Analysis of Potential Dam on the Maimon River in the Dominican Republic

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Cover Letter

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Dr. E. James Nelson:

The following report is an analysis of a proposed dam site on the Maimón River in the northeast region of the Dominican Republic. This report provides a hydrologic overview by way of engineering calculations and modeling the Maimón watershed. This watershed is considered a possible location for a future dam among many others in the country.

The analysis was a combined effort of our group from Brigham Young University, students Biarda Castillo and Hernan Gomez from the Instituto Tecnológico de Santo Domingo (INTEC), and engineer Vanessa Villa from Instituto Nacional de Recursos Hidraulicos (INDRHI). This report is not a professional design but is an analysis of the data obtained in our visit to the watershed area and provided to us by our counterparts in the Dominican Republic.

The results of our research will be given to the engineers at INDRHI where they can use the data to make decisions on the best place to build a dam and whether it would be needed or feasible in the region. Storage capacity curve, mass curve, flow duration curve, HMS model, GSSHA models, and environmental assessments are given in the following report to assist in the decision process.

Sincerely,

Noah Taylor　　　　Savannah Keane

John De Leon　　　　Kelsey Watkins

Executive Summary

The Maimón River, which travels through the province of Altagracia, provides a steady flow of water for the people living in the eastern part of the Dominican Republic. This water is used for the cultivation of rice, sugar cane, and cocoa. It can also be filtered and used as drinking water. Due to the tropical climate of the region, there is rainfall throughout the year to maintain the flow of this river. Unfortunately, the Dominican Republic is located in an area of the world that is highly susceptible to hurricanes. This causes rainfall to be unpredictable and uncontrollable which can have adverse effects on the economy of the surrounding area.

This report describes the current hydrological conditions of the river Maimon near the town of Las Lagunas de Nisibon. It also explains the benefits of improving the use of the river with a hydroelectric dam based on the recommendation of the Instituto Nacional de Recursos Hidraulicos (INDRHI). A dam would be able to regulate the flow of the river and provide consistent power and water for the economy.

The data collected and analyzed in this report serve the purpose of evaluating the feasibility and practicality of building a dam near the mouth of the river. Hydrologic models of stream flow and precipitation, consumptive use analyses of irrigation and hydroelectric power, and design parameters of the dam were calculated in order to determine what can be done to control the river in the future.

Introduction

In the Dominican Republic, there is a lot of potential for the people to efficiently take advantage of the natural resources all around them using modern infrastructure. The Maimon River is an example of a resource that can be utilized for the benefit of the country's economy and people. It is located in the northeast area of the Dominican Republic, and the agricultural area surrounding it provides a portion of the nation's cacao, rice, and sugar cane. Contrary to popular belief, droughts occur periodically in this country and can reduce the agricultural production of these crops. The construction of a dam can allow for water storage, which can supply an ample amount of water for irrigation, plumbing, hydroelectric power, and flood regulation. By observing the potential site for a dam that was proposed by INDRHI, information such as the capacity of the river, the feasibility of an earthen dam and characteristics of the watershed behind it could be gathered. Using programs like WMS, ArcGIS, HMS, SEEP2D, and Excel, models can be created to describe the effects of a potential dam including the change in maximum stream flow, and flooding after unexpected calamity.

Problem Description

In the Eastern Region of the Dominican Republic, they have traditionally developed an economy based on sugar cane and livestock. More recently, tourism has seen great success in the area. Compared to the rest of the country, this area of the country does not implement water resources and environmental management methods for their crops. There is limited use of water resources for agricultural purposes. This region has not developed enough to manage crops with modern water resource technology. Irrigation is not commonly used. Rain-fed agriculture dominates this region, and this puts crop growth at risk during dry periods.

The region has high potential for underground water, owed to the karst soil formation, causing high infiltration. The region also has large gaps where there are no rivers with shallow beds. Rainfall in this region, as with the rest of the country, is inconsistent. Rainfall is heavy at times and slow at others. Rainfall averages annually 1,000 mm (39.4 in) of depth near Higuey, near the Maimon River. The dominant land types are rainforest and subtropical wet forest. The average annual is 26.3° C. Relative humidity ranges from 78% to 84% and the annual potential evapotranspiration is between 1300 (51.2) and 1600 mm(63 in) for the whole region.

Depending strictly on rainfall to nourish crops in this area is dangerous. Rainfall is inconsistent and the area experiences droughts periodically. Infiltration and evapotranspiration is high, taking away from runoff that reaches crops in the lowlands. When intense rainfall occurs, loss of soil by water erosion is substantial because of the large amounts of grasslands.

This area has limited irrigation systems. The systems they do have exist mainly in Higuey and El Seibo. There are 4,068 hectares of land that are being irrigated by 2,033 people. Major crops in the area that are currently being irrigated are rice, cassava, maize and beans. Near Higuey, the production of sugarcane, rice, and livestock products dominate the use of land. More irrigation is needed to accommodate these growing economies. Because tourism is growing as well, there is an increased demand for more utilities such as drinking water and electricity.

A dam is proposed to increase irrigation in this area so that it can reach more users. The dam will also benefit surrounding area by generating electricity and clean drinking water. This report specifically looks at damming the Maimón River. The main benefits of installing a dam in this river would be to store water for irrigation and flood control downstream. Flood control would supply increased protection over soils used for crops. Soil erosion due to intense rainfall would be limited with the installation of a dam. The proposed dam is estimated to irrigate 2,015 ha with drainage and provide an additional 3,100 ha. This would provide irrigation to a total of 5,115 ha in the project area.

The proposed detention basin collects inputs from several streams connecting to the Maimón River. These rivers alone do not provide enough water supply for irrigation. However, during rainy seasons, they cause flooding problems for crops in the area. The most important rivers in the area are the Maimon River, the Duey River, the River Yoma, the Vacama stream and the Olivo stream. The Maimon River is the only plausible river for a dam site in the area. It would supply the best resources for irrigation.

The proposed dam location is approximately 1 km upstream from the road Higuey – Miches. It is proposed that an earth dam that is 31 meters high with a potential storage capacity of 60 million cubic meters be constructed at this site. The annual flow would be about 74 million cubic meters. Channel systems by land would be used to implement irrigation from the dam. The dam will also be equipped with a drainage system to discharge excess water. The channel systems will feed to 2,015 ha of gross area and 1,612 ha of net area. An additional rain fed area of 3,100 ha of gross area and 2,480 ha of net area will be equipped with the drainage system.

Hydrologic Analysis

Storm PMP

The Probable Maximum Precipitation (PMP) is the greatest depth of precipitation for a given amount of time that is physically possible over a certain geographical area. This is an important parameter in dam design because it governs how much water the dam needs to withstand in the greatest storm that could possibly occur. Unfortunately, due to the lack of data required to accurately calculate the PMP, methods have been developed to predict it. These methods were developed with a high degree of uncertainty. The method chosen to predict the PMP for this particular dam site is the Probabilistic Frequency Analysis, also known as the Hershfield Method. In statistics, this method is referred to as the frequency factor method. It utilizes the following equation in Figure 1:

$$PMP = \bar{x} + Ks$$

Figure 1: Equation for calculating the Probable Maximum Precipitation.

In this equation, $\bar{x}$ represents the mean of the data set, s is the standard deviation of the data set, the K value is 15 (this number ensures that the resulting precipitation value will be an appropriate amount greater than the average) and the PMP is the Probable Maximum Precipitation.

