From theory to practice: building more resilient communities in flood-prone areas

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This article is based on Tania López-Marrero's PhD work while at the Department of Geography, Pennsylvania State University. This study

ABSTRACT Enhancing community resilience is key to reducing vulnerability in the face of natural hazards. In this article, we discuss the elements that support or undermine community resilience to floods and propose ways of enhancing it. In the study, participatory methods and techniques were used with community members and emergency managers from a flood-prone municipality of Puerto Rico, including conceptual mapping, participatory mapping, and listing and ranking. The findings suggest that enhancing resilience in these communities requires: support for social learning by building on existing knowledge; stressing the importance of developing a diverse set of flood management options; and promoting effective linkages and collaborations between community members and emergency managers to encourage collective flood management. For this to happen, however, mutual distrust, lack of confidence and other obstacles must be overcome.

KEYWORDS floods / flood management / participatory methods / Puerto Rico / resilience

I. INTRODUCTION

Enhancing community resilience has been identified as a core element of disaster management, risk reduction and efforts to reduce vulnerability.(1) Growing numbers of disasters triggered by natural hazards, associated increases in affected people and economic losses,(2) and failures of top-down, technical approaches to control such hazards have resulted in a rethinking of disaster management strategies.(3) Consequently, increasing emphasis is put on the notion of "living with risk" rather than simply trying to prevent the occurrence of hazards. This alternative approach advocates for resilience – the capacity of a system to absorb hazard disturbances, learn from mistakes in past responses, reorganize after disturbance events, and prepare for possible future shocks and anticipated impacts. The central aim of this approach is to identify ways in which exposed communities can better anticipate, mitigate, prepare for and cope with the occurrence of present and future hazard events. Thus, resilience encourages managing hazards instead of merely controlling them.

In this paper we examine the factors that enhance or undermine community resilience in the face of floods, and provide recommendations for strengthening this resilience within the context of two flood-prone communities in northeastern Puerto Rico. We attempt to answer the following questions:

- How can flood-related knowledge and social learning enhance community resilience to floods?
- How do stakeholders' views of flood management options influence community resilience to floods?
- How can collaborations and partnerships enhance resilience to floods and what favours or undermines the development of such collaborations and partnerships?

To answer these questions, we approach resilience by accounting for two distinct sets of actors, community members and emergency managers, and by examining their understanding of floods and flood management.

II. RESILIENCE WITHIN THE CONTEXT OF NATURAL HAZARDS: A BRIEF OVERVIEW

Originally developed as an ecological concept,[4] resilience is being used increasingly in the field of human–environment interactions,[5] including disaster management and vulnerability reduction of natural hazards.[6] Within the context of natural hazards, resilience emphasizes the multiple ways a system can respond to hazard occurrence, including its ability to absorb hazard impacts, to learn from, adapt to and recover from them, and to reorganize after impacts. In other words, a resilient system is able to absorb hazard impacts without changing its fundamental functions; at the same time, it is able to renew, reorganize and adapt when hazard impacts are significant. Resilience advocates "bouncing forward" to a new state where the system can deal more efficiently with external shocks and stresses, especially those brought about by climate events.[7]

Following the work of Folke et al.[8] on resilience of social-ecological systems, Berkes[9] and Gardner and Denkens[10] list different elements that support community resilience in the face of hazards. These elements are interrelated and include:

- Learning to live in hazardous, changing and uncertain environments, which reflects the process of adaptation. Adaptation refers to the actions a system undertakes to better cope with, adjust to or manage hazards.[11] It is attained through social memory, the lessons that have been learned from past disasters, from accumulated experience and hazard knowledge, and from reorganization after prior disturbance events, which could include outside assistance.
- Using all types of knowledge for learning and adapting, which reflects the process of social learning and which is key to enhancing adaptive capacity – thus, resilience.[12] Social learning is defined as learning to enhance common knowledge, awareness and skills by engaging multiple participants, sharing diverse perspectives and thinking and acting together.[13] Identifying existing knowledge (e.g. what to adapt to, hazard characteristics and tested strategies and management options) of different stakeholders and bringing this knowledge together allows for the identification of gaps in information; it also allows for a common understanding of processes that promote social learning. Social learning involves refining

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1. See, for example, International Strategy for Disaster Reduction (2005), "Building the resilience of nations and communities to disasters", accessible at http://www.unisdr.org/eng/hfa/hfa.htm; also International Federation of Red Cross and Red Crescent Societies (2004), *World Disaster Report 2004: Focus on Community Resilience*, International Federation of Red Cross, Geneva, 231 pages.

2. Emergency Disaster Data Base (2006), "Natural disaster trends: 1900–2005", accessible at http://www.em-dat.net/disasters/trends.htm.

3. Dixit, A (2003), "Floods and vulnerability: need to rethink flood management", *Natural Hazards* Vol 28, pages 155–179; also Haque, C E, D Dominey-Howes, N Karanci, G Papadopoulos and A Yalciner (2006), "The need for an integrative scientific and societal approach to natural hazards", *Natural Hazards* Vol 39, pages 155–157; Mansilla, E (2006), "Katrina, Stan y Wilma: tres desastres en busca de un paradigma", *Nueva Sociedad* Vol 201, pages 11–19; and Wisner, B, P Blaikie, T Cannon and I Davis (2004), *At Risk: Natural Hazards, People's Vulnerability and Disasters*, (second edition), Routledge, London, 496 pages.

existing knowledge and generating new knowledge, which can then be used to guide planning for future actions toward hazard mitigation and preparedness.(14)

- Nurturing diversity and flexibility, which includes diversifying components such as knowledge, practices, management options, institutions, stakeholders and world views, and being flexible in the use of strategies that allow for adapting, preparing, mitigating and recovering from hazards.(15) Diversity and flexibility of management options, for example, increases the opportunities to cope with natural hazards. Management strategies that rely on only a few options can erode resilience by constraining the mechanisms for creative adaptive responses.(16) Diversity also maintains, supports and encourages social learning and adaptation through the inclusion of different stakeholders, knowledge and experiences. Moreover, it provides the starting point for new options and opportunities needed in the renewal and reorganizing phases of resilience.(17)
- Creating opportunities for (self-) organization, which emphasizes the building and enhancing of networks (both horizontal and vertical), partnerships and collaborations. Knowledge sharing, diverse experiences, skills and resources as well as common goals are all crucial elements that allow systems to reorganize, particularly after hazard impacts. These various factors can be translated into strategies and projects aimed at making systems better prepared to face future natural hazards and speed up the recovery after their occurrence.(18) Here, social capital (including bonds of trust, reciprocal relationships and collective actions) is a key source of resilience upon which partnerships and collaboration depend.(19) Networks, partnerships and collaborations of stakeholders and institutions operating at different levels also promote social learning, foster diversity and create opportunities for recovery, renewal and reorganization. (Self) organization can occur within the system or can be promoted by external components. It implies flexible decision-making and management in times of crisis.

