural or nonstructural, is high in both efficiency and feasibility. Feasibility depends on who is employing the strategies: homeowners, consulting service companies, the municipality of San Juan, the Corps of Engineers, or other government agencies. The range of fiscally reasonable solutions for an organization is far broader than that of an individual homeowner. Many strategies employed by residents are short-term and cost-efficient but may be solved by the implementation of a community flooding strategy (Lopez-Marrero, 2010). For example, the municipality of San Juan could acquire funding to implement an underground water storage or drainage system, like an infiltration trench or bioretention area. These types of Low Impact Development or Green Infrastructure projects are recommended by the Federal Emergency Management Agency (FEMA) and “mimic natural hydrology [including] innovations such as green roofs and permeable pavement” (Tyrrell, 2019). Although these systems may be more challenging to design, they may be more effective in the long-term and have greater tolerance for future disasters. Larger community strategies reduce the need for individual strategies, but both are important to create a more resilient Cantera.

To lessen the impact of property flooding, homeowners in the northeastern municipality of Fajardo, Puerto Rico use three strategies: landfilling, house-raising, and house rebuilding (López Marrero, 2011). Many residents in Puerto Rico employ these short-term strategies to different extents. Since these methods vary in cost, material, and skill to implement, the success with each strategy is favored by wealthier economic groups (López Marrero, 2008). When it comes to disaster aid, some less fortunate communities do not qualify for resources based on current policies. According to interviews in Fajardo, participants expressed discontentment with unequal distribution of financial relief, saying “aid has been a source of conflict between community members because not everyone received it or it is not distributed in accordance with damage,” (López Marrero, 2008). Not only is this issue stunting recovery, but it hinders community cooperation, which further reduces community resilience.

Increasing access to government aid or assisting in applications for resources would significantly improve adaptive capacity since it aids successful recovery. For these reasons, education and information outreach are often just as effective at increasing resilience, while remaining low in cost. With access to resources, long-term solutions are prioritized to address underlying flooding issues. Liao (2012) writes, “there is no guarantee that these resources, especially external aid, will be available in the future as they are today. In this respect, an overreliance on external aid may, in fact, reduce adaptive capacity in the long-term.”

2.2.2. Resource Policy: A Gap in Disaster Relief

Residents in Cantera struggle to access available resources, making disaster recovery incredibly difficult. Without aid, there is an endless cycle of disaster with no recovery period. In order to recover, resources must be accessible and the process to receive this aid must be clear. There is a point of contention between Puerto Ricans and the government about receiving necessary resources. When hurricanes hit in the past, the residents did not have the requisite paperwork to receive financial assistance from the federal government, negatively affecting their adaptability to flooding. This has raised questions: how do people receive aid? Where can people receive aid? And, who qualifies for aid?

Acquiring financial aid requires proof of property ownership. This became a complex issue for some residents of Cantera when they discovered that their homes were never authorized to be built. This means that they do not own the title to their property, leaving them ineligible for resources. The main source that aids Puerto Rico in times of disaster is the Federal Emergency Management Agency (FEMA). FEMA’s mission is:

> To reduce the loss of life and property and protect the Nation from all hazards, including natural disasters, acts of terrorism, and other man-made disasters, by leading and supporting the Nation in a risk-based, comprehensive emergency management system of preparedness, protection, response, recovery, and mitigation (FEMA Strategic Plan, 2008).

FEMA oversees the Department of Homeland Security grant programs that assist in rebuilding communities and manage government programs for emergencies. One such program is the Disaster Relief Fund which is the federal government's general disaster relief fund for programs within the United States and its territories (Painter, 2019). This assistance comes into effect when nonfederal levels of government are unable to fulfil the needs created by the disaster and is the pool of money that residents of Puerto Rico can apply for. In the past, Puerto Rico has received aid through the Disaster Relief Fund, replenished by Congress as needed (Severino Pietri, n.d.). When this happens, residents can then apply for aid to rebuild their homes or make necessary repairs.

The process of receiving aid involves significant paperwork and around 30.5% of Puerto Ricans were denied funding from FEMA due to residents' inability to prove that they own the land where their homes reside (How the Title Industry Can Help, 2018). Unfortunately, the need for a property title in order to receive funding after a disaster was not effectively communicated to residents prior to destruction and left many feeling abandoned and confused (Florido, 2018). Many people have had homes for generations without official titles and were told that they had to prove ownership after Hurricane Maria (Wamsley, 2017). The program, deemed the Title Clearance Program, has recently been set up for people to make the island more resilient by granting homeowners the documentation they need to apply for FEMA aid (Title Clearance). The program was created to ensure people are not facing the same situation they were in prior emergencies. The Title Clearance program recognizes property dwellers as the owners, protects property dwellers from third parties trying to acquire their property or claim it as their own, supports property value, helps support the housing market by allowing the sale of properties, provides protection by the courts, and the property owner can apply for loans, credit, or aid if repairs are needed (Title Clearance).

2.3. Infrastructure of Puerto Rico

Cantera's infrastructure is affected by how the Puerto Rican government is organized and the debt it has accumulated. Overwhelming debt that accumulated from frequent natural disasters and an ongoing need for aid has left the community struggling. Puerto Rico's financial problems have been tied to the Jones Act of 1917 by many government officials (Torres, Weidemeyer, 2019). The Jones Act granted Puerto Ricans United States citizenship, installed the governmental structure, and gave the United States the right to control economic and fiscal matters. From this, Puerto Rico was allowed to sell debt in the form of bonds freely, due to a lack of government protection under Chapter 9 bankruptcy; a policy that "provide[s] a financially-distressed municipality protection from its creditors while it develops and negotiates a plan for adjusting its debts" (Chapter 9). Since Puerto Rico does not have this right as a territory, more bonds have been sold to try to support their debt. These bonds could be purchased by anyone, regardless of residency, and allowed the debt to keep growing. For Puerto Rico to get out of debt, it needs billions of dollars before investing in new infrastructure. A sustainability plan that does not involve selling an excessive amount of bonds is a topic of discussion once Puerto Rico gets out of debt; however, the current focus is how to overcome the debt they are currently in.

Due to this amount of debt, Cantera has been heavily impacted by government organizations inadvertently establishing many hurdles to access funding. Much of the housing was established on previous marshlands that were turned into landfill sites; the residents of which are of lower to middle class (Rojas, 1995). The community's annual median household income ranges from $6,600 to $16,453, whereas the overall annual median income of San Juan Municipality is $23,012 (San Juan, PR | Data USA.). Most residents of Cantera spend their entire lives in the community and often inherit the homes they grew up in. Due to this, and the multitude of recognized unmet needs, Cantera has become a starting point for many socio-economic improvement programs (Cantera Capitals, 2020).

A lot of housing in low-income areas are not up to code or housing standards. This contributes to the intensity of flood damage that homes endure. Some of these homes, referred to as "barriadas," are located near the shorelines on former landfills (see Figure 1). These homes were created without regard to the housing standards or codes in place. New housing codes have been implemented in order to help with the resilience of Puerto Rico. This was accomplished due to funding provided by the FEMA under the Hazard Mitigation Grant Program (New Building Codes, 2019). The codes were created by Puerto Rico's Office of Permit Management, the Puerto Rico's College of Engineers and Surveyors, the General Contractors Association, the College of Architects and Landscape Architects, and the Builders Association are more rigorous than most states (New Building Codes, 2019). These codes account for the high winds that are common in hurricanes.

To combat housing code and zoning issues, the residents of Cantera decided to fund attempts to move these families out of high-risk flood zones through buyouts and relocation. However, this process was not fiscally sustainable, nor was it desired by residents. The families that relocated in the past insisted on relocating somewhere else within Cantera, due to their strong community values (Pérez Zapata, 2020). Thirteen households went through this process, costing an average of $90,000 per relocation from Cantera (Alfredo, 2020). Unfortunately, the project has been indefinitely halted due to a lack of funding.

In addition, former Chief Resilience Officer of Puerto Rico Alejandra Castrodad-Rodriguez (2020) stated that “There is very, very little no-risk land left over. The notion that you can… consider a Puerto Rico where you relocate residents… to areas with no risk to natural hazards is unreasonable to say the least. It’s a fantasy”, solidifying the need to find a different solution.

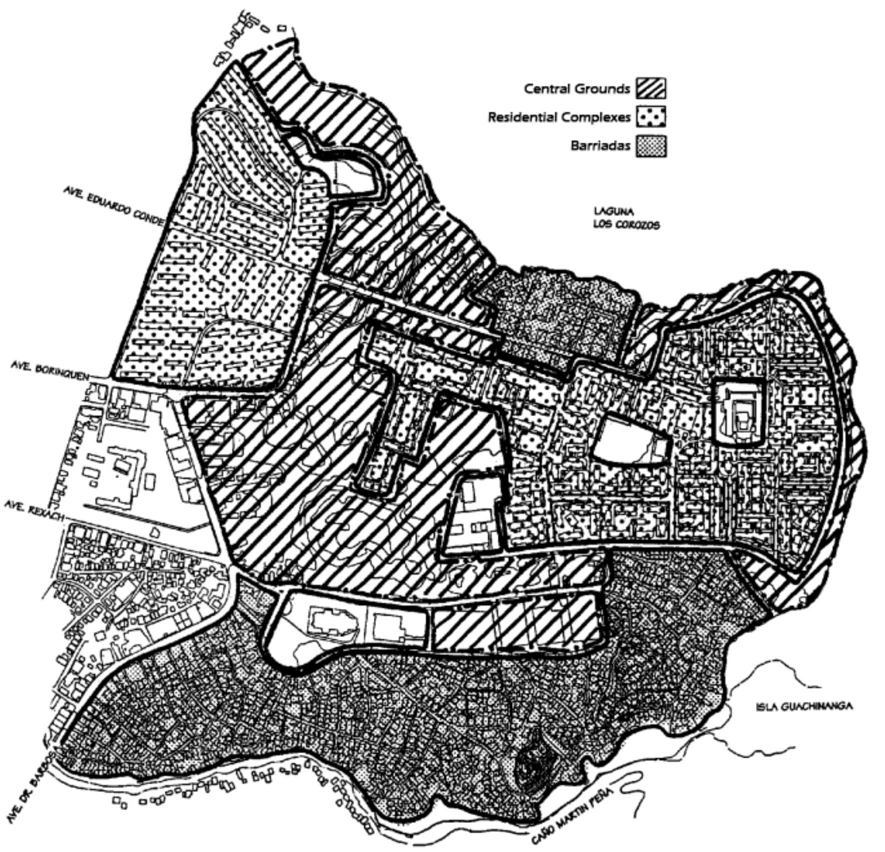

Figure 1. Map outlining the area of Cantera to show where the barriadas are located (Rojas, 1995)

With relocation no longer a viable option, alternative strategies are required to mitigate flooding in flood-prone areas. Strategies that increase adaptive capacity are exceptionally useful in Cantera where there are high population densities in known floodplains. Using census data, flood insurance rates, and FEMA flood maps, population densities within floodplains can be accurately estimated for understanding the impact flooding will have on an area (Reis-Silvia et al., 2011). An extensive study of floodplain population densities of Cantera has yet to be completed, however, FEMA has released maps of flood-prone regions within Cantera. The community of Cantera, shown in Figure 2, is highly susceptible to flooding for several reasons: low base elevation in the area, which is less than six feet above sea level in some areas (FEMA, 2018); the overflow of Laguna Corozos and the subsequent backup of El Caño Martín Peña; and the communities' sewage and stormwater drainage systems. Figure 3 shows the water levels throughout Cantera after Hurricane Maria hit in 2017, where the water levels rose 1.8 meters, shown in blue, leaving many sectors of the community underwater, with some southern communities flooded as much as six feet (FEMA, 2018).

