Guadalupe-Zacatecas Watershed Modeling

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Senior BYU Civil Engineering Capstone Project

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Abstract

Two basins, el Chilito and la Presa Bernardez, are located on the northeast side of the city of Zacatecas, Zacatecas, Mexico. The outlets to the basins exist where Zacatecas joins the suburb of Guadalupe. The rapid growth in this area of primarily low income families has caused people to move dangerously close to these streams into which these basins drain. Because of increased urbanization, runoff quantities are expected to continue to increase. This happens as a result of more land being paved that is no longer able to drain to the subsurface. The combinations of increased runoff and dwellings in closer proximity to the streams could spell disaster for greater numbers of individuals.

The group Zacatecas-Guadalupe modeled the basins in HEC-1 and HEC-HMS to calculate runoff quantities for the present and future models with storms that have a recurrence interval of five years and durations of two and twenty-four hours. Each of the eight scenarios was modeled in both HEC-1 and HEC-HMS. Peak flows increased 1.5 to 2 times after development was considered. Also, the HEC-HMS scenarios were 10 to 30 percent lower than HEC-1 models. While the HEC-HMS results are considered more accurate because the model is gridded and not computed with a lumped parameter, the time and effort required to obtain these values was substantially more than the time and effort required to run the model in HEC-1.

Introduction

Students from Brigham Young University and the Universidad Autónoma de Zacatecas have done a computer modeling study of the la Presa de Bernardez and el Arroyo el Chilito. The purpose of this modeling is to generate runoff hydrographs for surface runoff for these two basins. Watershed Modeling System (WMS), HEC-1, and HEC-HMS software, generated by the Army Corps of Engineers in conjunction with BYU, were used to model the basins. Once an electronic model of the area was generated, the effects of various durations and intensities of rainfall along with varied development patterns in the area could be tested to see their varied effects on runoff quantities.

Method and Materials

Computer Model

The students first sought to create an accurate computer model of the area of interest. The Digital Elevation Model (DEM) was obtained with a resolution of 30m and 90m. The 30m resolution was used on the grounds that this would be the most accurate because of the additional level of detail that it could provide for the area. Maps were obtained of soil types, land use, ground cover and vegetation, and an Auto-CAD file of roads, buildings and other features in the area. Google Earth images were used extensively to help us understand how the area had developed in the years since the

publication of our reference documents. The students in Mexico were also used as a

resource for site visits and to investigate upcoming development plans. These maps,

along with the information that we were able to obtain, were geo-referenced, that is put

into the same coordinate system as the DEM so that the maps would match up correctly

and the land cover information on them could be utilized. A screen shot from Google

Earth is presented below in Figure 1.

Figure 1. Delineated watersheds in Google Earth. La Bernardez is on the left and El Chilito is on the right.

From this data, curve numbers were generated for the various regions in the basin.

Accurate curve numbers are essential in obtaining a realistic model using the SCS

method of determining runoff. Curve numbers are an approximation of the amount of

water that a land surface is capable of absorbing. An illustration of this concept would be

if one was to imagine how much water runs off a grassy field growing on loamy soil

compared with a paved parking lot. The difference is that most of the rainfall would be absorbed in the first case as opposed to the second scenario where almost all the water would runoff.

The students in Mexico, along with the site visit, were extremely helpful because they could verify the information that was found as well as to inform where the developments had progressed to in the basins. After this information was integrated, the base model was constructed in WMS and multiple rainfall intensities and durations could be analyzed. This setup applies for both the HEC-1 method as well as the HEC-HMS model. With the knowledge of the area that is currently under development and the Auto-CAD files for projected development, we were able to model various scenarios of current conditions and future developments.