III. STUDYING RESILIENCE IN FLOOD-PRONE COMMUNITIES IN PUERTO RICO

a. Flood management in Puerto Rico

Puerto Rico, the smallest of the Greater Antilles, is the second most highly densely populated island in the Caribbean, with 428 persons per square kilometre in 2004. It is an unincorporated territory of the USA, with commonwealth status. Due to its geographical position and geological situation, the island is exposed to different natural hazards, including tropical storms, floods, landslides and earthquakes. Of these, floods are the most frequent natural hazard in Puerto Rico and have resulted in the greatest loss of life and economic damage.(20) Located on the border of the tropical North Atlantic Ocean and the Caribbean Sea, the island is typically exposed to the effects of hurricanes and other tropical systems from June to November. Many of the most severe and damaging floods have resulted from hurricanes and tropical storms that passed over or near the island. Other smaller-scale meteorological systems such as

4. Referred to as "social-ecological resilience".

5. Adger, W N (2000), "Social and ecological resilience: are they related?", *Progress in Human Geography* Vol 24, No 3, pages 347–364; also Folke, C (2006), "Resilience: the emergence of a perspective for social-ecological systems analyses", *Global Environmental Change* Vol 16, pages 253–267; and Folke, C, S Carpenter, T Elmqvist, L Gunderson, C S Holling and B Walker (2002), "Resilience and sustainable development: building adaptive capacity in a world of transformations", *Ambio* Vol 31, No 5, pages 437–440.

6. See for example, Berkes, F (2007), "Understanding uncertainty and reducing vulnerability: lessons from resilience thinking", *Natural Hazards* Vol 41, pages 283–295; also Buckle P, G Mars and R S Smale (2000), "New approaches to assessing vulnerability and resilience", *Australian Journal of Emergency Management* Vol 1, Winter, pages 8–14; Gardner, J S and J Denkens (2007), "Mountain hazards and the resilience of social-ecological systems: lessons learned in India and Canada", *Natural Hazards* Vol 41, pages 317–336; Manyena, S B (2006), "The concept of resilience revisited", *Disasters* Vol 30, No 4, pages 433–450; Klein, R J T, R J Nicholls and F Thomalla (2003), "Resilience to natural hazards: how useful is this concept?", *Environmental Hazards* Vol 5, pages 35–45; Paton, D, J Johnston and L Smith (2001), "Responding to hazard effects: promoting resilience and adjustment options", *Australian Journal of Emergency Management* Vol 1, Autumn, pages 47–52; and Tobin, G A (1999), "Sustainability and community resilience: the holy grail of hazards planning?", *Environmental Hazards* Vol 1, pages 13–25.

7. See Dodman, D, J Ayers and S Huq (2009), "Building resilience", in The Worldwatch Institute (editor), *State of the World 2009: Into a Warming World*, W W Norton & Company, New York, pages 151–172. These authors suggest the

cold fronts can also bring intense rains to Puerto Rico at any time of the year. When combined with the island's abrupt topography and dense hydrological network, these meteorological systems can generate floods, of which four types occur in Puerto Rico: riverine, urban, flash and coastal. Floods caused by the overflow of riverbanks are common. Rapid urban land cover change and the consequent loss of soil capacity to absorb rainfall, combined with poor maintenance of urban drainage, contribute to increased runoff and associated urban floods, which are also frequent.

Historically, flood management has concentrated on engineering controls and on response and recovery following floods. Being a commonwealth of the United States, Puerto Rican flood management has been highly influenced by federal management and legislation, relying heavily on hydro modifications as the principal structural measure for flood control. These engineering projects – which included river channel modifications, canals, dykes, levees and flood walls – were complemented by warning systems and response plans aimed at protecting life and property before and after floods. Moreover, they were responsible for a reduction in the number of deaths resulting from major floods affecting the island during the twentieth century. At the same time, flood control has allowed and even promoted intensive occupation of flood-prone areas for industrial, commercial and residential development and tourism. This intensive use of floodplains, combined with high population density and increased personal wealth and material acquisition, resulted in significant economic damage from floods despite the technical control projects that had taken place.

The land settlement pattern in Puerto Rico has tended to perpetuate recurrent flood damage in the long term. As a result, the country has produced 14 Presidential Disaster Declarations in the last 25 years, or roughly one disaster declaration every two years – among the highest frequencies in any United States jurisdiction.(21) The situation suggested a clear need to change the traditional disaster response to one focused on disaster preparedness and prevention. Consequently, to reduce the "damage–recovery–damage" cycle, the government of Puerto Rico, in conjunction with the United States government, started to concentrate on developing mitigation strategies as one of the central elements for long-term risk reduction.(22)

Puerto Rico has used mitigation strategies, including non-structural measures, since the 1970s, supported by policies such as the National Flood Insurance Programme, which the country joined in 1978. More recently, however, the government has placed greater emphasis on non-technical mitigation strategies by explicitly defining and elaborating this approach in the most recent island-wide mitigation plan, namely Puerto Rico's Natural Hazards Mitigation Plan.(23) This plan still includes technical measures of flood control as part of the main approach, but it also features non-technical and proactive flood management measures such as the development and redevelopment of policies, floodplain regulations (including land use planning), information dissemination and public awareness, and flood forecasts and warnings. The plan incorporates communities in the process of strategy planning and impact reduction. Most importantly, concepts that concern building community resilience to floods in this plan are considered essential elements of effective hazard mitigation strategies.

notion of "bouncing forward" when talking about increasing social resilience of vulnerable populations, as opposed to the "bouncing back" perspective in early interpretations of resilience.

8. See reference 5, Folke et al. (2002); also see Folke, C, J Colding and F Berkes (2003), "Building resilience and adaptive capacity in social-ecological systems", in F Berkes, J Colding and C Folke (editors), *Navigating Social-ecological Systems*, Cambridge University Press, Cambridge, pages 441–473.

9. See reference 6, Berkes (2007).

10. See reference 6, Gardner and Denkens (2007).

11. Smit, B and J Wandel (2006), "Adaptation, adaptive capacity and vulnerability", *Global Environmental Change* Vol 16, pages 282–292.

12. See reference 5, Adger (2000).

13. Tschakert, P (2007), "Views from the vulnerable: understanding climatic and other stressors in the Sahel", *Global Environmental Change* Vol 17, No 3–4, pages 381–396, after Schusler, T M, D J Decker and M J Pfeffe (2003), "Social learning for collaborative natural resource management", *Society and Natural Resources* Vol 15, pages 309–326.

14. Allen, K M (2006), "Community-based disaster preparedness and climate adaptation: local capacity-building in the Philippines", *Disasters* Vol 30, pages 81–101; also Tompkins, E L (2005), "Planning for climate change in small islands: insights from national hurricane preparedness in the Cayman Islands", *Global Environmental Change* Vol 15, pages 139–149.

15. Adger, W N, T P Hughes, S Folke, S R Carpenter and J Rockström (2005), "Social-ecological resilience to coastal disasters", *Science* Vol 309, pages 1036–1039; also see reference 6, Buckle et al. (2000).

16. See reference 5, Folke et al. (2002).

17. See reference 15, Adger et al. (2005); also see reference 6, Buckle et al. (2000).

18. See, for example, reference 14, Allen (2006); also Berke, P R, J Kartez and D Wenger (1993), "Recovery after disaster: achieving sustainable development, mitigation and equity", *Disasters* Vol 17, No 2, pages 93–109; and see reference 6, Buckle et al. (2000).

