Impact assessment of a Hydropower Plant Reservoir in Paru River in a Brazilian Natural Conservation Unit

Term Project Final Report for CEE 6440 – GIS in Water Resources

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Introduction

Paru River is a large, yet unexplored stream flow, located in the state of Para, Brazil. It is an affluent of the Amazon River from its left margin. Paru River detains a hydropower potential that is to be explored over the next years by several hydropower plants along its course. These power plants are still in planning design stage but some of the interferences with natural resources in the region are already under assessment. The main power plant in Paru River is called A41PA008. It is situated on the river's final section, approximately 120 km upstream from its mouth and will be the biggest and most energy productive plant of Paru's hydropower complex. Figure 1 illustrates the area of study.
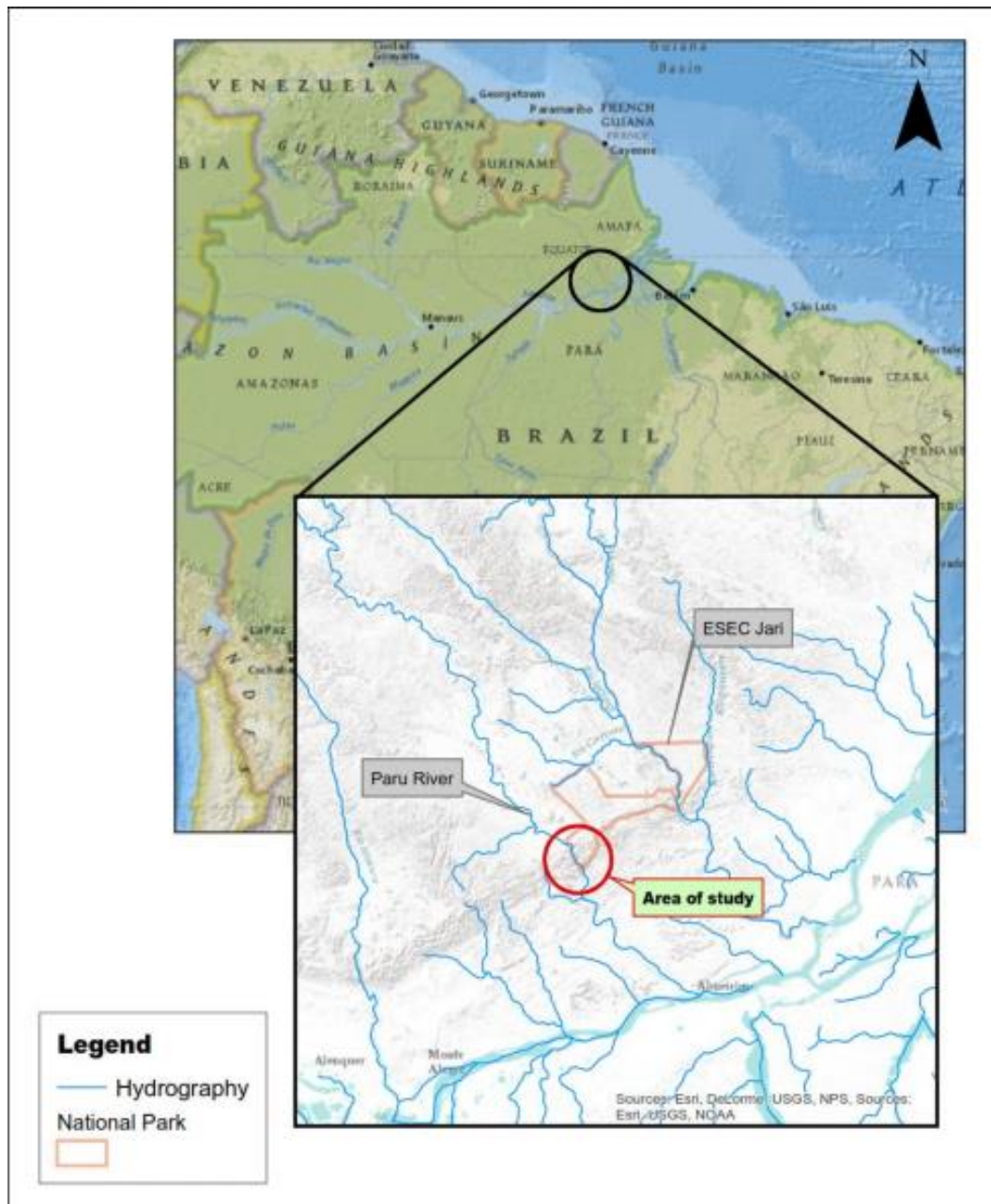

Figure 1 – Area of study

Along the development of A41PA008 design, different reservoir levels were tested in order to assess the flooding impact in the region. One special concern was the impact on Jari's Ecologic Station, a National Conservation Unit located in region in which any sort of environmental impact is strictly forbidden.

