Reservoir on the Rio Boba

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Executive Summary

The National Institute of Water Resources in the Dominican Republic (INDRHI) plans to construct a dam on the Rio Boba. In 1975 they began constructing 8 km of channel for irrigation purposes. The construction stopped in 1980 leaving just the channel. Our project analyzes the feasibility for INDHRI to construct a dam for irrigation, hydroelectric power generation, flood control, and drinking water. We conclude that the reservoir created by the dam on the Rio Boba would be able to fill in about two years depending on the rainfall in those two years. We also find that the demands of the water use downstream would be able to be met while still maintaining adequate storage in the reservoir. The reservoir would also be large enough to hold the volume of flow that would be seen from a large tropical storm.

Introduction

The Dominican Republic is a country full of rich natural resources. One of these resources is the availability of water. This water is used in irrigation, consumption, sanitary flows and many other uses. Proper management is an important part of conservation. This project details the feasibility of a dam constructed on the Rio Boba.

This dam will serve as a utile component of the water conservation in the area. The dam will provide water storage, mitigate negative effects of flooding, provide hydro-electric power generation, regulate flow in the river, provide recreation, and provide aquatic habitat.

This feasibility report focuses on the flowing areas: hydrologic conditions, climatological conditions, water availability, water balance, and flood control. While this report is not comprehensive in nature, the generated data will be useful in the decision making process for a dam on the Rio Boba.

With a goal to improve the availability of water for irrigation and taking advantage of hydroelectric power generation we have set some specific objectives that are found below.

- Assess proposed dam site for technical feasibility based on:
    - hydrological characteristics of watershed (basin delineation and computation of basin parameters)
    - climate patterns (Analysis of precipitation data)
    - flow regime (Analysis of stream flow records)
- Compute water availability and water balance
- Complete a flood control analysis (PMF, delineate floodplain extents of flood prone areas)

Figure 1 below shows the watershed location of the site for the project.

Figure 1. Watershed Location of site for the project in the Dominican Republic

In Figure 2 below is shown the proposed reservoir location and size based on prior analysis by INDRHI.

