Article

Not peer-reviewed version

Flow Measurement Methods in Small Tributaries of the Teles Pires River, Southern of the Amazon Hydrological Region

Daniela Roberta Borella , Rhavel Salviano Dias Paulista , Marco Aurélio Barbosa Alves , Charles Campoe Martim , Célio Jacinto da Silva , Frederico Terra de Almeida , Adilson Pacheco de Souza *

Posted Date: 30 September 2023

doi: 10.20944/preprints202309.2158.v1

Keywords: surface hydrology; bathymetry; acoustic method; hydrometric windlass; ADCP RiverRay; Cerrado-Amazon transition

Article

Flow Measurement Methods in Small Tributaries of the Teles Pires River, Southern of the Amazon Hydrological Region

Daniela Roberta Borella [1,2], Rhavel Salviano Dias Paulista [1,2], Marco Aurélio Barbosa Alves [3], Charles Campoe Martim [2], Célio Jacinto da Silva [1], Frederico Terra de Almeida [1,4] and Adilson Pacheco de Souza [1,2,4,*]

1 Postgraduate Program in Environmental Sciences, Federal University of Mato Grosso, Sinop, 78550-720, Mato Grosso, Brazil. daniela.borella@sou.ufmt.br (D.R.B.), rhavel.paulista@sou.ufmt.br (R.S.D.P.), celio.silva@ufmt.br (C.J.S.), frederico.almeida@ufmt.br (F.T.A.), adilson.souza@ufmt.br (A.P.S)
2 Postgraduate Program in Environmental Physics, Federal University of Mato Grosso, Cuiabá, 78060-900, Mato Grosso, Brazil. charles.martim@sou.ufm.br (C.C.M.)
3 Postgraduate Program in Agronomy-Soil Sciences, Federal Rural University of Rio de Janeiro, Seropédica, 23897-045, Rio de Janeiro, Brazil; marcoaurelio.monitor@gmail.com (M.A.B.A.)
4 Institute of Agrarian and Environmental Sciences, Federal University of Mato Grosso, Sinop, 78557-287, Mato Grosso, Brazil.
* Correspondence: pachecoufmt@gmail.com; Tel.: +55 (66) 98136-3805.

Abstract: The intensification of conflicts associated with the use of water in the transition region of the Cerrado and Amazon biomes caused by population and economic growth, combined with the interest in generating energy from hydroelectric plants, raise the need to quantify the surface water availability of rivers contributing with different drainage areas. The present study estimated and compared loco measurements of liquid flow (Q_L) and depth of rivers in the Teles Pires river basin by reference methods (*MLN-7* hydrometric windlass and metal rod/winch) and by Acoustic Current Profiler by Doppler Effect (ADCP *RiverRay*), in addition, evaluated the total measurement time underestimation uncertainty by ADCP. Field measurements were carried out at monthly intervals between March 2020 and October 2021, seeking to represent the water seasonality and depth and Q_L variations in the cross-sections of the Caiabi 1 and 2, Celeste, Preto and Renato rivers. The evaluated rivers had a net flow between 3.48 and 60.78 $m^3\ s^{-1}$ by the windlass and between 2.66 and 54.30 $m^3\ s^{-1}$ by the ADCP, while the depths obtained were from 0.17 to 6.34 m by the rod/winch and from 0.65 to 6.20 m by the ADCP. The methods resulted in similar measurements of net flow and depth in each of the cross-sections, and the statistical performance of the linear regression model was satisfactory with a Willmott concordance index of 0.9977 and 0.9819 for estimates of Q_L and of the depth of the cross-sections, respectively. The ADCP accurately measured net discharge and depth in shallow (up to 6.5 m) cross-sections of Teles Pires River in relative to the reference method. Determining the total measurement time and pairs of transects to obtain accurate Q_L by ADCP depends on the hydraulic characteristics of the watercourses.

Keywords: surface hydrology; bathymetry; acoustic method; hydrometric windlass; ADCP *RiverRay*; Cerrado-Amazon transition

1. Introduction

The management of water resources is increasingly necessary, given its importance for the various hydrological realities and the increase in the multiple demands for the use of water for human, industrial, animal watering, agricultural irrigation, energy generation, recreation, tourism, navigation, maintenance of natural ecosystems, among others [1]. In recent decades, with population growth, conflicts associated with water use have increased significantly in socioeconomic aspects, regardless of the spatial scale [1]. In this sense, for adequate water management, it is necessary to understand and quantify this natural resource through the components of the hydrological cycle in hydrographic basins.

Brazil is the most abundant country in surface water availability but has uneven spatial and temporal distribution over regions/biomes [2]. The intensification of conflicts over water use and climate change, caused by population growth and human activities, impacts the production chain, society's quality of life and the maintenance of natural ecosystems [3]. Impacts such as water scarcity, floods and inundation, as well as loss of surface water quality [4], increased concentrations of suspended solid particles [5], and the presence of contaminants and pollutants [6] are reflections of the suppression of natural vegetation, lack of conservationist practices [7], dumping of effluents from industrial processes and untreated sewage networks in water bodies [4,8].

In this regard, collecting hydrological information on the surface water availability of natural watercourses can serve as a subsidy for planning and proper management of water and soil. One of the components of the hydrological cycle that can be monitored and quantified is the flow of a river, called surface, subsurface and base runoff, which is dependent on the characteristics of rainfall (intensity, quantity, duration and frequency), vegetation cover, soil, climate [9,10] and the physiographic characteristics of the watershed [11].

In natural rivers, flow estimation is complex, as the cross-section can be irregular, in which case it is recommended to measure the flow in loco [12]. The main variables obtained in loco are the speed and water level and, in turn, the flow, regardless of the method. Among the methods, the most traditional is the flow measurement by velocity and area that can use mechanical equipment, such as the hydrometric windlass, or, in a more refined case, by electroacoustic equipment, such as the Acoustic Current Profiler by Doppler Effect (ADCP) [13].

The equipment above provides measurements with accuracy and acceptable uncertainty limits. However, they present methodological differences in the level of detail of the information obtained in the cross-section. The windlass performs punctual water velocity measurements through electromechanical pulses; its limitations focus on the greater demand for time and field staff and restriction to high speeds and depths in section [2]. The ADCP *RiverRay* model continuously maps the water velocity through the velocity and frequency of the acoustic wave emitted and reflected in suspended solid particles, which move at the same velocity as the water. Its main limitation is that it does not measure water velocity in depths < 0.4 m, in the water body's marginal, surface and bottom areas [14].

The in loco determination of flow in natural watercourses is fundamental for the definition of key curves and calibration of hydrological models that allow forecasting of flood events, water scarcity, soil loss and silting of reservoirs, in addition to helping in the taking mitigating measures for these problems, such as implementing appropriate land management practices [7,15], defining hydro-agricultural and forestry projects [16], regulating outflows in reservoirs [17] and supplying water for various human activities [1].