Precipitation Data

The rainfall data was also obtained from the students in Mexico. Various return periods and rainfall durations were obtained, from two to twenty years and a five minute to 24 hours respectively. The design storms that are most commonly used for design purposes in this area are have a five year return period and last two and twenty-four hours respectively, both of which were utilized in the model. A total depth of rainfall for the storm was calculated to be 42.6 mm for the two hour storm and 93.6 mm for the twenty-four hour storm. The SCS Type II- 2 hour and 24 hour storm were used for the respective rainfall depths. The IDF curves are presented below in Figure 2.
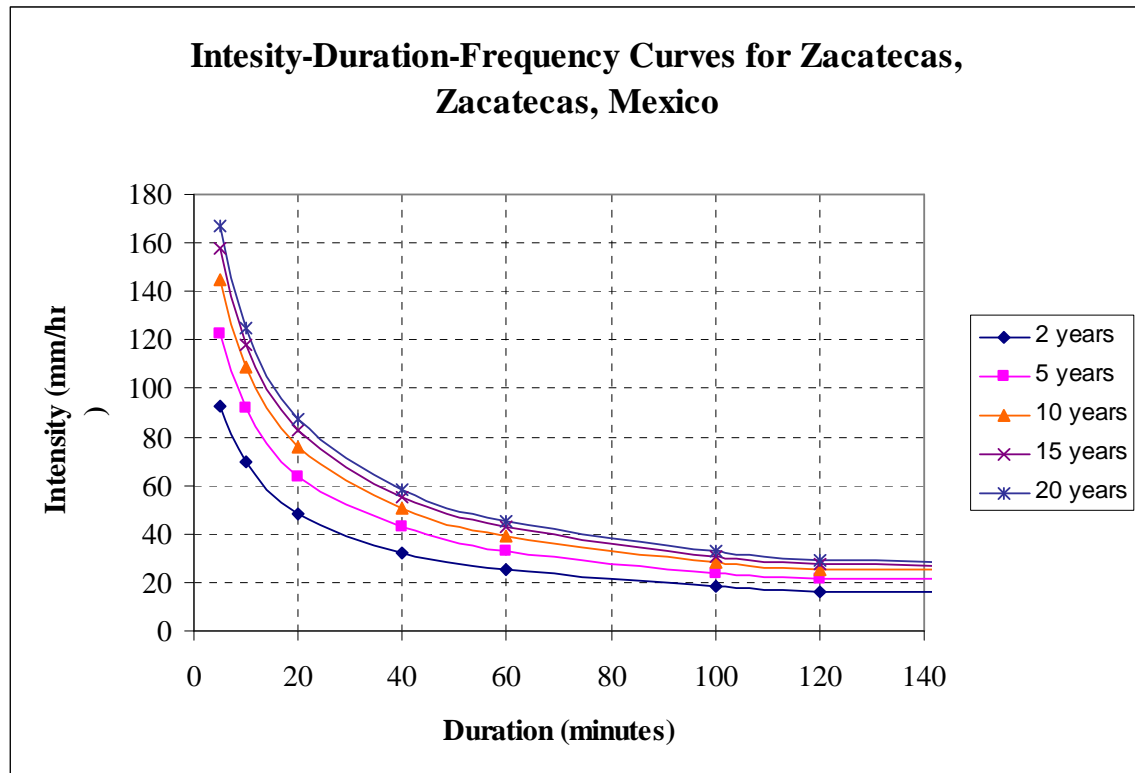
Figure 2. IDF curves for Zacatecas, Zacatecas, Mexico.

Results

WMS

The hydrologic model was developed in WMS and combined with the obtained precipitation data. HEC-1 utilizing the data that was in the model produced the following flows for pre- and post-development runoff. This is shown below in Table 1.

HEC-1 Peak Flow (m^3/s)			
		5 Year Storm	
Sub-Basin	**Type of Flow**	**2 Hour**	**24 Hour**
El Chilito	Present	6.28	15.14
	Future	11.31	19.5
La Bernardez	Present	11.31	19.31
	Future	16.09	26.8

Table 1. Present and future development flows from HEC-1.

Additionally, large volumes of runoff and presented below in Table 2. Further
investigation is needed to analyze or design detention basins of sufficient size.

HEC-1 Volume 1000 (m^3)			
		5 Year Storm	
Sub-Basin	**Type of Flow**	**2 Hour**	**24 Hour**
El Chilito	Present	22.9	89.9
	Future	39.2	117.3
La Bernardez	Present	39.2	103.5
	Future	50	145.9

Table 2. Present and future development total storm volumes from HEC-1.

HEC-HMS

One of the primary focuses of this study was to use the MOD-Clark method in the
HEC-HMS module to generate runoff hydrographs and to compare the results with
HEC-1. La Bernardez and El Chilito watersheds were divided into 10x10 and 10x20
grids respectively. A significant degree of difficulty was experienced in getting HEC-
HMS to work, but in the end, peak flows and volumes were obtained. They are
represented below in Tables 3 and 4.

HEC-HMS Peak Flow (m^3/s)			
		5 Year Storm	
Sub-Basin	**Type of Flow**	**2 Hour**	**24 Hour**
El Chilito	Present	4.6	9.9
	Future	11.31	12.1
La Bernardez	Present	7.3	16.6
	Future	13.9	21

Table 3. Present and future development peak flows from HEC-HMS.

HEC-HMS Volume 1000 (m^3)			
		5 Year Storm	
Sub-Basin	**Type of Flow**	**2 Hour**	**24 Hour**
El Chilito	Present	27.3	92.7
	Future	41.6	116.3
La Bernardez	Present	103.9	103.9
	Future	26.7	146.1

Table 4. Present and future -development total storm volumes from HEC-HMS.

HY-8

To better understand the infrastructural improvements that should be made in order to avoid flood damage, the culvert analysis program HY-8 was utilized to determine size of a culvert leading into the old reservoir in La Bernardez. Based on the 5-year 2 hour storm flow of 9.9 m^3/s, only about 20% of the flow would be able to pass the two-barrel 2.5 foot culvert that is currently in place. Below in Figure 1 is a photograph of the structure as it exists today.

Figure 3. Inlet works for La Presa Bernardez existing reservoir.