19. See reference 15, Adger et al. (2005); also see reference 6, Tobin (1999).

20. See López-Marrero, T and N Villanueva-Colón (2006), *Atlas Ambiental de Puerto Rico*, University of Puerto Rico Press, San Juan, 160 pages; also see reference 2.

21. Personal communication with Professor Félix Aponte, Graduate School of Planning, University of Puerto Rico.

22. Summarized in the president's Long-term Recovery Action Plan for Puerto Rico (1999), accessible at http://www.fema.gov/news/newsrelease.fema?id=10211.

b. Study area

The urban communities of Mansión del Sapo and Maternillo, located in the northeastern municipality of Fajardo, Puerto Rico, formed the study area for the investigation (Figure 1). Both communities are located in the alluvial deposits of the Fajardo River valley, at an average elevation of three metres above sea level, and are home to 230 and 380 people, respectively.(24) They are both flanked by the river, although only Maternillo is located adjacent to the coastal waterfront.

The area has an average temperature of 26.4ºC and a mean annual precipitation of 1,575 millimetres. The rainy season runs from June to November and is associated with the Atlantic hurricane season. Because of its geographic location, topography and the influence of trade winds, it is not unusual for the area to experience heavy rainfall episodes outside of the rainy season. All these factors contribute to the tendency for the area to flood, which includes rainfall and river inundations, but also floods resulting from storm surges. Approximately two to three "minor" rainfall-driven flood events take place in the communities every year.(25) Other than the ground becoming waterlogged, which usually lasts for about an hour and then the water drains away, these events have no major consequences.

The communities have also been subject to severe floods, usually associated with tropical storms or intense and prolonged rainfall periods.

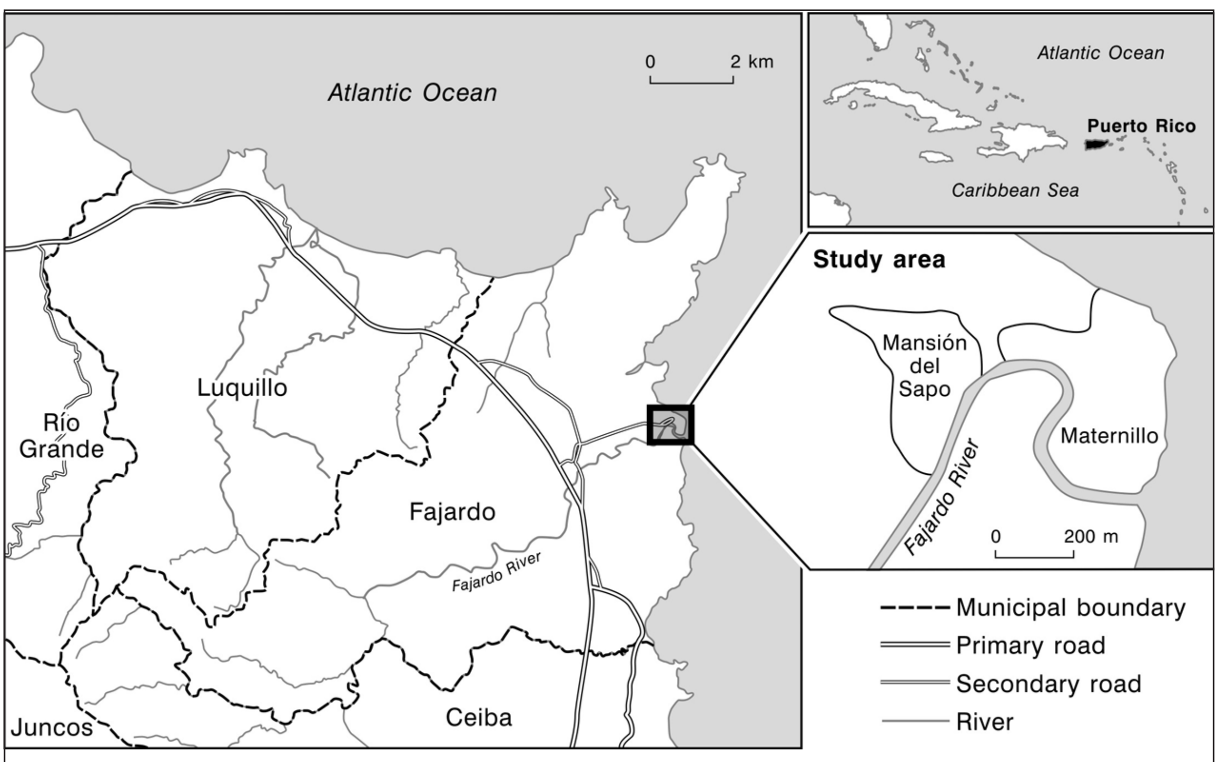

FIGURE 1
Location of the study area

SOURCE: Adapted from a map drawn by Tania López-Marrero.

Two of the major flood events in the last 20 years were associated with Hurricane Hugo in 1989, which brought about 200 millimetres of precipitation to the area,[26] and with an intense rainfall event that occurred outside of the rainy season, on 6 January 1992. The combination of river flow and storm surge resulting from Hurricane Hugo is remembered by community members as the most intense and damaging flood-related event. Both communities were flooded for about 10 hours and most structures were affected by floodwaters rising to almost 1.5 metres inside some houses. The 1992 flood was the result of river inundation brought on by approximately 280 millimetres of intense rainfall. The flood occurred at night and caught many residents by surprise. Only about one-third of the houses in Maternillo were flooded, but most houses in Mansión del Sapo were affected. In some areas, the water rose by about one metre and the inundation lasted for about five hours. The most recent major flood occurred on 17 April 2003, as a result of river encroachment due to intense rainfall (approximately 305 millimetres). Compared to the floods of 1989 and 1992, this flood lasted only two to three hours, the water did not rise as high, and floodwaters only affected the lower-lying houses.

The two communities are primarily fishing communities, although many residents work in the manufacturing and service sectors, including jobs as carpenters, mechanics and factory employees.[27] The Puerto Rican government formally classifies Mansión del Sapo and Maternillo as "special communities", a designation used to target low-income communities for development assistance. Special communities are determined by several factors, including high levels of economic poverty and unemployment, the existence of single-headed households, high rates of illiteracy and school desertion, and deficiency in services provision, among other. The large majority of residents do not have land tenure and many of the houses are in sub-standard condition.[28] All these characteristics heighten people's vulnerability in these two communities.

c. Methods

Focus groups and individual household interviews were the main forms of data collection. Community members and emergency managers took part in the study. Community members participated in the different research activities both as individual households (a total of 36 households, 18 from each community)[29] and as community groups (two groups: one consisting of 13 people (five females and eight males) from Maternillo; and the other of 16 people (seven females and nine males) from Mansión del Sapo). Emergency managers participated as groups and included participants from the Municipal Office of Emergency Managers (one female and eight males), the Municipal Committee of Emergency Managers (seven females and three males) and the Interagency Committee of Emergency Management for the Fajardo Region (four females and five males). The Municipal Office of Emergency Managers is composed of full-time government employees who coordinate the operation of any emergency that occurs at the municipal level (including floods), while the municipal and regional committees are composed of agency directors from different government agencies who support operations and provide services during the different phases of emergency management.

23. Autoridad Estatal para el Manejo de Emergencias y Desastres (2004), *Plan Estatal para la Mitigación de Peligros Naturales en Puerto Rico*, URS Caribe, San Juan, Puerto Rico, 273 pages.

