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PRELIMINARY ASSESSMENT OF DAM HYDROLOGICAL EFFECTS IN THE BRAZILIAN PANTANAL

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ABSTRACT

The Pantanal is the world’s largest tropical wetland, comprising c.150,000 km² of lowland floodplain in the Paraguay River basin. Its habitat diversity and climatological conditions support high biodiversity, including the richest wetland avifauna in the world. Recent increases in human activities in the region have raised concern about potential environmental impacts, especially impacts of dam building in the basin’s highlands. In this paper we assess the hydrological effects of APM Manso Dam, 10 years after its initial flooding (1999), specifically the magnitude and timing of median annual maximum and minimum flows. Flow changes were assessed at 13 downstream gauging stations on the Manso, Cuiabá and Paraguay rivers, with consideration of the influence of climatic variability through the assessment of two nearby unaffected gauging stations over the same time frame. Preliminary results suggest that changes in magnitude of 1-day minimum flows occurred as far as 266 km downstream of APM Manso Dam, reaching the city of Cuiabá. Changes in the timing of 1-day minimum and in the magnitude of 1-day maximum discharges are potentially reaching the city of Rosário Oeste, *c.* 122 km downstream of APM Manso Dam. Shift in the timing of 1-day maximum is limited to Manso River reaches. No clear alterations could be found at the heart of the Pantanal lowlands, which is located *c.* 400 km downstream of APM Manso dam. Further analysis is in progress, considering a larger set of flow statistics, including ecologically relevant hydrological statistics from IHA (Indicators of Hydrological Alteration) and RAP (River Analysis Package). Future studies on the ecological impacts of the dam will be based on this analysis of hydrological alterations in the Manso, Cuiabá and Paraguay rivers.

INTRODUCTION

The structure and function of a riverine ecosystem and many adaptations of its biota are dictated by patterns of temporal variation in river flows - the “natural flow-regime paradigm” (Richter et al. **Error! Reference source not found.**, Poff et al. [1], Lytle and Poff [3]). It is now recognized that to protect freshwater biodiversity and maintain the essential goods and services provided by rivers, it is necessary to mimic components of natural flow variability, taking into consideration the magnitude, frequency, timing, duration, rate of change and predictability of flow events (e.g., floods and droughts) and the sequencing of such conditions (Bunn and Arthington [4]; Arthington et al. [5]).

Dam hydrological effects are of great concern, among human interventions on river regimes, including possible homogenization of regional river dynamics (Poff *et al.* [6]) and its faunas (Rahel [7]; Moyle & Mount [8]). In response, knowledge on this kind of assessment is advancing, particularly in well-recorded stream sites (Richter *et al.* **Error! Reference source not found.**[9][10]; Magilligan & Nislow [11]; Graf [12]).

The Pantanal is the world’s largest tropical wetland, supporting high biodiversity. Recent increases in human activities in the region have raised concern about potential environmental impacts, especially impacts of dam building in the basin’s highlands. In this paper we assess downstream hydrological effects of the APM Manso Dam, 10 years after its initial flooding (1999), specifically the magnitude and timing of median annual maximum and minimum flows. Future studies on the ecological impacts of the dam will be based on this analysis of hydrological alterations in the Manso, Cuiabá and Paraguay rivers.

CASE STUDY PRESENTATION

The Brazilian Pantanal

The Brazilian Pantanal, one of the largest and still relatively pristine wetlands on the planet (Da Silva [13]; Junk & Cunha [14]), comprises c. 150,000 km² of lowland floodplain of the upper Paraguay River basin which drains the Cerrado biome. Climatological conditions induce a monomodal flood pulse (Junk & Cunha [14]) which is the Pantanal landscape driving force (Junk & Da Silva [15]; Junk [16]), creating great habitat diversity and, consequently, high biodiversity, including the richest wetland avifauna in the world and several threatened species (Da Silva [13]). Besides these ecological values the diversity of landscape units gives the Pantanal high aesthetic value as parkland landscape, as well as providing water, flood risk regulation (Swarts [17]) and a waterway for transport (Harris et al. [18]).

