

Partitioning of the Manso Reservoir, MT, Brazil

Compartimentação do Reservatório de Manso, MT, Brasil

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Abstract: Aim: The aim of this study is the partitioning of the Manso reservoir in the state of Mato Grosso using limnological and reflectance measures obtained in situ. **Methods:** Measures of chlorophyll-*a* concentration were distributed using the ordinary kriging for the water's surface, middle and bottom depths. The remote sensing reflectance was classified using the k-means technique. Limnological data was added to the classified result to assist in characterizing the water in the reservoir. **Results:** We observed the partitioning of the Manso Reservoir in two main regions: the river arm and the water body. **Conclusions:** Using the methods described, it was also possible to observe the water stratification and the underflow of the river Manso within the water body of the reservoir.

Keywords: reservoir, partitioning, water quality, radiometry, remote sensing.

Resumo: Objetivo: Estudar a compartimentação do reservatório de Manso no estado do Mato Grosso utilizando medidas limnológicas e de refletância de sensoriamento remoto obtidas in situ. **Métodos:** As medidas de concentração de clorofila-*a* foram distribuídas utilizando a técnica de krigagem ordinária para as profundidades superfície, meio e fundo. As medidas de refletância de sensoriamento remoto foram classificadas através da técnica de k-médias. Ao resultado desta classificação foram adicionados os dados limnológicos para auxiliar na caracterização da água do reservatório. **Resultados:** Foi observada a compartimentalização do reservatório de Manso em duas regiões principais: braço do rio e corpo do reservatório. **Conclusões:** Através dos métodos utilizados também foi possível observar a estratificação da água e o mergulho do rio Manso no corpo de água do reservatório.

Palavras-chave: reservatório, compartimentalização, qualidade da água, radiometria, sensoriamento remoto.

1. Introduction

Reservoir from Modern hydroelectric Power Plants provide socio-economic benefits such as energy production and options for recreational activities and sports, as well as helping commercial fisheries, flood control, water supply, and aesthetic beauty (Çamdevýren et al., 2005).

The effectiveness of management practices and conservation of water are key aspects of watersheds that supply urban and rural cities. The natural conditions of these nascent can be modified due to transport of sediment in suspension and the bottom sediment in the river, which results in changes of water quality and siltation. These processes eliminate or hinder the flow of the river and decrease the usable life of reservoirs (Pinto and Garcia, 2005).

Water within reservoirs has vertical and horizontal movements and a continuous flow of water toward the dam. These movements show temporal changes that depend on the flow of water and differences in level that occur during the different seasons of the year (Imberg, 1985 apud Tundisi, 1985).

Most of the nutrients and sediments found in water come from one or two main tributaries, located a consider-

able distance from the dam. Thus, as water moves toward the dam, three compartments can be noticed, having distinct physical, chemical and biological characteristics. These three compartments are the riverine, transition and lacustrine zones (Thornton et al., 1990).

The riverine zone is relatively narrow, contains well mixed water and brings significant amounts of particulate material. Light penetration is also reduced. In the transition zone, sedimentation occurs with subsequent increase in light penetration. The lacustrine zone operates similar to lakes, having low sedimentation of inorganic particles and sufficient penetration of light to promote primary production. This layer can also appear stratified (Thornton et al., 1990).

Thus, due to the continuous flow of water toward the dam and the variation of residence time, the reservoirs can be considered transitional systems between rivers and lakes, with specific mechanisms of the basin dependent and uses of the system.

In Brazil, reservoir water quality has shown, in general, large changes in their trophic states depending how the river

basin is used. To avoid such changes integrated management and thorough understanding of reservoirs is essential (Calijuri, 1999).

The use of remote sensing for monitoring and management of water resources is still growing (Novo, 2007). Applying this tool to aquatic environments allows study of water quality parameters such as the possible relationships between the properties of a field of incident light and the optical properties of water. The term "optical properties" describes the components responsible for the change of spectral response of the body of water (IOCCG, 2000).

This method can be used efficiently to prevent, observe and monitor changes in the aquatic system (Dekker et al., 1992).

