EVALUATION OF FLOOD CONTROL COUNTERMEASURES CONSIDERING CLIMATE CHANGE -CASE STUDY: ITAJAÍ RIVER BASIN, BRAZIL-

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ABSTRACT

In southern Brazil there is a watershed with many past disasters occurrences involving flooding recorded last 50 years. This target area, Itajaí-Açú River basin, suffered its worst one in 2008, and received a plan from JICA to improve flood control. It should include 8 new small dams and high ups for two dams out of three already existing. However, only the high ups were completed in April of 2015. Through flood simulations by Rainfall-Runnoff-Inundation (RRI) model, this work evaluated the efficiency of those adopted countermeasures. Regarding the climate change results, annual maximum five-day precipitation (RX5Day) were identified for future climate projections (2075-2099) under RCP 8.5 scenario with four different SST distributions. Results showed that values for RX5Day should increase and extreme discharge may occur for values twice higher than the actual ones. Flood simulation by RRI showed that inundation depths may increase almost 50% on downstream area if none retarding countermeasures facilities be adopted for upstream areas.

Keywords: Flood simulation, Climate change, Itajaí River basin, RRI model.

INTRODUCTION

Brazil is a country located in South America continent and this thesis work approaches about flood disaster countermeasures taken by different government levels regarding a river basin located at southern region of Brazil, and about its experiences and results from that. This watershed gathers a historical over disasters occurrences involving flooding and bringing many direct and indirect damages to the population that lives there and causing major losses to local public authorities. The first record of flooding was set out in 1853 and the most critical cases was recorded in 2008. That coastal basin, named as Itajaí-Açú River Basin, is presented in Figure 1.

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After 2008 disaster, State Government of Santa Catarina negotiated with Japan International Cooperation Agency (JICA) support activities. From this International Cooperation Term, the “Integrated Plan for Prevention and Mitigation of Natural Disasters on Itajaí River Basin” was presented in 2011 and the main point of this plan was the change of configuration on the dam system for upstream areas.

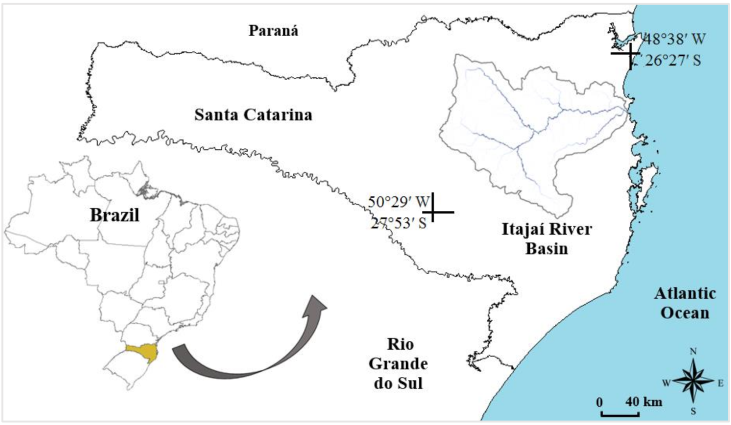
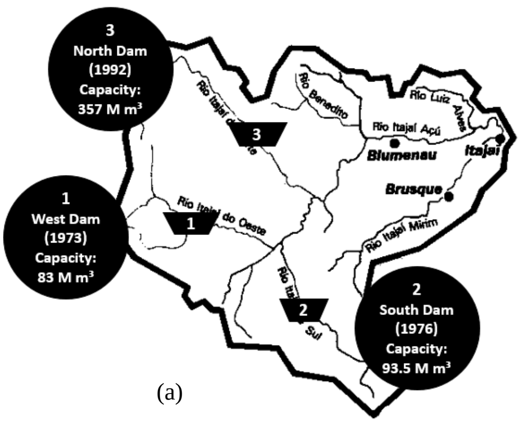
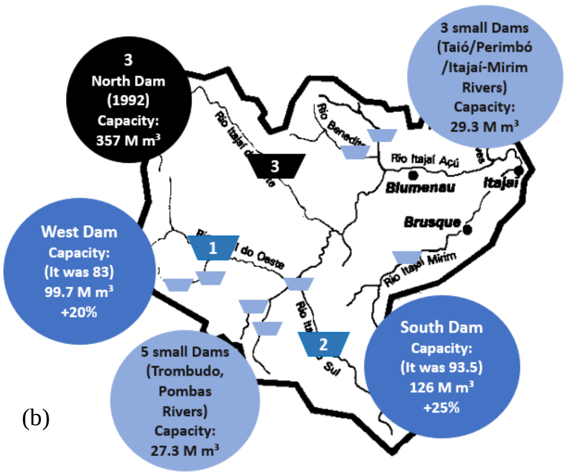