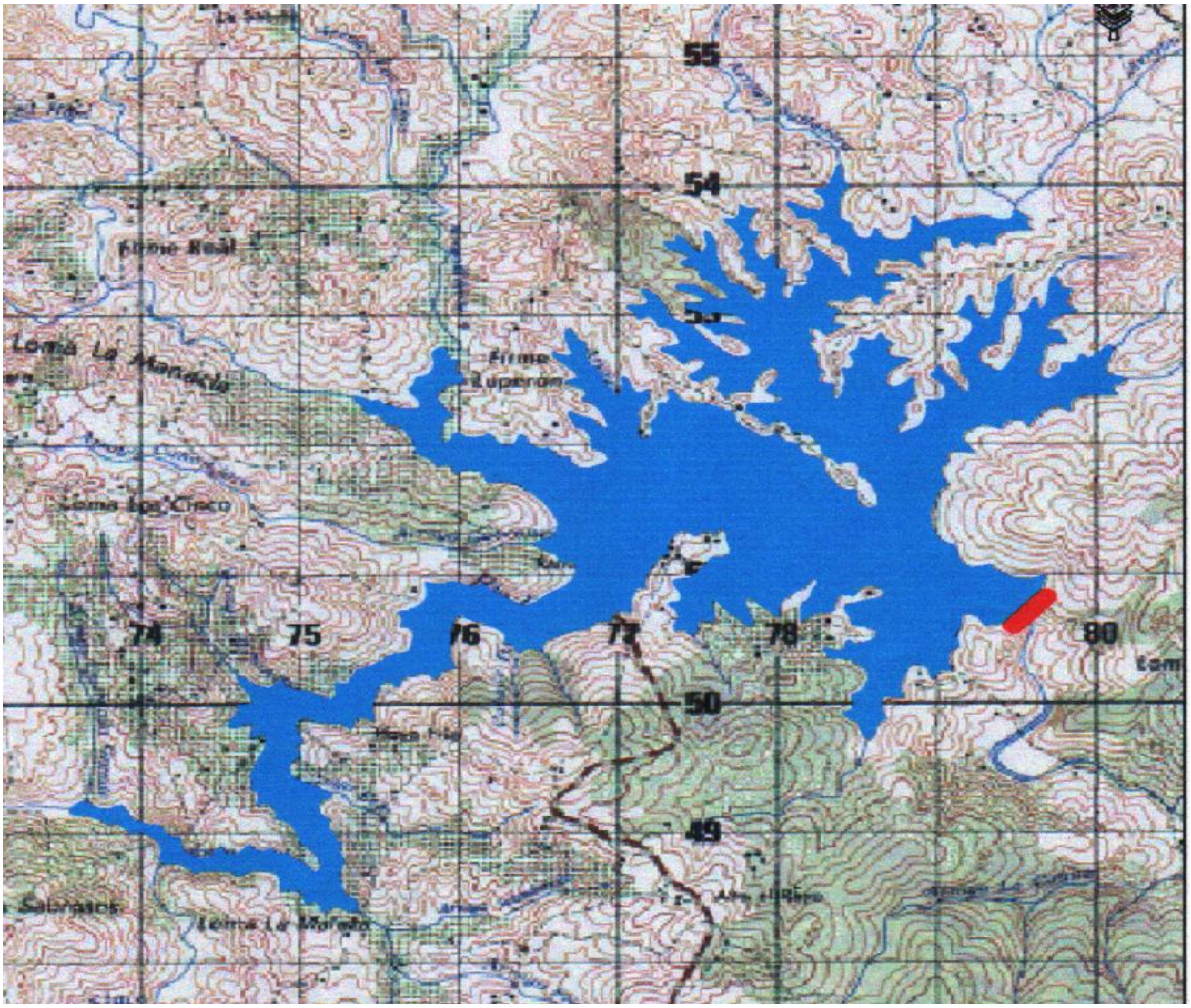

Figure 2. Proposed reservoir site location, size and shape

Materials and Methods

Hydrological conditions: the hydrological conditions of the dam will be analyzed using WMS and HEC-HMS software. These determinations will be based on soil type, land use, and digital elevation models. With these parameters, the team will develop different storm scenarios to forecast how much water will be available for the reservoir.

Climatological Data: Climate data will be used to develop “typical” conditions along with drought and flood conditions. This data will come from historical data, river stage data, and recorded data from various sources. This data will be used to properly calibrate the watershed model developed in WMS.

Flood Control: The flood control aspect of this project will identify locations where high risk of flooding exists. These are areas that would be susceptible in event of a large scale storm that exceeds the capacity of the reservoir. This allows for proper mitigation techniques to be applied before a flood event occurs. This will be done using ArcGIS 10, WMS and other flood forecasting techniques.

To improve the availability of water for irrigation and using this availability to generate power through a construction of a dam on the Rio Boba the team will have first to collect data. The collection of data will help see the hydrological cycles in the area, in that way developing the hydrological condition will be more accurate to what might occur in future scenarios. Understanding the hydrological cycles is vital for this project; all of the analysis will be done based on the understanding of the data collected.

Results and Discussion

From the WMS model we obtained the delineated watershed and the watershed characteristics that we needed to run the analysis which we had sent out to accomplish. In Figure 3 below is shown the delineated watershed as seen in WMS.