In the regional context of the Cerrado-Amazon transition, there is the watershed of the Teles Pires River, which, despite having good surface water availability, noted the existence of potential conflicts over the use of water, mainly associated with the generation of energy from hydroelectric plants. [15,18], since there are already five projects (Hydroelectric Power Plants – HPP) installed in its main course, demand for irrigation by central pivots [18], dilution of effluents and other demands of urbanization.

The scarcity of hydrological information on tributaries of the Teles Pires River basin has motivated studies on the hydrological dynamics and continuous monitoring of perennial channels and low drainage networks, as this information can contribute to the management of water resources in the Cerrado-Amazon transition region. In this context, the objective was to estimate and compare the flow and depth of cross-sections in hydrographic sub-basins of the Teles Pires River by different methods (mechanical and acoustic) of in loco measurement and, to evaluate the uncertainties in obtaining the flow by acoustic method.

2. Materials and Methods

2.1. Study area and installations

Our study area corresponds to the sub-basins within the Teles Pires River basin, located between 7º 16′ 47″ and 14º 55′ 17″ S and longitudes 53º 49′ 46″ and 58º 7′ 58″ W covering the territories of the states of Mato Grosso and Pará, Brazil. The drainage area of the watershed is approximately 141,278.0 km² and the length of the main waterway is approximately 1498 km. The Teles Pires River basin has predominant vegetation cover of Cerrado (Upper Teles Pires), a Cerrado-Amazon transition zone (Upper and Middle Teles Pires) and Amazon (Middle and Lower Teles Pires) biomes (Figure 1). Currently, this basin is inserted in the agribusiness hub region of Mato Grosso, with a predominance of agricultural activities, followed by hydroelectric and industrial projects.

The climate of the study region (Cerrado-Amazon transition) is Aw (tropical hot and humid), with climate seasonality defined by two hydrological seasons, the rainy season (October to April) and the dry season (May to September). The mean annual precipitation was 1,970 mm, concentrating more than 1,700 mm in the rainy season, the reference evapotranspiration ranges from 84 to 131 mm month^{-1}, between the rainy and dry periods of the region, respectively, and the mean annual temperature varies from 24 to 27 °C [19].

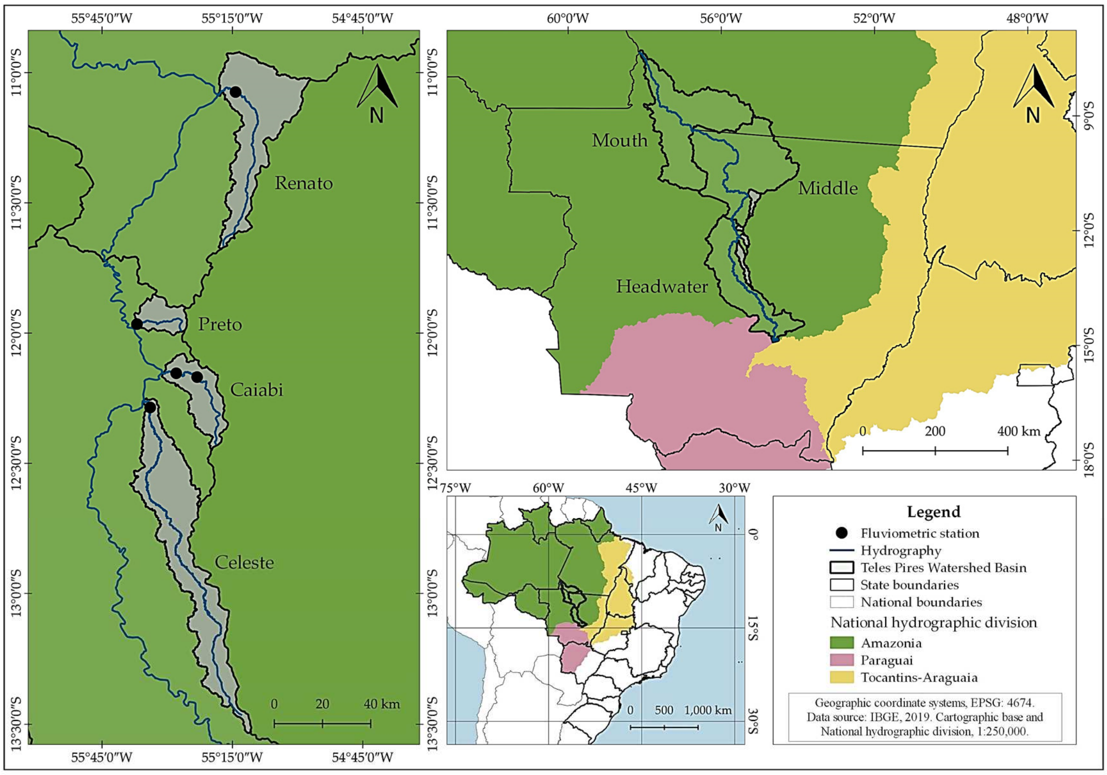


Figure 1. Location map of the four sub-basins of the Teles Pires River basin in the Amazon hydrographic region, Mato Grosso state, Brazil.

The definition of the five cross-sections for fluviometric monitoring followed the following criteria: ease of access and logistics, site free of anthropic actions, stretch with well-distributed speeds, bed and stable margin, well defined and free of vegetation, rocks and other obstacles, stretch rectilinear with parallel margins, regular longitudinal profile and free of backwaters and location far from confluences, location with adequate conditions for installation, maintenance and operation of equipment [20].

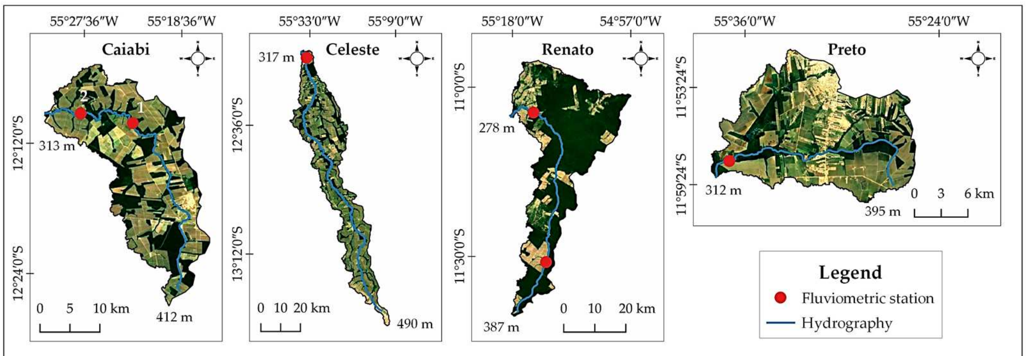
The general information of the fluviometric stations is presented in Table 1. The areas of the hydrographic sub-basins of the Caiabi, Celeste and Preto Rivers present a predominance of

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

agricultural activities, with the cultivation of soybeans, corn, cotton and beans and a considerable urban occupation in the Preto River area. In contrast, in the Renato River area, native vegetation and livestock are predominant, with a significant rise in agriculture (Figure 2).