Data for 16 years of precipitation was collected and analyzed from the station Naranjo De China. This weather station, which has coordinates at 18°48’48 N Latitude and 68°41’10’’ W Longitude, is located within the boundaries of our watershed.

The maximum precipitation in a 24-hour period for each year of the 16-year data was used to calculate a mean of 80.7 mm (3.18 in) and standard deviation of 37.1 mm (1.46 in) for the Hershfield method. The PMP that was calculated turned out to be 637 mm (25 in).

Storage Capacity Curve

The storage capacity curve is an effective graphical representation of the influence of a dam on reservoir capacity versus elevation. This curve is generated via the Detention Basin Calculator in WMS. The height specification for our dam site called for an elevation of 31 meters. According to our WMS model, the elevation above sea level of the base of our dam site was approximately 25 meters. This specification called for a retaining wall that reached an elevation of 56 m for the dam. Using this information, an outlet restriction was made at our dam site in the WMS model that prevented flow until an elevation of 56 meters was achieved. The volume of water that accumulated upstream from the dam site due to this outlet restriction was plotted versus the elevation of the water surface. This can be seen in Figure 2 below:

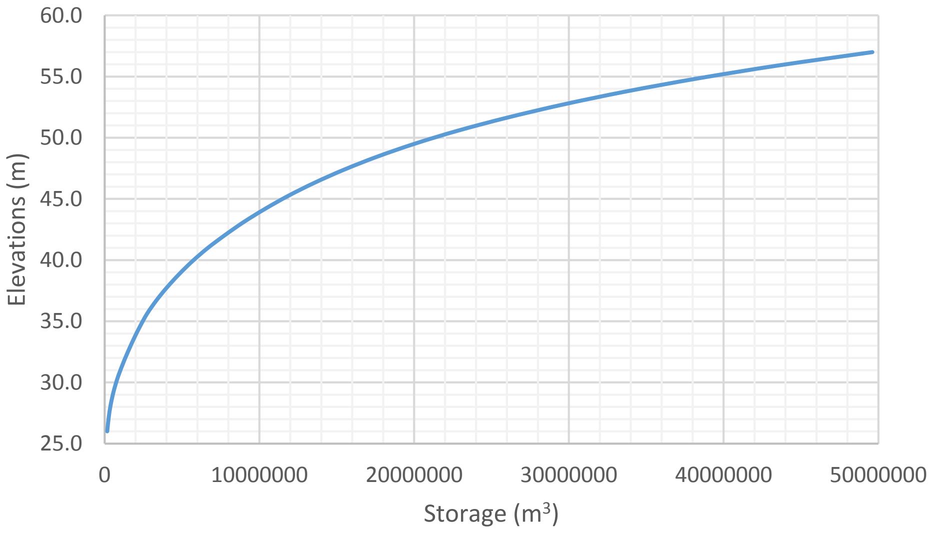


Figure 2: Storage capacity curve for a 5 meter high dam at the dam site.

As illustrated in Figure 2 above, the storage capacity curve can be best described as a concave down, increasing power function. Using the tools in Microsoft Excel, a trend-line equation was produced to accurately determine any desired storage value along this curve given a particular elevation. The equation is written below in Figure 3:

$$y = 8 * 10^{-5} x^{6.7531}$$

Figure 3: Equation derived from trend-line that follows the storage capacity curve.

In the Figure 3 above y is the storage (m^3), and x is the elevation (m). At the height of the dam, where elevation is 56 meters, the dam is predicted to store 50 million m^3 of water, before the water spills over the top of the dam. This amount of water can be effectively utilized for irrigation, plumbing, and hydroelectric power for the surrounding communities, especially in times of drought.

Mass Curve

The mass curve diagram is a graph of the cumulative flow of a river that occurs during a certain period of time. Time for these kinds of graphs are usually measured in years, months, or days. Because direct stream flow data was not available at the Naranjo de China weather station, precipitation data and curve number information were used to calculate possible stream flow values during the 16 years of collected data. With a runoff coefficient of 0.52 and a watershed area of 144 km^2, the volume of discharge was computed and plotted in Figure 4 below.

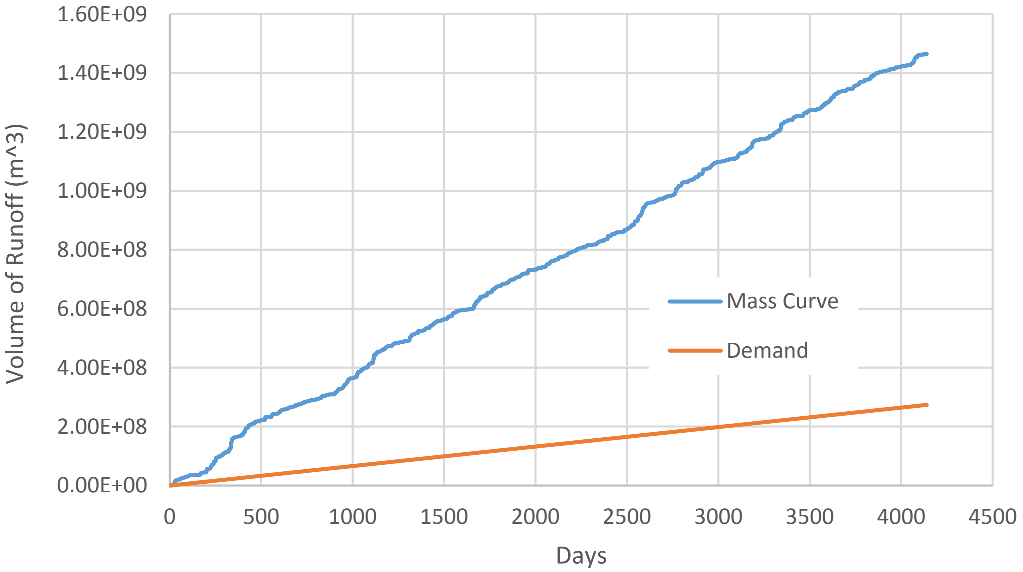


Figure 4: Mass curve diagram and demand line based on 16 yr of rainfall data.

As is illustrated in Figure 4 above, the mass curve diagram is indicated by the blue line. The orange line represents the demand for water in the area. This demand for water is based on evapotranspiration and domestic water usage. The volume of water that is depleted in the process of evapotranspiration was calculated using the Curve Number report produced by WMS and the Blaney and Criddle equation (Wanielista et al, 125). The volume of water that is depleted by domestic use was based on the population density of the area and the statistical water usage per capita per year in the Dominican Republic. The sum of these demands was calculated to be approximately 66,000 m^3/day. It is apparent In Figure 4 that the mass curve diagram has a much steeper slope than the demand line. This implies that, if the water demand in the area continues to be the same, the flow of the Maimon River will have enough discharge to supply the surrounding area with their irrigation and public water needs without having to store any water in a reservoir. However, if this area grew in agriculture and population, water usage would increase and small amounts of storage would be required during dry periods of the year. Assuming that economic growth will occur in this area, it is recommended that a dam be built to prepare against droughts and increased water demand.