By applying remote sensing techniques it's possible to evaluate the responses from disturbances introduced by human activity and predict the impact of these actions on the conditions of sustainability for the medium and long term (Novo, 2005).

Within this context, the aim of this study is the partitioning of the Manso reservoir in the state of Mato Grosso using limnological and reflectance measures obtained in situ.

1.1. Area of study

The Reservoir of Manso is located in the State of Mato Grosso, near to the Parque Nacional da Chapada dos Guimarães and ~100km of capital, Cuiabá. The reservoir is limited by following coordinates: 14° 14'-15° 20' S and

55° 20'-60° 00' W (Figure 1). The Rio Manso, where the reservoir is located, is the main tributary of the Cuiabá River (Balassa et al., 2004).

The reservoir has a water area of 427 km², volume of 7.3 km³ and the depth nearest to the dam is about 60 m. The reservoir was built between November/99 and February/00. The region is tropical and has two distinct seasons: dry (April-August) and rainy (September-March) (Hyland et al., 2006).

The flooded area is mainly composed of shrubs, although some regions have riparian zone, trees that were previously surrounded by rivers. The trees were left in place, they are now partially submerged with their branches exposed to the air and slowly dying off (Figure 2). During decomposition, the dead organic matter uses up much of the water's dissolved oxygen, changing the water quality in the reservoir, as well as of its biota (Hyland et al., 2006).

2. Material and Methods

Measurements were obtained from in situ remote sensing reflectance (R_{rs}) during the from February 29 to 02 March/08 using the following hyperspectral radiometers: an above-water radiometer (ASD FieldSpec Hand Held) and a subaquatic profiler (Satlantic HyperOCR Hyperspectral Radiometer). Radiometric measurements were taken following the protocol suggested by Fougne et al. (1999). The FieldSpec data processing followed the methodology suggested by Kampel et al. (2009). With the Satlantic profiler,

