Hydrology and Hydraulic Study of an Existing Bridge on Veguitas River

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Abstract**—***This paper summarizes the hydraulic and hydrology studies perform to determine the capacity and replacement structure of an existing bridge. The studies will be performed at a Bridge in Veguitas River in the Municipality of Jayuya in Vegitas Ward. The bridge is affected by frequents rainfall events. For these research two models HEC- HMS, HEC- RAS developed by the US Army Corps of Engineer were used. The existing and two proposed condition were evaluated. For the proposed condition a single slab a bridge with two box culvert were modeled in order compare the behavior of the flow in the channel.*

Key Terms**—** NOAA Atlas 14, NRCS, HEC-HMS, HEC-RAS, Veguitas River

INTRODUCTION

This hydrologic and hydraulic study was modeled to understand the behavior of the Vegitas River in the Municipality of Jayuya low through the bridge. The realization of this study was made using a recurrence of 100, 50, 25, 10, 5 year frequencies storm. The rainfall-runoff model for this storm was done using the USACE rainfall-runoff model HEC-HMS version 3.4[1].In order to obtain the maximum flow from HEC-HMS the parameter of time of concentration, lag time, curve number, watershed area need to be calculated. These parameters are going to be calculated using the Natural Resources Conservation Services methodology. Having obtained the maximum flow, we proceed to model both existing conditions and proposed. The hydraulic analysis was made by using the mathematical model HEC-RAS developed by the Corps of Engineers and choose one of the two proposed condition considering their compliance with the Regulation 13 of the Planning Board keeping also in mind the economic proposal that such project represent.

PROBLEM STATEMENT

This project consists of a bridge replacement on the Vegitas River on the Municipality of Jayuya. The existing bridge consists of a bridge of 4 meters width, an average height of 1.2 meters and with distance between the two points of support of 8 meters. The existing bridge has a low capacity for frequent events. Currently the events of 10, 25, 50 and 100 year has an over topping effect leading to a violation of Regulation 13 of the Planning Board stating that a hydraulic structure must meet the event of recurrence of 100 years[2]. Under these flooding events, a part of the Vegitas Ward has limited access.

A hydrology and hydraulic modeling of the existing and proposed bridge were made. This analysis will be model the existing and proposed conditions using the peak flow for 100 year frequency events. The proposed condition must comply with the Regulation13 of the Board Planning and provide a safe level of service acceptable to the needs of the traveling public. Also the proposed condition must consider the effects of constructing a bridge across a waterway to assuring the long-term stability of the structure.

HYDROLOGIC ANALYSIS

The following parameters were determined for the hydrologic analysis: drainage areas, average soil curve number, time of concentration and runoff lag time. Based on this parameters discharges for 100, 50, 25, 10 and 5 year frequencies storm were determined for existing and proposed condition. The Unit Hydrograph method and the Runoff Curve number (CN) method, both developed by the

"National Resources Conservation Service(NRCS)", were applied to determine the design hydrograph. The HEC-HMS model was used. The HEC-HMS program was developed at the Hydrologic Engineering Center (HEC) of the US Army Corps and it is designed to simulate the precipitation-runoff processes of dendritic drainage basins [1].

Project Location

The site is located in the Veguitas Community in the Municipality of Jayuya. The site is limited by a municipal road PR 527 to the north, in the south by Prietos River, on the east side by Caricaboa River and to east by Zamas River. An Aerial photograph of the site location is shown in Figure 1[3].

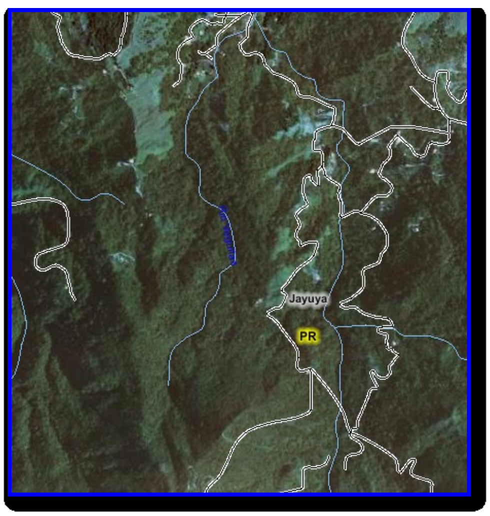

Figure 1
Project Location (Not to Scale)

Topography

The elevation at site project varies from 500 meters to 1200 meter; with respect to the mean see level. These elevations were obtained from the USGS Topographic Quadrangle of Jayuya shown in Figure No.2 [3]

Watershed Delimitation

The watershed is the basic unit of all hydrologic analysis and designs. Any watershed can be subdivided in to a set of smaller watersheds. Usually a watershed is defined for a given drainage point. This point is usually the location at which the analysis is being made and is referred to as the watershed "outlet" see Figure 1. The watershed, therefore, consists of all the land area that drains water to the outlet during a rainstorm. Delineating a watershed provides a bounded area wherein the physical processes are similar. Aquatic and hydrologic processes can be described and to some degree controlled or managed within a watershed. Figure 2 shows the watershed delineation under study. The delimitation of the basin was conducted using the topographic map shown in Figure 2 for a total area of 213 acres.