Figure 2. Map of Cantera, Puerto Rico in 2019 (Pérez Zapata, 2020).

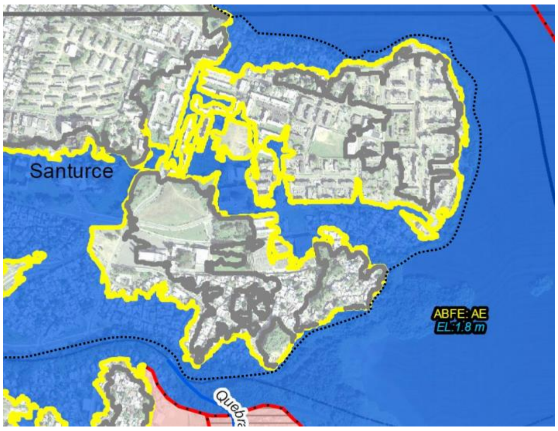

Figure 3. Map of Cantera, Puerto Rico depicting flood water as the blue area and possible at-risk areas in yellow after Hurricane Maria in 2017 (FEMA, 2018).

Due to the risks associated with climate change, the economic status of Cantera residents, the high population density, lack of basic protection from flooding, and the poor quality of infrastructure in the region, it is imperative that flood resilience strategies are quickly put into place. Programs, such as the Title Clearance program, have recently been increasing within the region to promote the adaptive capacity, however, more determinants (see Table 1) need to be considered to increase the community's resilience.

These programs are beginning to address glaring gaps with the access to resources. Additional, complementary strategies could make a considerable impact within the community of Cantera. This study addressed this pressing need by evaluating nonstructural strategies to assist these programs and boost community disaster awareness combined with structural strategies to improve flood resilience. In what follows, we describe our research methods, which included a comprehensive literature review of flood resilience strategies, analysis of the community needs and capabilities of Cantera, and interviews with flood resilience experts.

3. Methodology

The neighborhood of Cantera in San Juan, Puerto Rico faces recurring flooding with the increase in climate change and natural disasters. To improve the flooding resilience, we analyzed both structural and nonstructural strategies to address the key flooding problems in Cantera. Then, we recommended a list of strategies that would best help Cantera along with an implementation guide for the CDIPC. The proposed structural strategies reconstruct landscapes or divert flooding in Cantera, and nonstructural strategies address community disaster awareness and preparedness, including access to resources. To achieve this goal, the following objectives guided our research:

1: Identify and evaluate strategies to mitigate flooding from analogous case studies.
2: Investigate the community of Cantera's flood-related needs and capabilities.
3: Create a prioritized list of flood resilience strategies based on perceived effectiveness, feasibility, and community feedback.

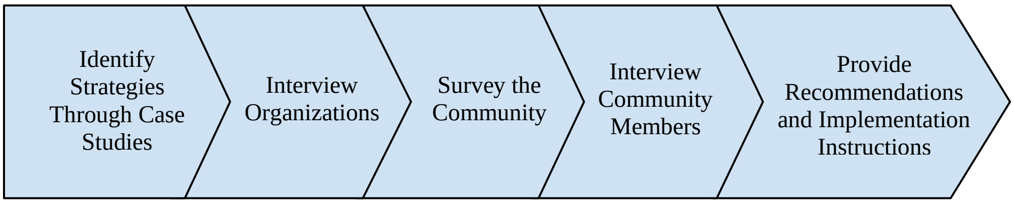

Figure 4. The sequential actions to present the CDIPC with flood resilience recommendations for Cantera.

Through assessment of literature, case studies, interviews, and surveys, the objectives were fulfilled as a list of flood resilience recommendations for Cantera. These methods produced both structural projects and strategies to improve adaptive capacity, ranging in effectiveness and feasibility.

3.1. Identifying Strategies from Case Studies

In order to present a list of recommendations, we needed to identify potential strategies proven to work in similar locations. We accomplished this by performing a literature review on analogous flood adaptation case studies from all over the world that experience similar flooding problems to Cantera. We systematically searched scientific databases including Google Scholar, Science Direct, JSTOR, and WIT Press for studies with a similar subject matter. We searched for keywords that were relevant to our research topic. These keywords were: community flooding resilience, adaptive capacity, adaptive strategies, flooding mitigation strategies, and flooding solutions case study. All articles that included words such as 'strategies', 'solutions', or 'case study' in their titles or abstracts were organized into a list. We identified 25 articles and determined their relevance to flooding resilience; of those 25 articles, we concluded 15 were relevant because they discussed flood resilience strategies in depth. Many articles focused on assessing an area's flood risk; however, a flood risk analysis has been performed on Cantera and is outside the scope of our research.

While researching these strategies, the following questions guided our review: 1) What structural solutions mitigate flooding? 2) What nonstructural strategies improve adaptive capacity? 3) What factors affect the feasibility of implementation? 4) Who can implement these strategies, residents or larger organizations? 5) How does this strategy improve flood resilience?

Along with the answers to these questions, we summarized themes, analyzed strengths and weaknesses of each strategy, and assessed the validity of the claims made by the author(s) as well as the methods used to acquire or test these claims. A total of 67 strategies were identified from these sources and compiled into a spreadsheet, where they were categorized based on the answers to the previous five assessment questions. This enabled us to offer a variety of strategies ranging in cost, ease of implementation, scale of project, effectiveness, and the purpose of each flood resilience strategy. We were especially interested in green infrastructure and low impact development projects because the Environmental Protection Agency (EPA) recommends these types of strategies for their sustainability and minimal impact on the environment. Once the list of strategies was compiled, the results of our surveys to Cantera homeowners and interviews with flood resilience experts aided to exclude non-feasible strategies and create an implementation guide.

3.2. Community Analysis

Amidst the current global COVID-19 outbreak, social distancing is recommended nationwide by the Centers for Disease Control and Prevention (CDC). As of March 15, 2020, bans were placed on large social gatherings in Puerto Rico and curfews were put into effect (Get Your Mass Gatherings, 2020). This prevented our travel to Puerto Rico to perform face-to-face observations and interviews. Before our trip was canceled, we intended to perform a walk-through of Cantera to become familiar with the area, which would entrust and educate ourselves with regards to the community. This would have entailed noting anything significant regarding the stability, safety, and accessibility of resources such as monetary aid or physical supplies for fortifying homes. By being physically present in the area and conversing with locals, we would have gained insight regarding the overall opinions and attitudes of Cantera residents regarding flood-related issues. These impact risk perception, which is a key part in building community resilience. In place of in-person observations, we read and analyzed literature about the area. In addition, we interviewed Cantera residents via video conferencing in order to better understand the composition and social structure. These answers guided our team to the most appropriate method of distributing online surveys and better shaped our final recommendations for flood resilience.

Unfortunately, without knowing the relationship between the CDIPC and Cantera residents, this introduces potential bias into our survey and interview responses. Residents who are estranged from the government are likely not receiving government aid. Since all surveys and information being relayed through the CDIPC, necessary due to COVID-19 safety measures, this could have garnered some wariness to interact with our project.

3.3. Interviews: Organizations and Homeowners

Interviews with organizations that assist community members and an interview with a community representative were conducted to gather feedback on the list of strategies. The organizations that participated are CDIPC, Atkins Global, and the former Chief Resilience Officer of San Juan. Interviewing these organizations helped us identify the current strategies and recommend new ones based on each strategy's feasibility and effectiveness. Interviewing homeowners of Cantera helped to further identify community needs and what strategies the community members are open to in order to refine our recommendation list.

3.3.1. Interviewing Experts from Government and Nonprofit Organizations

The experts that were surveyed work for companies or nonprofits that provide free resources, such as programs or guides, as well as work with the Corps of Engineers to implement community flood mitigation projects. We first surveyed members of the government agency we worked with, CDIPC, and then the companies they recommended that provide resources to Cantera. The solutions that organizations, such as CDIPC, focus on are large scale projects that cannot be completed by the individual homeowner.

By asking the CDIPC questions, we determined which organizations improve flood resilience within the community in Puerto Rico. From there, we connected with them via the CDIPC to set up a meeting regarding flooding strategies and available funding.

In a semi-structured interview conducted via Zoom, a video calling platform, we asked organizations questions about the solutions that have provided to residents in Cantera (see Appendix A). We asked about the cost of solutions that have been provided, the method of accessing resources currently available, and the type of funding the organization receives. From this, we gathered an understanding of the organization's current approaches, on a large and small scale, to help the community become more flood resilient.

After assessing the community needs through our initial survey of the organizations, we determined possible solutions that would be viable for Cantera that could be implemented by a group or organization, like the Corps of Engineers, with funding rather than the individual homeowner. A follow-up, structured questionnaire was sent via email after the group narrowed down a list of strategies to determine which large-scale solutions are most likely to be implemented by organizations (see Appendix A).

3.3.2. Surveying and Interviewing Homeowners

To better assess the needs of the residents and understand the flooding problems in Cantera, we created a survey for Cantera residents and interviewed a leader in the community. The culture in Cantera is structured around community member support, making it difficult to distribute outside information throughout the community (Ruiz-Marrero, 2000). To better ensure our research and recommendations can be effective for the people of Cantera, we examined how to best deliver information and conduct surveys. The CDIPC relayed that most Cantera residents have access to the internet via a smartphone, and Facebook was one of the primary sources of communication (Ramos Carmenatty, 2020). When creating the survey, we used Google Forms because it is user friendly and easy to view on a mobile device. The CDIPC posted our survey as a hyperlink on the CDIPC Facebook page. We recognize this may not have reached all Cantera residents, but it was our best option given the circumstances surrounding COVID-19.

The first section of the homeowner survey (see Appendix B) asked residents where they live and about the specific flooding problems. This helped us identify strategies to solve the specific problems residents are facing, such as ruined property or stagnant water issues. This portion also included a section on accessibility to resources. A general poll on where the residents get their information about flooding mitigation and disaster relief aid provided insight on how to best present available resources. This portion of the survey identified the distribution methods that are best suited for the community. Next, the survey assessed what strategies the residents have attempted. From this, we gathered information on what strategies have worked and what strategies have not. With each strategy, we asked how effective they perceived that strategy to be. The last section of the survey gathered socio-economic information about respondents. Socio-economic status is an important factor to determine the affordability of the solutions that are proposed. The survey included a question on how much a resident would be willing to spend on a flooding solution, how much they currently spend on flooding solutions, and how much they make annually. This helped give us a better understanding of the priorities of the residents, as well as other alternative methods of financial support that might be needed, such as small loans. Our semi-structured electronic survey allowed us to shape our recommendation to be feasible for the homeowners of Cantera with components to allow for residents to elaborate on specific problems.

Along with surveying the community members, we had an interview via Zoom with a president of a community council to get feedback on rain harvesting, bioswale and infiltration trenches, rain gardens, and AquaDams (see Appendix D). This interview informed the feasibility of these potential solutions as well as a description of what a typical home would be able to fit on its property; the lots in Cantera are rather small and people don't have large yards. This description of Cantera homes eliminated rain gardens as a solution the average homeowner could implement.

After the interview via Zoom, an exit survey was given via Google Forms to the community representative of Cantera where questions about government perception were asked. Since CDIPC is a government organization, we wanted to gauge if solutions provided by them would be accepted by the community since there is a general distrust in the government within Puerto Rico. We refined our flood resilience recommendations based on the interviews, community feedback, and data from our surveys which helped exclude infeasible options. Then, we distributed our recommendations and implementation plan to the CDIPC, the former Chief Resilience Officer, and Atkins Global.