Flow Duration Curve

The flow duration curve is a cumulative frequency curve that gives a discharge that was equaled or surpassed for a percentage of time data was recorded. Due to the lack of discharge data for the Maimon River, empirical equations were utilized to generate a flow duration curve based on watershed area, average slope, curve number, and annual precipitation. This information was obtained via the watershed delineation wizard in WMS, land use and soil type shape files, and ArcGIS precipitation files. The information in Table 1 lists these values:

Table 1: General Information Used to Obtain the Flow Duration Curve

Parameter	Value	Unit
Watershed Area:	144.73	km^2
Average Slope:	0.14	m/m
Curve Number:	53	
Annual Precipitation:	1600	mm

The equations that used the values in Table 1 to generate specific points on the flow duration curve can be seen in Figure 5 below:

$$Q_{99} = 7.683 * 10^{2} * A^{0.729} * P^{0.916} * CN^{-3.826} * S^{0.380}$$

$$Q_{95} = 2.785 * 10^{4} * A^{0.695} * P^{0.362} * CN^{-3.553} * S^{0.473}$$

$$Q_{90} = 1.168 * 10^{4} * A^{0.640} * P^{0.292} * CN^{-3.118} * S^{0.435}$$

$$Q_{85} = 1.088 * 10^{4} * A^{0.636} * P^{0.295} * CN^{-3.071} * S^{0.430}$$

$$Q_{80} = 1.376 * 10^{4} * A^{0.643} * P^{0.319} * CN^{-3.150} * S^{0.435}$$

$$Q_{75} = 2.065 * 10^{4} * A^{0.659} * P^{0.358} * CN^{-3.312} * S^{0.444}$$

$$Q_{70} = 2.452 * 10^{4} * A^{0.673} * P^{0.397} * CN^{-3.413} * S^{0.450}$$

$$Q_{60} = 2.836 * 10^{4} * A^{0.699} * P^{0.484} * CN^{-3.584} * S^{0.464}$$

$$Q_{50} = Q_{mean} = 4.070 * 10^{4} * A^{0.713} * P^{0.551} * CN^{-3.758} * S^{0.472}$$

$$Q_{40} = 2.734 * 10^{4} * A^{0.666} * P^{0.681} * CN^{-3.789} * S^{0.432}$$

$$Q_{30} = 8.512 * 10^{4} * A^{0.717} * P^{0.611} * CN^{-3.954} * S^{0.461}$$

$$Q_{20} = 3.221 * 10^{5} * A^{0.740} * P^{0.603} * CN^{-4.218} * S^{0.484}$$

Figure 5: Empirical equations used to generate the flow duration curve.

In the equations above, Q_{per} represents flow, *per* represents a certain percentage of time, A represents the area of the watershed, P represents average annual precipitation of the watershed, CN represents the Curve Number of the watershed, and S represents the average slope of the watershed.

The solutions for these equations are tabulated in Table 2 below in m^3/s and ft^3/s.

Table 2: Discharge Found for Each Percentage of Occurrence

Percent	Discharge (m^3/s)	Discharge (ft^3/s)
99	2.98	105.17
95	3.77	133.04
90	4.35	153.45
85	4.94	174.36
80	5.59	197.23
75	6.25	220.69
70	7.02	247.92
60	8.66	305.93

50	10.78	380.70
40	14.31	505.22
30	16.81	593.40
20	22.52	795.27

The flow duration curve generated from the values in Table 2 is illustrated below in Figure 6. It shows the discharge (m^3/s) vs. the percentage of occurrence. Flow of the river will be approximately 3 m^3/sec or greater 99% of the time. On the other hand, 20% the time flow has a chance of reaching 22.5 m^3/sec in the Maimon River.

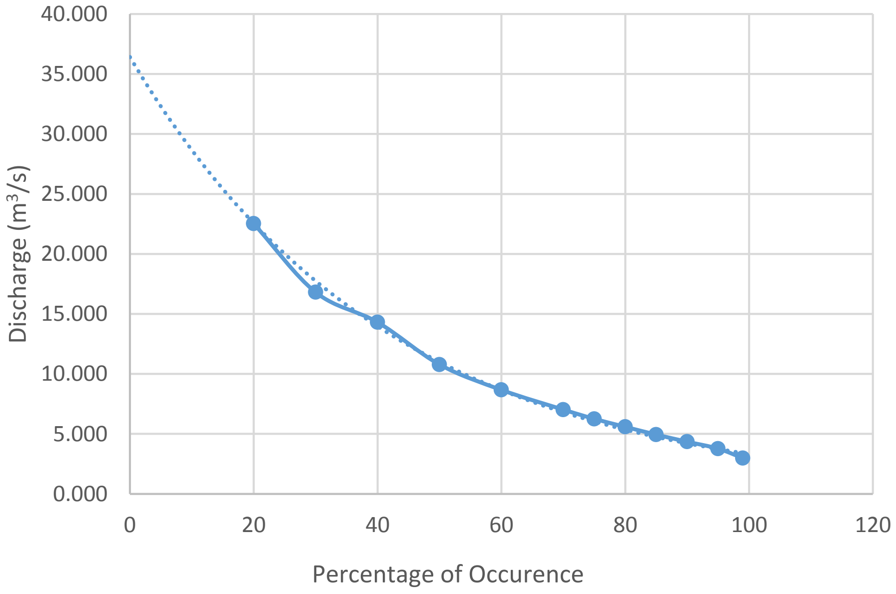


Figure 6: Flow duration curve of the Maimon River based on empirical equations.

Numerical Models

Introduction to the Models

The models used in this report were generated via WMS. WMS is a water modeling system created by Aquaveo to simulate various hydrologic occurrences. This software gives engineers the ability to accurately predict the outcome of hydrologic simulations. Models produced in this system can be used in HMS as well. GSSHA models were produced within the WMS program as well to more accurately predict flooding based on terrain.

Model Execution

The models were used to simulate flow with input precipitation values of 10-, 25-, 50-, 100-year storms and a PMP storm. The storm precipitation values were calculated using two separate methods. One set of values came from various isohyetal maps of the Dominican Republic found in the National Atlas. The other set of values came from the interpolation of 16 years of precipitation data using the Weibull Method (Wanielista 43-45). There was not hourly rainfall data to represent the behavior during a 24-hour storm; only total rainfall volume was available. To represent the behavior of the storm, the model was simulated using a standard 24-hour Type II storm. This value was chosen because it most accurately represents a storm that would occur in the watershed, although it is a generalization. A Curve Number was calculated using soil type and land use shape files obtained from INDRHI, which were specific to the watershed. The Curve Number was found to be 53. Although this is a low value for a curve number, it was the closest representation that could be found from the supplied information. Using the Curve Number, a time of concentration was found for the watershed during a specified storm. This number was used in the model to calculate runoff from a storm.

HMS Models

By using HMS, behaviors of the watershed during a storm were quantified. Total precipitation volume for various return periods were found from the Atlas maps provided by INDRHI. These values were input into the model to find runoff for each storm. The model was executed four times with four different precipitation values, outputting a runoff graph for each return period. The precipitation values from the Atlas are represented in Table 3.

Table 3: Precipitation Values from Atlas used in HMS Models

Return Period	Precipitation (mm)	Precipitation (in)
10	150	5.91
25	215	8.46
50	225	8.86
100	375	14.76

The graph depicted in Figure 7 shows the runoff behavior of each of the return period values from Table 3. It can be noted that the Atlas values for the 25- and 50-year storm are nearly the same, leading to a similar runoff graph.