Table 1. General characteristics of the Teles Pires River basin sub-basins, Mato Grosso, Brazil.

Sub-basin	Fluviometric station	Latitude	Longitude	Altitude (m)	Subarea (km²)	Hydrography (km)	Period of data
Caiabi	Caiabi 1	12°10'32.64" S	55°23'5.22" W	372	340	40	December 2020 to September 2021
	Caiabi 2	12°09'27.23" S	55°28'30.39" W	345	454	53	March 2020 to September 2021
Celeste	Celeste	12°17'39.02" S	55°33'56.90" W	319	1.788	211	August 2020 to October 2021
Preto	Preto	11°58'1.51" S	55°37'20.25" W	325	243	25	May 2020 to September 2021
Renato	Renato	11°4'6.29" S	55°14'59.05" W	281	1.181	80	April 2020 to June 2021



Soil use	Caiabi (%)	Celeste (%)	Renato (%)	Preto (%)
Natural vegetation	30.75	25.43	69.38	22.10
Pasture	8.19	6.00	18.87	12.18
Tillage	60.06	68.30	11.41	53.45
Urban area	0.76	0.01	0.18	12.16
Water	0.24	0.10	0.16	0.07
Soil exposed	0.00	0.15	0.00	0.01
Others uses	0.00	0.01	0.00	0.03

Figure 2. Location map of the fluviometric stations and principal land uses of the Teles Pires River basin sub-basins, Mato Grosso state, Brazil.

2.2. Measurements of depth and flow by the reference method

Each monitoring cross-section was demarcated with a graded string fixed between the channel margins and then divided into subsections, represented by fixed verticals, positioned longitudinally along the section. The distance between verticals and the number of verticals were defined according to the width of each cross-section, while the position and number of reading points were determined from the depth measurement of each vertical, according to the criteria established by Santos et al. [20]. The position and number of verticals and measuring points may vary according to the year's water season, which is necessary to measure the width and depth of the fluviometric cross-sections at each field campaign (Figure 3).

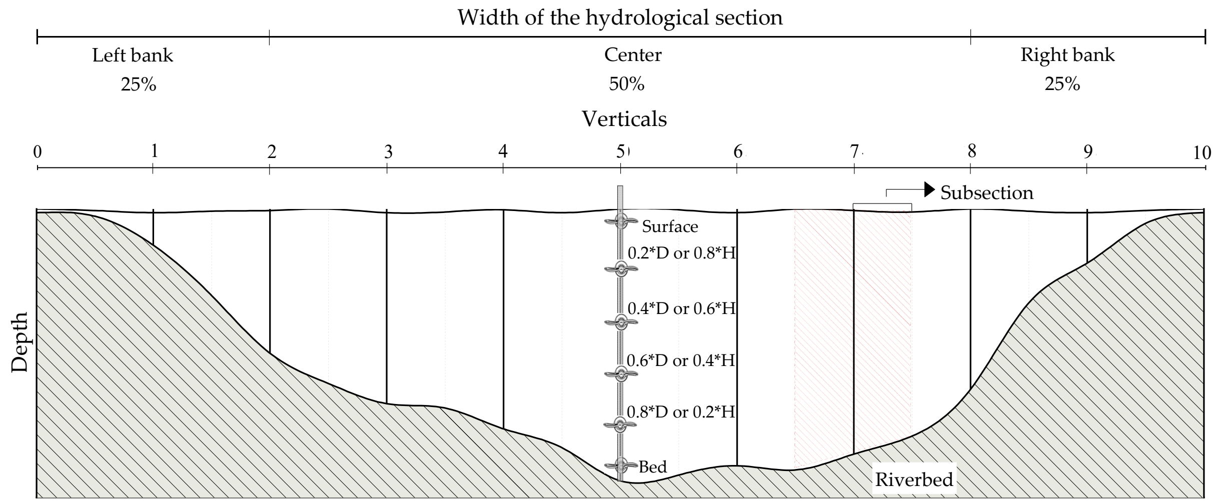


Figure 3. Representation of a hypothetical cross-section demonstrating the distance between verticals, the number of verticals, and the position and number of points for the bathymetry and flow readings of each vertical. Source: Adapted from Santos et al. [20].

The reference bathymetric survey of each cross-section was carried out from the direct measurement of depth in each vertical. Sections with a depth of less than 2.50 m were measured at hand, with a metallic rod graduated with a numerical scale of 0.01 m, the reference being the riverbed (obtaining H – height of the water column over the point). For sections deeper than 2.50 m, a *GFL*-25 model fluviometric winch and a fluviometric ballast manufactured by *JCTM Ltda*. model LAS-15 of 15 kg, installed on a boat. In this method, the water surface is the reference, and an analog odometer is used, which must be reset with the central axis of the hydrometric windlass leveled with the water surface and then submerged to the riverbed to obtain D (depth) of the vertical.

Water velocity measurements to obtain flow were performed by direct measurement with a hydrometric windlass manufactured by *JCTM Ltda*, model *MLN-7*, associated with an electronic revolution counter, connected together. In this case, the metal propeller rotates in the opposite direction of the flow under the action of the movement of the water in the river and sends electrical signals to the rotation counter, which relates the number of rotations per second with the flow velocity.

During measurements, the equipment was positioned with the propeller positioned against the direction of water flow and three readings of the number of rotations were performed for a time of 40 seconds per reading, considering a standard deviation ≤ 10%, in each position of each vertical of the cross-section, from the left bank to the right bank. To obtain the average speed in each vertical, the rotations were converted into speeds through the linear equation established by the manufacturer. The time of 40 s per reading was sufficient for average conditions of regular flow in all sections evaluated [20].

The wet area of influence of each cross-section was calculated using the numerical method of the half section or subsection (Figure 3), which consists of calculating the partial flows of each subsection by multiplying the average velocity of the vertical by the area of the trapezoidal segment, defined by the product of the average depth by the sum of the semi-distances to the adjacent verticals [20]. This method disregards the areas close to the margins (Equation 1).

$$A_i = \frac{\left(\frac{D_{i-1} + D_i}{2} + D_i\right)}{2} \cdot \frac{(d_i - d_{i-1})}{2} + \frac{\left(D_i + \frac{D_{i+1} + D_i}{2}\right)}{2} \cdot \frac{(d_{i+1} - d_i)}{2} \quad (1)$$

where: D_{i-1} is the depth of the vertical preceding the vertical whose area of influence is being calculated (m); D_i is the depth of the vertical whose area of influence is being calculated (m); D_{i+1} is the depth of the vertical behind the vertical whose influence area is being calculated (m); $d_i - d_{i-1}$ is the distance between the vertical whose area of influence is being calculated and the previous vertical

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

(m); $d_{i+1} - d_i$ is the distance between the vertical whose area of influence is being calculated and the posterior vertical (m).