Intergovernmental plans to develop the region have intensified natural resources exploitation, accelerated by the construction of roads and lines for electrical energy transmission aimed toward integrating the region into the national development scheme (Junk & Cunha [14]). These changes stimulated the region’s agricultural development (Swarts [17]), mainly in the highland catchment area (Cerrado reaches) where large farms exist, mainly used for cattle rising. As well, gold mining began to be explored in the lowlands near the city of Poconé in the 1980s (Junk & Cunha [14]). Over the last decade, a large hydroelectric power plant was constructed on the Manso River, a large Cuiabá River tributary (Girard [19]), being the first dam built to control the flood pulse in the

Pantanal. There are plans to build the Paraná-Paraguay Waterway to connect this interior zone with the Atlantic Ocean, which would facilitate commercial navigation and crop transportation.

Although the Pantanal wetland is a declared National Heritage (Brazil [20]), proclaimed in 1993 by UNESCO as a Ramsar site and in 2000 as a World Biosphere Reserve (Junk et al. [21]), only 2.5% of the Upper Paraguay River basin is formally protected (Harris et al. [18]), and multiple natural resource uses are planned for the remaining watershed area. These conditions threaten ecosystems and society as follows:

Water quality degradation by mining activities, due to mercury contamination (Junk & Cunha [14]; Swarts [17]) - high levels of mercury have been found in fish and in fish-eating birds (Swarts [17]). These species are also affected by fertilizers, herbicides and pesticides used in agriculture activities (Alho and Vieira [22]), besides domestic sewage and garbage (Swarts [17]) coming from the Cerrado reaches.

Erosion and sedimentation increases due to changes in land use and dredging for waterways (Junk & Cunha [14]), which in turn increases flood risk, lowers biodiversity and disrupts the overall basin's sediment budget (Swarts [17]). For instance, the Taquari River, one of the major Paraguay River tributaries, has received an exponential increase in sedimentation (Swarts [17]; Junk & Cunha [14]); resulting in substantial alteration of the channel, as well as lowered yields of significant commercial and sports fishing industries (Swarts [17]).

Local dam construction has altered the Pantanal's natural hydrologic regime (Swarts [17]; Girard et al. [19]; Junk & Cunha [14]). The damming of streams alters water-flow patterns, affects sediment budgets thus changing channel morphology and disrupts the natural balance between wet and dry seasons, altering the normal flood pulses regime into the floodplain, with significant impacts on biodiversity and productivity of species dependent on specific aquatic environments (Swarts [17]).

All these anthropic activities lead to large-scale, irreversible wetland degradation, increasing loss of biodiversity (Swarts [17]) and seriously effects on the dependent indigenous communities (Ponce [23]; Hamilton [24]).

The APM Manso Dam

Here we describe the APM Manso dam, its concept, goals, features and noticeable effects.

A flood event in 1974, with 9.9 m of water depth rise with respect to drought conditions, seriously damaged the city of Cuiabá, capital of the Mato Grosso State. That extreme event, associated with the Brazilian hydropower generation tradition and concern (Gomes et al. [25], Rosa [26]) resulted in the proposition of a multi-purpose (APM) reservoir (Figueiredo [27]). Such hydraulic work was planned to be installed in the Manso River, a Cuiabá River tributary, impounding a 9265 km² basin. Hydroelectricity, flood control, water supply to agriculture, tourism, fishing and recreation were defined as goals (Umetsu [28]) for the installation and operation of the nominated APM Manso Dam. The APM Manso dam design presents a 72-m high wall, flooding 427 km² with

73.10^8 m³, which renders a water residence time of 429 days. From that volume, 29.10^8 m³ are usable for electricity production on installed 210 MW power generation capacity (4 x 53 MW turbines; Furnas [29]). However, local natural biodiversity was a great restriction to developing such an intervention.

In a study carried out prior to the installation of the dam, Valeiro (*apud* Hylander et al. [30]) estimated, however, that the proposed project would slightly control floods, *i.e.* only 20% of the floodwaters at the city of Cuiabá comes from the Manso river basin's runoff. Furthermore, APM Manso dam's environmental impact assessment was, perhaps, the first study of that kind in Brazil. The lack of knowledge on potential dam effects on the environment, associated with its high costs were among the major factors for the long period between the dam proposition (late 1970s) and its licensing for construction (1987), installation (1996) and operation (November of 1999).

The damage caused by the 1996 flood helped in advocating the dam licensing, although it still has been under controversy. Hydropower generation initiated by the end of the year 2000 (Furnas [29]), with its last turbine commencing to operate only in 2002. A release of an extemporaneous flood in October of 2002, however, was responsible for cattle loss with damage to local communities (Germano [31]), re-fueling the dam opposition on the real need for such intervention.