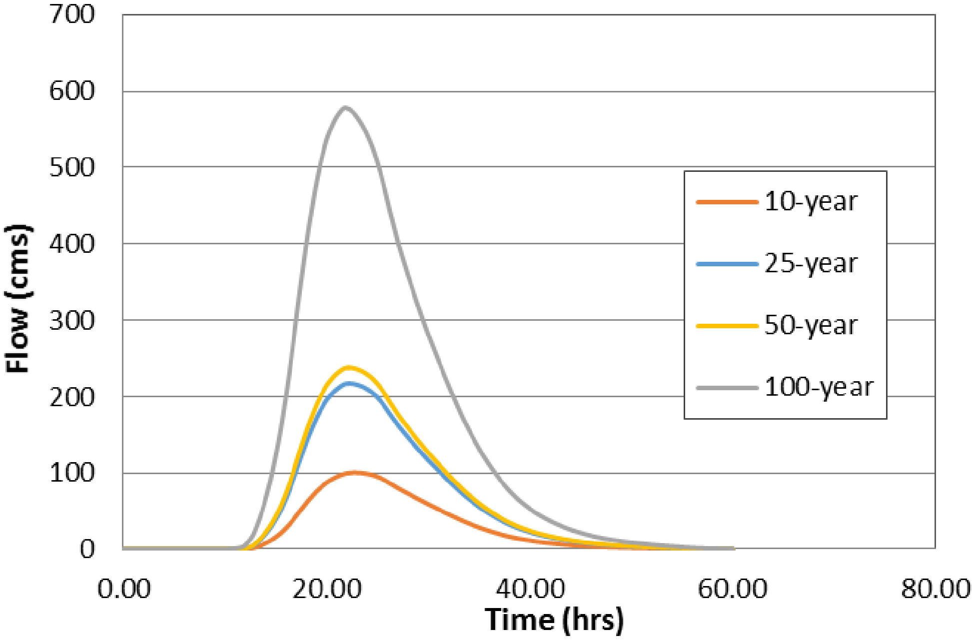


Figure 7: Hydrographs for various storms generated in HMS using Atlas data.

The 100-year storm is significantly higher than the other storms. This is due to the Atlas providing inaccurate return period values. From the isohyetal maps found in the Atlas, the 100-

year storm precipitation depth for the area around the Maimon watershed was smaller than the 50-year storm precipitation depth in that same area. The storm precipitation values in the Atlas maps covered the country as a whole and were not precise enough to estimate precipitation values over the Maimon watershed. This gave exceedingly rough estimates for the watershed under inspection. The 100-year storm was taken as the highest value in the 100-year storm isohyetal map of the country, not just the value estimated over the watershed.

Since the values from the Atlas were estimated with limited accuracy, values for the return periods were also found using precipitation data. However, there were only 16 years of precipitation data available, so the Weibull Method was utilized to interpolate the precipitation values for storms that had higher return periods. The data was provided by INDRHI. The values that were input into the HMS model are shown in Table 4.

Table 4: Precipitation Values from Recorded Data Calculated Using the Weibull Method

Return Period	Precipitation (mm)	Precipitation (in)
10	137.74	5.42
25	186.02	7.32
50	217.74	8.57
100	249.45	9.82

The precipitation values in Table 4 are a more plausible representation of the actual return periods. The runoff graph that was output from these values is more accurate than the graph generated from the Atlas map values. The runoff graph for the precipitation values in Table 4 can be seen in Figure 8 below.

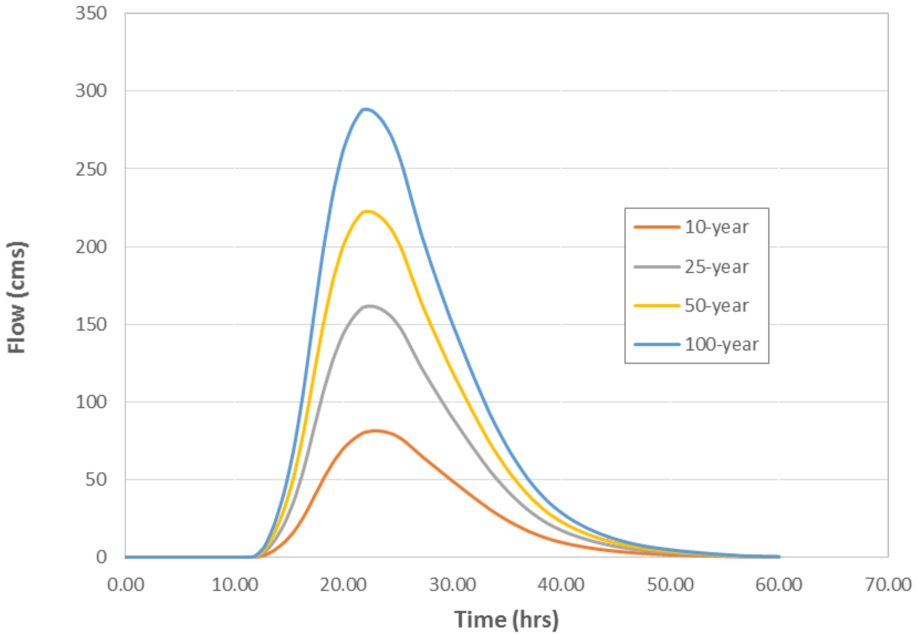
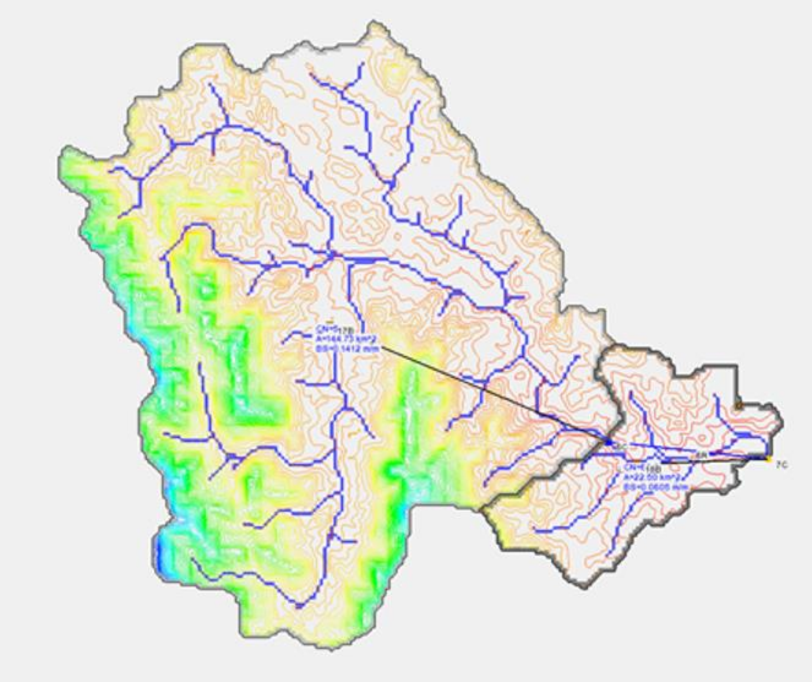


Figure 8: Hydrographs generated in HMS using precipitation data and the Weibull Method.

After the return periods were analyzed on the watershed, it was re-delineated, with a new outlet created downstream of the potential reservoir site. This was done so that the HMS models could generate data for the runoff that was both upstream and downstream of the hypothetical reservoir. The new delineated watershed is depicted in Figure 9.

Figure 9: Delineated watershed with additional outlet downstream of the dam site.