The total net flow for each cross-section was determined by the sum of the product of velocity and wetted area of each subsection (Equation 2).

$$Q_L = \sum q_i = \sum (V_i * A_i) \quad (2)$$

where: Q_L is the total net flow ($m^3\ s^{-1}$); q_i is the flow of each subsection ($m^3\ s^{-1}$); V_i is the average velocity of the vertical ($m\ s^{-1}$) and A_i is the wetted area of the subsection (m^2).

2.3. Measurements of depth and flow by the Acoustic Doppler Effect method

In addition to the measurements with the hydrometric windlass (reference method), a bathymetric survey and water velocity measurements were carried out by indirect measurement to obtain the flow of five cross-sections for monitoring with the Doppler Acoustic Current Profiler (ADCP model *RiverRay* manufactured by *Teledyne Marine RD Instruments*). This equipment consists of a transducer with two pairs of beams, standard temperature, pressure, inclination, acoustic depth and internal compass sensors, a 12 V battery and a trimaran for its operation (the GPS was not coupled to the ADCP).

The ADCP *RiverRay* is a robust equipment that measures the speed of propagation of a sound wave emitted and reflected by particles suspended in water, converting these sound waves into electrical signals interpreted by the *WinRiver II* acquisition software. The transducer performs readings in the vertical orientation, which makes it more accurate for detailed bathymetric surveys, emitting and receiving sound signals with a frequency of 600 kHz ranging from 300 to 3,000 kHz, and estimation of water velocity with a range of background pulse between 0.4 and 60 m [13,22].

The basic settings of file preparation, as well as the system tests, compass calibration, moving bed test, and depth and flow measurements, were carried out in the *WinRiver II* data acquisition software. The information was transmitted via Bluetooth from the notebook between the ADCP and the software.

They initially used this software to run the PC20 and PC40 system test protocols. Next, the compass calibration was performed, which consisted of slowly turning the ADCP clockwise by 360° with the transducer in contact with the water, adding a minimum time of 3 min for the complete turn, at this stage, at least 100 assessments must be performed during a complete rotation. In each measurement for each cross-section, the stationary, moving bed test was performed by the mean subsection method in a minimum time of 600 s (~10 min); in this case, the equipment was positioned in the center of the cross-section and fixed with two taut ropes between the edges of the section, seeking to avoid as much as possible the occurrence of vibrations [22]. The result of this test is analyzed in the data post-processing step (Figure 4).

Figure 4. Compass calibration and stationary moving bed test with ADCP *RiverRay*.

The bathymetric survey was carried out concomitantly with the flow measurement. The ADCP was positioned with the front of the trimaran against the water flow direction and at a profiling depth

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

of 0.10 m. Two operators guided the crossing of the ADCP, positioned one on each river bank, with the aid of two ropes fixed on each side of the trimaran, at a constant speed and lower than the water velocity. The measurement started from the left bank to the right bank, covering a continuous transect, parallel and upstream of the section in which the flow measurement was carried out with the hydrometric windlass (reference method) with an approximate distance of 2.5 m between the parallel sections (Figure 5).

Figure 5. Flow measurement with hydrometric windlass and ADCP in parallel hydrological cross-sections.

The first reading begins with the emission of sound pulses "pings", registering at least 10 beams with the ADCP stopped on the left bank and ends with counting 10 more beams with the equipment stopped on the right bank. A measurement with ADCP corresponds to a pair of transects, that is, a round trip between the edges of the section (Figure 6). However, strips close to each bank cannot be measured due to restrictions on the presence of roots and shallow banks (depth < 0.3 m), and the size of these strips close to the banks varies according to the width and depth of each cross-section and water season of the year. In this way, these ranges are measured at the beginning of the first reading of each section and inserted in *WinRiver II*, so that they can be considered in the extrapolation to obtain the total net flow.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

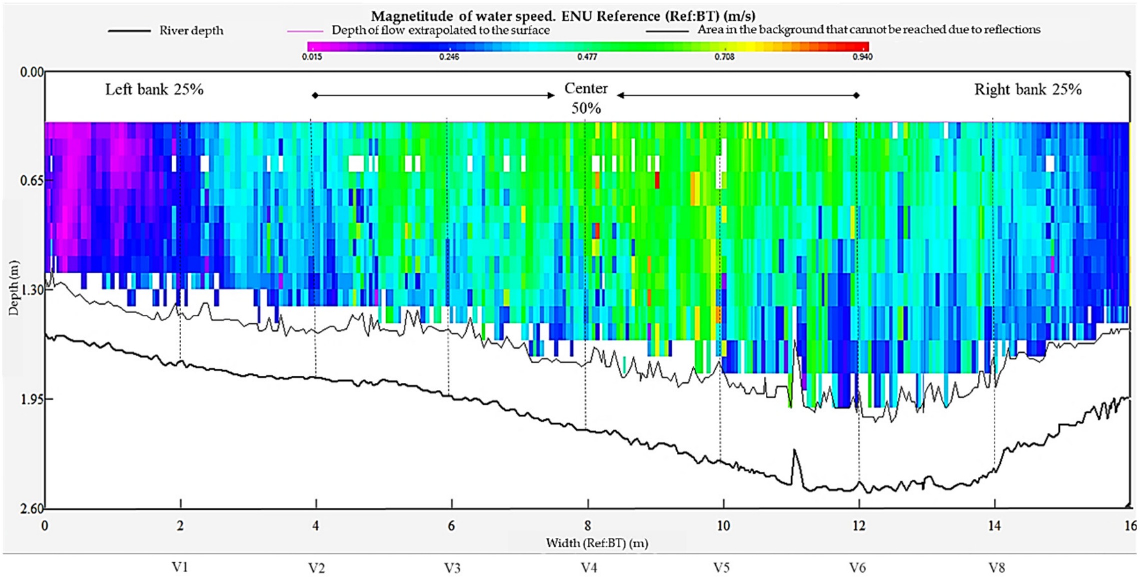


Figure 6. Transverse water velocity profile of a transect measured by ADCP identifying the margins and center of the cross-section.

The quality control of the field measurement for each transect followed the criteria pre-established by the *USGS* (United States Geological Survey), which were observed by the *WinRiver II* software at the time of the field measurements. Thus, for the reading to be valid, one must: i) count 10 more verticals in each transect at the beginning and end of the measurement of each transect, with static ADCP within the pre-defined limits of the margins; ii) the width of the measured strip must be greater than 50% of the total width of the cross-section; iii) compose the minimum time of 720 s adding all the transect pairs, that is, the total measurement; iv) the measured net flow (QL) must be ≥ 50% of the total net flow (Qt); v) the percentage of verticals considered bad must be < 25% of the total observed; vi) the verticals considered of poor quality + verticals with lost measurement must be less than 10% of the total number of verticals observed; vii) the "*pitch and roll*" must be less than 5° of variation (inclination of the ADCP in the longitudinal and transverse directions of the vessel); viii) and the ADCP velocity needs to be less than the water velocity (Figure 7) [22]. For the hydrographic sub-basins studied, 10 reading pairs (20 transects) were established per cross-section on each measurement date.