Since this power plant is an important step to provide clean and abundant energy to Brazil, the proper assessment of this impact is important to assure that the project is feasible.

Objectives

Since Jari's Ecologic Station cannot suffer any sort of environmental impact, there are three possible solutions for the mentioned issue: change the plant's design, change the conservation unit's boundaries or give up building the dam. In this project, we assume that the second solution is the best one and will be pursued.

The overreaching objective of this term project is to assess the impact of the future reservoir formed by building A41PA008 hydropower plant, using ArcMap to calculate some impacts and consequent relationships. The conclusions obtained from this project could result in a report that may convince the Brazilian authorities that the observed impact would be of such small scale in the conservation unit that changing its boundaries would not be a problem to the ecosystem of the region.

Tasks

The main tasks aimed in this project are:

1 – Calculate the total flooded area due to the hydropower plant for a given reservoir elevation using ArcMap tools

2 – Calculate, for the same given reservoir elevation, the flooded area inside the conservation unit using ArcMap tools

3 – Calculate the conservation unit area using ArcMap tools

3 – Calculate the ratio between the installed power capacity for the given reservoir elevation and the total flooded area using the ArcMap outputs from previous steps

4 – Calculate the ratio between total flooded area and flooded area inside the conservation unit using the ArcMap outputs from previous steps

Methods

ArcMap has a set of tools that were used to obtain the necessary information for this project. In order to automate the calculations, a user-defined tool was developed using Model Builder.

The necessary input data for the developed tool are the digital elevation model (DEM) the region, the feature class of conservation unit boundaries, the location of the future dam and the reservoir elevation that is going to be used for the impact assessment.

The DEM raster file was obtained from the Shuttle Radar Topography Mission (SRTM) for the study region in a 90m resolution. The feature class of the conservation unit boundaries were obtained from the ICMBio Institute website, which is the Brazilian government agency responsible for managing all the conservation units in the country. The dam geographical coordinates were obtained from its basic design.

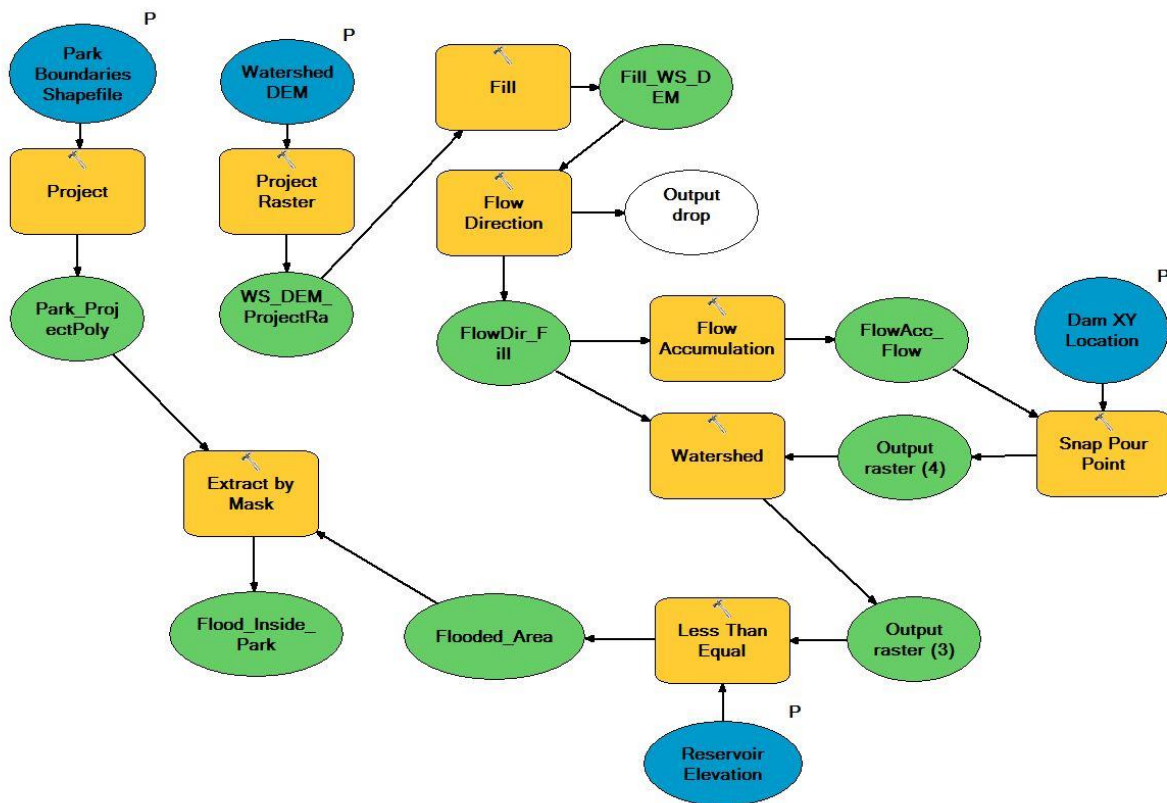Figure 2 illustrates the tool developed to perform the spatial analyses for this project:

Figure 2 – Tool developed using ArcMap Model Builder

The steps performed by the tool are:

1 – Project the DEM raster file and the conservation unit boundaries feature class into an appropriate projected coordinate system. Since we are assessing areas in the South America region, the chosen coordinate system was South America Albers Equal Area Conic.

2 – From the projected DEM raster file, obtain the catchment area of the dam, using the necessary tools to perform a watershed delineation for a given point. The output of this step is a raster file of the dam catchment area.

3 – Calculate, using the reservoir elevation as an input, the area that is equal or less this value. The output of this step is a raster file of the total flooded area for a given reservoir elevation.

4 – Extract the flooded area inside the conservation unit from the previous raster file using the unit boundaries feature class as a mask. The output of this step is a raster file of the flooded area inside the conservation unit for the given reservoir elevation.

5 – Calculate the area of the conservation unit from the same feature class used in the previous step.

From each output raster file, it is possible to obtain its area in linear units (in this case, square kilometer) by multiplying the number of cells that were less or equal than the reservoir elevation input and the area of each raster cell. The first number is obtained from the attribute table of each raster file and the second is obtained from the input raster file used in the first step.

From the data obtained in the previous calculations, it is possible to compute the two desired ratios. In order to compute the dam installed power capacity, it was necessary to use the monthly average flow time series for A41PA008 hydropower plant. The time series was obtained from the power plant basic design.

As previously mentioned, the desired ratios are:

a) $\dfrac{\text{Total Flooded Area (A1)}}{\text{Installed Power Capacity (P)}}$

b) $\dfrac{\text{Flooded Area Inside National Park (A2)}}{\text{Total Unit Area (A3)}}$

Since the available hydropower plant data is still preliminary, the installed power capacity was calculated using a simplified model described below:

E = γ.Q.H [MWavg]

- E $\rightarrow$ Firm Energy

- γ $\rightarrow$ Water specific mass x gravity x equipment efficiency x conversion factor – usually 0.0088

- Q $\rightarrow$ Monthly average flow during the Critical Period (established as the period between June 1949 and November 1956). For A41PA008, it equals 758.60 m³/s

- H $\rightarrow$ Net mean drop – in this project it will be equal the reservoir elevation minus 8, which is the tailrace elevation

P = E/Fc [MW]

- P $\rightarrow$ Installed Power Capacity

- FC $\rightarrow$ Capacity Factor – in Brazil, 0.55 for planning purposes

For each reservoir elevation, it is possible to calculate the installed power capacity and obtain the total flooded area and flooded area inside the conservation unit. Then, the desired ratios can be calculated.