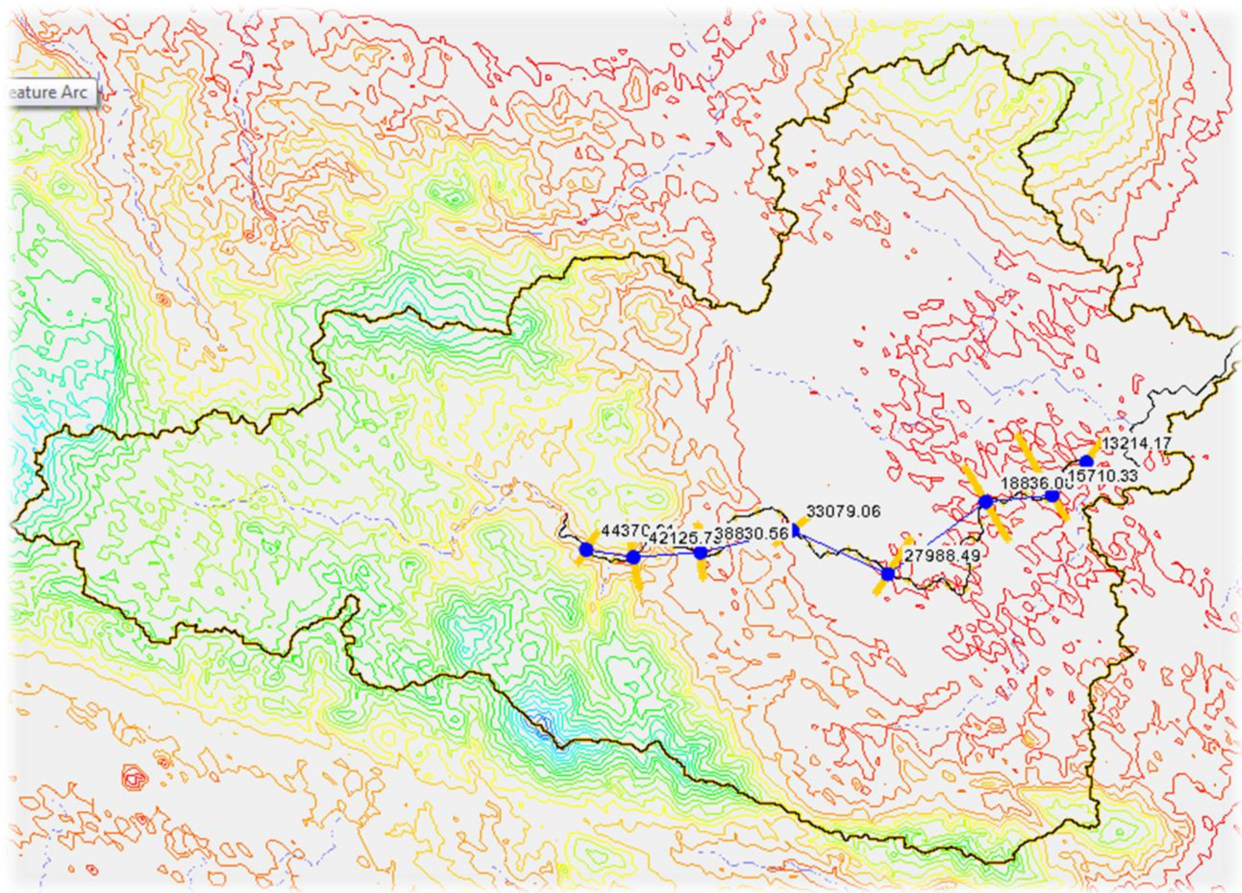

Figure 3. Delineated watershed

One of the key aspects of our project was to identify the risk of the flooding that would result if the dam were to fail. This was done using computer-aided tools including WMS and HEC-HMS. There were two types of flood simulations that were performed. The first flood simulation was created in WMS using a tool called SMPDMBRK. This stands for simplified dam break. The simplified dam break is based on the cross sections of the river channel, surface roughness, slope and the characteristics of the dam that is failing. These dam characteristics include: length of dam, stage of the reservoir, time that the failure occurs, type of dam structure and the capacity of the outlet structures. The results of this model were very good for the selected site of our reservoir. The results are most accurate in the upstream portion of the water shed, just below the dam wall. This is due to the fact that there is more elevation change in the upper portion of the river. As the water flows downstream and into the flood plain, the lack of elevation change becomes much more difficult to represent in this model.

The second model that we developed to represent a catastrophic dam failure was done using WMS. This model was built using a GSSHA grid for the conveyance of the flood wave. The GSSHA grid was formed using cells that each had an area of 200 m^2. To simulate the breaking of the dam a arc boundary condition was used that simulated the head as it changed over time. The initial elevation of the full reservoir was 255 meters above sea level. The bottom of the dam was located at 205 meters above sea level leaving 50 meters of head that was simulated over a 90 minute simulation. The difficulty in doing the boundary condition in this manner was making sure that the volume that left the reservoir in the 90 minute time frame did not exceed the 105,000 acre-feet of maximum storage that would be in the reservoir at failure. It is noted that this manual derivation of the head vs. time plot was manually calibrated. While the exact values are not known, the estimation does not exceed the maximum allowable storage that would be present at any given time.

Other considerations of the model are surface roughness, slope, stream arcs and precipitation. As a team, we assumed a uniform roughness across the entire model. This value is used in Manning's equation to calculate travel times and the velocity of the flood wave. We assume an average roughness value of 0.1. The slope and change in elevation is automatically accounted for in the GSSHA model. In order to model the capture zone and the effect that the stream and rivers had on the flood wave, we used a trapezoidal channel with an average roughness of 0.04. The smaller upstream river and streams were modeled using a channel width of 6 meters and 2.5 meters deep. The downstream rivers were observed to be larger and were modeled using 10 meters wide and 5 meters deep. It is noted that the flood model is less sensitive to these parameters due to the extremely high discharge that would be observed in a catastrophic flood event. For the GSSHA model to run it requires a precipitation event. Our purpose of the model was to represent the dam failure not precisely the precipitation. We entered a value of 0.05 mm per hour for a 24 hour storm event. Again this was done to be able to run a GSSHA model. It is also noted that the small amount of moisture would contribute to wet soil conditions and be an accurate representation of a fast moving flood.

