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Tropical Storm Impact on Infrastructure: A Case Study of Noel in the Dominican Republic

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ABSTRACT

A commission consisting of faculty from the University of Puerto Rico at Mayagüez and Universidad Autónoma de Santo Domingo visited the Dominican Republic to evaluate the disaster caused by the Tropical Storm Noel, that took place from October 26th to 31st 2007. Students also participated to have practical experience as part of their learning. This was the most intense tropical depression with extreme winds and torrential rainfall that hit Dominican Republic in 2007. This paper presents the findings and lessons learned from the consequences of the storm on three main aspects: the hydrology and hydraulic behavior of the system, the effect on the transportation infrastructure, and the impact on civil infrastructure. In addition, it mentions the disaster implications on the affected population in the visited areas.

The amount of rainfall exceeded the expected amounts for engineering designs. A significant number of deaths, economic, and material losses were registered. The rivers raise overflowed the banks, culverts, bridges, and drainage structures. The flooding caused several bridges to collapse and damaged rural highways and drainage systems, causing many communities to be disconnected and isolated from the rest of the country and limiting access to emergency support.

1. INTRODUCTION

A scientific team of faculties and students from the University of Puerto Rico at Mayagüez and Universidad Autónoma de Santo Domingo visited several of the affected areas in Dominican Republic, in an effort to assess the damage caused to different structures after the Tropical Storm Noel. The Storm occurred from October 26th to 31st, 2007. It was the 16th tropical depression of the season and the most intense that hit Dominican Republic in 2007 with extreme winds and torrential rainfall reaching over 21 inches during the period as estimated by NASA's Earth Observatory (NASA, 2007).

The Dominican Republic is a developing country, that had a National Gross Product of 31.8 Billion US dollars by 2006(MSN Encarta, 2008), with a beautiful environment and a growing economy due to agriculture and tourism. But still to date many aspects of the country's infrastructure are far from being suitable for the modern society, even though the conditions in some places are far better than in most developing and under developed countries. The current condition of the Island's infrastructure, coupled to non-effective political decisions, emergency response, and the occurrence of devastating rainfalls that brought along Noel, seem to be have contributed to the disaster.

2. OBJECTIVES

The severe impacts that Noel had on some communities in the Dominican Republic created interest in both national and international organizations. The extent of the disaster, and the concern for the implications of such, led to the formation of this commission. The main objectives of the commission's field reconnaissance are to:

- document lessons learned from the hazardous impact caused by tropical storm Noel by visiting some of the most affected areas.
- address possible causes for the magnitude of Noel's impacts on the Dominican Republic.

3. SUMMARY OF MAJOR IMPACTS

Noel's impact on the Dominican Republic was more severe that anyone anticipated. They ranged from the most severe to modern society, which is the loss of human lives, to damages on various infrastructure systems. Six months after Noel hit Dominican Republic, there was neither a complete nor an accurate account on all the damage caused by the storm, but some of the reports prepared by national and private institutions in the Republic throw light on the magnitude of the damage. Table 1 (COE, 2007) shows that over 60,000 refugees were accounted for, either because their houses were completely destroyed or because their communities were isolated.

Table 1: Evacuated Population (COE, 2007)

Total Refuges on Official Shelters	Total Refuges on Family & Friends Houses	Total Refuges	Reported Missing	Reported Deaths
22,758	41,338	**64,096**	**43**	**73**

The figures provided by the Emergencies Operations Center of Dominican Republic (COE, 2007) show that on the 1st of November (shown on Table 2), just one day after the storm had passed, over 16,000 structures were affected; 73 dead and 43 missing people were reported. This number eventually rose up to over 100 dead and 200 identified as missing; 62 communities were isolated; more than 143.85 square kilometers flooded; and over 32 highways and bridges were damaged.

Table 2: Summary of Infrastructure Damage

Isolated Communities	Bridges and Highways	Residential Structures
62	32	16,024

The most significant impact, besides human losses, was the damage to the highway systems, particularly the collapse of several bridges across the country which caused the loss of a significant number of lives. National and international emergency organizations made an outstanding effort to reach all affected zones as soon as possible. Figure 1 (CRC Team, 2007) shows the emergency response provided by these institutions on several places all over the country.