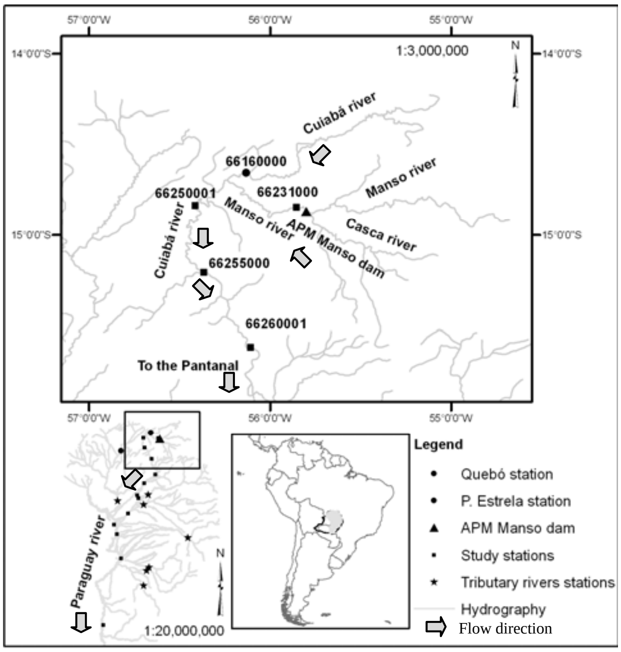

Figure 1. Location of the APM Manso dam and study gauging stations.

METHODS

An assessment of ecologically relevant hydrological alterations brought about by APM Manso dam was undertaken in 7 steps:

1. Selection of fluvial discharge gauging stations located at river reaches possibly affected (study stations) by APM Manso Dam. At this step, we considered every gauging station with records before 1999 and after 2000, the dam building and filling period.
2. Separation and selection of continuous data periods into pre and post-dam subseries. We considered stream gauges with less than the recommended (Richter et al. [9]) 20 years of data because this criterion would limit our analysis, given that the dam is only 10 years old.
3. Selection of fluvial discharge gauging (benchmark) stations located at reference sites, not influenced by the dam (*sensu* Richter *et al*.[1]), in order to use them as climatic controls: (a) Quebó station, at the Cuiabá River, ~15 km upstream its confluence with the Manso River, and (b) Porto Estrela station, at a Paraguay River reach under similar biophysical conditions. Benchmark stations are used only as a means for qualitative assessment of other than dam influences in hydrologic alterations, e.g. climate or even land use.
4. Trimming of hydrological records from the benchmark station to synchronize with study stations' pre and post-dam records' intervals and lengths.
5. Evaluation of magnitude and timing of hydrological descriptors for pre (press) and post-dam (postss) study station series, and for pre (prebs) and post-dam (postbs) benchmark station series, using IHA central tendency statistics. Specific flows, *i.e.* the ratio between fluvial discharges and its contributing area, were evaluated in order to diminish magnitude biases and ease graphical comparisons.
6. Identification of potential dam effects. This analysis consisted of isolating dam effects by the expression given by:

$$Dam = (press - postss) - (prebs - postbs) \cdot \alpha \tag{1}$$

where *Dam* stands for potential dam effect, *press* and *postss* are study station's pre and post-dam statistic, *prebs* and *postbs* are benchmark station's pre and post-dam statistic and $\alpha = press.\ prebs^{-1}$ if we are evaluating magnitude and $\alpha=1$ if we are evaluating timing of extreme events. Dam's effects obtained by Eq. (1) where considered as further as its value reversed or amplified in the downstream direction for any station. Reversions mean that dam's would affect until someplace in between study stations. Amplifications mean that some other factor might be influencing the analysis.
7. Classification of changes on hydrological descriptors. Once there is no compelling ecological justification for setting qualitative classes of hydrological alteration, we arbitrated (*sensu* Richter *et al.* [10]) to define 1 and 2 weeks as separators of low, moderate and severe shifts in 1-day minimum and maximum flows

timing and 10-25 $l.s^{-1}.km^{-2}$ for 1-day maximum and 1-3 $l.s^{-1}.km^{-2}$ for 1-day minimum.