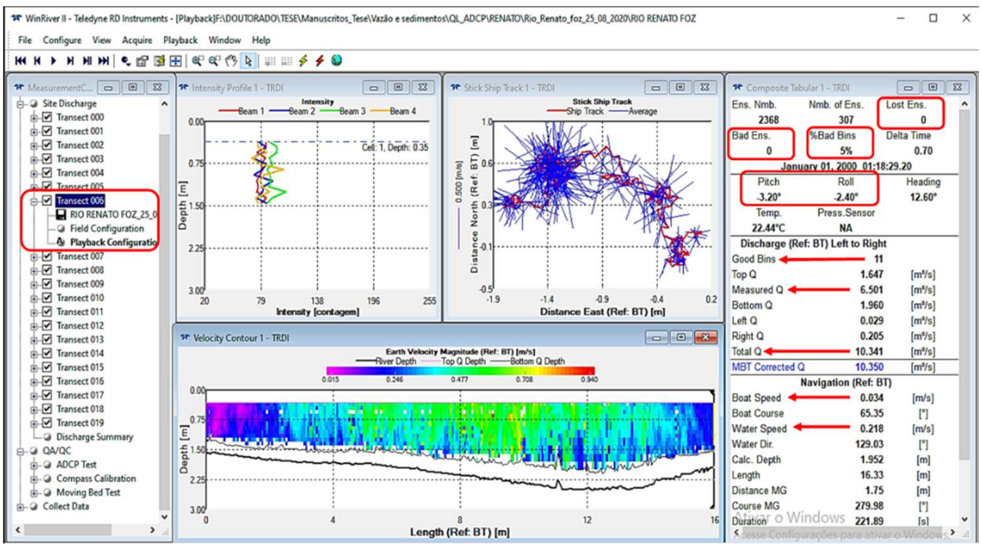


Figure 7. *WinRiver II* software interface indicates the criteria pre-established by the *USGS*, which are observed during field measurements.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

2.4. Processing of measured data

The bathymetric survey and flow measurements of the five monitoring cross-sections were analyzed for consistency and integrity of measurements by both equipment. The data obtained in the field by the hydrometric windlass were processed in an electronic spreadsheet, and the data obtained by the ADCP were analyzed using the *QRev 3.43* post-processing software.

The *QRev 3.43* software reviews and processes the data generated by *WinRiver II* using consistent algorithms, applying so-called automated data quality assessment (ADQA) of parameters of the net flow measured in the field. This software makes it possible to automate the filtering and verification of data quality through graphs and tables containing quality indicators generated in its interface. Thus, the present study decided to work with the standard configurations of extrapolation algorithms in automatic mode.

The ADQA takes into account several parameters/attributes of the measured flow, such as transect parity, minimum total measurement time (720 s), system tests (PC20 and PC40), compass calibration, temperature and salinity, stationary moving bed test, the validity of sets of verticals and cells per transect, transducer depth, extrapolation, and effects of margins on flow (Figure 8). The parameters of a measurement considered as "good", which passes the ADQA are identified by the green color; in a regular measurement with a reading problem, but not critical by ADQA the yellow color represents them; and in a bad measurement that does not pass the ADQA, that is, that there are critical reading problems that violate the *USGS* measurement policies and procedures, are indicated by the color red (Figures 8 and 9).

The *QRev 3.43* software also provides data classification categories based on the parameters of random uncertainties, invalid data, edge flow, extrapolation, stationary moving bed test, systematic errors, and, above all, based on estimates, all with 95% confidence level uncertainty. In addition, it allows the user to manually interpret and classify the category of each measurement: excellent (< 2%); good between (2 and 5%); regular (between 5 and 8%); poor (> 8%) (Figure 8).

In the present study, a total of 56 measurements (560 pairs of transects) were analyzed in the ADQA and 10 (100 pairs of transects) were excluded due to significant issues regarding statistical uncertainty that violated USGS policies (parameters in red). Of the 10 excluded measurements, 7 were obtained in the dry season and 3 in the rainy season, and the main problems identified were: i) operational errors such as system test not performed; ii) lack of transducer depth information and consequent errors in flow extrapolation; iii) ADCP velocity (BT *Filters*) and water velocity (WT Filters) reading errors; iv) bad cell reading and loss of vertical set (Figure 9).

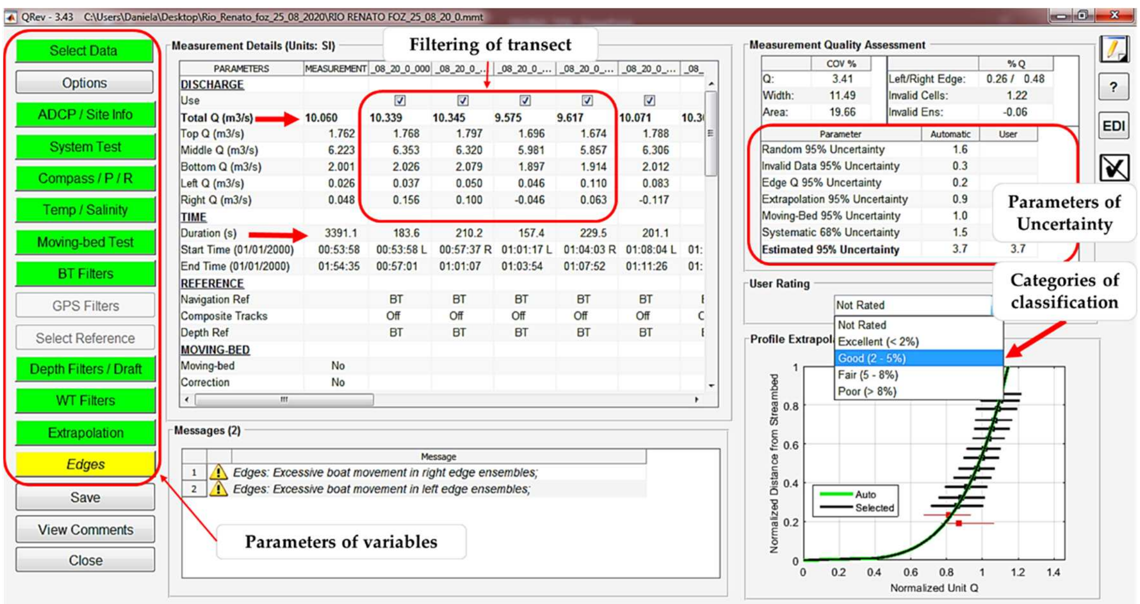


Figure 8. *QRev 3.43* software interface demonstrated good quality measurement, which passed ADQA according to *USGS* policies.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