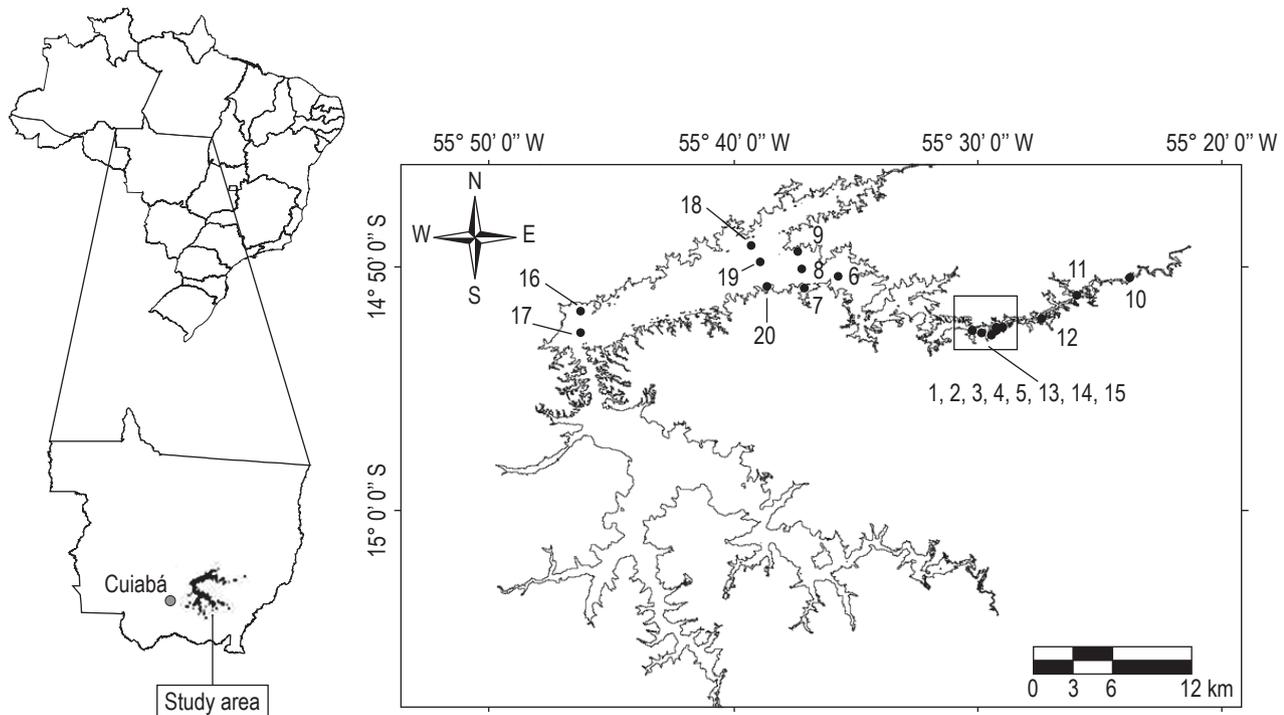


Figure 1. Study area, the Manso Reservoir, Mato Grosso, Brazil and data obtained from the arm of the Manso River.



Figure 2. Submerged trees in the Manso Reservoir with branches exposed to the air.

limnological parameters such as temperature, chlorophyll-*a* concentration (chl-*a*) and photosynthetically active radiation (PAR) were also estimated.

We performed 20 samples with concomitant measures of FieldSpec and Satlantic radiometers. Measurements were taken along the main arm of the Manso reservoir (Figure 1). Due to technical or meteorological problems, FieldSpec measurements were not taken at stations 11 to 16 and 18. For the same reasons, Satlantic measurements were not obtained at stations 6 to 10. Water samples were also collected to determine the concentration of chlorophyll-*a* at three depths: surface, middle (approximately 10 m) and bottom (20 m approximately) for stations 1-5, 16-20.

To show the horizontal distribution of the phytoplankton biomass, indexed as chl-*a* in the reservoir, the in situ chl-*a* data was interpolated using the ordinary krigage.

The k-means algorithm was used to perform the classification of the spectra collected with the FieldSpec radiometer, categorizing the water in the reservoir. According to the results obtained from this analysis, temperature, PAR and chl-*a* measured with the Satlantic profiler were also used to characterize the water masses previously compartmentalized by that classification. These 3 variables were analyzed for 2, 10 and 14 meter depths.

3. Results and Discussion

Using the method of ordinary krigage, it was performed a spatial analysis on the chlorophyll concentration data, estimated in laboratory. The method was applied to each depth of sampling: surface, middle and bottom. The analysis of these results shows the maximum relative displacement of the concentration of chlorophyll ($\mu\text{g.L}^{-1}$) along the Manso Reservoir (Figure 3).

In Figure 3a, we observe that the maximum concentration of surface chlorophyll is near the river arm. Figure 3b shows that the maximum of chl-*a* is in the middle of the

water column of the reservoir just after the Manso river. Figure 3c shows that the maximum chl-*a* at the bottom of the reservoir is found in the reservoir's body.

The displacement of the depth of the maximum chlorophyll-*a* concentration illustrated in Figures 4 a, b, and c shows a dive of the river in the body of the reservoir. This dive is due to the difference in the density of the river's water and the reservoir. This process is governed by temperature and dissolved and suspended material in the water (Wetzel, 2001). As for the Manso reservoir, the river water has greater density than the reservoir water ($\rho_{\text{river}} > \rho_{\text{reservoir}}$), which is confirmed by Assireu et al. (2008).

Thus, the distribution of chl-*a* in the reservoir is not very homogeneous. Therefore, to obtain the characterization of the waters in the reservoir, a non-supervised classification of *Rrs* was performed in the field using the k-means algorithm. After performing the k-means classification, it is possible to see in Figure 4 that the spectra could be separated into two groups.