Figure 1: Map of target area, within Brazilian territory.

The basin had, basically, three dams addressed for flood control, North, West and South Dams, respectively, shown by Figure 2 (a). And JICA Plan suggested that West and South should be heighted-up. Together with these two sizing ups, JICA suggested to build more 8 small dams within upstream areas. Thus, the product of JICA studies suggested a total increasing of 105.8 M m³ for reservoir capacity, represented by Figure 2 (b). However, due to problems related to environmental licensing, lack of financial resources and other conflicts, State of Santa Catarina Government only concluded the two sizing ups for the already existing dams, west and south, so far. Therefore, the actual configuration of the dam system is exhibited on the third piece, Figure 2 (c):





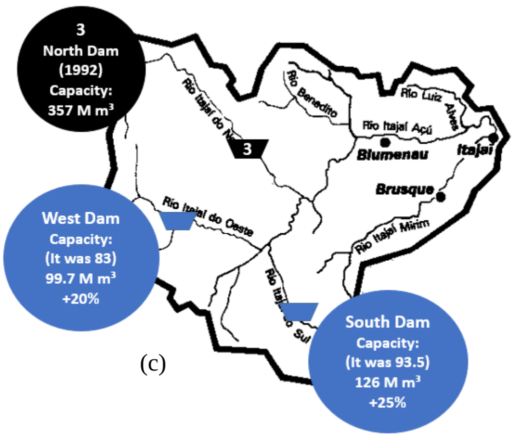


Figure 2: Different configurations for dams within the target area based on previous structure (a), planned one (b) and the actual scenario (c).

The main objective of this study is to evaluate the high ups of dam through simulations by Rainfall Runoff Inundation (RRI) model (Sayama, 2015), and after that, verify if the governments are taking into account the global warming and the change of climate patterns.

METHODOLOGY AND DATA

Considering specifically the Itajai Basin area, Marengo (2015), produced a map of vulnerability to flash floods for 2071-2100, and my target area would suffer from very high vulnerability. Based on that, society needs to be prepared for natural disasters to happen in a higher scale and more frequently. The Federal Government is already investing in counter measures aiming the flood control on that area, even considering a longer project return period (RP) than before. Nowadays, all the works which are under developing, has a minimum project RP of 50 years, before it was 25 years. Therefore, main route for this methodology can be pointed as first, proceed with flood simulation: Calibrate/validate RRI with extreme events of 2008 and 2011. Verify the effects of already built countermeasures (high-ups). Second, assess the climate change: Check if the basin countermeasures are getting well adapted to the climate change, using General Circulation Model (GCM) projections, bias-corrected with Global Meteorological Forcing Dataset (PGF), elaborated by Princeton (Sheffield et al, 2006). Finally, using inundation maps for observed rainfall and future projected rainfall (future climate) considering different scenarios – with High-Ups – and for hypothetical scenario - without High-Ups- for 2011 modified dataset event, I could evaluate efficiency of countermeasures adopted so far and under developing. Regarding the data, for executing this study, rainfall data was taken from the Brazilian Hydrological Information System (SISRH), online platform, called Hidroweb, for all simulated events and historical series on climate change assessment. Terrain data was 30 arc sec mesh resolution Digital Elevation Model data on USGS Hydrosheds website. Validation data were taken from reports about past disasters and through local civil defenses websites surveys. For climate change, I had dam coordinates, daily precipitation datasets projected with MRI-AGCM3.2S, bias-corrected using PGF as reference dataset (Inomata et al, 2011). After that, gridded daily precipitation dataset could be generated. One dataset for each dam grid. After the validation of these datasets, I computed annual maximum five-day precipitation (RX5Day) for future climate projections (2075-2099) under RCP 8.5 scenario with four different Sea Surface Temperature (SST) distributions according to Kito (2016), for each dam grid, and computed different ratios for future climates relative to present climate (PC) projection with MRI-AGCM3.2S (Bias-Corrected). From that relations, I used the maximum ratio for West Dam, critical case among all, and took that value for calculating my design precipitation for future extreme events for each dam. And compare them with present/observed values. This procedure is represented on Table 1. Finally, I produced inundation maps for my expected design rainfall and compared the effects with actual situation.