24. Oficina de Comunidades Especiales (2006), "Resumen del perfil socioeconómico de las comunidades de Mansión del Sapo y Maternillo en Fajardo", accesible at http://www.comunidadesespeciales.gobierno.pr/pages/reg_fajardo.html.

25. Interview with Miguel Dávila, Maternillo's community leader.

26. Scatena, F N and M C Larsen (1991), "Physical aspects of Hurricane Hugo in Puerto Rico", *Biotropica* Vol 23, No 4, pages 317–323.

27. González-Vélez, P A (2003), "El grito del silencio: historia oral de las comunidades Maternillo y Mansión del Sapo", Fundación Puertorriqueña de las Humanidades y Universidad Interamericana de Puerto Rico, Fajardo, Puerto Rico, 123 pages; also, López-Marrero, T and B Yarnal (2010), "Putting adaptive capacity into the context of people's lives: a case study of two flood-prone communities in Puerto Rico", *Natural Hazards* Vol 52, pages 277–297.

28. Fuller-Marvell, F (2002), "Inventario de comunidades urbanas espontáneas de Puerto Rico", Taller de Planificación Social, Oficina para el Funcionamiento Socioeconómico y de la Auto-gestión, San Juan, Puerto Rico, 44 pages.

29. The selection of community members is described in detail in López-Marrero, T (2008), "Adaptive capacity and resilience to floods in the Caribbean: a case study from flood-prone communities in Puerto Rico", PhD thesis, Pennsylvania State University, USA, 145 pages.

The study consisted of, and was built upon, participatory research methods and techniques. These included participatory concept mapping of the causes of floods, sketch mapping of flood exposure zones, and listing and ranking of strategies to minimize the negative effects of floods. Data collection took place between June and December 2006. At the community level, participatory conceptual mapping was carried out in each of the 36 households visited. The results from this component of the research were then aggregated to represent the community. The other methods – participatory sketch mapping, and participatory listing and ranking – were conducted as additional components of the community focus groups. At the emergency management level, all three activities (participatory conceptual mapping, sketch mapping, and listing and ranking) were carried out with the participating managers. Overall, five focus groups were conducted in the study, one with each of the two communities and three with emergency managers.

i. Participatory concept mapping of the causes of floods

Concept maps are used to gain an understanding of people's knowledge about a topic by graphically representing and relating elements (concepts) regarding the topic.(30) Concept maps have also been used to identify gaps in knowledge and information needs in various contexts, including climate-related subjects.(31)

The concept mapping exercise in this study started by asking participants to brainstorm all the possible causes of floods they could think of (including both natural and human-induced causes) and to write each cause (concept) on a separate card. Since some household members were illiterate, they were encouraged to represent the concepts graphically. Participants were then asked to arrange the cards on a large sheet of paper in the way they thought the various concepts related to the causes of floods, with floods being the central concept.(32) After arranging the cards, participants drew arrows to indicate the kind and direction of relationship they believed exists between the various concepts. Figure 2 is an example of a completed concept map.

After conducting and compiling all of the concept maps for each household and each emergency managers group, a composite concept map was generated. This composite map allowed comparisons between groups as it represented and differentiated the aggregate knowledge of community members and emergency managers groups.

ii. Participatory sketch mapping of flood exposure zones

Participatory sketch mapping was conducted to assess and compare participants' understanding of the spatial distribution of floods within the communities; specifically, the distribution of different exposure zones and water flow. Participatory sketch mapping is particularly useful in eliciting local experiences, knowledge and perceptions within a spatial context.(33) In participatory sketch mapping, the map-making process is not concerned with geographic and cartographic precision but with counting, estimating, ranking, comparing and discussing spatial phenomena.

30. Maxwell, D, M Armar-Klemesu, L Brakohiapa and J Annorbah-Sarpeil (1997), "Participatory concept mapping to understand perceptions of urban malnutrition", *PLA Notes* Vol 30, pages 11–15.

31. See, for example, Tschakert, P and R Sagoe (2009), "Mental models: understanding the causes and consequences of climate change", *PLA Notes* Vol 60, pages 154–159; also see reference 13, Tschakert (2007).

32. Concept maps were also used to elicit participants' understandings of the positive and negative effects of floods. This component of the study is explained in López-Marrero (2008), see reference 29.

33. See, for example, Kumar, S (2002), *Methods for Community Participation: A Complete Guide for Practitioners*, Intermediate Technology Publications, London, 333 pages; also Mascarenhas, J and P D P Kumar (1991), "Participatory mapping and modelling users' notes", *RRA Notes* Vol 12, pages 9–20.

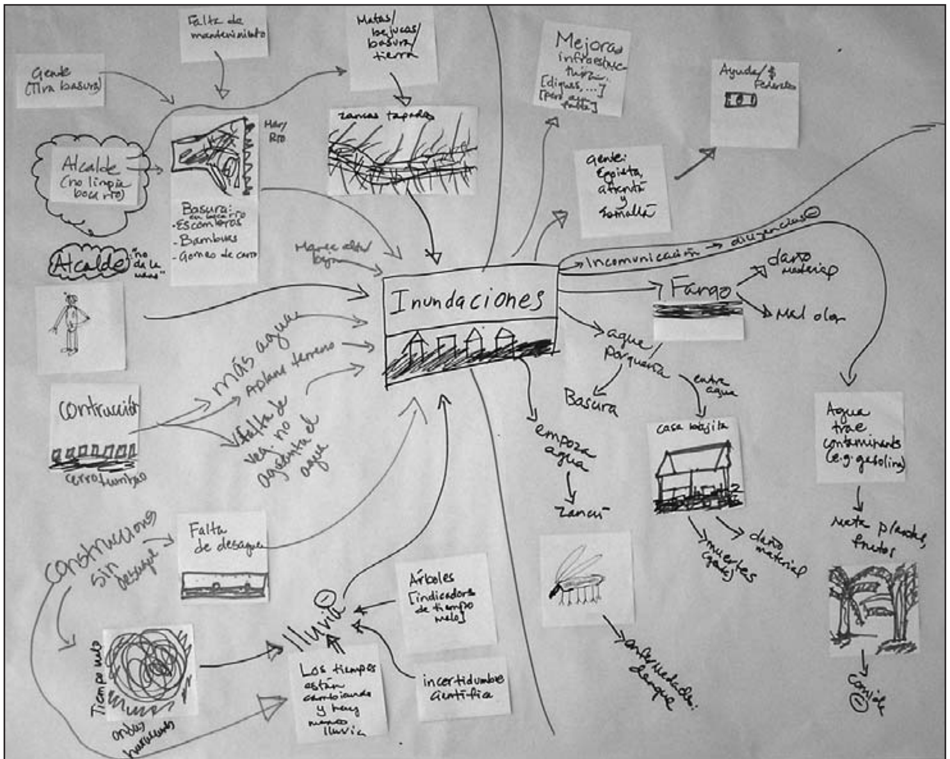

FIGURE 2
Example of a community-level concept map on floods (*inundaciones*) created by a household in Maternillo. The concept map shows causes of floods on the left-hand side, positive impacts in the top right-hand quadrant and negative impacts in the bottom right-hand quadrant.*

NOTE: *See, for example, Tschakert, P and R Sagoe (2009), "Mental models: understanding the causes and consequences of climate change", *PLA Notes* Vol 60, pages 154–159; also Tschakert, P (2007), "Views from the vulnerable: understanding climatic and other stressors in the Sahel", *Global Environmental Change* Vol 17, No 3–4, pages 381–396.