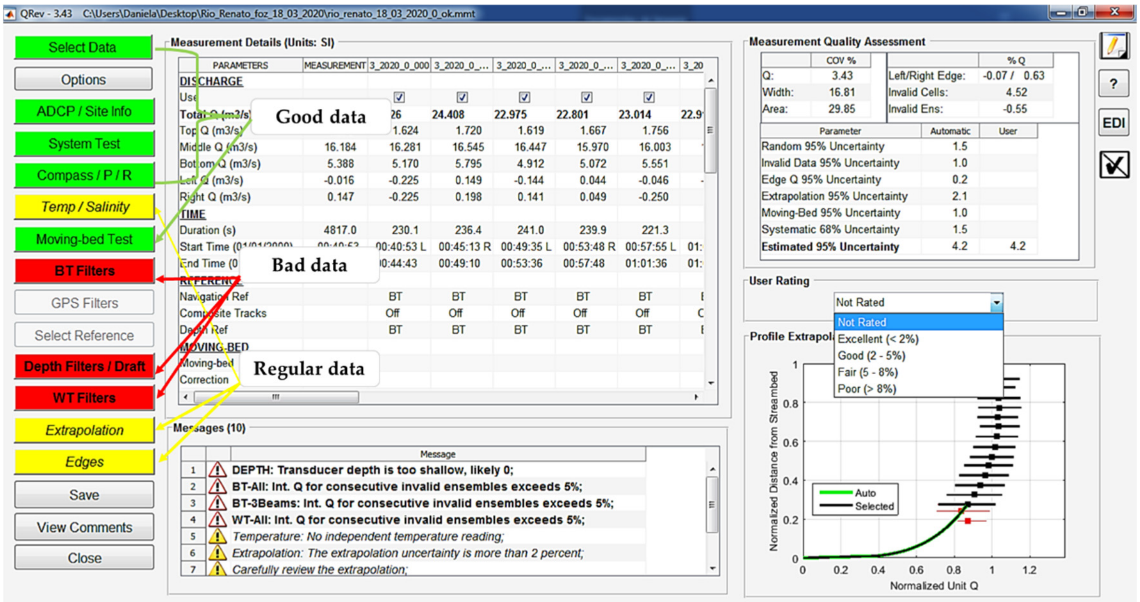


Figure 9. *QRev 3.43* software interface demonstrated a poor quality measurement, which did not pass ADQA according to *USGS* policies.

In the user's evaluation, the rate between 2 and 5% was defined as "good" quality for the estimated data uncertainty. Finally, after the joint evaluation obtained by ADQA and the classification of the estimated uncertainty, 46 measurements (460 pairs of transects) were established for analysis and estimation of the flow and 46 transects for the depth, obtained both with the metallic rod, windlass and ADCP. Obtaining the net flows with the ADCP occurred without the global positioning system and salinity sensor, however, the absence of these sensors did not compromise the quality and statistical security of the measurements.

2.5. Analysis and estimates for depth and flow

Depth and discharge measurements by the reference method and with the ADCP were carried out simultaneously, at monthly intervals (between March 2020 and October 2021), for the five monitoring cross-sections. From the 46 measurements established in the ADQA for the measurements with the ADCP, the same measurement dates were defined for the metal rod and windlass. The analysis of the flows obtained by the ADCP occurred as follows:

1. First, the minimum number of pairs of transects with a minimum duration of 720 s of the total measurement (minimum flow measurement time by ADCP *RiverRay* established by the USGS) on each measurement date of each cross-section was filtered in *QRev 3.43*. Subsequently, other transect pairs were added (one at a time) until the 10 measurement pairs defined in the study were completed. For each pair of incremented transects, the average values (annual) and amplitudes (dry and rainy seasons) of the flow, coefficient of variation, estimated uncertainty, number of pairs and total measurement time were determined;
2. The second part of the analysis consisted of establishing the minimum number of pairs of transects for each cross-section, based on the statistical security given by the uncertainty estimate at a 95% confidence level, defined in this study as a category between 2 to 5% (classified as good). The minimum number of pairs of transects was defined by measurements in the dry season since, in this period of drought, there are more limitations on measurements, such as smaller depths and widths of cross sections, factors that influence the quality of the ADCP measurements; and,

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

3. The last step was summarized by relating the average values of the outflows obtained by each set of transect pairs of each cross section measured by the ADCP with the average values measured by the hydrometric reel, seeking to verify the agreement between the methods of measuring the flow for rivers with low depth.

The analysis of the bathymetric survey obtained by the ADCP occurred as follows:

i) In WinRiver II, a representative transect of each cross-section was defined based on the following observations: transect whose flow value was close to the average net flow value of the section; transect that had the minimum number of cells and lost verticals and, transects absent of faults or noise interfering in the measurement of the depth of the verticals;

ii) In the sequence, the depth values were obtained in punctual verticals and representative of the selected bathymetry, the extraction of the values was carried out manually with the aid of the cursor (mouse) along the transverse profile mapped by the ADCP. At this stage, the objective was to relate the depth values of both methods in the same verticals (subsections) and,

iii) Additionally, the number of verticals per transect, time per transect, time per vertical and the time of the continuous bathymetric survey of the transect at the peaks of maximum and minimum flow were surveyed.

For the net flow, the data were evaluated in the total grouping, monthly measurements between March 2020 and October 2021 by simple linear regression (y = a + bx), between windlass and ADCP. For comparing bathymetry (fluviometric rod or winch and ADCP) data groups such as total section, margins and center were considered. The databases of the depth and flow variables in all the data above groups were separated by 70 and 30%, respectively, for calibration of the coefficients and evaluation of the statistical performance of the generated estimation models. Data separation occurred so that all hydrographic sub-basins and water seasons of the year (rainy and dry seasons) were represented in both data groups (calibration and validation).

In evaluating the performance of the adjusted models, the statistical indicators MBE - mean relative error (Equation 3); o RMSE - square root of mean relative error (Equation 4); and dw - Willmott concordance index (Equation 5) according to Souza et al. [23]. The MBE calculates the average of the mean deviations between the observed and estimated values (model prediction), the RMSE provides the squared difference between the observed and estimated values, and the dw is a coefficient that indicates how much the values estimated by the model deviate from the mean observed. It has an interval between 0.0 and 1.0, where dw = 1.0 represents the complete adjustment between estimate and observation, and 0.0 indicates the opposite.

$$\mathbf{MBE} = \frac{\sum_{i=1}^{n} \mathbf{P_i} - \mathbf{O_i}}{\mathbf{n}} \tag{3}$$

$$\mathbf{RMSE} = \left[\frac{\sum_{i=1}^{n} (\mathbf{P_i} - \mathbf{O_i})^2}{\mathbf{n}}\right]^{0,5} \tag{4}$$

$$\mathbf{dw} = \mathbf{1} - \frac{\sum_{i=1}^{n} (\mathbf{P_i} - \mathbf{O_i})^2}{\sum_{i=1}^{n} (|\mathbf{P'_i} - \bar{\mathbf{O}}| + |\mathbf{O'_i} - \bar{\mathbf{O}}|)^2} \tag{5}$$

where: P_i - estimated values; O_i - observed values; n - number of observations; $|P'_i - \bar{O}|$ - absolute value of the difference between the estimated value and the average of the observed values; $||O'_i - \bar{O}|$ - absolute value of the difference between the observed value and the average of the observed values.