RESULTS AND DISCUSSION

Flood Simulation

Among all three cases of rainfall data I had, the best one for calibrating and validating RRI model parameters was 2008, because dam effect was small, rainfall was concentrated in lower basin and I also had more stations data. After running and calibrating, model outputs for discharge had the same peaks patterns that the observed ones, shown in Figure 3, and they were around 3,370 m³/s and 3,540 m³/s for the simulated one and observed, respectively. Regarding water level, simulated output got by RRI was 11.6 m, while the real observed one, for that station was 11.5 m, on that occasion. Therefore, after this calibration, parameters setting was completed and I made simulations for the other rainfall cases, 2011 and 2015. For using boundary conditions I utilized CUI version of RRI model and input all just after dam observed water levels downstream points after barrage I had for 2011 case – as boundary conditions – for evaluating high-up effects in Blumenau station point. Then, I could compare the different scenarios of dams (before high ups and after it).

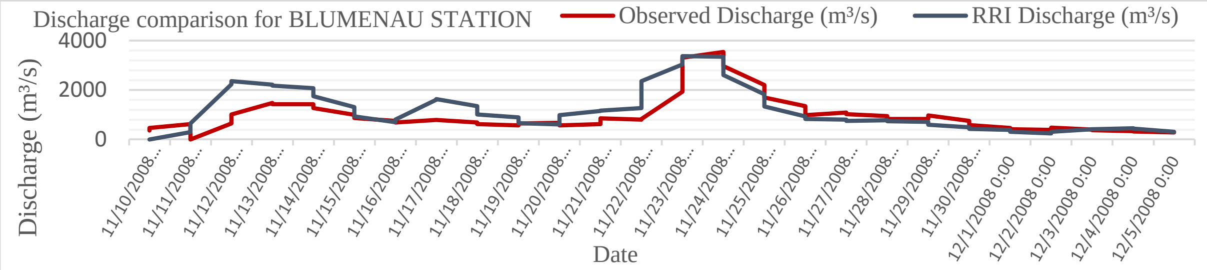


Figure 3: Comparison between RRI discharge and observed one for Blumenau river station

After running simulations, I could observe a positive effects for wider rainfall distribution cases, as this of 2011. For Blumenau location, I got reduction around 10-15% of discharge due to the high-ups works. Observing the West Dam records, still for 2011 case, from the stretch period where occurred overflow, the maximum overflow height was 1.65 m. So, if the high ups were already built on that time, there was no overflow occurring. First, the point selected for getting the outputs from simulation was Blumenau station. This is a very representative local because, besides its large floods historical, it concentrates many of upstream flow contribution suddenly. And it has 11,8 km² of catchment area, that is 76% of basin total area. As presented by Figure 4, for this simulation, although the two lines did not obey exactly the same route, their discharge peaks before the overflow happens had same values. However, after the overflow happened, on September 9th, the peaks changed and the "With High Ups" situation had a reduction of discharge of 10 to 15% for the flood peak days.