The *Rrs* clusters of two groups have high value in silhouette (above 0.5) indicating that these spectra are well separated from their neighbouring clusters. The silhouette plot displays a measure of how close each point in one cluster is to points in the neighboring clusters. This measure ranges from +1, indicating points that are very distant from neighboring clusters, through 0, indicating points that are not distinctly in one cluster or another, to -1, indicating points that are probably assigned to the wrong cluster. Still, in the second cluster, some *Rrs* presents low silhouette value (below 0.5) indicating that there wasn't a good separation of these *Rrs*, and they are close to other clusters.

Limnological data sets measured in field using the Satlantic profiler were gathered according to the clusters and classification for each collection point. This method was used to characterize the partitioning of the reservoir. The following products were chosen: temperature ($^{\circ}\text{C}$), PAR ($\mu\text{mol.m}^{-2}\text{s}$) and chl-*a* ($\mu\text{g.L}^{-1}$) for depths of 2, 10 and 14 m representing superficial, middle and bottom, respectively. The results are shown in Tables 1, 2 and 3.

When observing the clusters generated by k-means, note that the stations 1 to 5 (arm of the River Manso) have different attributes than the others. At 2 m depth (Table 1), the water has lower temperature and PAR, and the chlorophyll concentration is higher. These patterns are indicative of waters belonging to the Manso River, inside the reservoir.

Observing the temperature and PAR at different depths, we find that the temperature becomes homogeneous and the PAR decreases as it extends into the reservoir. Here the chlorophyll displays a reversal of values. That is, in stations 1 to 5 (arm of the river) its value is greater on the surface, but at a depth of 14 m, a sharp drop in value occurs. Already in the body of the reservoir the chl-*a* of the surface shows