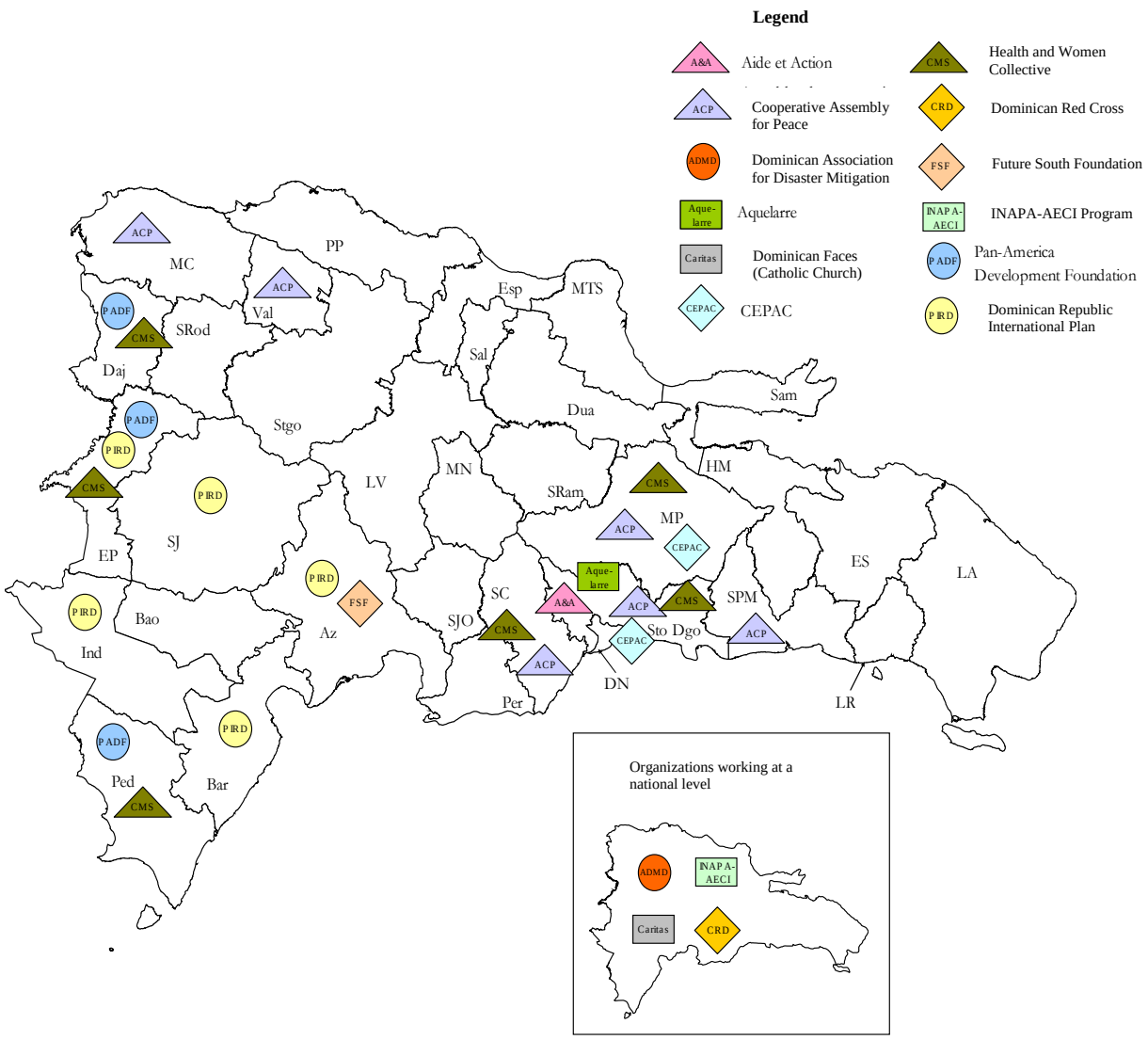

Figure 1. Emergency Response on the Affected Zones (CRC Team, 2007)

Figure 1 shows in a map some accounted affected areas and part of the emergency response provided in the aftermath of the storm. Various communities did not receive help for days. It only shows the help provided untill November 02, 2007. The most affected areas of the country were the low altitude such as the Southwest with provinces like Pedernales and Independencia; to the South with Azua, San Cristóbal, and the National District; to the Central Region with Monseñor Nouel and Sánchez Ramírez; and to the East with Villa Altagracia, amongst others.

Outstanding joint efforts from part of the local leaders who organized their communities in order to respond and cope with the extreme challenges caused by the tragedy were observed. The extraordinary willingness and determination of local organizations to enforce their plans for responding and recuperating, in places where no immediate help arrived, it is commendable

4. AREAS VISITED

4.1 COMMUNITY OF LOS CACAOS

Los Cacaos is a community located in a depression at the mountainous province of Monseñor Nouel in the central region of Dominican Republic. This province is marked as MN in the central part of the map in Figure 1. This community was severely affected; especially there was a considerable damage to its infrastructure. The National Emergency Commission of Monseñor Nouel informed that by October 30, 2007 there were nine (9) bridges affected by the storm (Valenzuela, 2007) and three (3) highways were washed away by rainfall and landslides (CRC Team, 2007). Twenty nine (29) communities were flooded by rivers in this province; among them Los Cacaos, Las Palmas, and the lower part of Maimon (Valenzuela, 2007), the latest being one of the most populated areas of Monseñor Nouel.