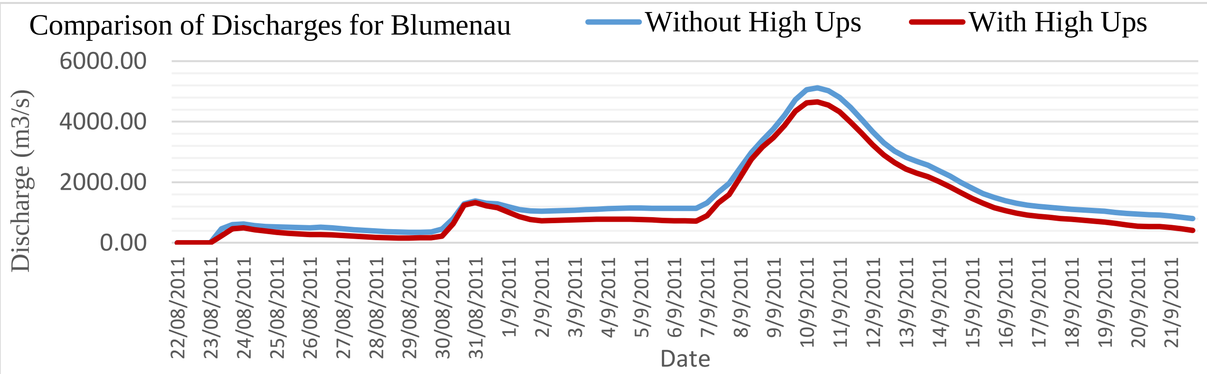


Figure 4: Comparison of discharges considering the adoption or non-adoption of High Ups for Blumenau

Nevertheless, Blumenau it is located on downstream area, these High Ups effects were not so highlighted. Then I chose a more upstream area location, Rio do Sul, just after the junction of West-Itajaí and South-Itajaí rivers, creating Itajaí-Açú River, gathering both high ups effects. And for that critical area, I got more clear outputs. The average of reduction of discharge values considering high-ups for that 2011 case was around 40%.

Climate Change Assessment

After these evidences of high ups efficiency, I had to consider the climate change effects regarding flood control counter measures adopted or under developing. After identifying RX5Day for each dam location and for each different four types of SST, SFA, SFA 1, SFA 2 and SFA 3 for future climate projections (2075-2099) under RCP 8.5, I divided the values by the present climate projection BC. After getting all relations, presented by Table 1, I decided to use the maximum ratio for West Dam - the most critical case due to lower storage capacity among that three and also located on higher value of isohyets, and adopted that value, 1.725, for calculating my design precipitation for future extreme events for all three dams. Applying this increasing rate for future rainfall expected on that grids and catchment areas, I compared them with present/observed values for that 2011 case. Therefore, I elaborated the design rainfall for the future, considering climate change trending using 2011 event rainfall data multiplied by obtained ratio between future/present rainfalls. I applied the ratio only for the flood peak of 2011 event, days between September 1st and 10th. Then, I ran RRI with my 2011 dataset multiplied by the ratio only during that period. Finally, compared my outputs between two situations: Considering and not considering the adoptions oh the High Ups. The first one I called "HU" and second one "WHU".

Table 1: Ratios of calculated RX5Day of Future Climate (SFA's) relative to Present Climate Projection (PC) in South, West and North dams.

	Ratio 1 SFA/ PC	**Ratio 2** SFA1/ PC	**Ratio 3** SFA2/ PC	**Ratio 4** SFA3/PC
SOUTH DAM	1.469	1.237	1.326	1.302
WEST DAM	1.095	1.347	**1.725**	1.606
NORTH DAM	2.387	1.240	1.330	1.577

After running this future projected rainfall, I got much larger values for discharge in future scenario, the maximum ever recorded so far is around 5,500 m³/s on Blumenau location and it reached approximately twice of it. Applying the "HU" or "WHU" on the dam conditions, I got the differences for discharge on Blumenau Station point. But, as I multiplied the ratio by only the peak days, my results were limited to that days almost. Although there was also a difference between both scenarios even a little before overflow days occur, due to some running model factor I did not considered here, the most important information is to observe the very clear and big potential of discharge increasing and also the reduction of discharge occurred due HU adoption, showed by the Figure 4.