The runoff from each return period with the hypothetical reservoir in place is represented in Figure 10. To create a hypothetical reservoir in WMS, some assumptions had to be made. The base elevation was assumed to be about 23.5 meters, a weir was assumed be 6 meters in length, and the height of the weir was assumed to be 26 meters. This simulation provided information about the retention of a reservoir during each storm. It can be used to determine which storm is most likely to cause the reservoir to overflow. The frequency of overflow can be considered and proper measures of preparation can be taken accordingly.

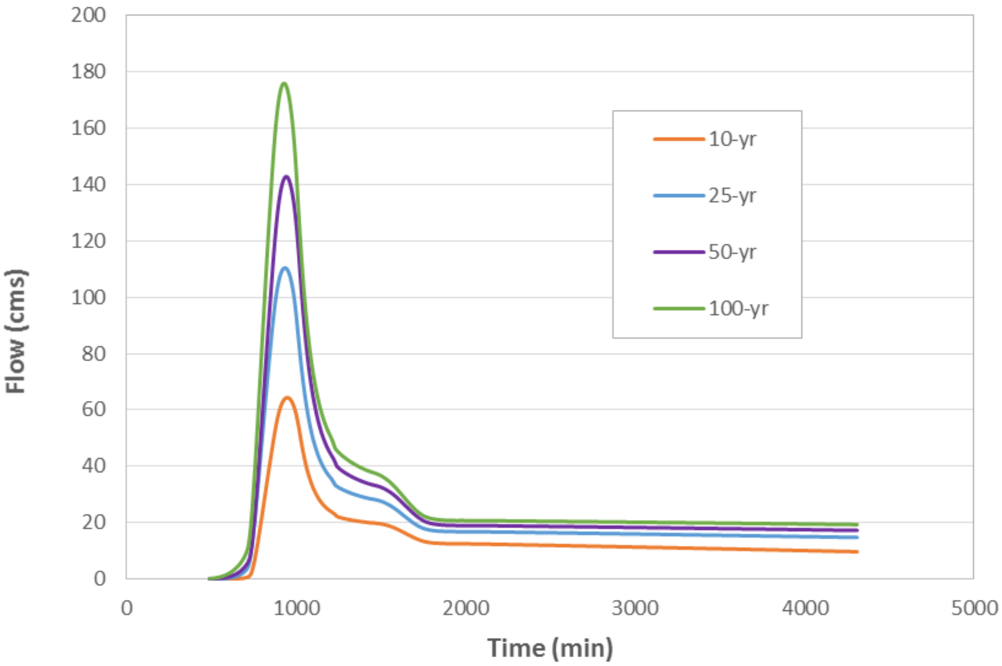


Figure 10: Dam model showing downstream flow

GSSHA Model

For the purpose of evaluating the potential flooding in the case of a dam break at the site, a Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model was built. The GSSHA model simulates stream flow generated by both infiltration-excess and saturation-excess mechanisms, as well as exfiltration, and groundwater discharge to streams. The model employs mass-conserving solutions of partial differential equations and closely links the hydrologic components to assure an overall mass balance (Downer 2004). The model area was focused downstream of the dam site to a conservative boundary area where flooding could potentially occur.

The model was composed of over 31,000 cells that were 75 x 75 meters in size. Each of these cells were associated with an infiltration rate based on the underlying soil type. The elevation associated with the cells was interpolated from the same digital elevation map that was used for the HMS model with a resolution of 30 meters as shown in Figure 11. There were two main soil types of loam and clay loam that covered the area. The dam break was simulated to take place over a very short period of time while the initial soil moisture was relatively high - this translates to the majority of the water contributing to runoff causing a more conservative scenario of water flood depth. The flow was assigned as a variable stage flow meaning that water was simulated along an arc from full-stage flow of 31-meters to empty in 1 hour. This conservative assumption implies that the dam break happens quickly. For specifics on the GSSHA model boundary conditions used, a copy of the Watershed Model System (WMS) project files can be supplied by contacting one of the authors.

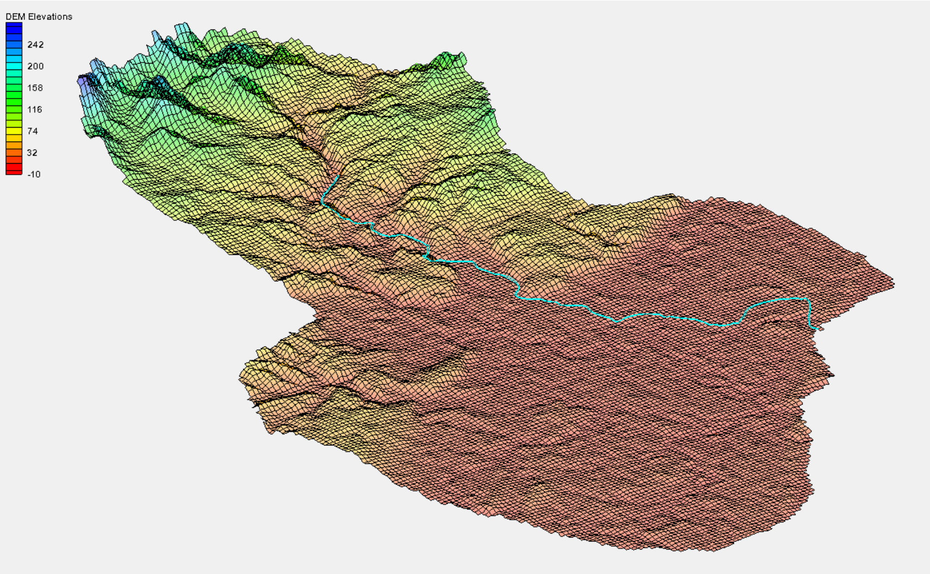


Figure 11: 3-Dimensional view of the flood plain.

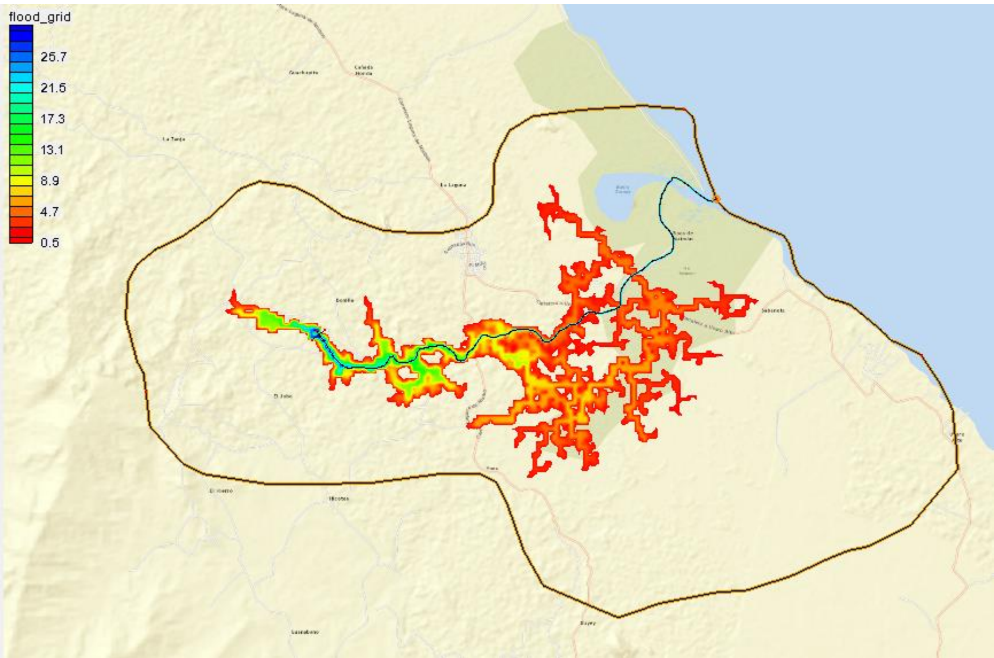


Figure 12: Color-contoured water depth of a flooding scenario.