4. Results

In this section, we discuss in detail the six final strategies we recommend to the CDIPC and how we narrowed down our list. The literature review produced an extensive list of 67 flood resilience strategies. Through analysis of the 15 sources, we learned about costs, implementation, effectiveness, and other requirements for the success of each strategy. Not all of these strategies were applicable to our area of focus, Cantera, so we narrowed down the list to 11 viable options by using a decision matrix to exclude unreasonable options. We categorized these strategies to recommend a few different approaches to help Cantera build sustainable flood resilience. To learn of past strategies or projects in progress, we interviewed resilience experts. This gave us more understanding of what kinds of large-scale strategies would succeed and be accepted in this area. We also interviewed a Cantera community leader via Zoom to ask for feedback on some of our final recommendations. From the feedback given by this community representative and the survey, we were able to narrow down our list to six final strategies and tailor our recommendations for the CDIPC.

4.1. Categorization of Strategies

We identified 25 articles from the literature review. Of those 25 articles, 15 of them gave examples of flood resilience strategies, their cost, effectiveness, and implementation process. From these articles, our team identified 67 flood resilience strategies that have successfully increased community resilience. These strategies included structural and nonstructural projects. Upon analysis, it became clear that these strategies then fit into six distinct categories: water barriers, diversion, home construction, education, relocation, and community support. We created the visual below and organized the strategies in two broad categories, structural and nonstructural, and six sub-categories (see Figure 5). We are recommending strategies across all categories to create a well-rounded resilience plan for Cantera. This is because resilience is affected by a range of determinants, from the typical structural designs to education and awareness (Lopez-Marrero, 2010).

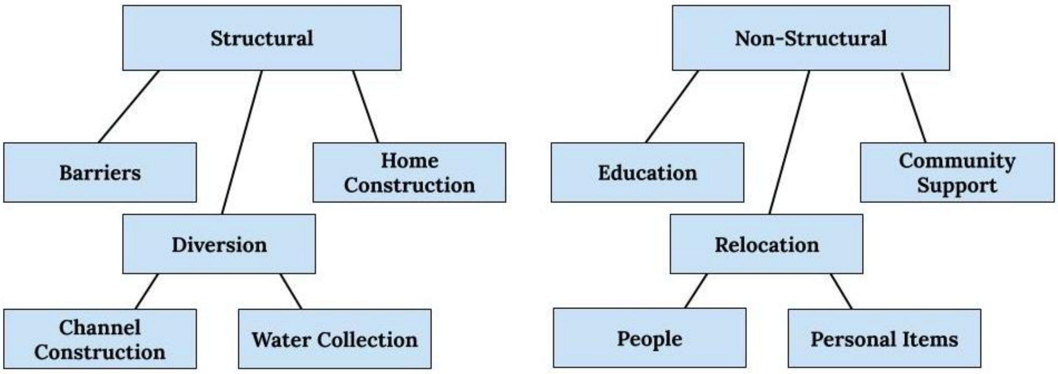

Figure 5. Categorization of flood resilience strategies based on the approach of the strategy.

We allocated each strategy with a level of expense: low, moderate, high, or very high relative to other strategies within the same implementation group (residents, CDIPC, or Corps of Engineers). All very high cost strategies were removed, which eliminated 24 strategies. The remaining 43 were analyzed based on ease of maintenance and implementation, number of people positively impacted, and availability of required resources. Values for these categories were assigned to each strategy relative to similar strategies. We input these numbers into a decision matrix we created with the options divided into six separate categories depending on the owner of implementation (e.g. residents, CDIPC, or Corps of Engineers) and whether they are structural or nonstructural. Two to four strategies with the highest values in each category were selected for further examination. This resulted in the 11 strategies found in Table 2; more detailed technical descriptions of these viable strategies can be found in Appendix C.

4.2. Analysis of Viable Strategies

Table 2 offers descriptive information on 11 flood resilience strategies we found were viable within Cantera. It shows the approximate cost, implementation, and maintenance required for each strategy. Of these viable options, we determined six strategies that would have the greatest impact and effectiveness in Cantera. The interview with a community representative and the results of our survey gave us a better understanding of the problems that need to be addressed by the CDIPC to build resilience in Cantera.

Strategy	Cost	Implementation	Maintenance
Structural Strategies			
AquaDam	$100/ft for an 8 ft tall AquaDam	● Along Cantera's full shoreline (8000 ft) ● Partial shoreline for lower cost ● Improved transportation along roads	Maintenance may be required to patch leaks and monitor the integrity of the canvas material
Rainwater Harvest	$200-$300 (small-scale)	● 155-gal tank is placed on the 1st story roof to collect rain from 2nd story roof ● PVC pipe attached to the barrel ● Requires technical experience	This passive system requires little maintenance
	$70,000-$100,000 (large-scale)	● Reduces the burden on existing storm drain systems ● Water could be used for plumbing	
Rain Garden (Absorbent Landscapes)	$5-16/sq ft	● Requires plot of land for long-rooted native vegetation ● Could be residential or large scale– depends on land is available	There would need to be tending to these gardens
Infiltration Trench	$5-$12/sq ft	● Built where water accumulates ● Semi-permeable pavement can replace roads to increase transpiration	The maintenance would be negligible
Bioswales	$5-$24/sq ft	● Built wherever there is available grassy land (e.g. by the roadside)	The maintenance would be negligible
Drainage System	N/A	● Already implemented in Cantera ● Recommend continued use	Maintain to avoid flow restriction and monitor for leaks
Nonstructural Strategies			
Community Committees	Varies	● Emphasis on flood management and maintenance, food/supplies delivery, and community support	Would require volunteers and possibly funding
Orientations and Educational Programs	Varies	● Could be held at the Haydee Rexach Elementary School ● Topics should center around increasing disaster awareness, risk perception, resources, and homeowner solutions	These orientations would need to be advertised and hosted by the CDIPC or community committees
Evacuation Plans and Safe Havens	N/A	● This topic could be discussed during community orientations	N/A
Construction Codes	N/A	● Discuss during orientations ● Meet with Habitat Humanity	N/A
Disaster Resources	N/A	● The Title Clearance Program (see Appendix E) should be advertised widely in Cantera or on Facebook ● Could be discussed during orientation	Continued effort to advertise the Title Clearance Program and other ways to increase access to resources should be maintained.

Table 2: Viable strategies and their associated cost, implementation, and maintenance requirements.

After interviewing Francisco Pérez, the former Chief Resilience Officer of San Juan, a local community leader, and analyzing survey data, we narrowed down our strategies in accordance to their responses. One strategy, rain gardens (absorbent landscapes), may not be viable for many properties due to small plots of land. Although drainage systems and community committees are already used in Cantera, we recommend strategies to support and expand them, respectively, to increase their success in flood mitigation. Additionally, strategies like evacuation, safe havens, construction codes, and resource programs are already in place and we recommend advertising them through education and orientations.

A major finding from our survey of 22 Cantera residents revealed that 45.5% of respondents do not spend anything on flood resilience strategies and 36.4% of people say it is not necessary at all. Improving the risk perception in this area is the first step the CDIPC should take to create a more resilient community. Preparation allows for a decreased feeling of helplessness, and increasing social memory reminds people of the dangers and frequency of flooding so the community can adequately prepare. Many residents in two other flood-prone areas in Puerto Rico felt secure with their flood strategies despite years without updating, endangering their safety (Lopez-Marrero, 2008). Offering flood resilience strategies is useless unless the community wants to become more resilient. A reason for this low-risk perception may be affordability. According to our survey, the median household annual income is $7,500, and 50% of respondents said they would only be willing to spend $100 or less on flood mitigation. A particularly poor community with little extra income to spend on flood strategies, may downplay its necessity.

For this reason, before recommending residents employ new strategies themselves, we recommend the CDIPC hosts orientations to increase disaster awareness in the community. This initial approach is inexpensive while having a significant impact on resilience. These orientations could take place at the Haydee Rexach Elementary School, which the president of the neighborhood council mentioned has tentative plans to be turned into a Resilience Center. Since this site already makes use of flood mitigation techniques, like rain harvesting, it could act as a showroom for strategies. The Haydee Rexach Elementary School has room for additional resilience strategies such as rain gardens. We determined rain gardens were an effective small-scale strategy for residents to use on their property, space permitted. One orientation could display a rain garden where residents learn about cost and how to plant one, so they can adapt to their own home.

Evacuation plans, disaster resources, and construction codes are a few other topics that would benefit the community. An orientation could discuss access to resources, specifically the

Title Clearance Program. This program works with homeowners to acquire the title to their home. Increasing awareness of the Title Clearance Program during community orientations will help bridge the gap between residents in need and available resources. For this reason, we created a flier to be distributed electronically via Facebook and eventually locally in Cantera when COVID-19 social distancing restrictions are lifted (see Appendix E).

An additional way for residents to qualify for more resources is by updating their homes to current construction codes. Residents' inability to afford and implement renovations disqualifies them for resources. Not only does this stunt recovery, but it poses a safety risk. However, there are nonprofit organizations that have worked in other parts of Puerto Rico, such as Habitat for Humanity and All Hands and Hearts, that specialize in updating homes. If residents choose to volunteer, the cost is minimal compared to updating on their own. We recommend the CDIPC set up meetings with these organizations to see if they would be willing to assist with the rebuilding in Cantera.

Rebuilding these homes would increase access to future disaster resources, but there are structural measures that should be taken care of to avoid further destruction of these homes. According to our survey of residents, less than 23% of respondents felt they could afford a strategy costing $250. For this reason, the only possible resident flood resilience strategies could be rain gardens or small rain harvesting systems. Both strategies can vary in cost depending on the size of the system and materials, for example, a smaller tank would cost less but still contribute to reducing flood water volume. We recommend residents install rain gardens if they have space on their property; rain gardens do not require a specific skill set and they are relatively easy to maintain. Individual rain harvesting requires more skill to install, but almost no maintenance (more details about these strategies can be found in Appendix D).

Francisco Pérez Aguiló, a resilience expert for Atkins Global, commented on rain harvesting stating, "the more people [that] use [rain harvesting], the larger the benefit" (Pérez, 2020). For this to significantly benefit the area, many homes should be equipped with the tank and PVC system. Alternatively, the CDIPC could investigate the possibility of implementing a linked neighborhood scale rain harvesting system and the water could be used for plumbing. This minimizes the cost associated with this strategy since it saves money on plumbing over the years. It may be more successful for a service consulting company or the Corps of Engineers to design a plan to retrofit this system to current drainage systems, rather than asking individual homeowners to install rain harvesting systems in their own home.

Two significant problems indicated by the residents in our survey were stagnant water and transportation. About 36% of survey respondents felt transportation is the worst problem associated with flooding. To combat these problems, we recommend the AquaDam, Bioswales, and Infiltration Trenches. With the eight-foot-tall model, the AquaDam acts as both a water storage container, filling up with floodwater, then as a barrier that blocks mass amounts of water. It has been used along major access roads or along the shoreline of coastal cities to stop some of the water from impeding transportation. One respondent from our survey specifically expressed worry because of the “high population of older adults.” Transportation is necessary to recover from disasters and provide emergency services.

Over 50% of survey respondents felt the worst problem associated with flooding in the area to be stagnant water, which poses a serious health threat to Cantera. Bioswales and infiltration trenches offer a viable solution to this issue. By replacing existing vegetation with more absorbent vegetation or material, the ground can hold more water and prevent stagnant water on the surface. Because we were unable to travel to Puerto Rico, we cannot specifically say where these strategies could be utilized, but we recommend consulting a hydrology expert to design a bioretention plan for Cantera to maximize the effectiveness of these strategies. Based on research of similar coastal cities, we recommend implementing these two strategies wherever possible in Cantera, such as roadside grassy areas, or the center of the peninsula where there is a vegetative area that can be made more absorbent.