Results and Discussion

The tool developed for this project was used to assess several input reservoir elevation options, providing a set of outputs for analysis. The following example shows calculation steps for the reservoir elevation equals to 100 meters:

$E = 0.0088 \times (100-8) \times 758.6$

$\quad = 614.15$ MWavg

$A2 = 1.16$ km^2

$A3 = 2310$ km^2

$P = 614.15 / 0.55$

$\quad = 1116.66$ MW

$A1 = 101.92$ km^2

A1/P = 0.091 km^2/MW

A2/A3 = 0.05%

For this case, we can see that the first ratio equals 0.091km^2 and the second one, 0.05%. Table 1 contains the areas and the ratios obtained for different reservoir elevations:

Table 1 – Ratios for different reservoir elevations

Cell # below elevation	Cell # inside unit	Cell area (m2)	Elevation	A1 (km2)	A2 (km2)	A3 (km2)	E (MWavg)	P (MW)	A1/P (km2/MW)	A2/A3 (%)
8250	75	9344.51	92	77.09	0.70	2310.76	560.76	1019.56	0.076	0.03%
8829	79	9344.51	94	82.50	0.74	2310.76	574.11	1043.83	0.079	0.03%
9470	97	9344.51	96	88.49	0.91	2310.76	587.46	1068.11	0.083	0.04%
10170	111	9344.51	98	95.03	1.04	2310.76	600.81	1092.38	0.087	0.04%
10906	124	9344.51	100	101.91	1.16	2310.76	614.16	1116.66	0.091	0.05%
11662	140	9344.51	102	108.98	1.31	2310.76	627.51	1140.93	0.096	0.06%
15438	235	9344.51	110	144.26	2.20	2310.76	680.92	1238.04	0.117	0.10%
19455	342	9344.51	115	181.80	3.20	2310.76	714.30	1298.72	0.140	0.14%
25391	511	9344.51	120	237.27	4.78	2310.76	747.68	1359.41	0.175	0.21%

We can compare these numbers with other hydropower plants in Brazil and in other countries.

Table 2 – A/P ratios of hydropower plants in the world

Plant	Location	Power Capacity (MW)	Flooded area (km2)	A/P Ratio
Belo Monte	Brazil	11,187.00	440.0	0.039
Jirau	Brazil	3,900.00	258.0	0.066
Santo Antônio	Brazil	3,580.00	271.3	0.076
Three Gorges	China	22,500.00	1045.0	0.046
Itaipu	Brazil/Paraguay	14,000.00	1350.0	0.096

Comparing the A/P ratios, we see that A41PA008, for a range of elevation from 92 up to 102, is not different from other power plants.

It can also be seen that for A41PA008, we can generate a reasonable amount of energy for all the different elevations used as in input. This is an indicative that the power plant flood impact is not large when compared to its energetic benefit.

The analysis of the second ratio, which illustrates how much of the park is actually flooded, shows that only a small portion of the conservation unit is affected, even when considering higher reservoir elevations. This is also an indicative that, regarding the flooded area inside the conservation unit, the reservoir impact does not seem to be relevant.