Upon comparing the results of the two models it is observed that the upstream portion of both models is very similar in the flood plain delineation. The SMPDMBRK model is based on a radius or a buffer around the main channel. This is better suited for flood plains that are near a valley or well defined channel. Both of the flood models that we created are useful in determining the limits and travel times of the flood. We determined as per our GSSHA model that the initial flood wave would hit the agricultural rice patties approximately 25 minutes after the initial failure of the dam. It is also observed that the flood wave would reach the populations near the cost approximately 2 hours and 15 minutes after the dam ruptures. There is a large population center named Nagua located a few kilometers to the south of the outlet of the Rio Boba to the Atlantic Ocean. It is noted that the flood will not have an impact on these population centers.

Figures 4 and 5 below show the screenshots of the GSSHA flood simulation. Figure 4 shows the flood prior to exiting the mountainous region.

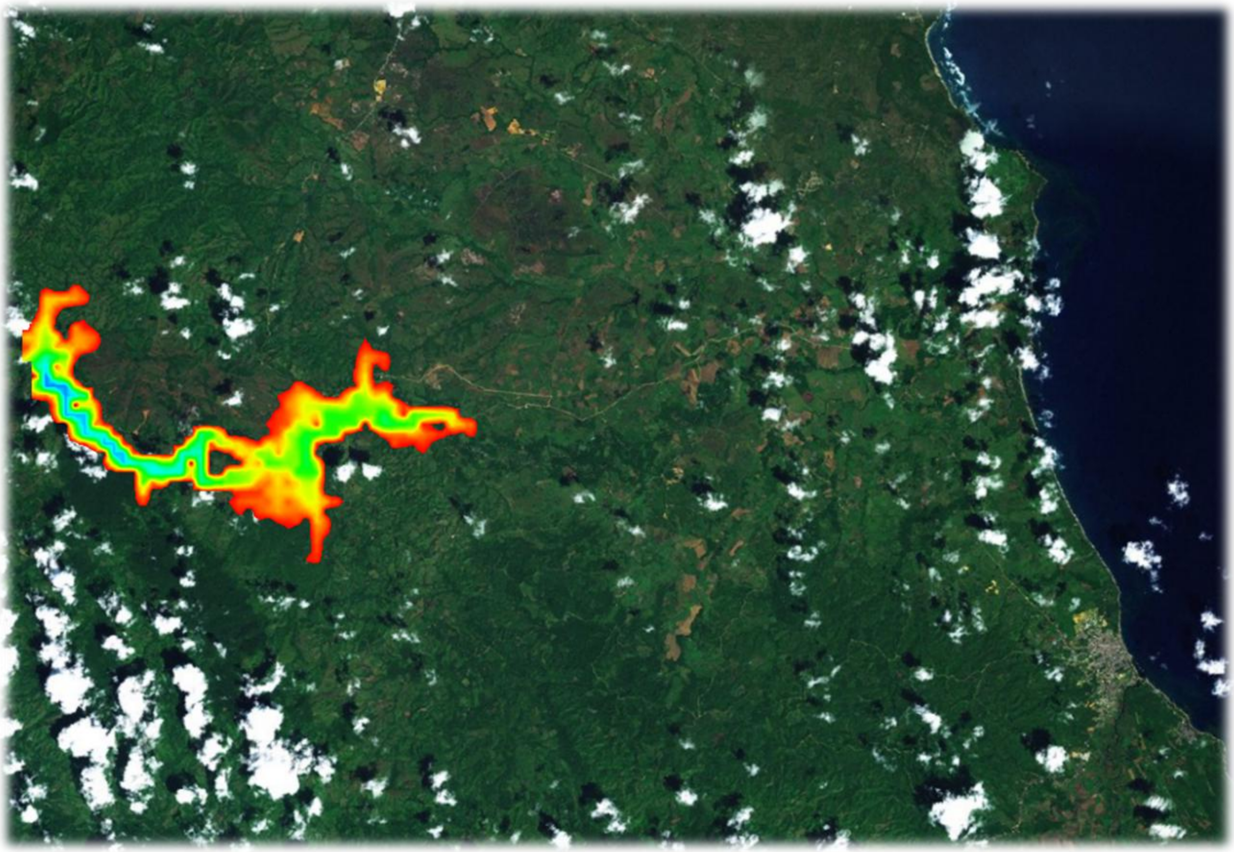

Figure 4. GSSHA model flood wave in mountainous region

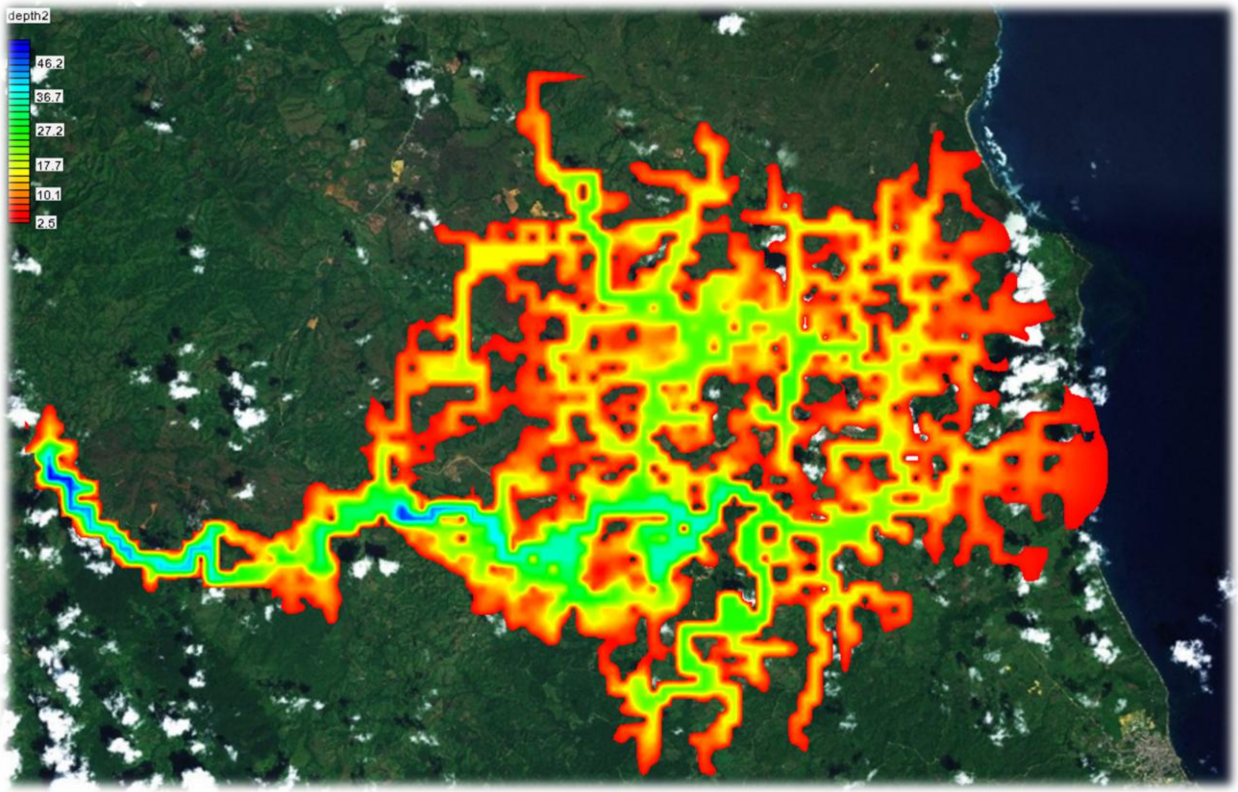

Figure 5. GSSHA model flood wave

Our project also included an HMS simulation of the PMP for this area and PMF as routed through the outlet of our watershed. The PMP was found to be 600 mm of water in a 24 hour period. This data was taken from NOAA. There was no data that was specifically designated for the Dominican Republic. Our team applied the PMP for Puerto Rico under the assumption that the tropical storms that cause such a large precipitation event are similar between the two island countries.