Our findings suggest to build resilience in Cantera, nonstructural strategies should be prioritized and implemented first to improve flood awareness and risk perception. Organizing orientations or educational programs about structural strategies, access to resources, construction codes, evacuation plans, and safe havens, would significantly improve the flood awareness of Cantera and therefore community resilience. There could also be orientations teaching residents how to implement smaller-scale strategies, such as rain harvesting, since they may not have the skills to do this on their own. This community engagement may improve the effectiveness of current community committees, which are vital to the effectiveness of structural strategies. The structural strategies we recommend are mostly larger-scale projects that would require implementation by the CDIPC, service consulting companies, or the Corps of Engineers because our survey showed many residents do not have the skill or financial resources to install individual systems. Our survey also indicated the major flooding issues are standing water and transportation. The structural strategies we recommend to mitigate these issues are AquaDams, bioswales, infiltration trenches, and rain harvesting systems retrofitted to the neighborhood's existing drainage and plumbing system.

5. Conclusions

Our survey of the homeowners identified the main problems homeowners face stem from the large amount of stagnant water that is in Cantera after a hurricane. The standing water inhibits emergency vehicles, prevents residents from traveling to get necessities, causes pungent odors, and poses a health concern to residents. To mitigate these problems, we propose implementing harvesting rainwater, bioswales and infiltration trenches, and AquaDams. The structural strategies of harvesting rainwater, bioswales and infiltration trenches, and AquaDams address this problem by diverting and capturing water. The nonstructural solutions of orientation and education programs and an increase in access to resources for the area of Cantera will help to support the structural solutions and increase resilience to flooding. The best method of action would be to start with implementing the nonstructural solutions to spread knowledge and awareness before implementing the structural solutions. We recommend the CDIPC or the municipality of San Juan to implement educational programs in order to encourage residents to apply strategies to their homes. We created a flier for the Title Clearance program to help advertise this vital program (see Appendix E), and we recommend distributing it on the CDIPC Facebook page or locations around Cantera. For the large-scale structural solutions, bioswales, infiltration trenches and AquaDams, we recommend companies expand the current trench projects and begin assessing optimal locations for the AquaDam to be placed.

During our research, we discovered future valuable projects and steps that would further our objectives in Cantera. We recommend looking more thoroughly into larger scale rain harvesting units that could potentially be used by the entire neighborhood. The larger the system, the more effective it will be at temporarily storing stormwater, but the higher the cost. Further research into how to effectively implement the training needed for maintenance would greatly increase these solutions' longevity. Also, we recommend an expansion of community committees. Along with our recommendation of educational programs, bridging the knowledge gaps about the resources available (e.g. safe havens, evacuation plans, resources, construction codes, etc.) and effectively distributing information would make these programs effective. From our survey, we determined that people across all socioeconomic backgrounds primarily hear about flooding resources from other people within their community rather than an outside source. Creating programs where residents can get more involved will help to not only educate the people that attend, but others as well.

After further looking at the feedback from residents, CDIPC, and the former Resilience Chief Officer, we recommend establishing plans for maintenance prior to construction. It was conveyed to us that typically in Puerto Rico, projects are created without a maintenance plan (Pérez Zapata, 2020). These preparations are an integral aspect for increased structural longevity. Specifically, the AquaDam and infiltration trenches may require repairs over time. Existing community committees could possibly fill this role but, if it is not possible, funds would have to be allocated by the municipality for repairs to the structural solutions. Along with delegating the responsibility of maintenance, we recommend also performing an analysis of the logistics for installation and location for the AquaDam.

After finding that the biggest problems residents have is standing water, we were able to effectively recommend the solutions AquaDams, bioswales, infiltration trenches, and rain harvesting. This project outlined a variety of flooding resilience recommendations for the CDIPC despite the limitations of working remotely without direct access to the area or the people. Without these limitations, researchers will be able to better assess community perception and need to dive deeper into where and how these strategies can be implemented. If these strategies were implemented, it would positively affect Cantera, building the overall resilience to flooding while addressing the prioritized needs of residents. These recommendations address the growing need for flood resilience due to climate change and the potential of severe floods. We expect the recommendations we have provided for the CDIPC to positively impact the residents of Cantera and inspire programs around resilience.

6. References

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Appendix A: Interviewing Resilience Experts in Puerto Rico

Interview Questions for CDIPC

We are students from Worcester Polytechnic Institute doing a project to help with flooding solutions in Cantera. This data will help us to provide recommendations for flooding solutions. This interview is voluntary and will be recorded with your permission (this includes video and audio). If you would rather we not record one or both of these, please let us know at this time.

- What flooding programs have been provided by your organization?
- What physical flooding solutions have been provided to homeowners (ex. Raising homes or waterproofing)?
- What is the cost of the solutions that have been provided for a homeowner to implement?
- What is the current method of contacting residents to tell them about the resources that the organization provides and how successful has this method been? (i.e. pamphlet, television advertisement, internet advertisement…)
- How is your organization funded? (government, nonprofit, etc.)
- What is the price range your organization is willing to spend on a large-scale project that would greatly help the community?

Interview Questions Resilience Experts

We are students from Worcester Polytechnic Institute working on a project to increase flooding resilience in Cantera. This data will help us to provide recommendations for flooding strategies to the CDIPC. This interview is voluntary and will be recorded with your permission. If you would rather we not record one or both of these, please let us know at this time.

Advisor Channel Project Team Leader Atkins Global

- What flooding projects have you been a part of?
  - What was the problem being solved?
  - Was the solution effective?
  - How cost-effective was this solution?
  - Are there any other solutions you have seen that are highly effective and cost efficient?
- Where were these projects located? How did funding for the project work?
- What kinds of destruction does flooding cause? Are there any specific to Cantera that we should be focused on?
- What flooding strategies do you know of that homeowners use already? Are they effective? (Example: Raising homes using various materials, waterproofing, flood barriers, moving valuables upstairs)
- What work is being done to Caño Martín Peña?
  - What are the problems that are trying to be fixed?
  - Why was this solution chosen?
  - What were some other ideas for solving this problem?
- Is there any additional information you think could help us?

Follow-Up Questions

1. What flooding strategies do you know of that homeowners use already? Are they effective? (Example: Raising homes using cinder blocks or other various materials, waterproofing, flood barriers, moving valuables upstairs)
2. What work is being done to Caño Martín Peña?
   a. What are the problems that are trying to be fixed?
   b. Why was this solution chosen?
   c. What were some other ideas for solving this problem?
3. You mentioned your personal rain collection system was easy to implement, what are the specific steps to create a residential rain catching system and does the average person have the skills to assemble it?
4. Approximately how much water does the residential rain catching system remove from the streets?

Chief Resilience Officer for San Juan

We are students from Worcester Polytechnic Institute working on a project to increase flooding resilience in Cantera. This data will help us to provide recommendations for flooding strategies to the CDIPC. This interview is voluntary and will be recorded with your permission. If you would rather we not record one or both of these, please let us know at this time.

- What flooding projects have you been a part of?
    - What was the problem being solved?
    - Was the solution effective?
    - How cost-effective was this solution?
    - Are there any other solutions you have seen that are highly effective and cost efficient?
- Where were these projects located? How did funding for the project work?
- What kinds of destruction does flooding cause?
- What flooding strategies do you know of that homeowners use already? Are they effective? (Example: Raising homes using various materials, waterproofing, flood barriers, moving valuables upstairs)
- What were the biggest issues you identified from your work as Chief Resilience Officer?
- Is there any data you could share with us from your previous research in the area?
- Is there any additional information you think could help us?

Follow-Up Questions

1. In Cantera people do not have titles to their homes and this causes difficulty receiving disaster aid. Do the people of Playita have titles to their homes?
2. What key information should we be looking for from the community members?
3. After creating our list of recommendations, we plan to discuss these options with a focus group from the area. What are some tips that could help us improve community engagement on the project?
4. You mentioned being able to send us an updated presentation, would that still be possible?
5. We have an initial survey created for the residents of Cantera to grasp more information on flooding within the area, would you be able to review this and give us comments on it?

Appendix B: Cantera Homeowner Survey

Hello! We are students from Worcester Polytechnic Institute doing a project to help with flooding solutions in Cantera. This data will help us to provide recommendations for flooding solutions. This survey is voluntary and anonymous; it is also only to be taken by property owners.

1) Where do you live?

- ❏ VILLA KENNEDY
- ❏ PASEO DEL CONDE
- ❏ LOS PINOS
- ❏ HÁBITAT
- ❏ LAS CASAS
- ❏ VILLAS DEL COROZO
- ❏ PARQUE VICTORIA
- ❏ EL MIRADOR
- ❏ LAS MARGARITAS
- ❏ VILLAS PELICANO
- ❏ PUENTE GUANO
- ❏ SANTA ELENA
- ❏ COREA
- ❏ CONDADITO FINAL
- ❏ ULTIMO CHANCE
- ❏ BRAVOS DE BOSTON
- ❏ VILLA ESPERANZA
- ❏ Other

2) What is the biggest flooding problem for you?

A. Home flooding
B. Land flooding
C. Stagnant water
D. Ruined belongings

3) Specifically, what is the problem you are dealing with?

4) Where do you go to obtain information about flooding solutions?
   A. People in your community
   B. The newspaper
   C. Television
   D. Internet
   E. Other:

5) What flooding solutions have you tried in your homes?
   A. Raising your home (with various materials, stilts, wood, cinder blocks)
   B. Water barrier (sandbags, temporary barriers, permanent barriers)
   C. Waterproof material (concrete)
   D. Raise beds and valuable objects
   E. Other:

6) How effective are these? (Please rank from 0 to 10, 10 being the best)

7) What is your annual income?
   A. $0-$5000
   B. $5000-$9,000
   C. $9,000-$13,000
   D. $13,000-$17,000
   E. $17,000-$21,000
   F. $21,000+

8) How much do you currently spend on flooding solutions within your home in a year?
   A. Nothing
   B. $50
   C. $100
   D. $250
   E. $500
   F. $1000
   G. I don't know.

9) What would you be willing to spend on a good flooding solution in a year?
   A. $50
   B. $100
   C. $250
   D. $500
   E. $1000
   F. Nothing. I don't need one.

Thank you for completing our survey on flooding solutions.

Appendix C: Supplemental Strategy Research

Our research yielded many viable strategies for Cantera. We selected the most promising to discuss in-depth in the Results section of the report (see page 26). However, we found a wealth of information on the following 17 viable strategies and three nonviable strategies. This is detailed below.

Structural

Harvesting Rainwater

Rainwater harvesting is a solution at the residential level that doubles as both a way to remove water from the streets during a flood and save on water costs throughout the year. Francisco Pérez Aguiló, the project team leader for El Caño Martín Peña resilience project lead by Atkins Global, put forth this solution for our team to investigate. He has made himself a personal rainwater harvesting system that can hold up to 155 gallons of water and be used for watering his garden year-round. Francisco mentioned how, due to the passive nature of the system, this is very durable and low maintenance, something supported by the National Stormwater Management Calculator finding maintenance costs to be negligible throughout the life of the system (National Stormwater Management Calculator). Speaking to the durability of the strategy, Francisco Pérez said, “Right before [Hurricane] Maria, I left my house and left it closed for two years and I came back. It was right there.” The effectiveness of this strategy only becomes apparent as more of them are installed. Francisco stressed the importance of removing any amount of water from the streets of Cantera. This is due to the very low base elevations throughout the area, preventing the use of many common mitigation strategies. Therefore, implementation of a rainwater harvesting system on as many two-story, or taller, buildings would help to remove significant amounts of water because of the pressure provided (see Table 3 for an estimated amount of water storage for various strategies given their size). A residential system like this would cost $200-$300 to implement (Francisco Pérez Aguiló, 2020), something which may not be possible for many residents. For people with one-story homes, the cost would only increase due to the need to install a separate water pump. According to our survey of residents, less than 23% of respondents felt they would be able to afford this system. However, the savings in water costs by implementing this system could help offset the cost for the residents and allow more people to contribute to this system. Additionally, a local community leader was enthusiastic about implementing this strategy in Cantera.