For all reservoir elevations that were assessed, it seems that the values between 94 and 102 have similar impact, generating a reasonable amount of energy and not increasing by much the total flooded area. So the highest elevation in this range could be chosen a more accurate assessment during the hydropower plant design. Figure 2 shows a map for this reservoir elevation, showing the impacted areas.
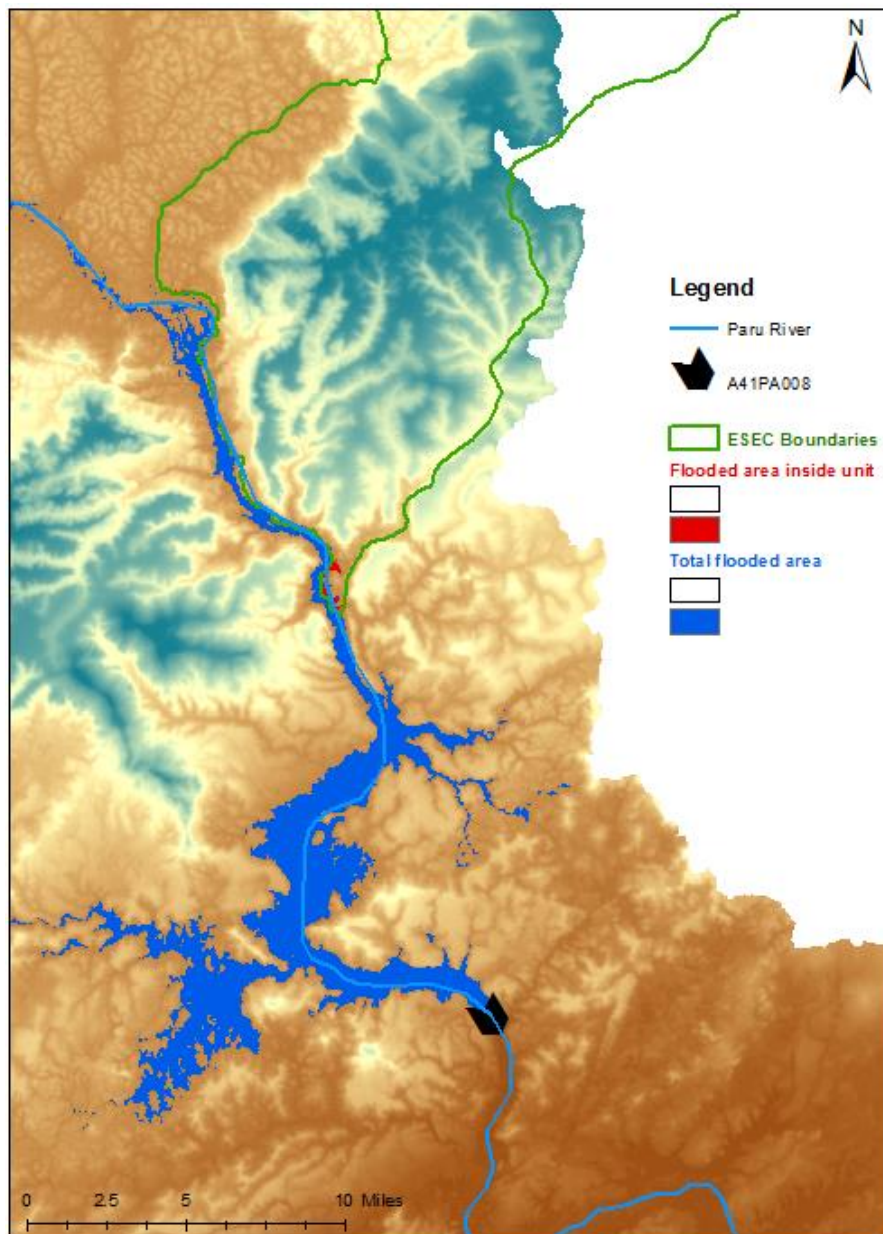

Figure 3 – Map of the impacted area for 102 m reservoir elevation

Important considerations

Every spatial analysis performed using a digital elevation model is as good as the input model resolution. In this case, it was used a 90m elevation model resolution. According to Ozah and Kufoniyi (2008), the maximum vertical precision that can be obtained from a digital elevation model of this resolution is ±16m. For a flood impact analysis in a region as plane as the Amazon watershed, this is not the ideal scenario. For a more accurate assessment of A41PA008 impact, it would be required to obtain a DEM with better resolution, possibly obtained using LIDAR or field measurements. The analysis performed in this project and the conclusions obtained must consider this aspect.

Another important aspect to consider is that the formulation used to calculate the installed power capacity is simplified, usually used for planning purposes. A better estimate of the energy generation capacity of the plant can be obtained using simulation tools. Hence, a more accurate A/P ratio could be calculated.

Finally, in this project it is assumed that the reservoir has no leaking points. In a more advanced design stage, leaking points could be identified, and by building levees to contain the reservoir, it would be possible to decrease the total flooded area.

Conclusion

The use of ArcMap and the development of a user-defined tool to assess the impact of a hydropower plant reservoir in the Paru River region proved to be effective, enabling anyone who has access to the software to obtain the necessary information to perform this analysis with little effort.

The tool that was developed can be used for any other region where this kind of impact is present, and with a few modifications could also be used to obtain different types of information such as the volume of the future reservoir or the impact in more than one area of interest.

Regarding A41PA008 impact inside Jari's Ecologic Station, it is possible to conclude that, from the perspective of flooded area and energy production, the negative impacts are not relevant and this project should not be discarded based on the fact that the conservation unit cannot be affected. Since this hydropower plant is of great interest for the Brazilian electrical energy generation expansion, different approaches to this issue should be considered.

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