In order to set up our HMS model we created a reservoir outlet in our WMS model and assigned it certain conditions that matched the specifications of the proposed dam and reservoir on the Rio Boba. A storage elevation curve was obtained using the digital elevation model. This allowed us to simulate the probable storage that we could use for flood control. We also defined outlet, spillway, and dam crest characteristics for the Boba dam. We included two 4 meter tube outlets at the bottom of the dam and a 10 meter spillway weir outlet condition 2 meters below the dam crest elevation. The top of the dam or dam crest was defined as a 200 meter long weir so that we could measure the flow that would top the dam in an outrageous flood event. These exact characteristics may not be included in the dam, but these simulate a reasonable amount of flow that could be released when needed during a PMP event. To generate runoff from the PMP we used an SCS curve number of 68.5 for the loss rate method and the Clark transform method with a lag time and storage coefficient of 3.45 hours and 10.5 respectively. We determined these parameters to be conservative given James' experience when visiting the jungley area in the Dominican Republic. We started our HMS simulation with the reservoir 75% full and in swallowed up the PMP with no problem. Upon further investigation with these parameters we discovered that the reservoir needed 24.7 million cubic meters of storage to be able to catch the PMP without overtopping the dam. This figure could change with a change in any of the parameters that we have assumed, but the most important constraint that we would have control over is the outlet flow rates which determine the speed with which we can drain the reservoir and make room for the incoming flood.