Along the same vein, Francisco discussed a larger scale version designed for a public building in a nearby area. They were able to save nearly $12,000 a year in water costs by adding a harvesting system costing only $70,000 (Francisco Pérez Aguiló, 2020). This level of investment is highly viable for organizations in Cantera to implement as the return on investment is merely 6 years. We found this could further be implemented to run entire neighborhoods' water systems. According to Pérez, if a neighborhood took part in this strategy, they could recycle thousands of gallons of flood water in a week. This is backed up with a case study from Italy where this kind of system was created to reduce the amount of floodwater burdening existing drainage systems (Freni, 2019). This study showed the rainwater harvest tanks produced a 34.9% reduction of flooded areas for the average maximum rainfall event (Freni, 2019). The larger the cistern water collecting capabilities, the larger the volume reduction of stormwater. This is also true for a neighborhood of people using individual rain harvesting systems. Francisco Pérez Aguiló commented on this saying, "the more people use it, the larger the benefit." (Pérez, 2020). The homeowner survey detailed how residents feel they may not be able to afford it or feel organizations should secure funding for these projects. As such, a connected larger scale rain harvest system may be more feasible and effective for Cantera.

Bioswales and Infiltration Trenches

Utilizing the space between rocks to store water has been gaining momentum as flooding becomes more intense. Rocks of varying sizes allow water to infiltrate this space and be stored during a flooding event. This is the goal of an organization level bioretention strategy; infiltration trenches. When implemented on a larger scale, Francisco Pérez Aguiló stated "what [organizations have] done is they have enhanced the [storage] volume [of infiltration trenches] with culverts buried under the gravel," drastically increasing the storage capacity (see Table 2 for an estimated storage capacity for an infiltration trench of the given size). This could be implemented in large parking areas or other areas with dense levels of concrete, due to the poor drainage capacity of standard concrete (Francisco Pérez Aguiló, 2020). 36% of survey respondents felt the worst problem associated with flooding was transportation and access to many of the areas of Cantera. By replacing standard concrete patches with infiltration trenches, this water could infiltrate the streets and be stored below them.

Strategy	Storage Capacity (gal)	Distance to Groundwater (cm)	Surface Area (ft^2)	Length (m)	Height (m)
Dams or Ponds	1,320,861	-	-	100	10
Infiltration Trench	126,803	120	-	100	10
Bioswale	147,936	80	-	100	10
Rainwater Harvesting	2,131	-	1,300	-	-

Table 3. Estimated water storage capacity of various strategies to address issues with El Caño Martín Peña. (Francisco Pérez Aguiló, 2020)

Infiltration trenches may also be designed to store water and slowly release it into the main storm drainage systems. This prevents the storm drains from quickly becoming inundated, preventing mass amounts of backflow as the volume of water peaks during a storm. Alfredo Pérez Zapata talked of one such system currently installed in Cantera. This system, although accidental, was able to remove and store large amounts of standing water within its area of effect, one of the biggest problems residents face.

In a similar manner, Bioswales are frequently used to slow the amount of water entering the drainage systems. Bioswales are an organizational version of the rain garden, utilizing vegetation able to absorb large amounts of water and store it between the spaces in their roots. In addition, geotextile, sand, and rock are all used to further increase the storage capacity (see Table 3 for an estimated storage capacity for a bioswale of the given size). Bioswales can be connected to the storm drain system by replacing typical drains, or they can be utilized to replace large concrete areas with vegetation. This performs the exact same role as an infiltration trench would, however at a much lower cost. The Center for Neighborhood Technology has determined cost-effective bioswales could cost only $5.50 per square foot to implement and as low as $0.06 per square foot to maintain. In addition, with a longevity of over 25 years, these would be a long-term solution for Cantera. The CNT also provides an extensive list of the cost to implement and maintain various green infrastructure projects, as well as the estimated longevities. We recommend referring to the National Stormwater Management Calculator for further pricing on green infrastructure strategies. A community leader from Cantera relayed a possible area that could be used for this solution is a broad swath of land near the central Cantera (shown in Figure 6).

Figure 6. Displays the area where green infrastructure can be implemented.

Due to low levels of elevation above groundwater in most of Cantera, this option would be difficult to implement. According to Francisco Pérez Aguiló, an engineer working on improving El Caño Martín’s drainage, infiltration trenches and bioswales must be at least 6 feet above the groundwater level to be effective (Pérez, 2020). The areas of Cantera most hit by flooding are unfortunately under this required elevation. However, bioswales and infiltration trenches built in areas with this elevation could reduce the amount of runoff flowing into the more flood-prone areas and flatten the curve of flood inundation.

Absorbent Landscapes

Altering naturally occurring vegetation and soil to provide better drainage, and absorption, ultimately leads to increased flood mitigation. Replacing standard concrete with such vegetation can greatly improve the groundwater storage capacity during storm events. In addition, increasing vegetation along channels helps to prevent erosion, increasing the efficiency of the canal (Our Programs, 2020). Creating designated wetlands could further improve this by temporarily storing and gradually releasing stormwater. By designating wetlands, stormwater can be stored away from residential areas. These solutions, however, require large amounts of space to implement, something currently lacking in Cantera. A potential location to implement this solution is shown in Figure 6.

Rain Garden

Rain gardens use the concepts of bioretention and revegetation to mitigate flooding. Respectively, these concepts discuss how the soil is aerated to have more voids to hold and drain water, and how altering naturally occurring vegetation can provide better absorption, and, therefore, flood mitigation (Rain Gardens, 2005). Rain gardens are basically a residential version of creating an absorbent landscape to reduce flooding. If the composition of the rain garden is designed properly, it will dispel collected water in two to three days (Nash, 2018). The rain garden should be made 10 feet from a house and not near septic sewage. Absorbent, long-rooted native plants should be planted in loose mulch in sunny areas to promote water storage. This is an example of a low impact development approach to flood management. Rain gardens reduce the amount of stormwater entering the stormwater management system by increasing infiltration of run-off into the ground (Rain Gardens, n.d.). A typical rain garden is between four and eight inches deep. A rain garden less than four inches deep will need too much surface area to provide enough water storage to infiltrate larger storms.

Many strategies use the concept of bioretention to temporarily store floodwater, also called green infrastructure. Green infrastructure is a recommended flood resilience strategy by FEMA and the EPA since it is a low impact development project (LID), sustainable, and long lasting (Tyrrell, 2019). This residential strategy would be easy to implement for any Cantera homeowners. However, because plots of land are usually small, this strategy would be limited to larger properties. Costs are generally less expensive for LID projects than traditional drainage systems. Because rain gardens are small in size, its effectiveness is mild. However, this strategy still reduces the burden on larger systems and increases resilience by engaging residents in flood management. Rain gardens, bioswales, and infiltration trenches are more effective when used across large or multiple areas since the elevation is low in this area.

Drainage Systems

All bioretention strategies inherently rely on existing drainage systems to remove the water from them both during and after storms; they are all at risk of becoming inundated and having minuscule effect. As such, proper storm drainage systems must be in place to eventually divert the water to an area able to hold it. However, storm drainage systems' flow rates are often impeded due to a lack of proper maintenance. Storm drains often get flooded with trash or vegetation, and this can flow into the main piping, causing flow restrictions within the system. In addition, continued observation of the integrity of the pipes helps ensure leaks in the system do not inhibit flow. The effectiveness of these and other structural projects often relies on the maintenance of them.

Mobile Water Barriers (Sandbags, Rags)

Mobile water barriers, such as sandbags or rags, are an affordable way to help slow the flow of water into the home; assuming water is primarily coming from under doors or a distinct place where the flow can be identified. These objects can then be shoved into gaps within doorways to slow the movement of water. This method does not usually completely stop water from going into a home but helps to decrease the amount. Within Cantera, most homes are not up to current housing codes. This means they probably do not have floors capable of keeping water out. This poses a problem for this recommendation because if water is coming through the floor, there is no distinct point where water is coming in. One might recommend putting the sandbags on the entire floor; however, this will only delay the inevitable leaking and not fully keep it out. This method is a good option only for people who have identifiable leaks because it is so inexpensive. A homeowner can use rags they have around the house to stuff in the leak at no cost or pay for a sandbag.

Aqua Dam

AquaDams are used for temporary water storage and add the additional benefits of turning into an acting flood wall. AquaDams store flood waters as they begin to inundate an area, storing large amounts of water during flooding events. AquaDams are used for flooding in numerous places to keep otherwise flooded homes safe. Francisco Pérez Aguiló of Atkins Global stressed the difficulty of solving the flooding problem in Cantera, due to low base elevations. Any amount of water stored in a system would not only improve access to various areas in Cantera, but also help protect houses from flood damages. After filling with flood water, the AquaDam then acts as a flood wall to further protect the community. For Cantera, we recommend acquiring an eight-foot-tall version, ensuring 1.8 meters of water are kept out. Cost estimations for the dam is $100 per foot for an eight-foot-high dam. We recommend, based on flooding maps, placing these around or along the sea line. While this project is costly, it would save the most amount of homes and minimize the most damages.

Nonstructural

Increase Access to Resources

We determined that an increased awareness of the Title Clearance Program would significantly improve the community's resilience. The Title Clearance Program was created by the Puerto Rico Housing Department to work with homeowners to acquire the title to their home. Since the title to a home is needed to receive disaster aid, increasing awareness of the Title Clearance Program during community orientations will help bridge the gap between residents and available resources. This need was identified prior to the start of the project by the CDIPC. For this reason, we created a flier to be distributed electronically via Facebook (See Appendix E). After the restrictions from COVID-19 are lifted, we recommend distributing a paper form of the Title Clearance flier. To further spread awareness of the Title Clearance program, this flier can be distributed in communal spaces in Cantera, such as recreational areas or places of gathering in the area since 50% of residents surveyed stated that they get their information from people in the community.

Title Clearance Program

The Title Clearance Program was created by the Puerto Rico Housing Department to allow homeowners that do not currently have a title to their home obtain it. The title to a home is needed to receive disaster aid. Increasing awareness of the Title Clearance Program, among other programs in the area, will help set people up for success bridging the gap between available resources, the Title Clearance Program in particular, people will be able to be more resilient in the future by being one step closer to full aid from FEMA or another organization.

Connecting people to the Title Clearance program would have a significant impact within Cantera since many homes were unauthorized to be built. For this reason, we decided to create a flier (see Appendix E) to be distributed electronically via Facebook. The format of this flier would also be able to be printed and distributed on paper later when the COVID-19 restrictions are lifted so that the information can reach those that do not have access to the internet.

Orientation and Education

By increasing awareness of flooding effects, resources, and protections, residents are more likely to take care in preparation for the next flood. Increasing awareness of available resources, preventative measures, and effects of flooding, residents are more likely to take care in preparation for the next flood. We determined orientation and education to be highly compatible in all categories. The Chief Resilience Officer stressed the importance of community feedback, supporting the interactive atmosphere of an orientation. With continued outreach from the CDIPC and related organizations, this strategy can be implemented effectively by volunteers in public locations with little cost.

