2,975 Hurricane Maria: The Role of Land Surveyors in Infrastructure Resiliency

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Key words: Hurricane Maria, Puerto Rico, Land Surveyor, Resiliency, Geospatial Data, Precise Measurement, Natural Disaster, Critical Infrastructure

SUMMARY

On September 20, 2017, hurricane Maria hit Puerto Rico with disastrous force, taking thousands of lives, devastating communities, infrastructure and the environment. Time stood still for too long after the catastrophic strength of this natural disaster left our territory. Critical infrastructure was severely damage, threatening thousands of people. Guajataca Dam, one of the principal dams in Puerto Rico that serves many municipalities, suffered damage due to water accumulation and spillway failure. The heavy rainfall of hurricane Maria caused the lake's levels to exceed the flood limit, crossing over state highway PR-119, and, as consequence, having access to the spillway located west of the dam. The combination between the accumulation of water having access to the spillway and the curve that the course of the water should take, caused what is identified in engineering as a "Hydraulic Leap". Topography and As-built Surveys of all Guajataca Dam area was performed, including Geodetic Control Points monitoring and dam instrumentation localization. New Geodetic Control Points were established, and the use of UAVs was implemented to survey dangerous and unreachable areas. All field spatial data was completed during a two weeks window, even though no internet access and no power was available due to the collapse of major infrastructure. Land surveyors provided precise data measurement needed to ensure the success of fast reconstruction and restoration of this infrastructure.

RESUMEN

El 20 de septiembre de 2017, el huracán María impactó a Puerto Rico con una fuerza desastrosa, arrebatando miles de vidas, devastando comunidades, infraestructura y el ambiente. La infraestructura critica fue severamente afectada, arriesgando la vida de miles de personas. La represa Guajataca, una de las principales represas en Puerto Rico, sufrió daños como consecuencia de la acumulación de agua y fallas en el aliviadero. La combinación entre la acumulación de agua que tiene acceso al aliviadero y la curva que debe tomar el curso del agua, causó un "salto hidráulico". Se realizaron topografías y estudios de "as-built" de toda el área de la represa, incluyendo el monitoreo de los puntos de control geodésico y la localización de instrumentación de la presa. Se implementó el uso de vehículos aéreos no tripulados para el levantamiento de datos en zonas peligrosas e inalcanzables. Los Agrimensores proveyeron datos exactos y precisos, medulares para asegurar el éxito de la pronta reconstrucción y restauración de esta infraestructura.

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1. INTRODUCTION

On September 20, 2017, after only two weeks after Hurricane Irma passed just north of the island and left 1 million people without electricity, hurricane Maria hit Puerto Rico with disastrous force, taking thousands of lives, devastating communities, infrastructure and the environment. Maria made landfall in Yabucoa, Puerto Rico as a devastating category 4 hurricane with maximum sustained winds of 155 mph. As the center of the storm moved west-northwestward over southeastern Puerto Rico into the interior and northwestern PR, widespread hurricane force winds spread all over mainland, along with extremely heavy rainfall that produced major to catastrophic flooding and flash flooding, especially across the northern half of Puerto Rico.

An unprecedented loss of 2,975 lives have been estimated in the six months following the hurricane[1] (George Washington University, 2018). The National Oceanic and Atmospheric Administration (NOAA) have estimated Maria's damage in Puerto Rico to be around $90 billion in 2017 U.S. dollars. Along the critical infrastructure that was severely affected by the catastrophic force of wind and water, was the Guajataca Dam between the municipalities of Isabela and Quebradillas. Part of the Guajataca Dam collapsed after the impact of Hurricane María in Puerto Rico.

The professional skills and knowledge of land surveyors where employed in helping communities as they struggled with issues regarding infrastructure resilience during this emergency. This paper presents the important role Land Surveyors had in protecting human life during the disaster.

2. HURRICANE MARIA

Hurricane Maria formed from an African easterly wave that moved across the tropical Atlantic Ocean during the week of September 10th to September 17th, 2017. Maria gradually intensified and became the 8th hurricane of the 2017 Atlantic hurricane season. Within the next 24 to 30 hours and within an 18-hour period, Maria underwent through fast intensification, strengthening from a category 1 to an extremely dangerous category 5 hurricane.

[1] Excess mortality study analyzed past mortality patterns (mortality registration and population census data from 2010 to 2017) in order to predict the expected mortality if Hurricane María had not occurred (predicted mortality) and compare this figure to the actual deaths that occurred (observed mortality). The difference between those two numbers is the estimate of excess mortality due to the hurricane. Milken Institute School of Public Health.

Figure 1. Hurricane Maria, a category 5 hurricane before making landfall in Puerto Rico. (NOAA, 2017)

At 6:15 a.m. on September 20, 2017, Maria made landfall in Yabucoa, Puerto Rico as a devastating category 4 hurricane with maximum sustained winds of 155 mph. Up to 40 inches of rain was reported. After 12 hours of catastrophic force over Puerto Rico, hurricane Maria was gone, and time stood still for too long.