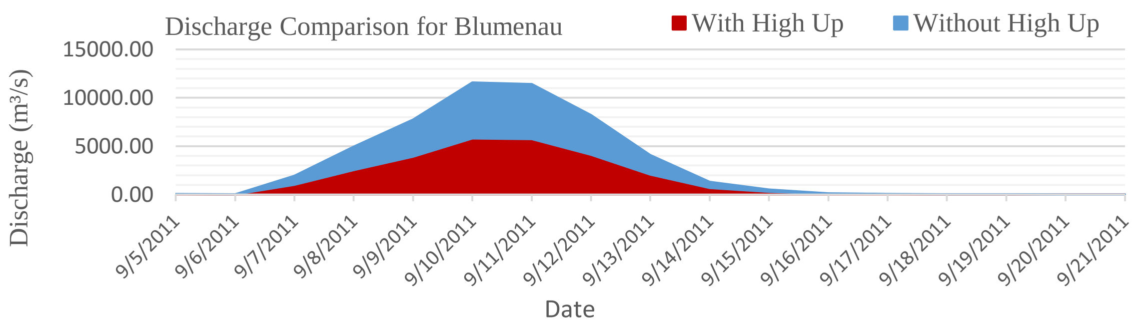


Figure 5: Discharge results considering the ratio of 1.725 for rainfall on downstream area

However it is very clear to notice a very big potential of discharge increasing (almost double) and also the reductions of discharge occurred due the High Ups adoption. After this RRI stage, I was able to make my considerations about climate change on the basin. Because, from my outputs, I was already able to have some conclusions but not enough to analyze clearly about the Disaster Risk Reduction (DRR) suggestions within the basin area. At last, in practice, I got all my outputs from simulations and

Figure 6: Different inundation patterns between cases X, Y and Z, respectively.

transformed them into inundation maps, assuming different scenarios. For Case X, I considered what really happened in 2011, with the real rainfall data and adopting "WHU" at that occasion. For future climate one scenarios, on Case Y, the same conditions were adopted, "WHU", but for the future expected rainfall (design rainfall with 1.725 increase for peak days), and for Case Z, I considered the adoption of the countermeasures, "HU" scenario, for that same expected rainfall in future. Regarding the inundation maps, I compared them and it is clear to see that between Case X and Case Y, I got much different inundation patterns and points. There was almost 50% deeper inundation depth for future one. Maximum inundation depth for Case X was 13m and for Case Y was 19 m. Finally, applying the future rainfall for the actual scenario of dams, "HU", on case Z, I got a very good reduction of inundation area, but still happening inundation on key points in downstream area. My maximum inundation depth here was reduced to 14 m, what shows some good result from the high-Ups intervention, but not enough. Therefore, my basic results for climate change projections utilizing PGF for Bias-Correcting are according to other studies developed for that same area. The overall values for RX5Day should increase within the basin area. Extreme discharge may occur for values around twice higher than the actual extreme ones. Inundation depths also can increase almost 50% on downstream area if none retarding countermeasures facilities be adopted for upstream areas. And this different inundation patterns and almost 50% deeper inundation depth for future rainfall allows me, then to make some recommendations to DRR countermeasures on Itajaí River Basin.

RECOMMENDATION

After I ran some simulations for three different occasions, I presented some of the adopted high-ups effects for mitigating flood disasters. And regarding the climate change assessment also, it was possible to conclude that the expectation for that area is an increasing of extreme events. Concluding, if local government accepts the all the upstream dams suggested by JICA plan in 2011, it would have a very positive effect for DRR within the target area. With that configuration, there will be more upstream area, more than twice to be clear, capable to work integrated in order to avoid large amount of water reaching flood plain area so quickly, where are the major risk of losses of life and large financial impacts.

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