3. Results

The studied rivers are natural and perennial channels and show seasonal variations in the volume and velocity of surface runoff flow. The five hydrological cross-sections showed similar hydraulic dynamics between the hydrological stations in the region, with maximum peaks between March and May (rain-dry transition) and minimum points between August and October (dry-rain transition) for the flow and the other hydraulic variables (Tables 2 and 3 and Figure 10).

In general, between the reference method (windlass) and the ADCP, the lowest values of net flow were obtained using the ADCP, but with a low difference in this variable between the methods used, ranging between 0.02 and 6.48 $m^3 s^{-1}$ between cross-sections. The highest and lowest flow amplitudes obtained between the methods were recorded in the cross-sections of the Celeste and Preto rivers (Tables 2 and 3). The depths obtained by the reference method (metal rod or fluviometric winch) were 0.17 to 6.34 m between the cross-sections of the Preto and Celeste rivers, respectively, and those obtained with the ADCP were 0.65 and 6 20 m between the Caiabi (fluviometric station 2) and Celeste rivers (Table 2 and Figure 10).

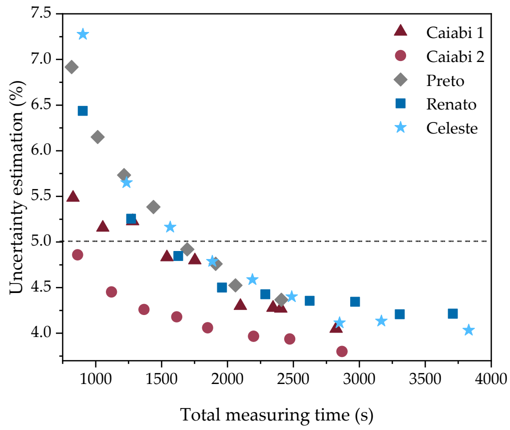


Figure 10. Time of total measurement for uncertainties estimates less than 5% of five cross-sections in the Teles Pires River sub-basin, Mato Grosso, Brazil.

The minimum number of pairs of transects needed to obtain flow measurements with a time greater than 720 s and an uncertainty estimate between 2 and 5% (good quality measurement) in the (dry) period of more limiting conditions was 7 pairs (1507 s) for Caiabi (fluviometric station 1), 5 pairs (1087, 1563 and 1517 s) for Caiabi (fluviometric station 2), Celeste and Renato, and 9 pairs (1581 s) for Preto, under these conditions the average coefficient of variation ranged from 3.50 to 6.18% between cross sections (Table 3). The total measurement time for an uncertainty estimate of less than 5% varied in each cross-section; a reduction in the uncertainty estimate was also observed with the increase in the total measurement time (Figure 11).

As for the bathymetric profile, the punctual depth of 8 to 13 verticals was obtained by the reference method according to the width of the cross-section (Figure 12), while by the acoustic method with ADCP, the continuous depth along each section was obtained with an average of 180 to 263 verticals per transect between cross-sections (Table 3). During the rainy season, with the increase in water level and depth of the cross-sections, "more complete" measurements can be obtained with the ADCP *RiverRay*, resulting in fewer margins, bed and surface extrapolations.

The cross-sections studied showed a stable bed and margins, similar in shape to a triangle, with continuous and unidirectional flow but fluctuations in hydraulic variables throughout the year. The water level fluctuated on average 0.66, 0.87, 0.98, 1.20 and 1.60 m from the average depth for the sections of the Preto stream and Caiabi rivers (fluviometric stations 2 and 1), Renato and Celeste, in that order. The average width ranged from 8.40 to 26.00 m between the cross-sections of the Caiabi (fluviometric station 1) and Celeste rivers, with amplitudes from 1.00 to 6.70 m observed for the same sections between the dry and rainy seasons of the region (Table 2 and Figure 11).

In the relationship between the methods, most of the flows measured by the ADCP *RiverRay* were underestimated, especially from 15.0 $m^3 s^{-1}$ (Figure 12). The flow estimation equation between windlass and ADCP showed satisfactory statistical performance with adjustment dw 0.9977. The mean deviation was only 0.15 $m^3 s^{-1}$, considered small for the flows obtained in the present study, while the RMSE indicated a strong approximation of the flows measured by both methods (Figure 12).

The estimation equations of the depths measured by the reference method and with ADCP *RiverRay* grouped in total section, margins and center of the five transversal sections showed

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

satisfactory performance of the statistical indicatives (Figure 13). Most depth values obtained by ADCPs were overestimated near the margins with differences of 0.37 to 1.11 m, and underestimated at the center of the section with differences of 0.34 to 0.91 m, between the evaluated methods. There was a greater mean deviation (4.0 cm) and spread (25.0 cm) of the depth values in the grouping of the margins and smaller in the center of the section (Figure 13).

Table 2. Hydraulic characteristics obtained by reference methods in cross-sections of sub-basins of the Teles Pires river, Mato Grosso, Brazil.

Variables		Caiabi 1	Caiabi 2	Preto	Renato	Celeste
Flow (m^3 s^{-1})	Q_{Lmax}	8.91	14.58	6.03	24.11	60.78
	Q_{Lmean}	5.43	7.29	4.69	16.46	30.47
	Q_{Lmin}	3.63	3.81	3.48	9.18	22.07
Water velocity (m s^{-1})	V_{max}	0.43	0.61	0.23	0.42	0.63
	V_{mean}	0.35	0.41	0.22	0.37	0.47
	V_{min}	0.33	0.32	0.27	0.29	0.38
Wet area (m^2)	A_{max}	20.15	24.47	23.37	54.55	118.61
	A_{mean}	14.41	16.12	19.39	40.33	62.42
	A_{min}	10.24	11.10	12.25	29.65	53.18
Width (m)	W_{max}	9.00	12.50	12.00	19.20	31.30
	W_{mean}	8.41	11.70	11.22	18.63	25.98
	W_{min}	7.80	10.25	9.50	18.00	24.60
Depth (m)	D_{max}	3.24	3.04	2.41	3.77	6.34
	D_{mean}	1.87	1.35	1.69	2.29	2.25
	D_{min}	1.02	0.20	0.17	1.18	1.09

where: max – maximum value of a single measurement obtained in the rainy season; min – minimum value obtained in the dry season; med – average value of all measurements over the period. * Evaluation period between March 2020 and October 2021.

Table 3. General characteristics obtained by the acoustic method by Doppler Effect - ADCP *RiverRay* in transverse sections of sub-basins of the Teles Pires River, Mato Grosso, Brazil.