Data

Fluvial discharge data were obtained from the Brazilian National Water Agency - ANA [33] website. We selected gauging stations downstream APM Manso until the mouth of the Upper Paraguay Basin (Table 1), containing records in pre and post-dam flooding and operation start periods, *i.e.* 1999 and 2000. As we were working with annual maximum and minimum flows, we selected continua intervals, encompassing complete Julian years, with a maximum of 5 daily data gaps per month. Those choices reduced our already scarce data in order to limit biases on the detection of annual extreme flows.

Table 1. Benchmark and study gauging stations areas, distance downstream APM Manso dam and applied data intervals.

Name	**River**	**Station (Code)**	**Area[a] (km²)**	**Distance (km)**	**Data intervals[e]**	
					Pre-dam	**Post-dam**
Porto Estrela	Paraguay	66015000	12,319[b]	-	-	-
Quebó	Cuiabá	66160000	4,129[b]	-	-	-
Faz. Raizama	Manso	66231000	9,571[b]	15	82-86,**82-90**	**02-05**
Rosário Oeste	Cuiabá	66250001	15,908[b]	122	74-86,**79-89**	01-05,**01-07**
Acorizal	Cuiabá	66255000	19,458[b]	197	72-86,**79-93**	01-05,**01-07**
Cuiabá	Cuiabá	66260001	23,226[b]	266	72-86,**79-93**	01-05,**01-07**
Barão do Melgaço	Cuiabá	66280000	27,050[b]	402	72-84,**79-84**	**01-05**
Porto Cercado	Cuiabá	66340000	35,309[c]	490	72-86,**79-88**	**01-02**
São João	Cuiabá	66360000	38,920[d]	597	72-86,**79-86**	**01-04**
Ilha Camargo	Cuiabá	66370000	39,576[c]	613	94-97,**95-97**	**01-04**
Porto do Alegre	Cuiabá	66750000	102,750[b]	730	72-86,**79-88**	**01-05**
Amolar	Paraguay	66800000	233,900[c]	815	72-86,**79-87**	01-05,**01-06**
São Francisco	Paraguay	66810000	243,000[b]	865	72-86,**79-88**	**03-04**
Porto da Manga	Paraguay	66895000	316,000[b]	1067	72-85,**79-85**	**01-04**
Porto Murtinho	Paraguay	67100000	474,500[b]	1509	72-86,**79-93**	**01-02**

[a]for some of the gauging stations there are uncertainties about drainage area due to local topography; Data sources: [b]ANA [33]; [c]ANA [34]; [d]ANA *et al.* [35]; [e]First interval was included in assessments with Porto Estrela as benchmark station , and the second one, with Quebó station.

RESULTS

Table 2 summarizes the results of hydrological analyses on 1-day maxima and minima magnitude and timing at each study station. From those, we observe that APM Manso dam operation may be decreasing 1-day maximum flows as far as the city of Rosário

Oeste, *c.* 122 km downstream, or even a bit further as revealed by the analysis against the benchmark station of Porto Estrela. About dam effects on 1-day minimum flows magnitude, we might suggest that an increase in drought conditions may affect as far as the city of Cuiabá, *c.* 266 km downstream. Regarding shifts on timing, the results for Julian dates of 1-day maximum flows are not so clear, given that comparisons against the Porto Estrela and Quebó benchmark stations show controversial results. Examining polar plots (Figure 2ab) on 1-day maximum flows magnitude and timing, represented respectively as the radial and angular axis, and observing the data intervals presented at each comparison (see Table1), we would suggest considering Quebó station's results, once it does assess a greater data interval. For that benchmark station, we observe some anticipation on 1-day maximum flows at least until the Manso River confluence with the Cuiabá River. Some anticipation is also observed for 1-day minimum flows at least until the Manso and Cuiabá River confluence, *c.* 15 km downstream APM Manso dam. Such findings suggest that no clear hydrological alteration is routed to the Pantanal lowlands.

Table 2. Qualitative results on dam hydrological effects on extreme events.