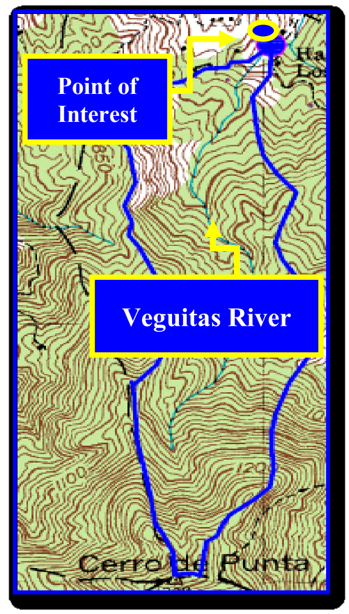

Figure 2
Watershed Delimitation (Not to Scale)

Hydrologic Parameters

In this section will be describing the hydrologic parameters used in this investigation.

Curve Number

The Curve Number represents the runoff potential within a watershed and is estimated based on soil type (hydrologic soil group). The NRCS methods classify the land use and soil type by a single parameter called curve number, CN. This method can be used by for any sized homogenous watershed with a known percentage of imperviousness. If the watershed varies in soil type or in cover, it generally should be divided into regions to be analyzed separately. Equation (1) calculates a composite curve number by weighting the curve number for each region by its area.

The principal physical watershed characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope. The NRCS method uses a combination of soil conditions and land uses (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher the CN, the higher the runoff potential. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. In hydrograph applications, runoff is often referred to as rainfall excess or effective rainfall, and is defined as the amount of rainfall that exceeds the land's capability to infiltrate or otherwise retain the rainwater. The soil type or classification, the land use and land treatment, and the hydrologic condition of the cover are the watershed factors that will have the most significant impact on estimating the volume of rainfall excess, or runoff [4].

According to this study, the soils found in the site were identified as Ingenio clay loam, Lirios clay loam, Los Guineos-Maricao-Rock outcrop, Maraguez silty clay loam and Pellejas clay loam. Figure 3shows the soil distribution inside the watershed [3].

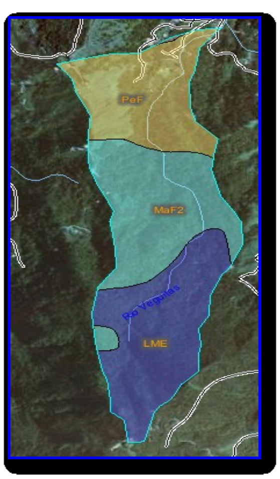

Figure 3
Land Cover Based on NRCS Web Soil Survey
(Not to Scale)

For the purpose of this study, the Curve Number was calculated using a cover description presented on Table.1, this cover description and curve number were developed by the NRCS [1].

Table 1
Hydrologic Soil Group by Cover Description

Cover Description	Hydrologic Soil Group	CN	Area (acres)
Woods and Grass Combination(Fair)	C	60	172.53
Impervious Area(Streets and Road)	B	98	21.3
Residential Districts	B	75	19.17
		Total Area	**213 acres**

Average Precipitation

The variation of rainfall volume with time was required as part of the storm input developing the modeling in HEC-RAS. Therefore, the development of a design storm with a rainfall frequency and duration was necessary to compute the design hydrograph for the watershed. Rainfall data used in this study were from the US Weather Service "Precipitation Frequency Atlas of the United States NOAA Atlas 14". The rainfall depths for 100, 50, 25, 10, 5 year frequency for several duration was used and a duration of 5 y 15 minutes, 1,2,3,6,12 y 24 hours are shown on Table 2[5].