The mapping for this study was based on a large-scale print of a high-resolution satellite image of the two communities. Transparent paper was overlaid onto the original image so that participants could draw and erase the elements they identified until all of them agreed on the final map. In each group, participants were asked to identify, draw and define areas of high, medium and low exposure to floods within each community. They were also asked to draw arrows identifying the flow of water during flood events. Several participants took turns drawing different elements of the map, while others helped with locating and identifying important areas or features (Photo 1). The process of map making, as well as the maps themselves, provided insights into the reasons why participants identified the areas they did and what the implications of the floods were for each community. Each community produced a map just for their locale, whereas the emergency managers produced a map for both communities.[34] All maps were digitized to a Geographic Information System format for representation and comparison.[35]

34. The mapping activity was omitted in one emergency manager focus group because of time constraints.

35. The maps were digitized to a Geographic Information System format to facilitate their representation and reproduction in this article (see Figure 4); they are not meant to be geographically precise.

PHOTO 1
Women from Mansión del Sapo during the participatory mapping activity

© Tania López-Marrero (2006)

iii. Participatory listing and ranking of strategies to minimize flood impacts

The final technique consisted of a participatory listing and ranking of possible strategies to minimize the negative effects of floods. This activity was conducted with each of the focus groups. First, participants brainstormed all possible strategies and wrote them onto a large piece of paper. Then, participants discussed and ranked all the strategies in terms of their efficiency and feasibility. They first ranked the strategies by how efficient they perceived them to be in reducing floods and impacts, regardless of feasibility. They then ranked the strategies in terms of perceived feasibility of implementation (while efficiency was left constant). Participants then discussed the rationale underlying each ranking.

Participatory pair-wise matrices were used with each of the three groups of emergency managers because they had identified a whole array of strategies and a simple consensus would not have been possible. Pair-wise matrices are a means of prioritizing or ranking group lists.[36] For each group, two pair-wise matrices were constructed, one for ranking efficiency strategies and the other for feasibility. In each case, and after the group had listed all strategies, a matrix was prepared on a large sheet of paper with all strategies listed both on the top (columns) and on the left-hand side (rows). The group began filling in the matrix by comparing the first strategy on the left-hand side of the matrix with all other strategies listed across the top. Participants discussed each pair of strategies and decided which was the more important in terms of the characteristic being ranked. This process was repeated until participants had covered all combinations of strategies. Every time a strategy was judged as more important than its alternative, the strategy received a score. The ranking for each strategy was then determined based on its total score. If two strategies received the same count, participants were asked to prioritize between the two.

36. See reference 33, Kumar (2002); also Russell, T (1997), "Pair-wise ranking made easy", *PLA Notes* Vol 28, pages 25–26.

IV. UNDERSTANDING AND MANAGING FLOOD HAZARDS

a. Understanding of the causes of floods

The conceptual mapping revealed that community members and emergency managers have considerable knowledge of the causes of floods; many of the factors cited agree with those cited in the literature.[37] Moreover, there was general agreement between community members and emergency managers regarding the main causes of floods. Participants considered the causes of floods to be driven by both natural and human factors (Figure 3). For them, the main natural agent of floods was rainfall, either causing direct rain inundation or river overflow. Other natural agents of floods included tropical storms and hurricanes, causing rain and riverine and coastal floods. Landforms and river channel morphology were also mentioned as influencing flood occurrence and magnitude. Specifically, participants identified abrupt topography, river form and narrow channels as causing river inundation in the communities.

While acknowledging the natural causes of floods, participants emphasized the importance of human causes of floods. As Figure 3 shows, concepts associated with human actions (or lack thereof) were mentioned several times. Non-existent or poorly maintained drainage systems were the most cited human-induced cause of floods. When discussing poor drainage, each group of participants tended to avoid directly assigning responsibility for the conditions. Discussions also revealed a lack of consensus about who should take the lead on, and responsibility for, maintaining suitable drainage.[38]

In addition to clogged drainage channels, participants showed awareness of the role of deforestation, increased urbanization and landscape modification in aggravating floods. Participants pointed out that these human activities exacerbated the effects of other causes of floods such as rain and tropical storms. Emergency managers went a step further and put forward possible effects of atmospheric (climatic) and human-driven changes that can influence floods. Yet, the specific processes of

37. See, for example, Few, R (2003), "Flooding, vulnerability and coping strategies: local responses to global threat", *Progress in Development Studies* Vol 3, pages 43–58; also Jones, J A A (2000), "The physical causes and characteristics of floods", in D J Parker (editor), *Floods*, Volume II, Routledge, London, pages 93–112; and Parker, D J (2000), "Introduction to floods and flood management", in Parker (editor), as above, pages 3–39.

38. Trash, for instance, was repeatedly mentioned as clogging water drainage. Community members usually identified people from outside the community and from the industrial sector as the ones causing the trash problem; in contrast, emergency managers attributed responsibility to community members as the ones causing the problem. Furthermore, community members blamed the municipal and national government for not cleaning and maintaining the drainage systems, while municipal and regional emergency managers attributed these responsibilities to upper levels of government.

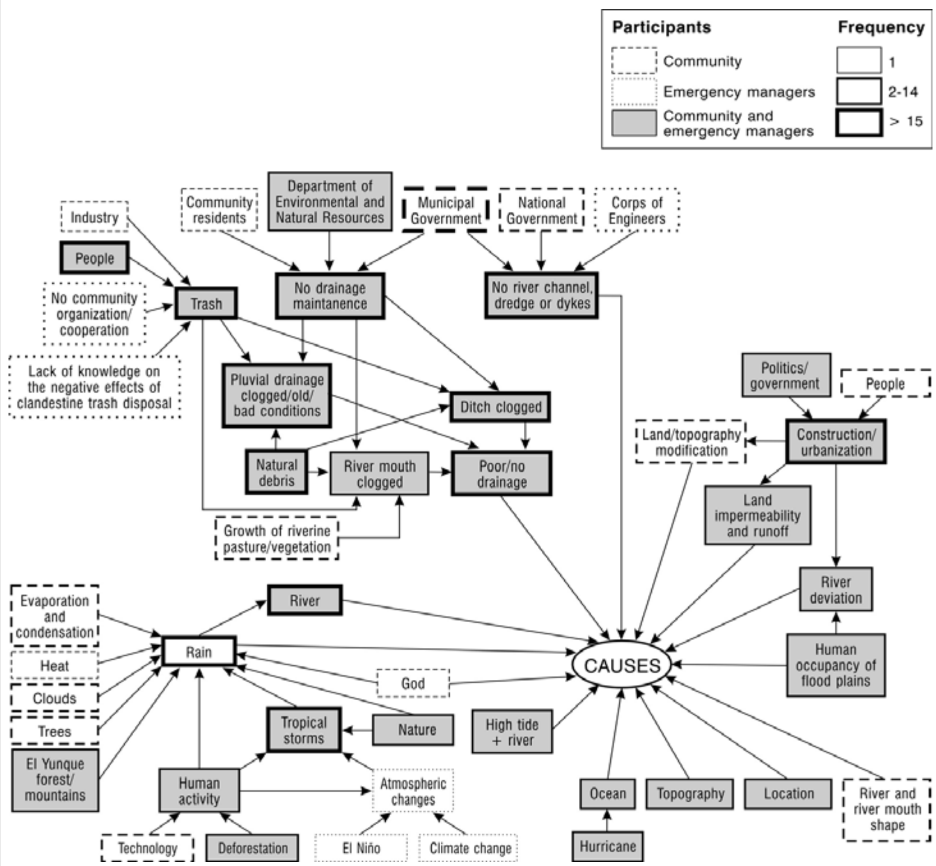

FIGURE 3
Composite map of the causes of floods as understood by community members and emergency managers. The thickness of the line around each concept illustrates the number of times the concepts were mentioned.