Increase Social Memory and Risk Perception

In similar communities in Puerto Rico, a majority of residents feel that their current mitigation strategies are sufficient for protecting themselves (Lopez-Marrero, 2008). At the same time, these communities have become inundated by floods on multiple occasions over the past 40 years (Lopez-Marrero, 2008). Lopez-Marrero found increasing social memory to be one of the most effective and feasible solutions to help these communities during her study. It was evident that residents had short memories for bad flooding events and often felt secure after a few years, even without changing their strategies. In addition, Lopez-Marrero went on to find that many homeowners do not implement strategies due to economic hurdles, stating:

> “Participants noted the lack of access to economic resources as the main limitation to undertaking more effective adaptation actions. Not knowing that other economically viable strategies are available leads to low perceived adaptive capacity”

Construction and Land Development Codes

Puerto Rico has some of the most updated housing codes within the United States. These codes help to ensure that homes can withstand high winds and are resilient to flooding. Due to the economic state of Cantera, residents have not been mandated to update their homes to comply with regulations (Pérez Zapata, 2020). Updating homes was determined to be a viable option due to its high scores in cost, number of people positively impacted, estimated impact on resilience and availability of required components. The Chief Resilience Officer confirmed the updating of homes by outside organizations as a viable option. Complying with housing codes would not only increase the safety and resilience of Cantera, but it would qualify more people for resources. We recommend partnerships and programs to help fund the updates these homes require. Habitat for Humanity, All Hands and Hearts, and other volunteer-based organizations and mission trips travel to Puerto Rico to accomplish this. Habitat for Humanity currently does home construction projects in an area called Quintana, a short drive from Cantera, and has a base in San Juan (Habitat for Humanity). We recommend looking further into meeting with Habitat for Humanity to determine interest in their involvement. Making this partnership would minimize or eliminate homeowner costs. This aligns with community feedback given in the survey of members not wanting to spend money on solutions.

Evacuation Plans

Evacuation plans are predetermined routes and areas residents in floodplains are directed to follow and stay in the event of flooding. According to Alejandra Castrodad-Rodriguez, the former Chief Resilience Officer, once trust was established, evacuation saved the lives of those that had refused to leave their homes previously in La Playita after Hurricane Maria. Evacuation plans are already in place, but the existence of these plans should be advertised to the people of Cantera to increase their resilience. This strategy is valuable in that it protects the physical safety of the residents. Away from the floodwater, citizens avoid drowning or other injuries caused by debris or structural collapse. Ensuring this plan is properly in place, it would significantly increase the community's resilience to future disasters.

Safe Havens

Safe Havens are designated areas that affected citizens stay in the event of flooding. This strategy is valuable in that it protects Cantera residents from personal injury. Kept away from the floodwater, citizens aren't in danger of drowning or other injuries caused by debris or structural collapse. This strategy is a strong short-term solution, but it does not significantly increase the community's resilience to future disasters.

Community Committees

Community committees are a prime example of how much structural strategies truly depend on nonstructural strategies. Francisco Pérez Aguiló commented on the culture of maintenance in Puerto Rico saying, "We build things and expect them to keep working without providing for (budgeting) maintenance" (Pérez, 2020). There is currently a neighborhood council in place, but their duties could extend far beyond their current responsibilities. We recommend continuing the support of these kinds of committees where members maintain the integrity of other flood management systems. It was brought to our attention by a community leader that these committees lack a solid infrastructure and funds to operate effectively. Eventually, these committees should work towards self-dependency and create a committee specifically for acquiring funds independently. Not only would this establish a culture of flood management, but it would increase community engagement.

Committees can be formed depending on the needs of the community. For example, in Gloucestershire, England village agents provided an emergency hotline number and brought seniors clean water and food (Designing with Water, 2014). Because England had a high population of elderly people, this was an effective way to build social resilience. One respondent from our survey specifically expressed worry because of the "high population of older adults." Community committees that specifically look after vulnerable populations, including seniors, people with disabilities, and children, would greatly improve Cantera's own resilience. This is a strategy to increase adaptive capacity of a community. It promotes community support by banding together in groups, as well as tasks these groups with productive actions like delivering food or maintaining structural flooding strategies committees of community members could also be responsible for maintaining integrity of the flooding management systems.

There is currently a neighborhood council in Cantera, so we recommend continued support of these kinds of committees that clean drain systems and maintain other flooding management systems through organizational funding or community fundraising. As per the request of a Cantera resident, we also recommend the Compañía para el Desarrollo Integral de la Península de Cantera and/or associated organizations allocating more funds to this strategy. Not only would this increase community engagement, but it would establish a culture of independence, maintenance, and flood management, while also increasing risk perception and social memory.

Elevate Items

Elevating household items and valuables is a common avoidance measure used by homeowners in other areas of the world that deal with flooding (Atreya, 2017). Moving belongings to a higher level within houses helps to decrease damage and cost of replacing items after a storm occurs.

We found that about 44-55% of homes within Puerto Rico are not up to code (Garcia, 2020). Since many of Cantera's homes were not authorized to be built, the number of homes that are not up to code is assumed to be roughly most, if not all, unauthorized builds. Within Cantera, not all homes are two stories. Thus, moving belongings to a higher location is an unwieldy solution. In addition, safe havens are out of flooding zones, so telling people to move their belongings to a higher elevation or safe place could potentially concentrate these places with items instead of residents. For residents that do have multiple levels to their homes, the recommendation of moving belongings and valuables to the top level when a storm is forecasted, regardless of predicted severity, would help to improve the individual homeowner's resilience.

Place Belongings in Plastic

This strategy involves storing personal belongings in plastic bags or boxes prior to a potential flood disaster. This prevents water from damaging belongings that are sealed in plastic. The cost of doing this is estimated to be $50-$200, allowing many residents of Cantera the ability to do this. This strategy can be further expanded to include placing vehicles in plastic bags, of which are available for $350-$400 (Texas Flood Bag). The protection of belongings can save a household thousands of dollars recovering from the disaster, as well as speed up the time of recovery. However, utilizing these large amounts of plastic in an ocean community could harm the surrounding marine life.

Nonviable for Cantera

Dams and Ponds

The construction of ponds or dams are another effective way of storing water during a storm. Water could be diverted into a pond during storm events, potentially removing significant amounts of water from the streets (see Table 3 for an estimated amount of water storage given the size of the solution). Stormwater ponds detain stormwater to prevent flooding. They collect runoff in a basin designed to fill with water during a storm. An added outlet structure drains the pool once it reaches a certain level. These are beneficial for storing water, preventing flood water entering residential areas. Due to the lack of base elevation within Cantera, this solution has been deemed non-viable.

Dams function in the same way, but typically used to slow the flow of a river or canal instead of using open space. Regular dams can be very costly, and they require proper design to ensure diverted water will not be harming another community. However, there are little to no areas within Cantera that have the space to divert the amount of water needed to make ponds and dams effective. In addition, the construction of a pond or a dam costs between $10 million and $1 billion (Petheram and Mcmahon, 2019), well out of the range for Cantera.

Permanent Barrier Around House

Permanent residential floodwalls are barriers constructed around a home to prevent flooding in the case of rising water levels. These barriers use mainly concrete because it is waterproof and praised for its strength against water pressure. This means they are likely too expensive for the single homeowner, though with organization or government funds it may still be possible. Additionally, with houses in close proximity, these barriers can reroute floodwater into neighbors' property, necessitating barriers for most, if not all, of the Cantera residents. Considering how a lot of Cantera have elevated housing already, the flood walls would have to be tall. These barriers also would not help the issue of street flooding. These barriers would protect individual homes for long durations and require little maintenance if they are initially built sturdily. Also, with these floodwalls, no preparation is needed if a flood is predicted.

Elevate House

This strategy involves raising houses above the expected flood level using various techniques. One of the most common solutions, and heavily employed by residents in Puerto Rico (Lopez-Marrero, 2008), is to raise the house using bricks or cinder blocks. However, these measures require a wide range of experts to elevate a house. According to FEMA, "Elevating a home requires the services of plumbers, electricians, house movers and contractors" (Protecting

Your Home), leading to total construction costs nearing $45,000 in some cases (Kusito & Campo-Flores, 2018). This price tag makes this solution not feasible for the average resident living in Cantera that according to the census has an annual income of around $16,000.

When following suggested FEMA guidelines for elevating houses, a significant amount of flooding damage can be mitigated. Homeowners are recommended to raise their homes 1-3 feet above the flood levels for a flood with an estimated 1% annual chance as identified by FEMA. This elevation could add a garage to their homes with the new space, leaving little to no damage for floods lower than the estimated 1% annual chance flood. However, with the increasing intensity of storms and rising water levels, this would only be a short-term solution. In addition, a significant portion of Cantera would need to implement this solution, as many parts of the community are less than 1 foot above the water level. The residents are not financially able to take this on at such a scale without proper government intervention, compounded by the fact that the resident would then be required to purchase flooding insurance, something they cannot currently afford. Finally, elevating a house requires building permits, which often requires a title to the property or house.

Appendix D: Cantera Resident Interview Questions

Hello! Do you all have a preference of English or Spanish? First off, I would like to record the audio and video of this meeting. Is that okay with everyone? We are students from WPI. My name is Justine and my groupmates Jackie, Reed and Gracie. We are doing a project to help with flood management in Cantera. Your participation is voluntary and anonymous.

1. Have you all gotten a chance to take the online survey about flooding solutions? https://forms.gle/yaUsQPV8VF3DiT5u7
2. What are you currently doing to mitigate flooding damage to your home?
    a. Are they successful?
3. Is there anything the community is doing as a whole to mitigate flooding?
4. How would you feel about a group of people from Cantera to help maintain flood solutions or deliver food/water/supplies to your community? Do you already have these?
5. These are some solutions:

Rain Garden - A small low-lying area on your property where you plant absorbent native plants to help drain water. You can also dig up ground and put in rocks to create space for water storage.

Rain Harvest - Collecting rain from roofs and gutters to use for plumbing like flushing toilets or watering plants. You can install a 155-gallon barrel and PVC pipe, and this would reduce the volume of stormwater.

6. Do you think that these solutions are viable for people in Cantera?
    a. Has this been tried before?
    b. Would these be easy to implement?
    c. How would you adapt the strategy to fit your needs?
7. Are these solutions possible for you?

These are larger solutions that we are recommending for organizations to implement:

Bioretention and Infiltration - This has the goal of trapping water in the landscape and slowing the draining into the lagoon.