Los Cacaos suffered in several important aspects from this tropical storm. First, landslides occurred alongside most of the rural highway that connects the community with the rest of the province; secondly, the obstruction of the closest bridge to the village (both situations caused this town to be isolated from the help provided by the emergency response centers); scouring of the river banks downstream from town; thirdly, the destruction of the drinking water distribution system; fourthly. the destruction of the local school "Liceo Nocturno Mariano Garabito" shown on Figure 2 (one of the best constructed structures in town for its apparent structural integrity), located in the left bank downstream of the main obstructed bridge; and lastly, imminent state of emergency due to the unstable slopes threatening the community to be impacted by landslides and debris flow from nearby mountain. The area was isolated from their neighbors for several days because various sections of the access road were severely damaged or destroyed.

Figure 2: River Impact on the Mariano Garabito School

The emergency response to this community was provided by means of helicopters. Medical personnel and food were part of the limited help received on time (Peguero, 2007). Therefore, the community did not have the opportunity to completely recover promptly from the disaster, staying behind without the support to properly recover. As of March 10, 2008, this community was still suffering the aftermath of the storm complaining that the accountable authorities had forgotten their commitment to help (Listin Diario, 2008).

It was extremely significant and relevant to this commission to note the extraordinary leadership and team work that developed among the community leaders and various national and international organizations that created and put into action contingency plans and strategies to overcome the risks and uncertainties of the disaster. Several organizations were represented and three (3) headquarters were developed at the local Civil Defense Office.

4.2 BRIDGE IN SECTOR MADRE VIEJA, SAN CRISTÓBAL

The Madre Vieja Bridge is located in the province of San Cristóbal, south of Monseñor Nouel. This was one of many bridges that suffered severe damages due to the effects of flood forces in the area. What makes this case special is the extent of damage suffered. The force of the river caused so much erosion and scouring that two spans of the bridge completely collapsed (see Figure 3).

The bridge failure was triggered by erosion and scouring of the left abutment, which was flushed away. The extent of the scouring around and below the left abutment looking downstream with the water current helped the abutment to overturn in the direction of the largest scouring depression. A similar mechanism most probably occurred with the bridge piers supporting the two spans that collapsed. Over 30 feet of embankment was eroded far behind of the bridge abutment. It was observed that highly populated communities along the river banks were under the flood levels. It is of extreme concern that a whole community was living under adverse conditions under the bridge on the floodway. It was obvious the social and infrastructure weaknesses of the community. This community was completely flooded during the tropical storm, lost all their scarce belongings and had very difficult moments during the disaster and its aftermath. The social, economic, and sanitary conditions in which Noel left them where deplorable.

Figure 3: Damages to Madre Vieja Bridge.

4.3 RECONNAISSANCE OF OTHER DAMAGED BRIDGES

The commission also evaluated other damaged bridges in other sites. These were:

- **Bridge Los Jovillos in Azua over the Los Jovillos River (Figure 4):** Azua is located in the Southern part of the Dominican Republic and is known for being an arid province with a great extent of low level land forming a large flood plain. The water level rose above the bridge structure and the embankment of one of the approach structures was washed away. The structure of the bridge showed apparent lack of capacity due to either insufficient hydraulic conveyance or by debris obstruction during the flood. The evidence of the size of sediment's load transported, from fine to coarse (including cobbles), was impressive. This impressive size was probably due to two things: first the magnitudes of flood discharge; and secondly the high velocities capable of transporting stones of 2' to 3' in diameter.

Figure 4: Los Jovillos Bridge

- **Bridge San José de Ocoa**: This situation was similar to Los Jovillos Bridge in Azua. The evidence showed overtopping, huge sediment loads obstructing the bridge openings, and tremendous levels of erosion and scouring. The left approach embankment between the bridge and the road was flushed away for a distance of over 100 meters. This bridge was under the process of restoration by reconstructing a similar embankment and removing the sediments deposited upstream, downstream, and under the bridge. The bridge structure proved to be structurally resistant to the event. In the rehabilitation an upgrade of the bridge hydraulic capacity by clearing the bridge opening from sediments was observed.

Figure 5: Reconstruction of San José de Ocoa Bridge

- **Bridge over Paya River on Sanchez Highway (Figure 6**): This road connects Santo Domingo with Baní (at Province of Peravia, between Azua and San Cristóbal) in the South Region of the Dominican Republic. The most relevant finding was that the sediment load was so large that mountains of gravel and cobbles were deposited upstream, under, and downstream of the bridge impeding the water to flow freely and causing overtopping. The structure integrity of the bridge was conserved but some surface damages were observed to the bridge platform.