Table 2
Precipitation Frequency Estimates (in)

Precipitation Frequency Estimates (in)	
Duration (hr)	24
Frequency (yr)	
5	7.81
10	10.1
25	13.7
50	16.9
100	20.7

Time of Concentration and Lag Time

The time of concentration, t_C is defined in two ways. In terms of physical characteristics of a watershed, which is more important in peak flow assessment, it is defined as the travel time of a water particle from the hydraulically most remote point in the basing to the outflow location [7]. Based on rainfall and hydrograph characteristics, it is taken as the time from the end of the rainfall excess to the point of inflection on the falling. Time of Concentration was calculated with the NRCS Equation.(2) that is applicable for watersheds under 2000 acres.

Using the Time of Concentration Equation (2), the lag time or delay time was calculated using the empirical relation of:

Once all the required input data, drainage area, unit hydrograph parameters, soil infiltration rates, stream flow routing parameters and rainfall amounts a HEC-HMS model was made. This model was generated using a single basin with a discharge point as shown on Figure 4 .The rainfall-runoff model for this storm was done using the USACE rainfall-runoff model HEC-HMS version 3.4[1]

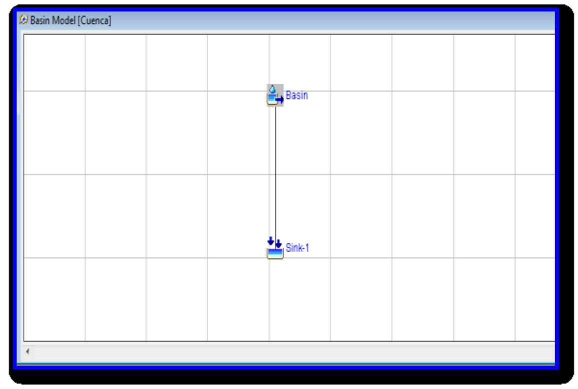

Figure 4
Rainfall-Runoff Model Schematic Diagram

Hydrologic Analysis Results

The data presented on Table 3 are a summary of the peak flows for 5, 10, 25, 50, 100 years floods that were computed using HEC-HMS. Also the hydrograph for the 100 year flood is presented on Figure 5 were it shows the peak flow of 26.94 CMS.

Table 3
Peak Flow for the Study Area

Hydrologic Study Results Summary		
Recurrence Year	Peak Flow (cfs)	Peak Flow (CMS)
5 year	388.7	11.015
10 year	513.6	14.55
25 year	683.2	19.36
50 year	814.2	23.073
100 year	950.5	26.94

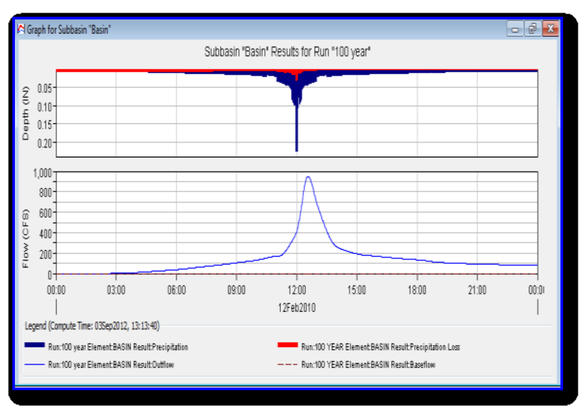

Figure 5
Hydrograph for the 100 Year Event

HYDRAULIC ANALYSIS

The hydraulic analysis of a bridge replacement on Rio Veguitas in the Municipality of Jayuya was made in order to find the water levels and foot print of a 100-year rainfall event according to the Regulation 13. The hydraulic analysis was performed using the mathematical model HEC-RAS developed by the Corps of Engineers. HEC-RAS has the ability to simulate natural and artificial channels with irregular sections, variable slopes, bridges and other control structures and variable flow regimes. HEC-RAS calculates various water parameters flood levels, speeds, top width and other hydraulic characteristics [6].

For the analysis, a total of seven cross-sections were defined. The cross-sections included four sections located upstream of the crossing and three sections located downstream of the crossing as shown on Figure 6. Also a total of four cross-sections were interpolated between the river cross section two and three, four and five and five and six in order to see the behavior of the flow more accurately.