how human activity affects rainfall and weather systems were not well articulated or understood, either by community members or emergency managers. Another perceived cause of floods was flood control engineering. Some community members were concerned that “nature was being modified” and that future interventions could lead to increased damage. However, other participants attributed community flooding to the lack of engineering interventions to effectively channel or divert river flow.

b. Spatial distribution of flood exposure zones

The results of the participatory sketch mapping are shown in Figure 4, constructed by community members (4a) and two groups of municipal emergency managers (4b) and (4c). An examination of the maps illustrates some similarities in the patterns of water flow and flood zones described by each group of participants. There was a tendency for all groups to recognize that areas nearer the river and at low elevations have “high exposure”. In fact, participants consistently cited these two factors as two determinants of the exposure zones. All groups also agreed that proximity to sources of water flow, along with differences in slope that direct water drainage are additional factors influencing zones of high exposure.

More interesting, however, were the differences in the spatial distribution of flood exposure zones and how these differences can influence flood management. The most notable disagreement concerned exposure zones in the community of Mansión del Sapo. In this case, local residents stressed proximity to the drainage channels as an important factor for high exposure in their community (Figure 4a). Yet, neither group of emergency managers made this observation, at least not directly. Water flow was another example of discrepancy between residents of Mansión del Sapo and emergency managers. Residents pointed out that there were three sources of floodwater: the river, drainage channels and runoff from nearby urban areas. While one group of municipal emergency managers did recognize urban runoff (Figure 4b), neither of the manager groups acknowledged the drainage channels as an important source of floodwater; they only identified river overflow (Figure 4c). Such discrepancies are likely to negatively affect flood management and strategies, as an overemphasis on managing river inundation may overlook management of other flood types.

None of the groups paid particular attention to floods as a result of ocean intrusion. Despite acknowledging storm surges as one of the causes of floods in the conceptual mapping, no group identified a source of floodwater as coming from the ocean nor did they consider the coast when delineating areas of exposure. This result was unexpected because the communities have certainly experienced floods as a result of storm surge. When storm surge entered the discussion, community members from Mansión del Sapo acknowledged this type of flooding for Maternillo but not for themselves. All other groups eventually acknowledged sea intrusion as a potential source of high exposure but perceived it as being a clearly less important and distant threat than river and rainfall inundation. After the discussion, Maternillo's community members did include an area of high exposure associated with sea intrusion but limited this area to a small zone along the coast (Figure 4a).

c. Flood management and impacts on mitigation

The results from the participatory listing and ranking revealed that strategies aimed at minimizing flood occurrence, magnitude and impacts within the communities included technical and non-technical ones (Table 1). In many cases, the proposed strategies related to several of the factors that participants perceived as being the causes of floods in the concept mapping and participatory sketch mapping exercises.

Both community groups viewed their own options to manage floods as limited, arguing that solutions were out of their hands. The few strategies proposed by community members involved some kind of engineering intervention that required large amounts of financial resources and government coordination. Community members cited constructing a dyke to divert river flow during intense precipitation events as the most efficient flood management strategy; they also acknowledged it as the most feasible because the initial phases of the project had already begun. However, since the dyke project had not been finished, residents were somewhat sceptical about the likelihood of completion in the near future; moreover, they showed concern about maintenance issues.

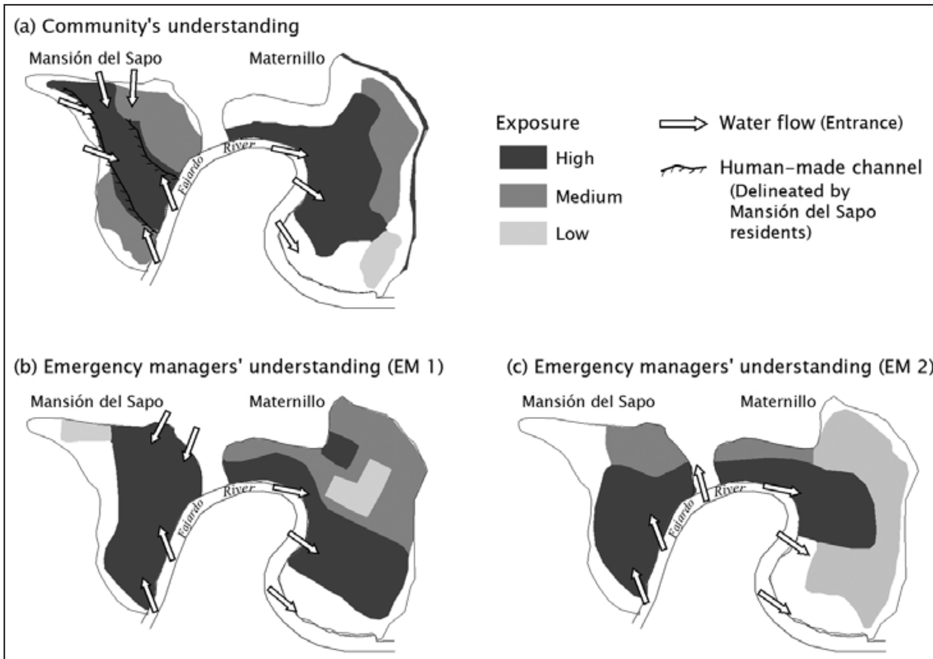

FIGURE 4
Participants' spatial delineation of the different flood exposure zones and water flow within the communities of Mansión del Sapo and Maternillo. EM 1 and EM 2 are municipal emergency managers.*

NOTE: *See for example, Kumar, S (2002), *Methods for Community Participation: A Complete Guide for Practitioners*, Intermediate Technology Publications, London, 333 pages; also Mascarenhas, J and P D P Kumar (1991), "Participatory mapping and modelling: users' notes", *RRA Notes* Vol 12, pages 9–20

As they are directly affected by drainage channels, Mansión del Sapo residents emphasized the importance of lining these channels with concrete and ensuring constant maintenance. In fact, this was for them the second most efficient long-term solution. Although maintaining the drainage channels was recognized as least expensive in the short term, this strategy was found to be problematic because of the negative experience they had had with government agencies being responsible for cleaning and maintaining the channels. Moreover, this lack of trust and confidence extended to members of their own community. Participants explained that the community used to clean and maintain the drainage channels, but eventually this task remained in the hands of a few.