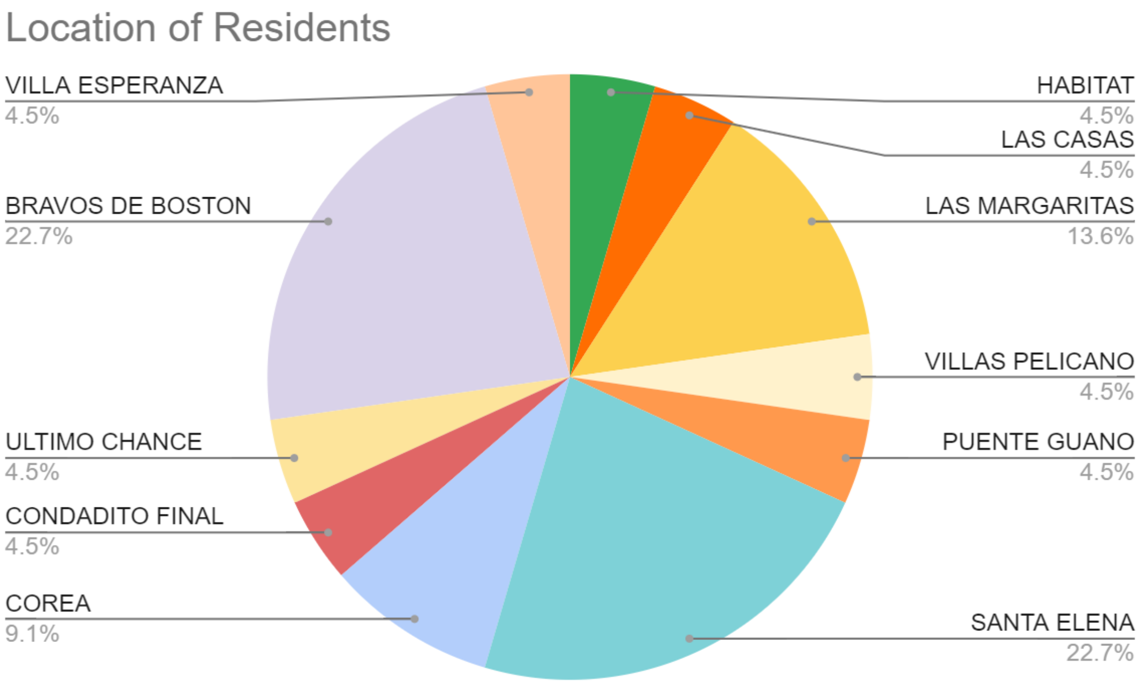
AquaDam- un Dam de agua- Fills with flood water to keep homes protected. This could be used along the seawall or only safe haven areas.

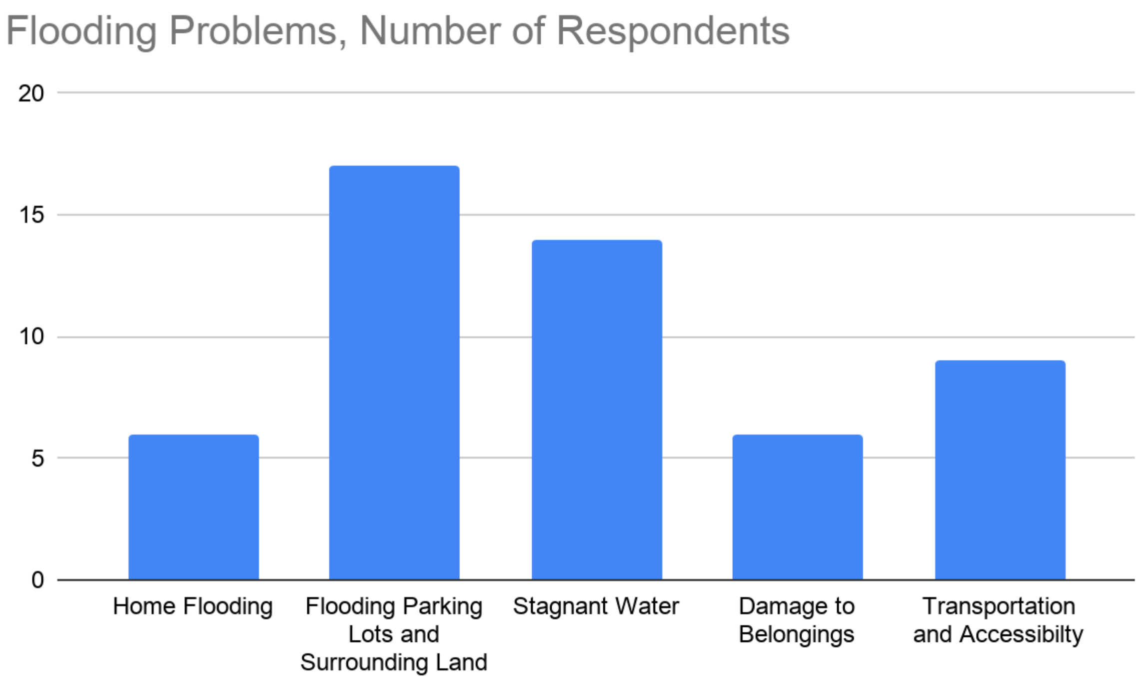
Exit Questions

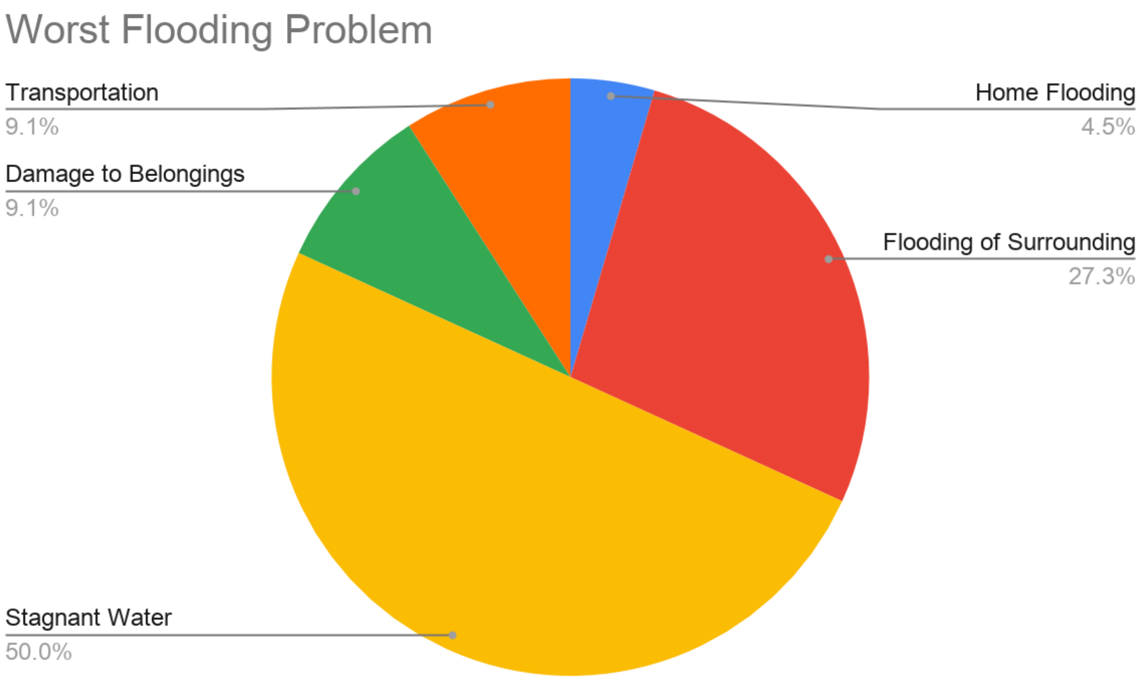
8. *What is your perception of La Compania para Desarrollo integral de la península de cantera?*
9. *How do you think others perceive CDIPC?*
10. *How do you feel about the government? Do you trust the government?*
11. *If you have time, please take our online survey about flooding solutions.*