The results of the GSSHA model suggest that deeper flooding would occur just downstream of the dam. As the water moves downstream, it decreases in depth. This is due to the widening of the floodplain as well as a decreasing steepness of slope which would allow the water to spread and cover more area compensating for depth. See Figure 12 and Figure 13, for flood mapping depths of the results.

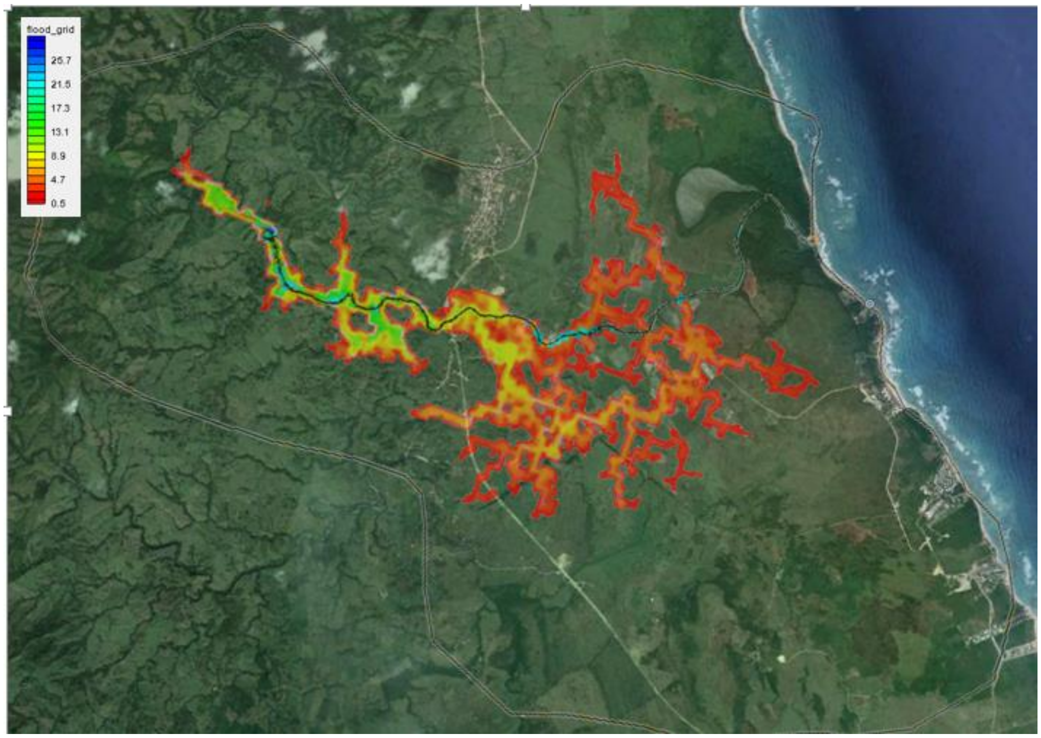
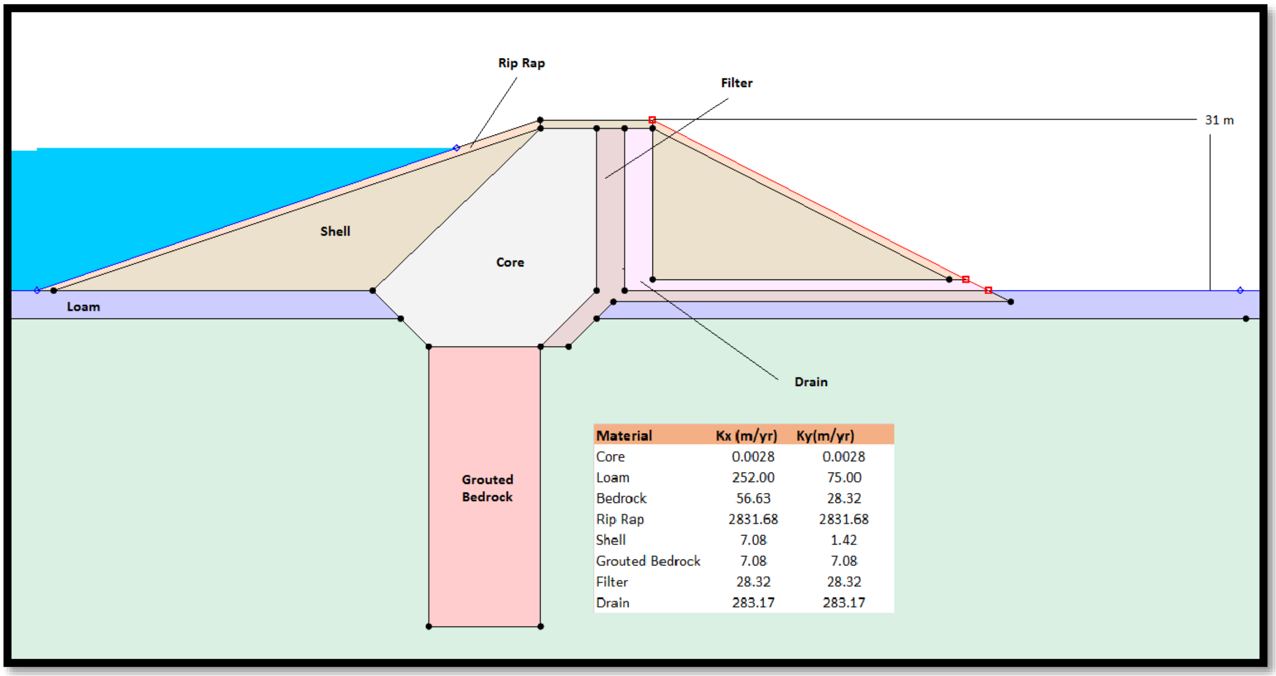


Figure 13: Color-contoured water depth of a flooding scenario.

Seepage Analysis

In attempts to understand what losses of water might contribute to seepage through the dam, a general design was chosen and a SEEP2D analysis was performed. SEEP2D is a 2D finite-element seepage analysis model designed to compute seepage on profile such as for earthen dams and levee cross sections (Kimura 1994). It was determined that the assumption constraints for this model dictated that the hydrologic structure would be an earth dam and that it should be 31 meters in height as suggested by local engineers. Using these constraints, a conceptual model was chosen using materials local to the site. Figure 14 shows the conceptual model from a 2D profile of the dam.



Material	Kx (m/yr)	Ky(m/yr)
Core	0.0028	0.0028
Loam	252.00	75.00
Bedrock	56.63	28.32
Rip Rap	2831.68	2831.68
Shell	7.08	1.42
Grouted Bedrock	7.08	7.08
Filter	28.32	28.32
Drain	283.17	283.17

Figure 14: Profile of earth dam in SEEP2D with color-coded materials.

SEEP2D is a steady state model and the result produced is an equilibrated flow over the finite element mesh. The flow output is in vector format and shows magnitude and gradients of the flow produced from the upstream head. The head used in the model was 25.5 meters from the base of the dam.