In Figure 6 below is shown the streamflow into the reservoir for the 10 year the 50 year and the 100 year storm form the HMS model.

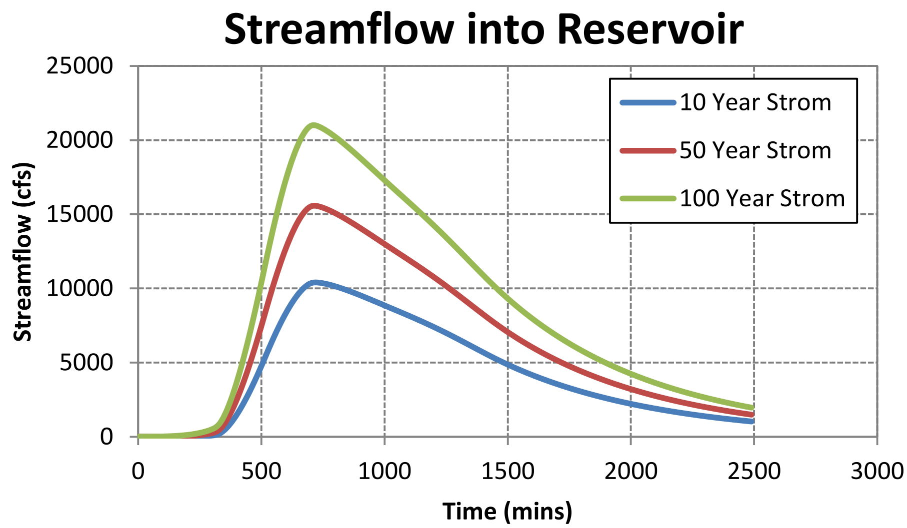

Figure 6. Streamflow into the reservoir from HMS model

For the water availability and water balance calculations we used the daily flow data from 1968 to 1995 and the rainfall data from 1975 to 2004. We compared this data with an analysis in ArcGIS using Blake's toolset. The toolset uses equations to estimate the flow for ungaged rivers and streams using nearby streams and rivers that are gauged. Upon comparing the flow duration curves of the daily flow data and the ArcGIS toolset we were able to verify the validity of the toolset because the flow duration curves matched. This can be seen in Figure 7 below.