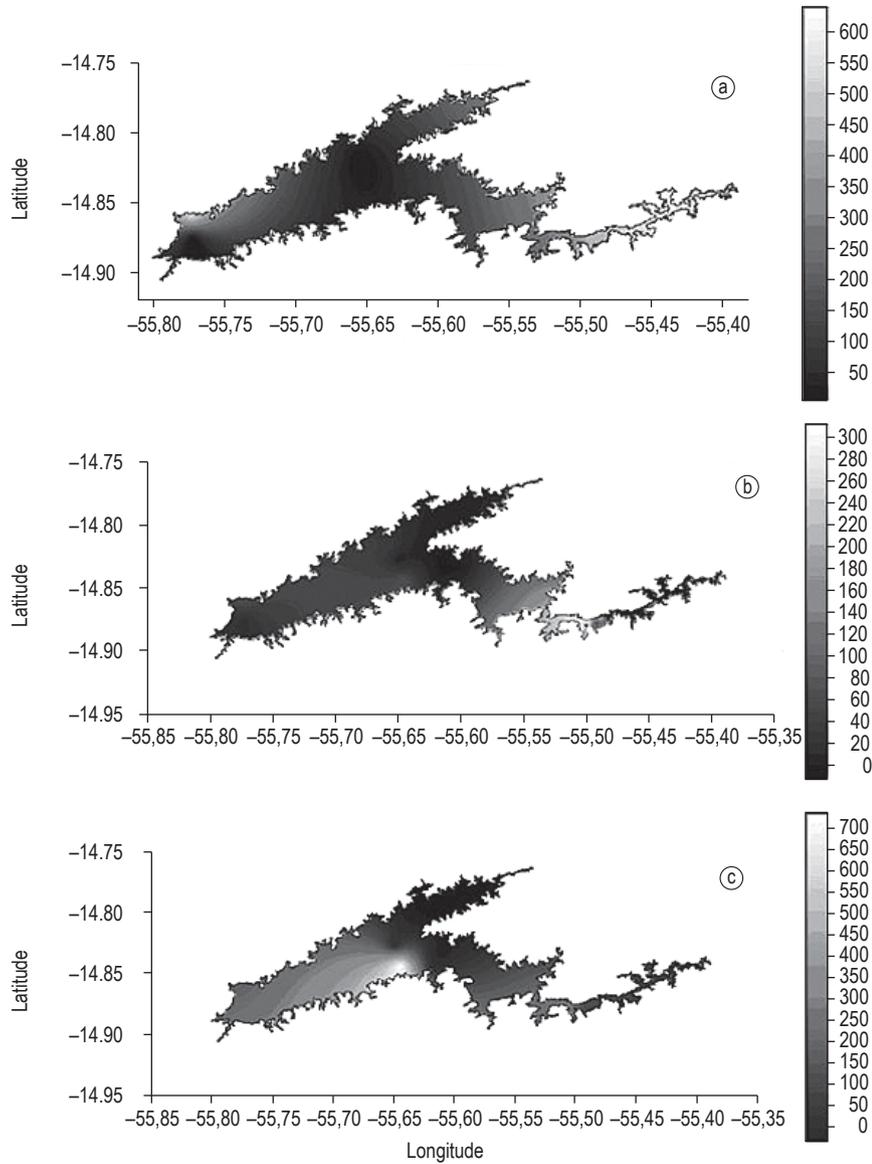


Figure 3. Ordinary krigage applied to in situ chlorophyll-*a* concentration (mg.L^{-1}) at 3 different depths of the Manso Reservoir: a) surface, b) middle (~10 m), and c) bottom (~14 m).

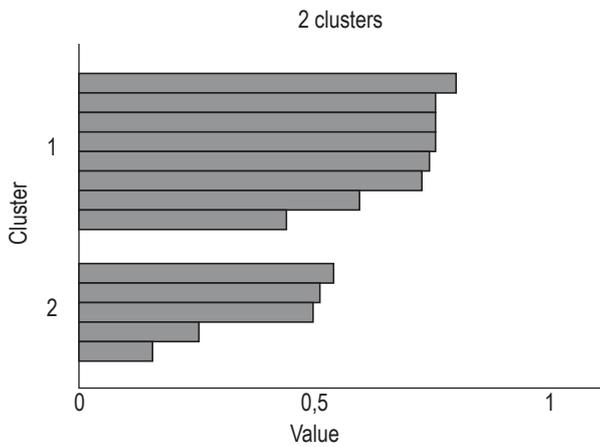


Figure 4. K-means applied to collected R_{rs} in March 2008 in the Manso Reservoir.

Table 1. Clustering classification of remote sensing reflectance by k-means and parameters collected by an hyperspectral profiler (Satlantic) to a depth of 2 m.

| | 2 clusters | Temperature | PAR | Chl- <i>a</i> |
|--|------------|-------------|--------|---------------|
| | P1 | 26.63 | 3.90 | 456.01 |
| | P2 | 27.14 | 9.87 | 198.79 |
| | P3 | 26.98 | 26.08 | 337.22 |
| | P4 | 27.52 | 35.39 | 185.47 |
| | P5 | 28.39 | 61.78 | 540.28 |
| | P6 | - | - | - |
| | P7 | - | - | - |
| | P8 | - | - | - |
| | P9 | - | - | - |
| | P16 | 29.23 | 124.18 | 16.94 |
| | P18 | 29.11 | 768.26 | 11.33 |
| | P19 | 29.34 | 877.94 | 17.11 |
| | P20 | 29.24 | 627.36 | 28.29 |