In Figure 15, it shows the contoured velocities of the flow. Notice the largest vectors or velocities are at the toe of the dam. The annual seepage flow resulted to be 653.4 (m^3/yr)/m.

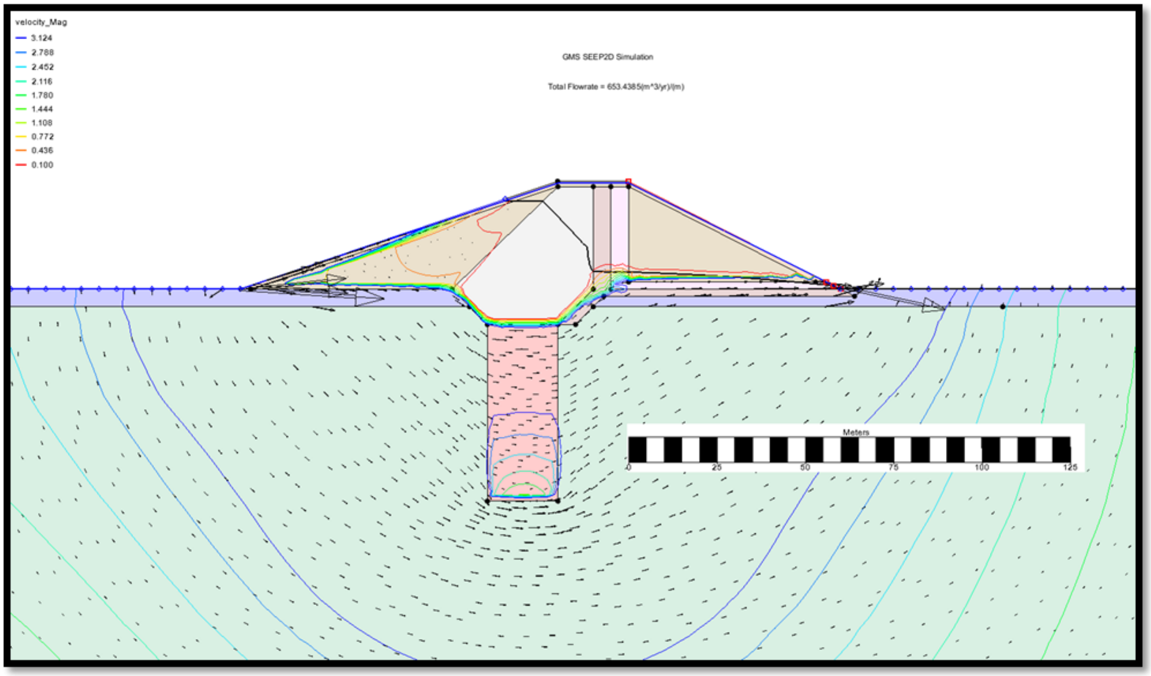


Figure 15: Profile of earth dam with gradient vectors.

Another perspective of the output of SEEP2D is shown in Figure 16. The gradients or magnitudes of significant change in velocities are shown below.

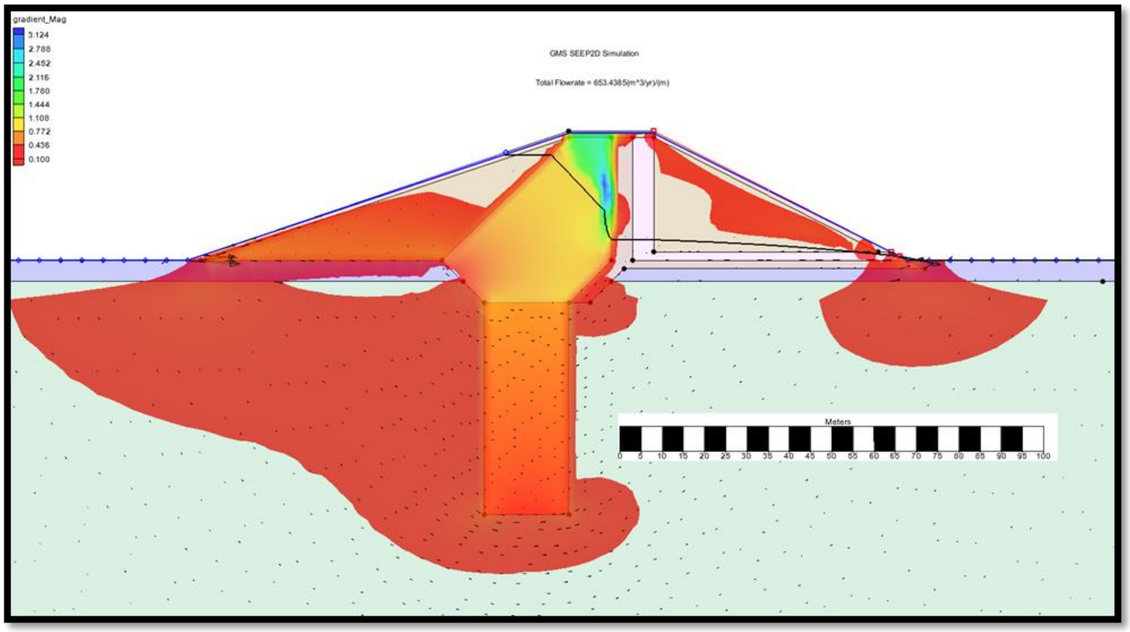


Figure 16: Profile of earth dam with velocity contours.

Hydroelectric Power

A basic analysis of hydroelectric power potential was analyzed for a dam on the Maimon River. A simple power equation was used, as seen in Figure 17 below.

$$P = \gamma H Q e$$

Figure 17: Equation for hydroelectric power

In Figure 17, P represents power, γ represents the unit weight of water (9.807 kN/m^3), H represents elevation head, Q is flow in cms and e represents efficiency.

From the flow duration curve, a flow associated with a 95% frequency in the watershed was used to calculate the hydroelectric power. The flow came out to be 3.77 cms, (133 cfs). An elevation head was used of 28 m, (91.9 ft), which was representative of a water surface elevation that is 3 meters shy of the top of the dam. Efficiency of the system was assumed to be 85%. The estimated hydroelectric power that could be generated by the dam was 878.9 kW or 1178.6 hP. This estimate represents an elementary power system with the stated assumptions. With a more involved pipe system design, a more accurate power estimate could be created. This assumption is not taking into account major or minor losses.

Environmental Assessment

Current Conditions

Figure 18: Photo of the dam site.

The watershed of Rio Maimón is surrounded by subtropical forests and grasslands. The watershed experiences little climatic deviation, though it experiences seasons of heavy rainfall or drought. Average annual temperatures stay fairly static, ranging from 25.3° C to 27° C. The relative humidity also stays somewhat constant ranging from 78% to 84%. Annual evapotranspiration is generally between 1300 and 1600 mm. The soil in the area is dominated by type III and type IV. There are large amounts of karst soil in the area. With the combination of the soil type and steep slopes, the watershed is highly susceptible to soil erosion during times of flooding. Some Class II soils may be present as well. Much of the land surrounding the Maimón River, is used for livestock grazing.