Maternillo's residents proposed flood proofing houses – essentially elevating them – as an efficient strategy for flood management. Since elevating houses has been shown to reduce damage in the past, this strategy was noted as effective. Feasibility was considered high because in fact only a few houses needed to be elevated. However, this strategy was seen as an individual responsibility and, given the limited financial resources of most households, further implementation is likely to be limited.

Municipal and regional emergency managers proposed more strategies for regulating and controlling floods in the two communities (Table 1). Similar to the understanding of community members, they

TABLE 1
Potential strategies to minimize flood impacts as proposed by community members and emergency managers (EM). An efficiency and feasibility rank is given for each strategy and strategies are classified as structural (S), non-structural (NS) and structural/non structural (S/NS). EM 1 and EM 2 are municipal emergency managers, while EM 3 is regional.

Strategy	Mansión del Sapo		Maternillo		EM 1		EM 2		EM 3	
	Efficiency	Feasibility	Efficiency	Feasibility	Efficiency	Feasibility	Efficiency	Feasibility	Efficiency	Feasibility
Dyke construction (S)	1	2	1	1	2	5	2	4	-	-
Dyke construction (concrete) (S)	2	1	-	-	-	-	-	-	-	-
River channel (S)	-	-	3	3	3	4	1	3	1	6
Flood proofing (S)	-	-	2	2	-	-	-	-	-	-
New drainage (S)	-	-	-	-	-	-	3	2	7	5
Drainage maintenance (S/NS)	3	3	-	-	4	1	-	-	6	4
Displacement (NS)	-	-	-	-	1	6	5	5	2	7
Land privatization (NS)	-	-	-	-	-	-	-	-	3	8
Community committees (NS)	-	-	-	-	5	3	-	-	4	2
Community orientation (NS)	-	-	-	-	6	2	4	1	5	1
Local preparedness (NS)	-	-	-	-	-	-	-	-	8	3

ranked engineering interventions such as dykes, river channels and drainage constructions as the most efficient strategies. They considered these to be definite and long-term solutions, hence their high efficiency rankings. Nonetheless, these technical solutions were not suggested without recognizing inherent problems. High costs of construction and lack of financial resources were seen as potential barriers to implementation, which explains their lower feasibility scores. Emergency managers also emphasized non-technical strategies for flood damage mitigation; in some cases, they argued that these strategies were more efficient than engineering ones. For instance, one group of emergency managers stated that acquiring and privatizing land at risk and thereby purposefully displacing members from the communities would be the most effective action against flood damages. They preferred this strategy over technical ones, basing their argument on the failure of existing flood control projects, as exemplified in the dyke breakdown in New Orleans.(39) However, the feasibility of displacing the population was perceived as being low. In the past, residents had expressed their unwillingness to leave the communities, or simply did not have anywhere else to go.(40)

39. Colten, C E (2006), "Conspiracy of the levees: the latest battle of New Orleans", *World Watch* Vol 19, No 5, pages 8–12.

40. In the mid-1980s, for instance, the government gave land located upstream to residents who were living very near the river and who had inadequate housing conditions, so that they could move to a safer place. However, many of these residents returned later because they did not like living in a new community or because they needed to be in their original community in order to pursue their livelihoods (particularly the fishermen).

Overall, all groups of emergency managers ranked non-technical strategies for flood management as being more feasible than technical ones, although not necessarily as more efficient. Community orientation and awareness, the development of local preparedness plans and the creation of community committees to implement local strategies were among the strategies proposed for promoting self-action in flood management. The managers saw these types of strategies as more feasible because they required fewer financial resources and could be promoted with resources and skills that exist locally. Despite acknowledging the value and potential of non-technical strategies, emergency managers insisted that such strategies could be less efficient since they required cooperation, collaboration, commitment and continuous interaction among community members and between community members and emergency managers, while many community members were unwilling to get involved. Nonetheless, the managers showed interest in the possibility of collaborating with local communities to increase their participation in flood management.

Another strategy favoured by emergency managers was the maintenance of existing community drainage systems and the creation of new ones. Compared to major technical interventions, such as dyke and river channel construction, maintaining and creating new small-scale drainage systems in communities is clearly less expensive. In addition, the local government has the personnel and skills necessary for this type of strategy. It was stated, however, that local agencies and personnel had to deal with many competing pressures and that, often, they were under-resourced both in personnel and available funding. Moreover, local emergency managers noted that they were usually excluded from decision-making in flood management. This result indicates that some facets of emergency management occur beyond the local level and that existing institutional frameworks can constrain local resilience.

V. DISCUSSION

Resilience emphasizes enhancing human capacity to improve the anticipation of, preparation for and mitigation of natural hazards. Floods have always been part of Mansión del Sapo and Maternillo's environment, and their residents have developed local adaptations that have contributed to their resilience.(41) What is needed next is to identify ways of enhancing this resilience. The findings of this study suggest that increasing resilience to floods in these communities requires:

- promoting social learning by building on existing knowledge about floods, which refers to combining different types of knowledge, with explicit recognition of local knowledge;
- stressing the importance of developing a diverse set of flood management options that overtly acknowledges the complementary nature of technical and non-technical strategies. This finding echoes the need to nurture diversity and provide space for flexible management options; and
- promoting effective linkages and partnerships between community members and emergency managers to encourage collaborative flood management. This last finding puts particular emphasis on social networks that allow for rapid reorganization after a flood-related crisis, and creative preparation for future flood occurrence.

The results from the conceptual mapping reveal a considerable and convergent knowledge about floods among community members and emergency managers. This common knowledge provides an opportunity to start a social learning process about flood management in the area. Existing knowledge about floods should facilitate the development of appropriate strategies to deal with flood hazards. Social learning is enriched by using the complementary knowledge that each group of participants brings to the table. Similarly, in the ranking and scoring of strategies to minimize negative flood impacts, emergency managers identified a variety of flood management strategies such as the development of community committees and local preparedness plans. Emergency managers have the skills to develop preparedness plans and they expressed a willingness to work with the communities to provide training so that community members could develop their own. While self-sufficiency and self-organization are key to resilience, actions must not rely on just one group.(42) Instead, it is important to promote joint projects that involve both community members and emergency managers.

Although participants demonstrated knowledge about floods, their comprehension needs to be refined; misunderstandings need to be reduced and information gaps need to be filled. This point is especially true with respect to the potential relationships between human activity and flood occurrence, particularly in the context of climate change. Climate change is expected to bring drier conditions to the Caribbean region, including Puerto Rico.(43) However, some climate models predict that global climate change might lead to a warming of the Atlantic Ocean, which could increase the intensity of tropical cyclones and thereby could result in significant increases in peak precipitation.(44) Assuming such a scenario, the intensity and frequency of extreme precipitation events could increase the current intensity of all flood types. Thus, the potential impacts on hydrological processes causing floods need to be stressed so that strategy development incorporates such possibilities. For instance, while floods caused by storm surges were mentioned, this type of flood received less attention among participants. Because of the coastal position

41. López-Marrero, T (2010), "An integrative approach to study and promote natural hazards adaptive capacity", *The Geographical Journal* Vol 176, No 2, pages 150–163.

42. See reference 14, Allen (2006).

43. Neelin, J D, M Münnich, H Su, J E Meyerson and C E Holloway (2006), "Tropical drying trends in global warming models and observations", *PNAS* Vol 103, No 16, pages 6110–6115.