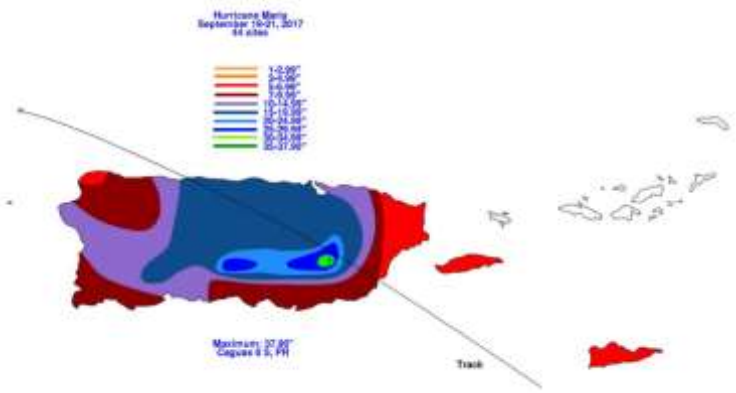

Figure 2. Storm total rainfall (inches) from Hurricane Maria. (David Roth, NOAA, 2017)

Maria is by far the most destructive hurricane to hit Puerto Rico in modern times, as the previous costliest hurricane on record for the island was Georges in 1998, which in 2017 dollars "only" caused about 5 billion dollars of damage (Pasch, R., Penny, A., and Berg, R., 2018).

3. GUAJATACA DAM

Guajataca is an area between the municipalities of Quebradillas, San Sebastián, and Isabela. The Tainos, indigenous people of the Caribbean, named this region "Guajataka" meaning "the water ladle". Rio Guajataca is a river located in this area, which flows from the south and drains into the Atlantic Ocean. Lago Guajataca was constructed in 1929 by the Puerto Rico Electric Power Authority (PREPA). The dam was originally intended for public water and irrigation

water supply. This 120-foot wall dam is one of 38 dams in Puerto Rico and is considered a high hazard potential structure.

Figure 3. Aerial photos courtesy of Puerto Rico Energy and Power Authority (PREPA).

In 1995, about 52 percent of the water was used for public water supply equivalent to 25 million gallons per day (95 million liters per day), supplying potable water to a population of about 179,000 persons among the municipalities of Aguadilla, Isabela, Moca, Aguada, and Quebradillas.

4. DAMAGE AFTER THE STORM

The heavy rainfall of hurricane Maria caused the lake's levels to exceed the flood limit, crossing over state highway PR-119, and, as consequence, having access to the spillway located west of the dam. The combination between the accumulation of water having access to the spillway and the curve that the course of the water should take, caused what is identified in engineering as a hydraulic leap.

This hydraulic leap caused the water to jump, falling into the spillway and causing the collapse and fracture of this structure. There was also a fault in the gate that gave way to the 54" pipe from the tunnel that crosses under the dam and the gate that feeds the river through a 96" pipe.

Figure 4. Erosion at base of dam. (Seda, 2017)

Another damage caused by this catastrophic storm was the collapse of a 54" reduced to 48" concrete pipe siphon, which fed the diversion channel that carries the water to municipalities served by the dam.

Figure 5. Erosion at base of dam. (Seda, 2017)

Emergency warnings were issued informing pertinent authorities of this situation. The National Meteorological Service issued a Notice of Failure in the dam. This situation caused thousands of people to be without drinking water service with their lives at risk due to this collapse. 70,000 people were evacuated from their residences as a preventive measure.

Figure 6. Aerial view showing the damage to the Guajataca Dam in the aftermath of Hurricane Maria. (Alvin Baez/ Reuters, 2017)

4.1 MITIGATION STRATEGIES

As soon as the Puerto Rico Power Authority acknowledge the damage, mitigation efforts began to avoid the erosion of the land in the western part of the dam. With help from the US Army Corps of Engineers' personnel, New Jersey-type concrete barriers and sandbags were arranged in the lower part of the spillway, creating a dissipator in which the levels of the lake were lowered, and flow was completely controlled. Rip rap and gabion stone were also deposited on the entire surface.

Figure 7. US Army Corps of Engineers' personnel collaborating in the mitigation efforts at Guajataca Dam after hurricane Maria. (Seda, 2017)

4.2 RECONSTRUCTION AND RESTORATION PLAN

The US Army Corps of Engineers is working on a design to avoid events like this in the future. They are currently working on the construction and connection of a new siphon below the spillway to feed the diversion channel. The construction of a spillway in the center of the dam and the restoration of the existing one is projected as a next phase of the mitigation plan.

5. LAND SURVEYING TECHNIQUES DURING INTERIM RISK REDUCTION MEASURES

Authorities were aware of the need of Land Surveying techniques, since Land Surveyors provide precise data measurement needed to ensure the success of fast reconstruction and restoration of this infrastructure. Due to the lack of power and communication, Land Surveyors were finally contacted one week after hurricane Maria hit Puerto Rico. A topographic survey and as-built survey were immediately prepared. Geodetic controls monitoring began, as well as locating dam's instruments.