Sedimentation

For the proposed dam site in the Maimón River, sedimentation can pose a threat if ignored. Sedimentation build up will be very prominent in the reservoir considering the amount of soil erosion that occurs due to the soil type of the area. If precautions are taken to prevent sedimentation issues, the life of the dam will be extended. It is estimated that “reservoirs in the world” last “around 22 years” (Palmieri et al., 149). Sedimentation decreases the efficiency of a dam by reducing usable storage capacity, which is a common problem with many dams around the world. “With the creation of a reservoir, the river banks downstream of the impoundment become affected by accelerated erosions” (Palmieri et al., 150).

Once a dam is created, measures must be taken to stay as close to the former water-sediment equilibrium. There are many possible methods to manage sediment. One is measuring in the catchment area or by debris dams. Another is sediment routing by constructing off-stream reservoirs or sediment exclusion structures, and allowing sediment to pass through the dam. Sediment flushing is also a possibility, which increases velocities in the reservoir such that deposited sediments are re-mobilized and sent through outlets. Lastly, there is also dredging or siphoning but those can pose high costs.

Conclusion

The main economic activity that occurs in the region of Altagracia near the Maimon River is agriculture. Tourism has increased in popularity as well during the recent years. Based on domestic water usage, population, and evapotranspiration due to farming, the demand for water for these industries is modest, and does not exceed the amount of flow that the Maimon River generates during the year. If a dam was built, its main purpose would not be to supply the surrounding area with irrigation water and hydroelectric power, because the demands for such resources are relatively low compared to the flow of the river. However, if these water demands were to increase, then a dam would be a reasonable solution for these conditions in the future. Another result that would indicate the need for a dam comes from the HMS Models, which showed that the peak flow of the Maimon River could be significantly reduced during severe storms and properly regulated during droughts. A regulated flow could result in an increase in agricultural production, a decrease in the erosion of farmland soil, and an increase hydroelectric power, which could be used for the tourism industry. These benefits would merit the construction of a dam in the future, but the current demand for water and electricity has not reached a point where the benefits of building a dam exceed the costs. The analysis presented in this report could be useful for future infrastructure projects.

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Appendix

Table 5: Storage Capacity Data

Elevation (ft)	Elevation (m)	Storage (ac-ft)	Storage (m^3)
85.3	26.0	139	171051
88.81	27.1	211	260359
92.32	28.1	315	388981
95.82	29.2	465	573208
99.33	30.3	663	817528
102.84	31.3	914	1127572
106.34	32.4	1198	1477220
109.85	33.5	1507	1858597
113.36	34.6	1846	2277045
116.86	35.6	2228	2747711
120.37	36.7	2707	3339356
123.88	37.8	3265	4026830
127.38	38.8	3891	4799375
130.89	39.9	4592	5664594
134.4	41.0	5388	6646053
137.9	42.0	6297	7767258
141.41	43.1	7283	8982878
144.92	44.2	8391	10350474
148.42	45.2	9609	11852224
151.93	46.3	10983	13546869
155.44	47.4	12529	15454664
158.95	48.4	14275	17608346
162.45	49.5	16255	20050189
165.96	50.6	18526	22850964
169.47	51.7	21123	26055387
172.97	52.7	24034	29645656
176.48	53.8	27349	33734681
179.99	54.9	31124	38391497
183.49	55.9	35378	43638023
187	57.0	40224	49615803

Table 6: Yearly Precipitation Values used in the Weibull Method of Interpolation

Precipitation (mm)	Plot Position	Probability	Ex Probability	Return Period
112.5000	1	0.037	0.963	1.04
140.9000	2	0.074	0.926	1.08
155.8000	3	0.111	0.889	1.13
155.8000	4	0.148	0.852	1.17
165.4000	5	0.185	0.815	1.23
182.8000	6	0.222	0.778	1.29
183.6000	7	0.259	0.741	1.35
184.1000	8	0.296	0.704	1.42
219.8000	9	0.333	0.667	1.50
227.3000	10	0.370	0.630	1.59
232.3000	11	0.407	0.593	1.69
242.6000	12	0.444	0.556	1.80
281.0000	13	0.481	0.519	1.93
297.1000	14	0.519	0.481	2.08
297.9000	15	0.556	0.444	2.25
311.3000	16	0.593	0.407	2.45
317.9000	17	0.630	0.370	2.70
324.5000	18	0.667	0.333	3.00
350.5000	19	0.704	0.296	3.38
370.4000	20	0.741	0.259	3.86
420.0000	21	0.778	0.222	4.50
426.8000	22	0.815	0.185	5.40
454.8000	23	0.852	0.148	6.75
464.9000	24	0.889	0.111	9.00
470.1000	25	0.926	0.074	13.50
543.7000	26	0.963	0.037	27.00

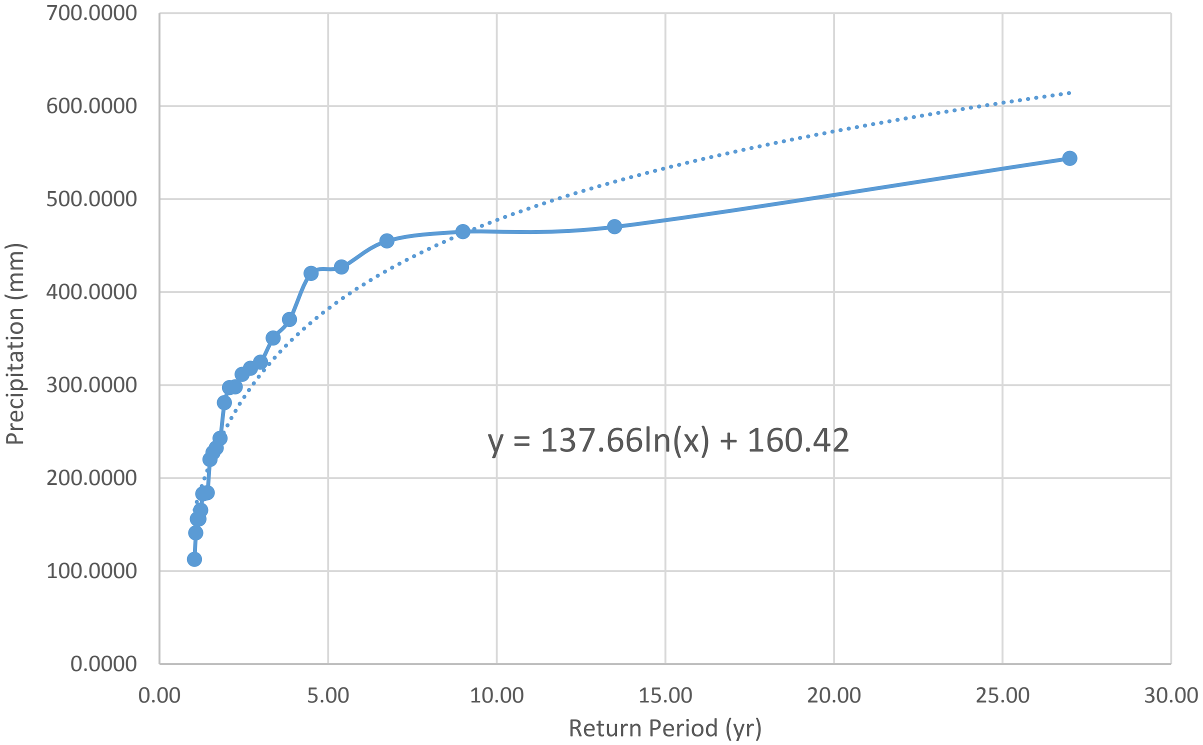

Figure 19: Weibull Method interpolation of precipitation values for high return period storms.