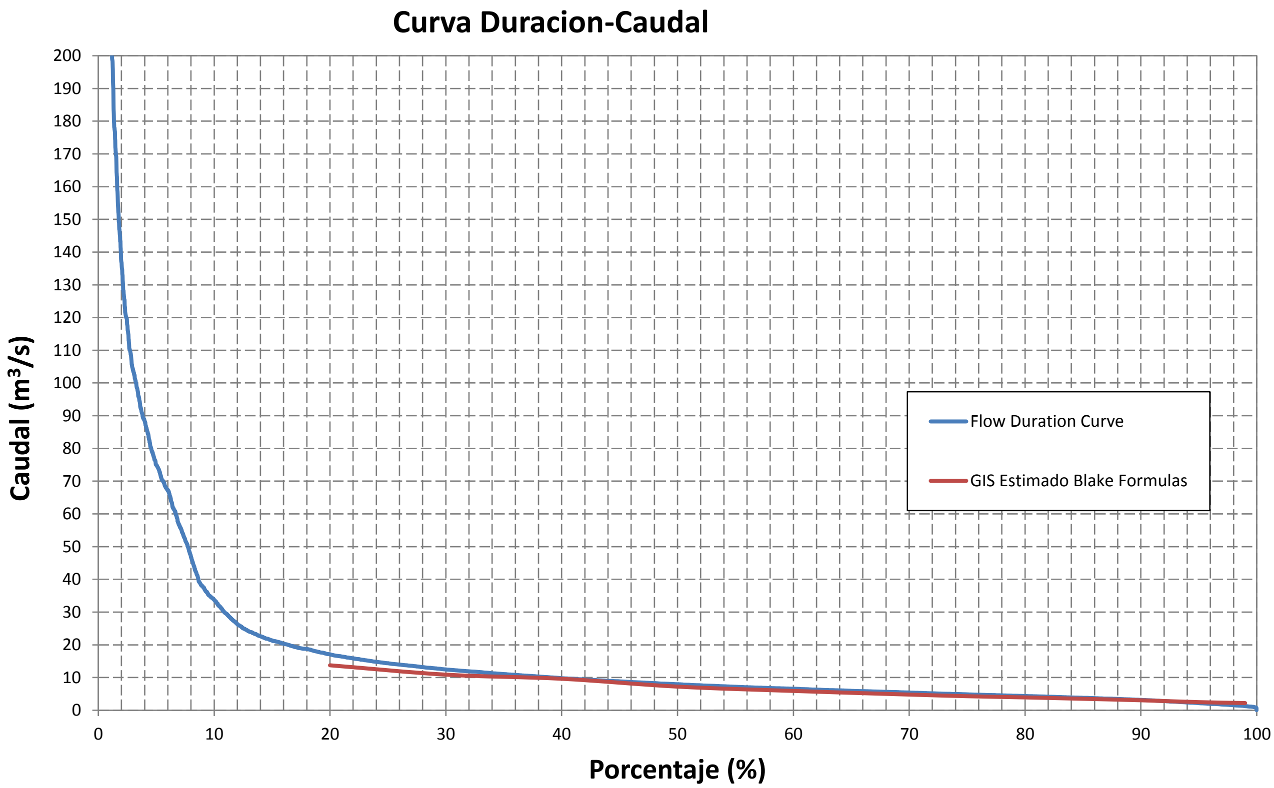

Figure 7. Flow Duration Curve comparison

We developed a mass curve using the accumulative flow over the time period of flow data we had and creating a line representing the demand of water that is needed downstream of the reservoir on an average basis. We made sure to match the demand line to the less steep section of the flow data because that section represents a dryer period of time than the previous years in the data. Figure 8 below shows the mass curve for the river.

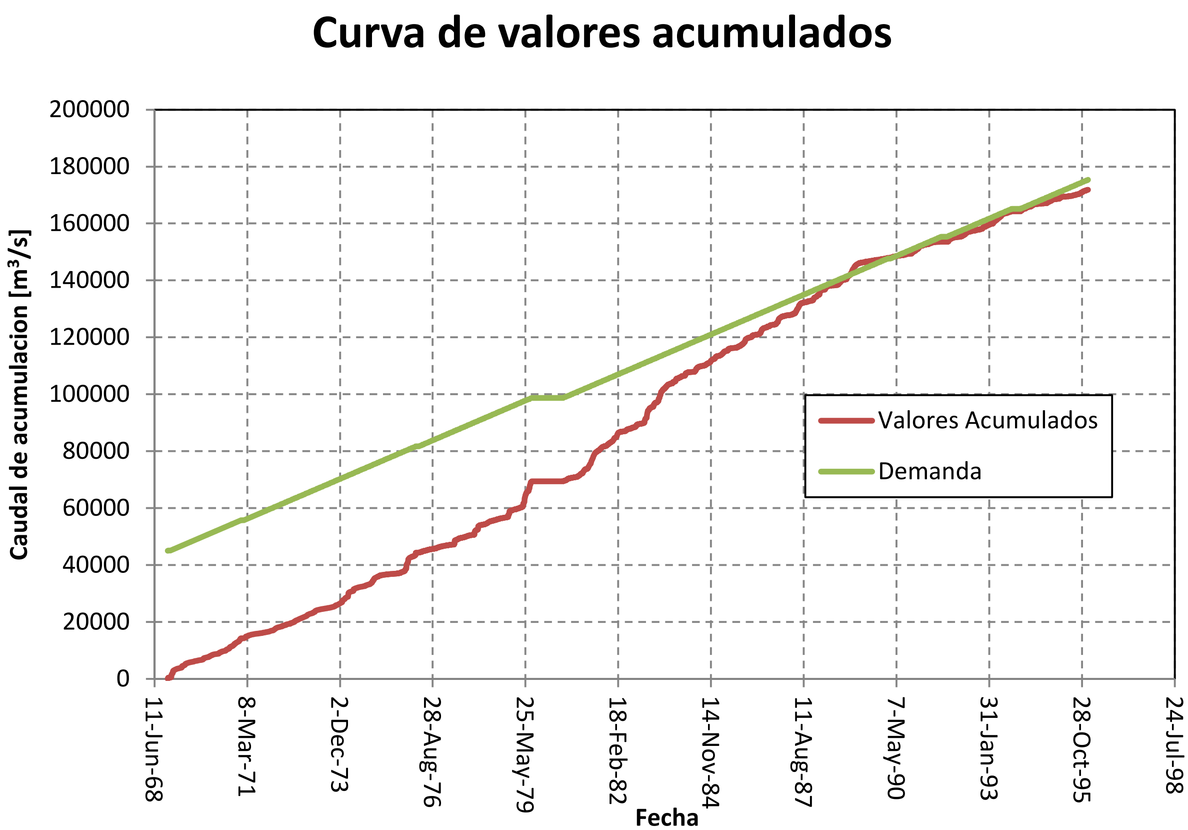

Figure 8. Mass Curve

Using the data from the flow duration curves and the mass curve and applying them to hydrology equations we came up with a water balance in Math CAD as well as a time to fill the reservoir. Shown in Figures 9 and 10 below are the Math CAD screenshots.