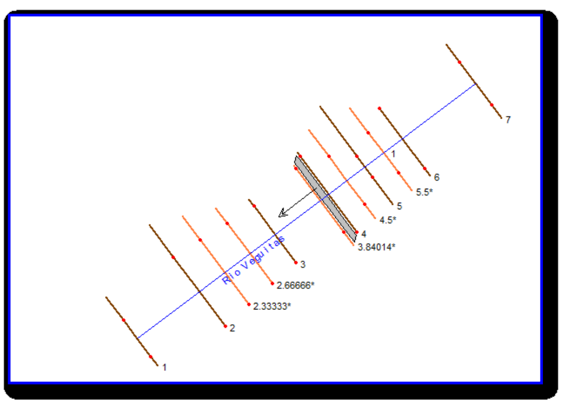

Figure 6
Cross – Section along the Vegitas River

In order to define the cross – section along the river on HEC-RAS an end value of Manning's roughness coefficient to estimate energy losses in the flow due to friction were assumed. The value of Manning's is highly variable and depends on a number of factors such as surface roughness; vegetation; channel irregularities; channel alignment; scour and deposition; obstruction; size and shape of the channel; stage and discharge; seasonal changes; temperature and suspended material [6]. The Manning's roughness coefficient' value for the main channel was 0.035 since is a natural stream with some weeds and stones [6]. For the left and right banks, a Manning's 'n' value of 0.4 was used since the flood plain has some trees and light bushes [6].

Contraction and Expansion of flow due to changes in the cross section is a common cause of energy losses within a reach (between to cross-section). The expansion and contraction coefficients used to represent the channel were 0.3 and 0.1.These values describe a creek or slough with gradual transitions between cross-sections. The expansion and contraction coefficients used in the vicinity of the bridge and culvert were 0.5 and 0.3, respectively [6].

Existing Condition

The proposed hydraulic analysis of the existing bridge over Veguitas River consists of a bridge of the evaluation of 4 meters width, an average height of 1.2 meters and with distance between the two points of support of 8meters. Currently the bridge doesn't comply with the Regulation 13 from the Planning Board because the water surface elevation for the 100 year is 100.67 meter and the top of road elevation is 100.50. Regulation 13 establishes that for any structure needs to have a capacity for the peak discharge of 100 years of recurrence. The Planning Board emphasizes that such replacement or new construction for such purposes must not aggravate flooding conditions that could exist in the area. Figure 7 and Figure 8 shows that the existing bridge does not have capacity for 100 year event and therefore doesn't comply with the Regulation 13. Also the Regulation 13 establish that the freeboard which is defined as the clearance between the lowest point of the superstructure (bridge soffit or bottom of girder) and the design water surface elevation should be no less than 1 ft (0.30m) .In the hydraulic of the existing condition only the five year of recurrence have a freeboard of 0.07meter shows on Table 4, which clearly states that the bridge needs to be replaced.

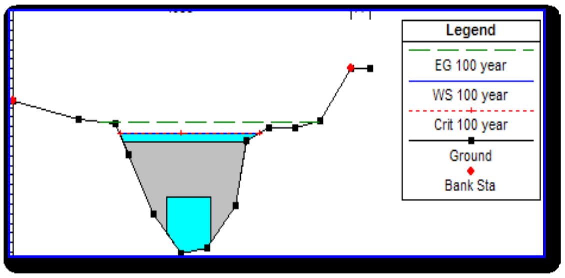

Figure 7
Existing Condition

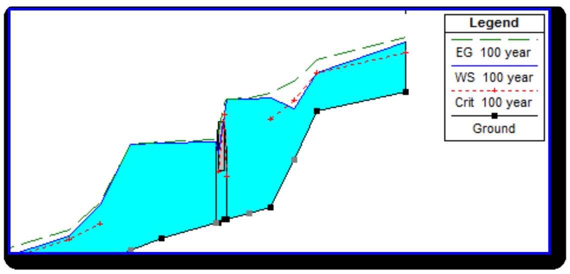

Figure 8
Existing Condition 100 Year Event Profile

Proposed Condition

For the proposed condition two options were considered; single slab and two box culvert.

Single Slab

A single slap was modeled under the same hydraulic properties as the original condition. This proposed condition consists of a bridge of 4.5 m width, an average height of 2.5 meter and with distance between the two points of support of 12.43meter shown on Figure 9. Figure 10 shows the profile capacity for the 100 year event.