44. Bengtsson, L, M Botzet and M Esch (1997), "Numerical simulation of intense tropical storms", in H F Diaz and R S Pulwarty (editors), *Hurricanes: Climate and Socioeconomic*

of the communities, developing strategies to deal with this type of flood is crucial. It is thus fundamental to increase people's understanding of the potential relationship between climate change and the frequency and magnitude of tropical storms, and between sea-level rise and increased storm surge. In this respect, it is necessary to provide more detailed information about different types of flood and their potential occurrence under human activity and climate change, yet in a way that is accessible by non-technical audiences.

Resilience to natural hazards is greater if there are diverse ways in which communities can prepare for and deal with hazard occurrence.[45] Dependency on a single strategy to respond to natural hazards has negative consequences for resilience because this dependency constrains adaptive capacity. The ranking and scoring of flood prevention strategies revealed a preference for technical strategies in these communities. This over-reliance on engineering solutions is not surprising given the many years of government policies that have focused on technical strategies for flood control. Although it is true that technical measures can provide resilience by decreasing exposure, they may erode resilience in the long term. This is particularly the case when management focuses primarily on rigid technical controls that remove mechanisms that support the creative and adaptive responses needed in systems that are characterized by complexity, surprises and unpredictability.[46]

Participants proposed primarily dyke construction to control riverine floods as the preferred strategy to deal with floods; but floods in this area have multiple sources, as rightly identified by participants in the concept map and participatory mapping activities. Consequently, a mere focus on technical measures and riverine floods undermines resilience to floods. Technical measures alone also undermine self-organization – one crucial component of resilience – because these measures often involve external resources and require little or no community involvement. What is needed in these communities is a clear emphasis on the complementary benefits of both technical and non-technical approaches as well as the promotion of non-technical measures, even with the existing dyke along the Fajardo River. Awareness of the limitations of technical measures, in this case of the dyke, must be increased. The large majority of participants perceived the dyke as a "once and for all solution". Awareness needs to be raised that dyke failure can occur and that, in the case of a high-magnitude flood event, the results of dyke failure are likely to be catastrophic.

The previous points emphasize the importance of diversity by continuing current strategies and planning new ones. The fact that the emergency managers acknowledged non-technical measures is a positive step towards resilience enhancement. Up to now, none of the non-technical flood management strategies cited by emergency managers (i.e. the creation of community committees and the creation of local preparedness plans) have been put into practice in these two communities. It appears vital to promote the implementation of these strategies so that the process of "learning-by-doing", which is part of social learning, is initiated.

The benefits of creating linkages and collaborations between community members and emergency managers are unambiguous. These linkages provide for sharing of diverse knowledge and skills, and for thinking and acting together to develop potential flood management strategies. In Mansión del Sapo and Maternillo, vertical and horizontal social networks have provided resource flows and assistance in the

Impacts, Springer Verlag, New York, pages 67–90; also Knutson, T R and R E Tuleya (2004), "Impact of CO_2-induced warming on simulated hurricane intensity and precipitation: sensitivity to the choice of climate model and convective parameterization", *Journal of Climate* Vol 17, No 8, pages 3477–3495; and US Global Change Research Programme (2000), "Climate change impacts on the United States: the potential consequences of climate variability and change. Overview: islands in the Caribbean and the Pacific", accessible at http://www.usgcrp.gov/usgcrp/Library/nationalassessment/overviewislands.htm.

45. See, for example, reference 14, Tompkins (2005); also Thompson, M and I Gaviria (2004), "Weathering the storm: lessons in risk reduction from Cuba", Oxfam America Research Paper accessible at http://www.oxfamamerica.org/newsandpublications/publications/research_reports/art7111.html.

46. See reference 15, Adger et al. (2005).

aftermath of floods.[47] But resilience goes beyond recovery: it advocates anticipation and preparedness in the face of natural hazards. For this reason, linkages and collaborations between community members and emergency managers need to be more effectively developed. Unfortunately, several barriers impeding the development of partnerships and collaborations for local flood management emerged from the research. These include avoidance of responsibility, mutual distrust, lack of confidence, distrust in government institutions, disenchantment and conflicting opinions about options to reduce flood damage. On the one hand, community members expressed their frustration with their neighbours' unwillingness to take responsibility for flood impact reduction. Frustration was also voiced towards government agencies. Years of promises without concrete actions have resulted in a high degree of distrust vis-à-vis government agencies in general and municipal emergency management agencies in particular. On the other hand, emergency managers expressed scepticism about community members wanting to participate and collaborate in strategies that require long-term involvement and commitment. Moreover, tension between community members and emergency managers is likely to occur, particularly when extreme and conflicting proposed measures such as land privatization and residents' displacement accentuate existing distrust and undermine emerging partnerships. Ultimately, social learning and designing strategies for enhancing flood resilience requires developing effective linkages and partnerships. Undoubtedly, this takes time and a continuous commitment to negotiate priorities and, collectively, overcome existing obstacles.

47. See reference 41.

VI. CONCLUSIONS

This article characterized elements that support community resilience in the face of floods and explored ways to enhance it by focusing on participants' knowledge about floods, on their views of flood management options, and on potential collaborations and partnerships between community members and emergency managers. In order to enhance community resilience to floods, the research findings suggest the need to:

- build upon existing knowledge about floods, particularly in relation to the multiple types of floods and to the potential influences of human activity on floods;
- increase awareness of the potential risks associated with technical measures in the area and emphasize the importance of developing and implementing non-technical strategies for flood management to complement technical ones; and
- develop partnerships and collaborations for flood management. This last point requires overcoming barriers that at present undermine the effective building of such partnerships and collaborations.

Developing a pilot project that brings together community members and emergency managers could be a way of initiating partnerships and promoting social learning. This research provides the basis for conducting workshops where discussions about flood management can take place between the two stakeholder groups. Community committees and co-management are among the potential strategies for developing collaborative flood management. For instance, community committees could:

- monitor the local conditions that cause floods and exacerbate their negative impacts (e.g. drainage channel maintenance, trash disposal);
- coordinate actions to be taken;
- monitor dyke conditions and co-maintenance; and
- develop community preparedness and evacuation plans, all in collaboration with skilled personnel.

These local actions have proven to be effective in diminishing the loss of life and property elsewhere in the Caribbean.[48] If the goal is to promote sustainable community development, including the long-term reduction of floods, as stated in the latest Puerto Rican government hazard mitigation plan, these actions provide a useful starting point.

48. See, for example, reference 45, Thompson and Gaviria (2004).

In theory, the concept of resilience implies the potential to enhance the anticipation of, preparation for, and mitigation of natural hazards. In practice, however, the challenges are often numerous. Thus, there is an urgent need for more case studies at the local level that address multi-faceted drivers and distill key characteristics of resilience to hazards. Such case studies are likely to provide vital lessons from which all parties involved, including researchers, can learn about ways to support and enhance community resilience. Filling this gap will nurture research in applied resilience. More importantly, it will engage diverse stakeholders in a social learning process that, ultimately, can facilitate adaptive capacity as an essential element in an adaptation policy process. Consequently, increasing resilience requires approaching and understanding resilience as a process; one that can facilitate transformations in the long-term management of the risks posed by natural hazards.

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