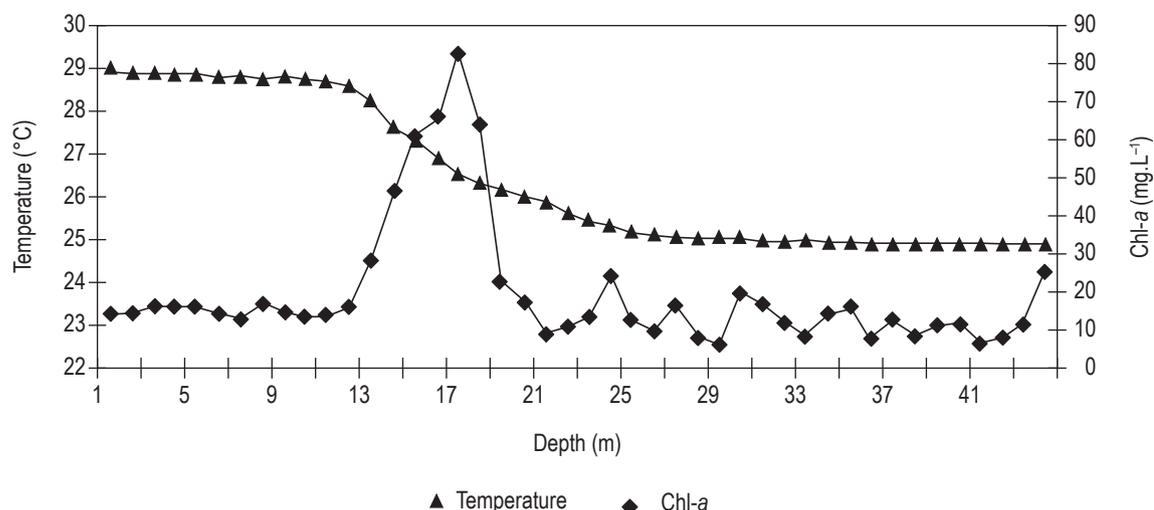


Figure 5. Concentration of chlorophyll-*a* profile and temperature at point 18 (see text) during March/08 at Manso Reservoir. Data obtained using an hyperspectral profiler with attached ancillary sensors (Satlantic).

Table 2. Clustering classification of remote sensing reflectance by k-means and parameters collected by Satlantic to a depth of 10 m.

| 2 clusters | Temperature | PAR | Chl- <i>a</i> |
|------------|-------------|-------|---------------|
| P1 | 26.41 | 0.01 | 6.48 |
| P2 | 26.55 | 0.01 | 16.54 |
| P3 | 26.47 | 0.02 | 39.55 |
| P4 | 26.59 | 0.01 | 13.96 |
| P5 | 26.55 | 0.01 | 11.63 |
| P6 | - | - | - |
| P7 | - | - | - |
| P8 | - | - | - |
| P9 | - | - | - |
| P16 | 28.84 | 4.49 | 13.56 |
| P18 | 28.51 | 31.74 | 24.55 |
| P19 | 28.44 | 27.89 | 37.59 |
| P20 | 28.40 | 8.78 | 45.53 |

Table 3. Clustering classification of remote sensing reflectance by k-means and parameters collected by Satlantic to a depth of 14 m.

| 2 clusters | Temperature | PAR | Chl- <i>a</i> |
|------------|-------------|------|---------------|
| P1 | 26.42 | 0.01 | 41.02 |
| P2 | 26.49 | 0.04 | 17.19 |
| P3 | 26.46 | 0.01 | 24.08 |
| P4 | 26.52 | 0.07 | 0.33 |
| P5 | 26.54 | 0.01 | 23.43 |
| P6 | - | - | - |
| P7 | - | - | - |
| P8 | - | - | - |
| P9 | - | - | - |
| P16 | 27.58 | 0.84 | 29.99 |
| P18 | 27.02 | 1.18 | 62.39 |
| P19 | 26.95 | 1.00 | 69.70 |
| P20 | 26.68 | 0.05 | 280.35 |

low values, but as the depth increases the chl-*a* increases as well, with a peak at 14 m.

This behaviour suggests a stratification of water layers, common in summer in reservoirs (Wetzel, 2001). This depth of maximum chlorophyll coincides with the formation of a thermocline as illustrated in Figure 5.

4. Conclusion

By the methods used, three types of behaviour in Manso Reservoir was observed: partitioning, stratification of the water column, and the river diving into the body of the reservoir.

The water of the reservoir could be partitioned into two regions: 1) the river arm and 2) in the main body of water itself. At the surface of the arm there is a higher chl-*a*, and the penetration of light in the water column is lower due to the presence of suspended sediments causing turbidity of the water. Within the body of the reservoir, the chl-*a* is lower and the light penetration is higher, with a lower *K*.

Due to the time of year in which the measurements were taken, the water was stratified, a fact confirmed by water sample analysis at different depths.

The dive of the river was also observed by applying the ordinary method of krigage.

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