When Land Surveyors arrived at the site, there was no internet connection and therefore no access to a Virtual Reference Station (VRS), which operates using a network of reference stations and sends data through a wireless connection. In substitution, a local control network using Real-Time Kinematic (RTK) techniques with approximate locations in order to create a control polygon and begin survey work.

Figure 8. Land Surveyors perform As-built Survey applying Real-Time Kinematic (RTK) techniques at Guajataca Dam after hurricane Maria. (Seda, 2017)

Even though official geodetic control points were found at project site, Land Surveyors were unable to occupy them, since there was no access to data sheets. Weeks after, when internet was restored near the dam, data was obtained, and the correct transformation was performed.

Obtaining Topographic data at the spillway was an overwhelming challenge for Land Surveyors. Due to the difficulties in accessing this area, the use of Unmanned Aerial Vehicles (UAVs) was applied. A DJI Phantom 3 Professional was used with the following software to process data:

- Drones Made Easy: this application was used for planning. The survey area was identified, taking into consideration the terrain and all tall features. Altitude was adjusted based on the scope of work, level of detail needed and tall structures. Flight's path was selected with proper overlapping.
- Agisoft: this software was used for the processing of images obtain by the DJI Phantom 3 Professional drone.
- Global Mapper: this application was used to process geospatial data. Different data management tools were employed to analyze collected data.
- Carlson Survey 2014 Embedded AutoCAD – this software -specially designed for land surveying's plat preparation- was used to draw the topographic and as-built surveys to be delivered.

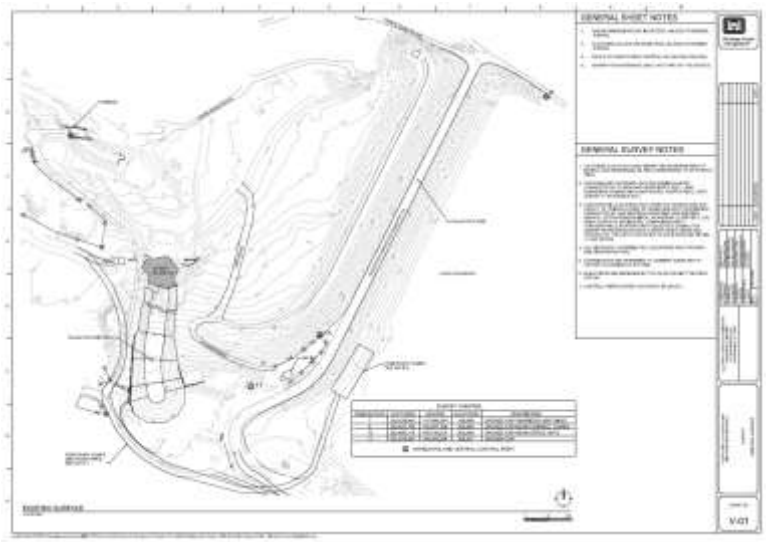

Figure 9. Exiting surface plat. (USACE, 2017)

The National Geodetic Survey (NGS) Coordinate Conversion and Transformation Tool (NCAT) application was used to transform data collected with the VRS under the North American Datum (NAD83) epoch 2010 revision 2011 to NAD83 (FBN1997).

Figure 10. Land Surveyors perform As-built Survey applying Real-Time Kinematic (RTK) techniques at Guajataca Dam after hurricane Maria. (Seda, 2017)

Topographic and As-built surveys were finished in a period of 2 weeks. Additional work was requested once the urgent surveys were finished. The next phase of the project is to map the existing conditions of the diversion and irrigation channels from the Guajataca dam to Isabela, Moca and Aguadilla (approximately 35 linear miles of canals). This survey is scheduled to be completed soon. Currently being carried out in the project is the stakeout of drill holes for soil testing and Soil Nails to hold the existing spillway and the redefinition of the 54 "siphon pipe that will connect the bypass channel with the dam.

All this geospatial data was used by the engineering department of the U.S. Army Corps of Engineers - Jacksonville District to design plans for the restoration and mitigation of the dam's damage. After the first deliverable, Land Surveyors have continued with the compilation and delivery of updated topographic data as the improvements to the dam are being executed.

6. CONCLUSION

Due to climate change, the frequency and intensity of natural disasters will continue to increase, such like floods, landslides, inundations, droughts, soil and water salinity. Eighty percent of Puerto Rico's power lines were knocked down by hurricane Maria. No power, no gas, no communications, no internet. Shortage of food, potable water and medicine and difficult access due to landslides and fallen trees across the roads. This was still the panorama a week after the storm. But this was no impediment for Land Surveyors to provide the precise data measurements during interim risk reduction measures. All geospatial data obtain at Guajataca dam during the emergency was used by the engineering department of the U.S. Army Corps of Engineers - Jacksonville District to design plans for the restoration and mitigation of the dam's damage. When it comes to constructing -or in this case, reconstructing- the infrastructure required to conserve and deliver water to where it is needed, it is the Land Surveyor who collects precise data needed to ensure the success of such projects.

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BIOGRAPHICAL NOTES

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