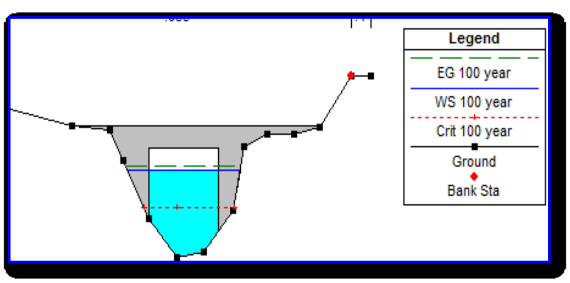

Figure 9
Proposed Condition of a Single Slab

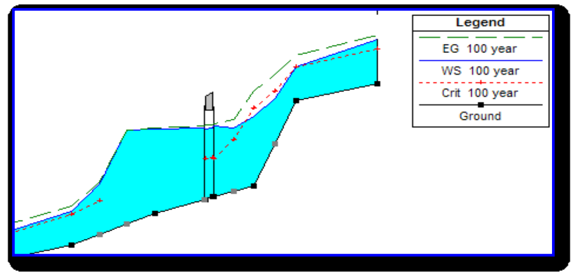

Figure 10
Single Slab profile 100 Year Event Profile

Bridge with Box Culverts

A bridge with two box culverts was modeled under the same condition of the existing condition. This proposed condition consists of a bridge of 4.5 m width and two box culvert of 6 meter by 2.5 meter shown on Figure 11. Figure 12 shows profile capacity for the 100 year event.

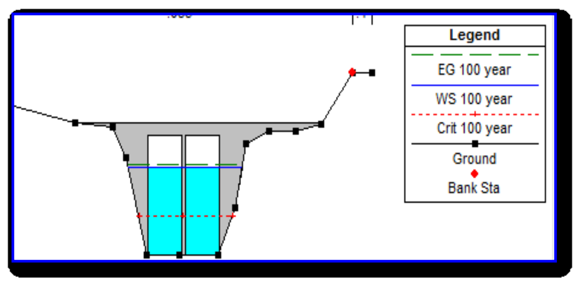

Figure 11
Box Culvert Bridge

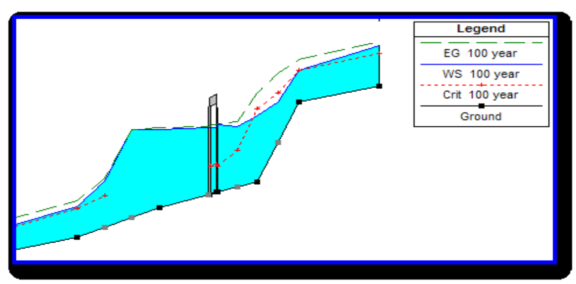

Figure 12
Box Culvert Bridge100 Year Event Profile

Table 4
Comparison of the Existing Condition and Proposed Condition

	Existing Condition			**Single Slab**			**Box Culverts**		
Design Flow Return Period (yr)	WS Elevation Original Condition (m)	V (m/s)	Freeboard (m)	WS Elevation Condition (m)	V (m/s)	Freeboard (m)	WS Elevation (m)	V (m/s)	Freeboa rd (m)
100	100.67	0.89	0	100	1.09	0.5	100.01	1.09	0.5
50	99.87	0.83	0	99.87	1.04	0.63	99.87	1.04	0.63
25	99.7	0.78	0	99.7	1.01	0.8	99.71	1.01	0.79
10	99.44	0.72	0	99.44	1	1.06	99.44	1	1.06
5	99.25	0.65	0.07	99.25	0.97	1.25	99.25	0.97	1.25

Recommendation

The general hydraulic design criteria for bridges are to allow for a minimum of 1.0 foot of clearance between the 100-year peak flow water surface elevations. As shown on Table 6 a comparison of the existing and proposed condition were made .Since all two proposed condition comply with the Regulation 13 of the Planning Board a selection of one of the proposed condition are based on how the proposed condition will affect the river bed, less most economical proposal along its useful life.

Single slab bridges required more structural work, are more expensive shown on table than a box culvert bridge. Nevertheless require less maintenance since are less susceptible to clogging with debris leading to a less cost over its useful life. A box culvert bridge can have less hydraulic capacity than a bridge, lowest overall profile and more impact on the river bed, require periodically clean out since is susceptible to clog with debris. The constructions of a bridge with box culverts are $167,000 less expensive than the construction of a single slab bridge, nevertheless require more maintenance since it's required a periodically cleanout, leading to a higher cost over it useful life. [7]A comparison of the cost of both proposed condition are shows on Table 5.

Table 5
Approximate Bridge Cost (Cost Include Material, Labor and Equipment)

Bridge Type	**Approximate Cost**
Single Slab Bridge	$945,000.00
Two Box Culvert Bridge	$778,000.00

The proposed condition choose to this research is a single slab bridge since it's have less impact on the river bed and require less cleanout of debris reducing its cost over its lifetime. The use of erosion control system are recommended since the velocities increase compared of the existing bridge and the proposed condition see table 6.The use of best manage practice is highly recommended for the basin. This bridge will consist of 4.5 m width, an average height of 2.5 meter and with distance between the two points of support of 12.43meters.

Future Works

For future works is highly recommended to realize a sediment transport study and a backwater effect for the new structure.

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