Station (code)	**Distance (km)**	**qmax($l.s^{-1}.km^{-2}$)**		**dmax(days)**		**qmin($l.s^{-1}.km^{-2}$)**		**dmin(days)**	
		bs1	**bs2**	**bs1**	**bs2**	**bs1**	**bs2**	**bs1**	**bs2**
66231000	15	-97(H)	-53(H)	21(H)	-11(M)	7(H)	5(H)	-139(H)	-144(H)
66250001	122	-14(M)	3	-6	-42	5(H)	3(M)	18	-6(M)
66255000	197	-28	0	-6	-34	4(H)	2(M)	18	-12
66260001	266	-7	7	8	-35	2(M)	0	-6	-7
66280000	402	8	10	0	-61	3	1	7	-16
66340000	490	-3	-2	-14	-72	1	1	-33	-39
66360000	597	1	3	18	-20	1	1	9	-4
66370000	613	0	3	23	5	1	0	-21	21
66750000	730	-2	1	-5	-50	0	-1	14	-17
66800000	815	-1	1	14	-22	0	-1	9	-21
66810000	865	-3	-2	20	-8	0	-1	152	152
66895000	1067	-2	-2	47	15	0	-2	-29	-47
67100000	1509	-3	-5	-32	-91	-1	-1	27	15

where *bs1* and *bs2* are related to Porto Estrela and Quebó benchmark stations, respectively, *qmax* and *qmin* mean 1-day maxima and minima and *dmax* and *dmin*, Julian dates of maxima and minima. Negative figures denote decrease for magnitude statistics or anticipation for timing ones. Letters inside parenthesis classify dam effect as High or Moderate.

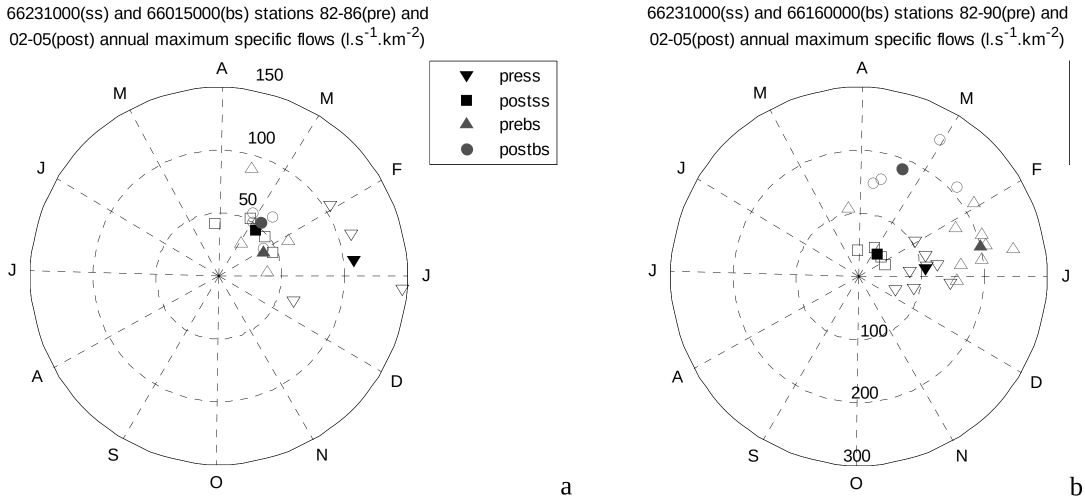

Figure 2. Polar plots on 1-day maximum specific flows magnitude and timing before and after the APM Manso dam at the Fazenda Raizama station against Porto Estrela and Quebó benchmark stations. In this plots, only median values' markers show a face color.

DISCUSSION

Assessing hydrological alterations based on scant data, e.g. Fazenda Raizama station's information extent, can't give us any but qualitative results. In this paper we assessed preliminarily APM Manso dam hydrological effects on 1-day median maximum and minimum flows' magnitude and timing.

Beyond the study limitation due to the data extent, the method applied needs further investigations, e.g. through its application in a case study with adequate information in order to validate it. Aside those, we guess that the analysis of reference sites' data helped on diminishing method's vulnerability, aiding to achieve the main objective of preliminarily identifying APM Manso dam's spatial influence on extreme events. As we have found, APM Manso dam effect on controlling peak flows are limited at the city of Cuiabá, while maintained drought conditions at a higher level for this site. The anticipation of 1-day maximum and minimum flows medians is relevant only for Manso river reaches, with its shifting directions being coherent with the dam's operational goals.

As we mentioned before, there is still a lot to be advanced in this research area in order to couple science with the reality of countries where water works infra-structure has been continuously installed. We intend to advance on the analysis of other hydrological regime features, recommending as future studies the identification of hydrological regime shifts' potential linkages with ecological processes.

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