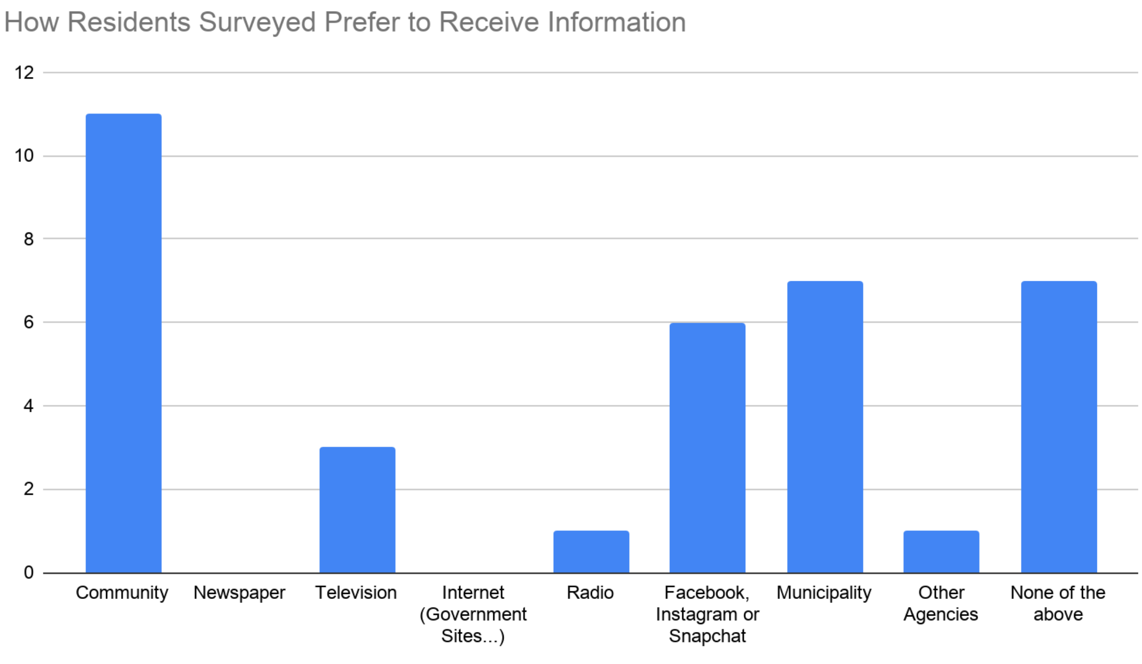
Appendix E: Title Clearance Flier

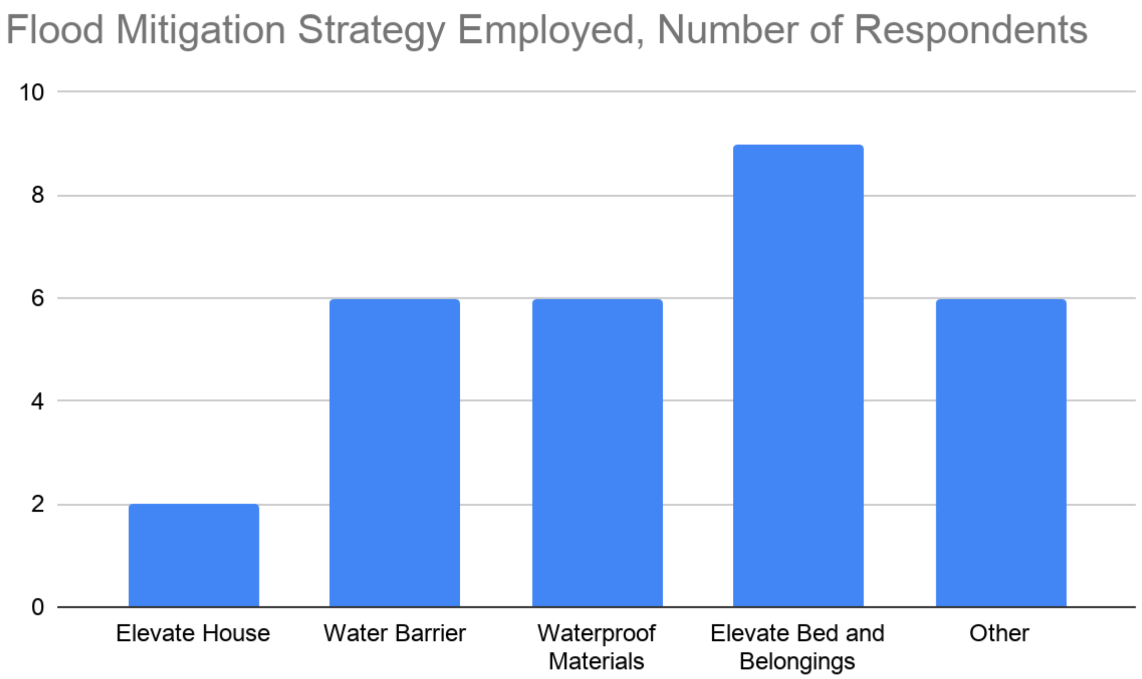
Appendix F: Homeowner Survey Results

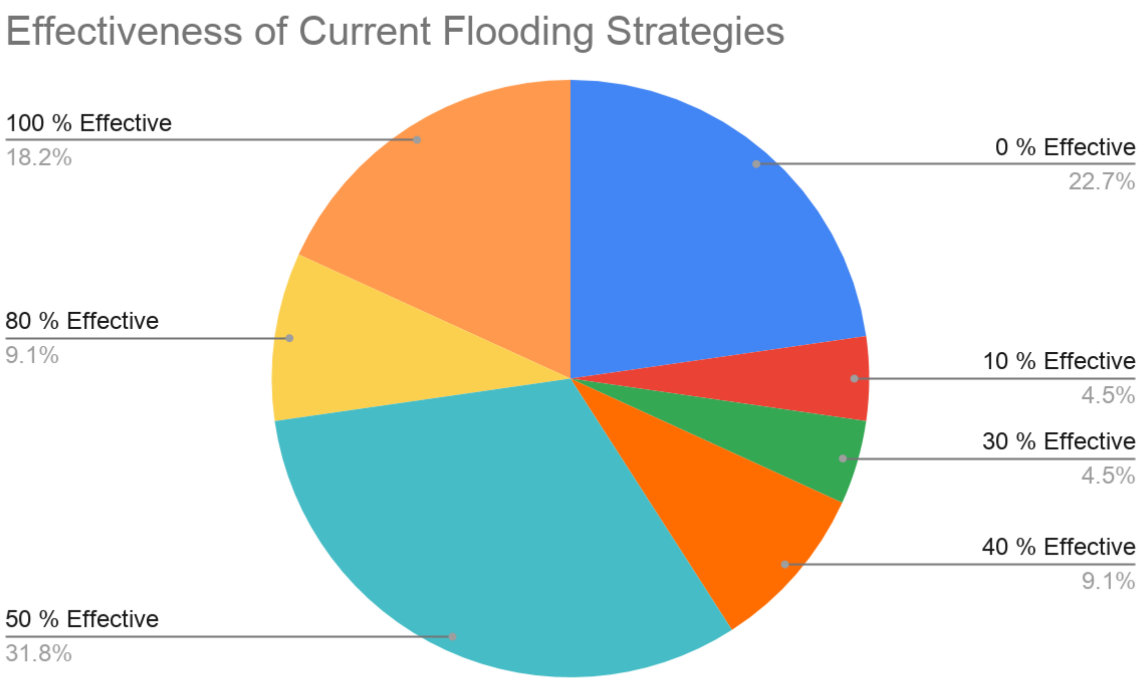


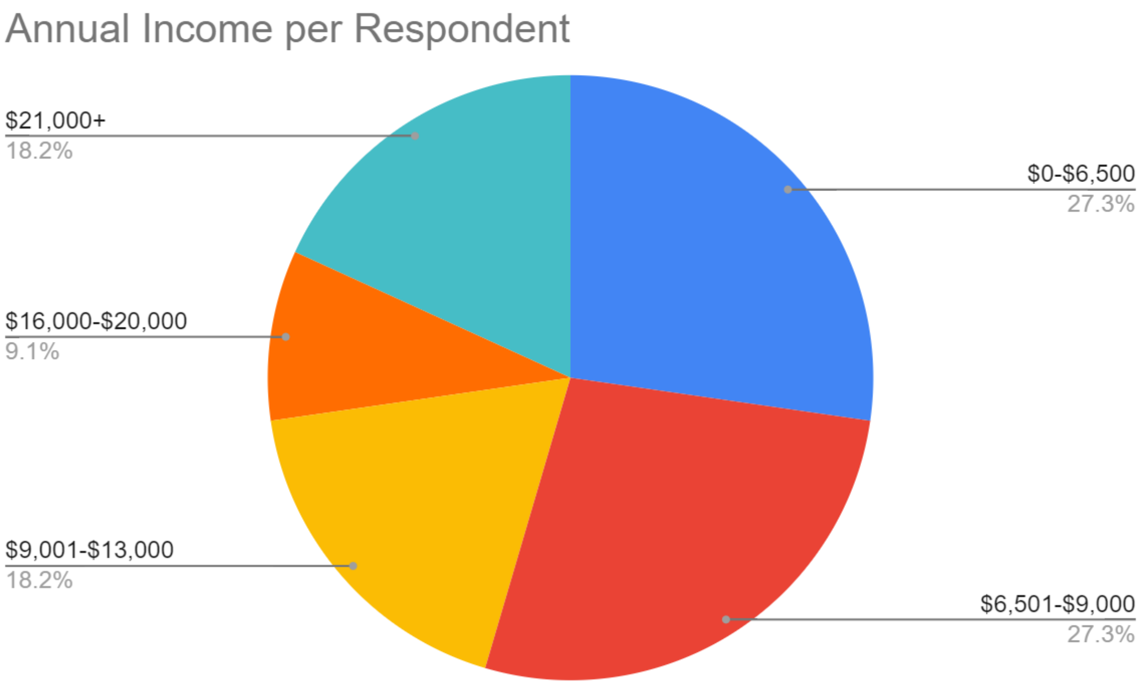


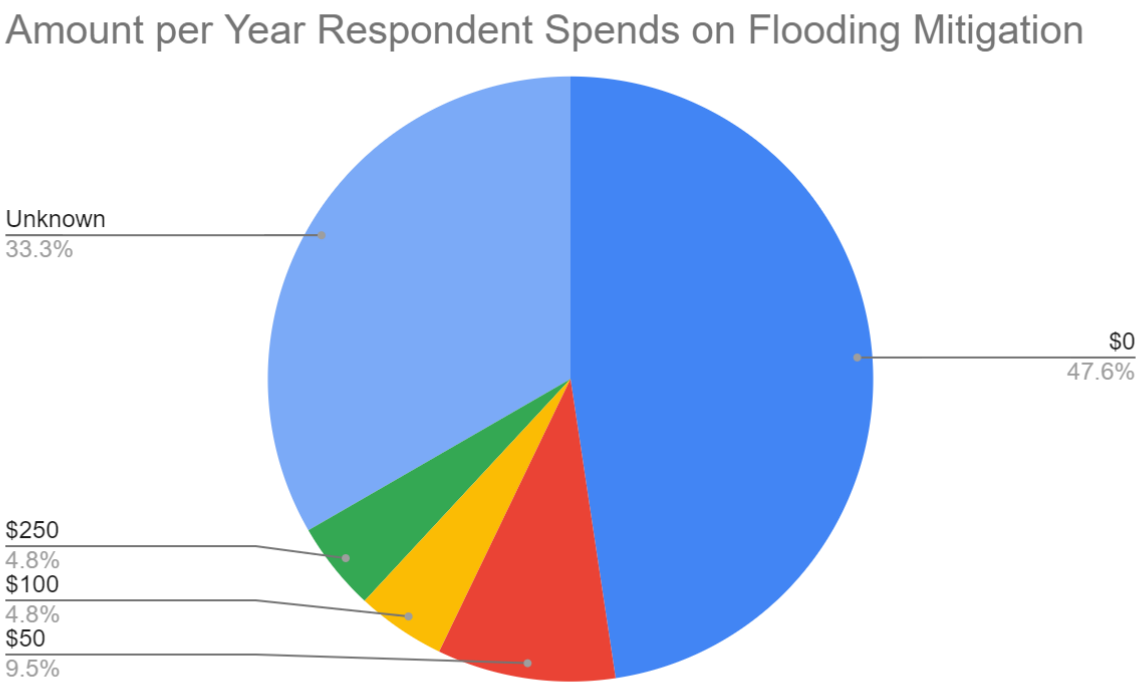

Worst Flooding Problem
Transportation
9.1%
Home Flooding
4.5%
Damage to Belongings
9.1%
Flooding of Surrounding
27.3%
Stagnant Water
50.0%

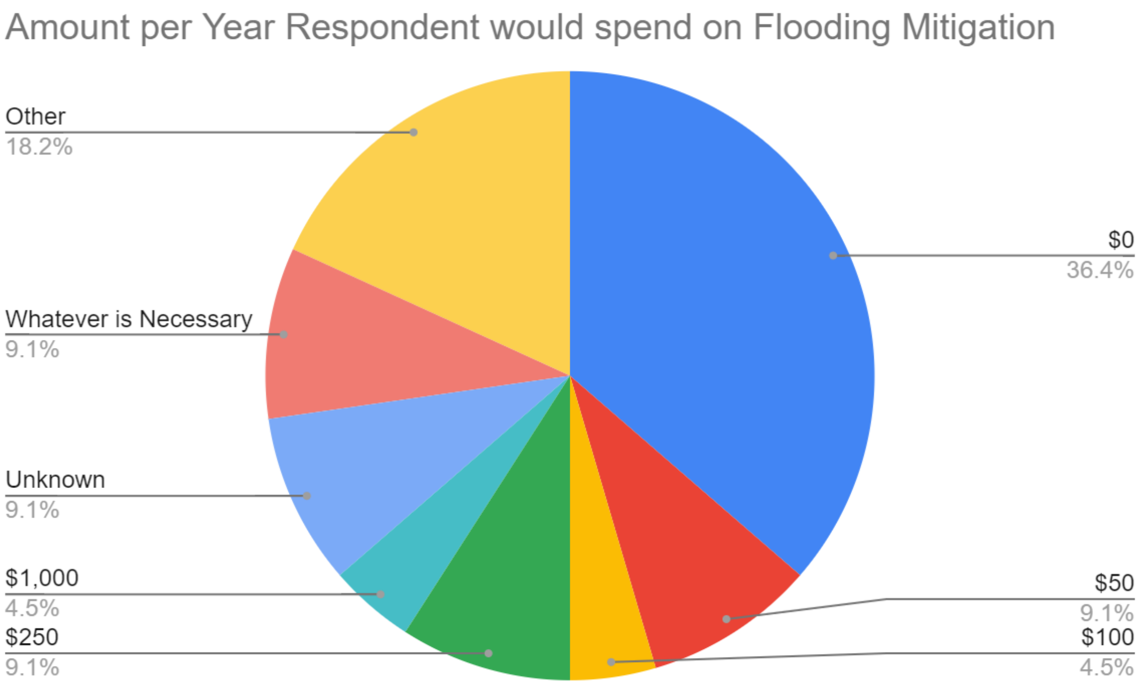

How Residents Surveyed Prefer to Receive Information
12
10
8
6
4
2
0
Community
Newspaper
Television
Internet (Government Sites...)
Radio
Facebook, Instagram or Snapchat
Municipality
Other Agencies
None of the above


Flood Mitigation Strategy Employed, Number of Respondents
10
8
6
4
2
0
Elevate House
Water Barrier
Waterproof Materials
Elevate Bed and Belongings
Other


Effectiveness of Current Flooding Strategies
100 % Effective
18.2%
0 % Effective
22.7%
80 % Effective
9.1%
10 % Effective
4.5%
30 % Effective
4.5%
40 % Effective
9.1%
50 % Effective
31.8%


Annual Income per Respondent
$21,000+
18.2%
$0-$6,500
27.3%
$16,000-$20,000
9.1%
$9,001-$13,000
18.2%
$6,501-$9,000
27.3%


Amount per Year Respondent Spends on Flooding Mitigation
Unknown
33.3%
$0
47.6%
$250
4.8%
$100
4.8%
$50
9.5%


Amount per Year Respondent would spend on Flooding Mitigation
Other
18.2%
$0
36.4%
Whatever is Necessary
9.1%
Unknown
9.1%
$1,000
4.5%
$250
9.1%
$50
9.1%
$100
4.5%