Balance Hidrico

$Area_{embalse} := 3000\ acre$

$Area_{cuenca} := 384\ km^2$

$P_{anual} := 2150\ \frac{mm}{yr}$

$Escurrimiento := 11.9\ \frac{m^3}{s}$

$E_{anual} := 1.317\ \frac{m}{yr}$

$P := P_{anual} \cdot Area_{embalse} = 0.827\ \frac{m^3}{s}$

$R := Escurrimiento = 11.9\ \frac{m^3}{s}$

$E := E_{anual} \cdot Area_{embalse} = 0.507\ \frac{m^3}{s}$

$Riego := 10\ \frac{m^3}{s}$

$R_1 := Riego$

$\Delta s := P + R - E - R_1 = 2.22\ \frac{m^3}{s}$

Figure 9. Water Balance from Math CAD

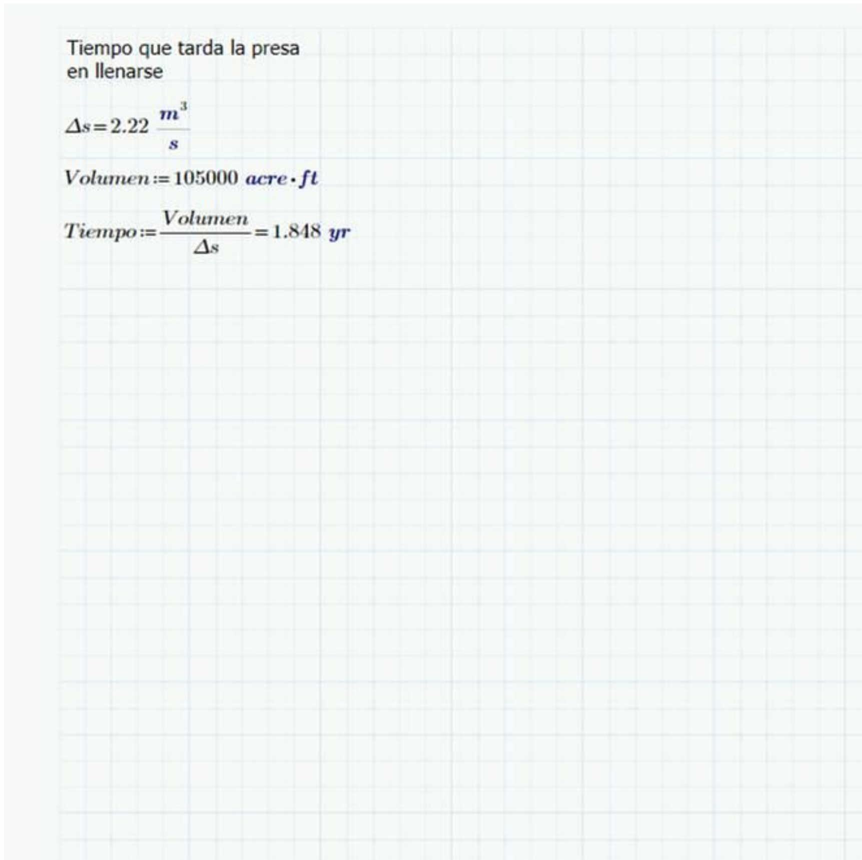

Figure 10. Time to fill reservoir from Math CAD

From our calculations the reservoir would fill in approximately two years. This would ultimately depend on the rainfall in the region during those two years. However, based on average annual flow for the river the reservoir would fill during those two years and still be able to meet the water demands for downstream use. For the purposes of flood mitigation it was found that the volume of a typical probable maximum flow would be able to be held within the reservoir and not cause serious damage downstream. The reservoir would have to be drained to about 80% capacity or less to hold the flood wave of a PMP event.

Conclusion

We conclude that the reservoir created by the dam on the Rio Boba would be able to fill in about two years depending on the rainfall in those two years. We also find that the demands of the water use downstream would be able to be met while still maintaining adequate storage in the reservoir. The reservoir would also be large enough to hold the volume of flow that would be seen from a large tropical storm.