This would be almost adequate for a two hour storm with current conditions, but the consequences of urbanization will increase the runoff to the point that threatens the interstate on-ramp under which the culvert passes. Consequently, a new reinforced concrete box culvert with dimensions of 2.5 meters by 1.5 meters was designed that fully passes the flow without any overtopping. The design drawings are included in the Appendix.

Discussion of Results

WMS

The results clearly show that urbanization has a major impact on the expected runoff in both watersheds using both HEC-1 and HEC-HMS models. This is qualified, however, because the flow paths will also change as the study areas are developed. This

will in turn affect the time of concentration, peak flow, and volume of runoff. The model

does show that urbanization does increase the runoff substantially. This is important as

flooding already occurs, even before the increased flows are accounted for. It is

imperative that changes be made to the routing and infrastructure of the runoff in order to

avert extensive flood damage for those downstream.

The values obtained using HEC-HMS were only acquired after an immense

amount of time and effort. While the HEC-HMS values can be considered more accurate

due to the gridded calculations. Volumes were very similar for the HEC-1 and HEC-

HMS models with the same scenarios. However, peak flows were 10 to 30 percent

smaller in HEC-HMS than in HEC-1. A full listing of the data can be found in the

Appendix.

The reason for such a difference in the peak flows between the two models can be

based on the manner in which they are computed. Most of the development is occurring

at the lower half of both watersheds. HEC-1 basically averages the development

throughout each individual watershed, while HEC-HMS places the proper curve numbers

where development is occurring. This basically lags the flow slightly, and the falling

limb is slightly longer. Because losses are basically the same, the volume is basically

equal in both HEC-1 and HEC-HMS, but the peak flows are attenuated in HEC-HMS

because of the manner in which the gridded model is computed. Table 5 below presents

a comparison of HEC-1 and HEC-HMS for both 2 and 24 hour storms for La Bernardez

watershed, assuming future development.

	Future Bernardez			
	5-year 24-hour		5-year 2-hour	
	HEC-1	HMS	HEC-1	HMS
Peak Flow (m³/s)	26.8	21	16.09	13.9
Volume (1000 m³)	145.9	146.1	50	54

Table 5. A comparison of the HEC-1 and HEC-HMS for La Bernardez watershed assuming future development for both 2 and 24 hour storms.

HY-8

Undoubtedly, the original culvert underneath the off ramp was not designed to pass the entire flood flow. This can be seen by the much larger sized culvert upstream. Without considering urban development, the culvert would be adequate to pass the flood flow with minimal overtopping of the road. However, the increased flow based on urbanization represents an overtopping flow approximately 0.5 meters deep. This would not only pose problems to the stability of the on ramp, but would also be a public safety hazard. Consequently, the larger box culvert would pass the 5-year 2-hour storm and avoid such threats. It would probably not be feasible to redesign a culvert based on the 5-year 24-hour storm because of its large magnitude. A bridge would probably have to be built to handle the flow.

Conclusions and Recommendations

When considering any recommendations, several constraints are immediately recognized. First, funding is a constant issue for any project, but especially in the state of

Zacatecas where many development issues must be addressed. The government supports

these hydrological studies and is interested in the results, but may be unable to effect

change due to lack of funding. Also, the poverty of some of the residents of these

watersheds makes it important to make changes in a socially sensitive manner. With

these and other constraints in mind, the following recommendations have been developed

to protect public safety and mitigate the flooding in both El Chilito and La Bernardez

watersheds.

El Chilito
1. Create a detention basin upstream of the new highway by carefully landscaping and clearing the existing depression and sizing the outlet culverts to attenuate the peak flows. Also, clear the channel downstream periodically to allow the flood to pass without as much water backing up.

2. Study the floodplain downstream from the new highway by obtaining cross sections, and using HEC-RAS to delineate the flood plain.

3. Using the HEC-RAS model, design a channel that will work in conjunction with the upstream detention basin to mitigate flooding.

4. Analyze existing infrastructure such as culverts, channels, and detention basins and design to accommodate flows based on the increased runoff from the effects of urbanization.

La Bernardez

1. Restore the abandoned detention basin and control the outflow with an adjustable gate retrofitted to the existing basin outlet.

2. Determine the basin volume necessary to sufficiently delay and attenuate the peak flow through the outlet, and size the detention basin accordingly.

3. Grade the basin side slopes 3:1 or less to reduce the risk of having children get stuck and drown.

4. Study the floodplain downstream from the new highway by obtaining cross sections, and using HEC-RAS to delineate the flood plain.

5. Using the HEC-RAS model, design a channel that will work in conjunction with the upstream detention basin to mitigate flooding.

6. Analyze existing infrastructure such as culverts, channels, and detention basins and design to accommodate flows based on the increased runoff from the effects of urbanization.

We suggest that future studies utilize these suggestions to design actual infrastructural changes to attenuate the peak flows and mitigate the impact of the floods on the primarily impoverished residents in both watersheds who suffer the brunt of the floods' force.