Figure 6: Paya River Bridge

4.4 COMMUNITIES OF ANGELITO, JENGIBRE, AND LIMON

Three other communities suffered from severe landslides. These communities remained under high risk for their unstable slopes in accidental topographic reliefs. Torrential rainfall triggered previous and new landslides in the area. This commission expressed concern for the improvised solutions previously implemented which failed during Noel. Lack of proper engineering evaluation, planning, design, and construction provided for potential future risk for repeating the situation.

It was evident that the structures did not have the required structural integrity to withstand stresses during the storm event. In addition, the drainage system demonstrated to be deficient causing disaster and destruction of houses, and loss of accessibility to these communities.

4.5 HAINA AND DUEY RIVERS

The Haina and Duey Rivers are among the most known rivers of Dominican Republic, because they flow through many important areas, and it is the only main access to the harbor area of the capital. The city itself grew alongside Haina River and over the years small communities gather on its banks. This situation increased the risk of the area to natural disasters. The upstream reaches of the river showed overnight significant geomorphologic change. The river thalweg depth and width at least duplicated in many places. The potable water intake that serves a significant faction of the population in Santo Domingo was severely damaged.

The most relevant impacts observed during the field reconnaissance are:

- Significant geomorphologic river modifications, including the channel diversion and relocation, huge embankment erosion and deposition, and change of the river local reach slopes and cross section.
- Flushing of a housing community alongside the river (Las Cuevas, see Figure 7), which accounted for over 150 deaths (most probably over 200 because of inaccurate population census in the area).
- Severe damages to the water supply dam, intake, pumping house, and water transportation system (foot & water main) to the potable water treatment plant.

Figure 7: Remains of Las Cuevas Community

Figure 8: Water Supply Intake Damages

5. CAUSES OF THE MAGNITUDE OF THE IMPACTS

There are many possible causes to explain the magnitude of damages that the storm Noel had on the Dominican Republic. It was not an individual factor that made this disaster so devastating, but rather it was the net result of many factors. Some of the most important were the state of risk of the infrastructure of the country, the lack of social conscience in the development and expansion of urban communities, and the lack of a warning systema to alert people with anticipation to be prepare to face the storm. Most of the people pointed out that the late notice they received did not give them enough time to react.

Many social aspects contributed to the allocation of low income communities in hazardous places. No matter how many times it happened they always come back to same spots where, in cases, only day's earlier communities were washed away by a disaster. As long as people keep developing their homes and communities in areas that are designated as flood zones (e.g. the flanks of rivers) they will be under imminent danger during storms like Noel.

The last factor to be taken into consideration (the infrastructure) is one of extreme complexity. The damage observed indicates that several components of the infrastructure were not able to withstand the effects of the storm. Drainage systems all over the country lack capacity for the usual rains, let alone the unusual storms like Noel.

The other aspect of infrastructure is the Transportation system in Dominican Republic. There is a documented history of storms and hurricanes destroying many roads and bridges along the country. Noel stressed the importance of having a resilient transportation system, therefore it should be a priority of the country to improve the design, construction and maintenance of roads and bridges to prevent future damage caused by hurricanes and storms like Noel.

6. LESSONS

Each case study and each of the sites visited presented different situations and lessons to be learned. Here the most salient are summarized:

- Vulnerable state of infrastructure in Dominican Republic.
- Limited resources for the lower income communities.
- The process of dealing with a natural disaster is really fragile with lack of preparation, management and recuperation.
- Some organizations like the Dominican Red Cross in Dominican Republic have very good response to emergency relief and rehabilitation, but limited resources to provide help.
- Many social and economical factors lead people to move into areas that are clearly flood zones of rivers or simply low lying areas.

- There is a need for a better organization when it comes to relocating refuges.
- Materials brought down by streams need to have special attention at the time of recuperation.
- Information of river banks and flood history is needed to improve the ability of emergency authorities to prepare for future extreme events.
- Lack of maintenance leads to decreased structural safety and systems malfunctioning.
- Bridges and highways need better attention and supervision.
- There is a need for the improvement in advance notification system of the emergency and disaster control agencies.

7. CONCLUSIONS AND RECOMMENDATIONS

The passage of an important rainfall event like Noel, gives the country the opportunity to identify important initiatives for future similar events like hurricanes and storms. Some of the steps suggested to reduce the effects of natural disaster in the future:

- To limit and discourage social development on known flood areas.
- To develop an information system, database or maps of susceptible and flood areas to identify risk levels.
- To develop an educational program to prepare the general public so that they have a plan of action to face situations of emergency.
- To create a periodical and continuous supervision program of the infrastructure, especially the transportation systems, since this is the mean to provide help in case of emergency.
- To create regional and local action plans to cope with cases of emergency.
- To revise design parameters for bridges and hydraulic structures, considering extreme events.

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