Variables	Caiabi 1	Caiabi 2	Preto	Renato	Celeste
Maximum Flow (m^3 s^{-1})	8.16	14.74	6.22	23.03	54.30
Coefficient of variation (%)	5.29	2.44	4.10	2.57	7.68
Estimate 95% Uncertainty (%)	4.70	4.30	4.10	4.10	6.60
Number of transect pairs	6	4	8	4	5
Time of total measurement (s)	1640	1353	1668	1946	1326
Number of verticals per transect	188	230	139	392	211
Time per transect (s)	135	165	100	285	127
Time per vertical (s)	1.40	1.40	1.40	1.37	1.67
Mean Flow (m^3 s^{-1})	5.17	7.16	4.63	16.04	27.56
Coefficient of variation (%)	5.11	3.50	6.18	3.42	4.86
Estimate 95% Uncertainty (%)	4.80	4.50	4.80	4.90	5.20
Number of transect pairs	7	5	9	5	5
Time of total measurement (s)	1541	1120	1910	1627	1565
Number of verticals per transect	180	176	152	263	204
Time per transect (s)	127	119	108	190	144
Time per vertical (s)	1.42	1.49	1.40	1.39	1.42
Minimum Flow (m^3 s^{-1})	3.44	4.30	2.66	10.00	20.95
Coefficient of variation (%)	6.78	3.88	6.72	3.55	3.45
Estimate 95% Uncertainty (%)	5.10	4.50	4.90	4.40	4.20
Number of transect pairs	7	5	9	5	5

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 30 September 2023 doi:10.20944/preprints202309.2158.v1

Time of total measurement (s)	1507	1087	1581	1563	1517
Number of verticals per transect	171	178	124	307	218
Time per transect (s)	117	110	90	222	156
Time per vertical (s)	1.46	1.61	1.38	1.38	1.40

where: The minimum and maximum values represent a single measurement obtained in the dry and rainy seasons, respectively, and the mean values represent the measurements of the entire evaluated period. * Evaluation period between March 2020 and October 2021.

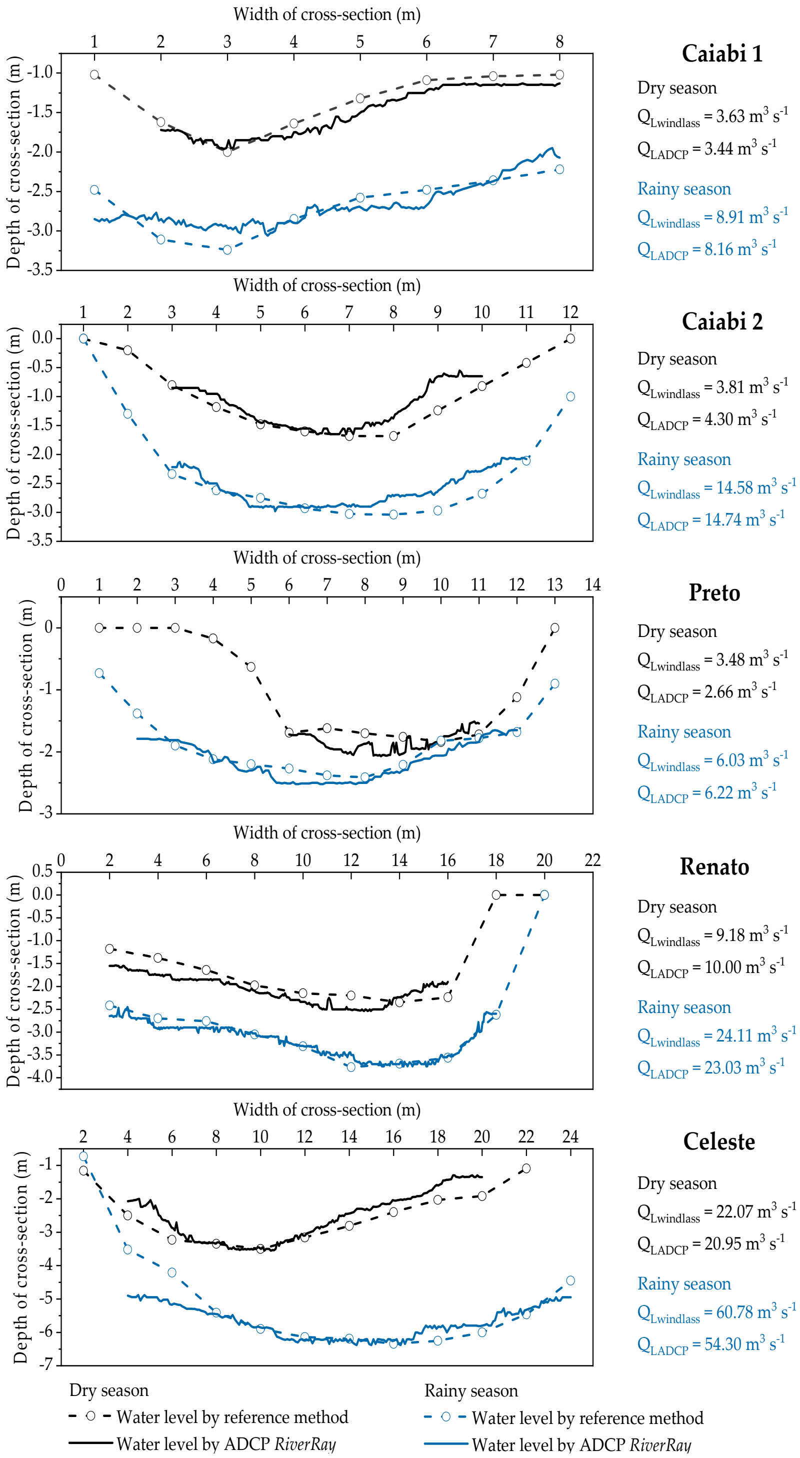


Figure 11. Bathymetric profiles by the reference method (dotted line) and ADCP (solid line) in the dry and rainy season of five monitoring cross-sections in hydrographic sub-basins of the Teles Pires River,

Mato Grosso, Brazil. * The dry and wet season values are represented in this Figure by a single measurement of the respective periods.

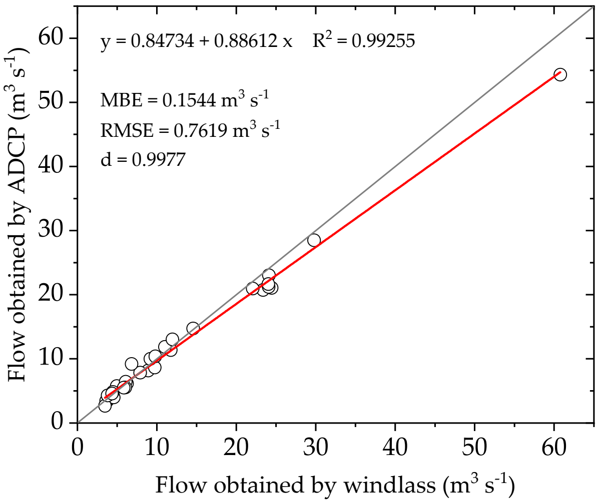


Figure 12. Linear estimation equation and their statistical performance of the annual flow, obtained by the reference method about the ADCP, of the five cross-sections of monitoring of sub-basins of the Teles Pires River, Mato Grosso, Brazil.

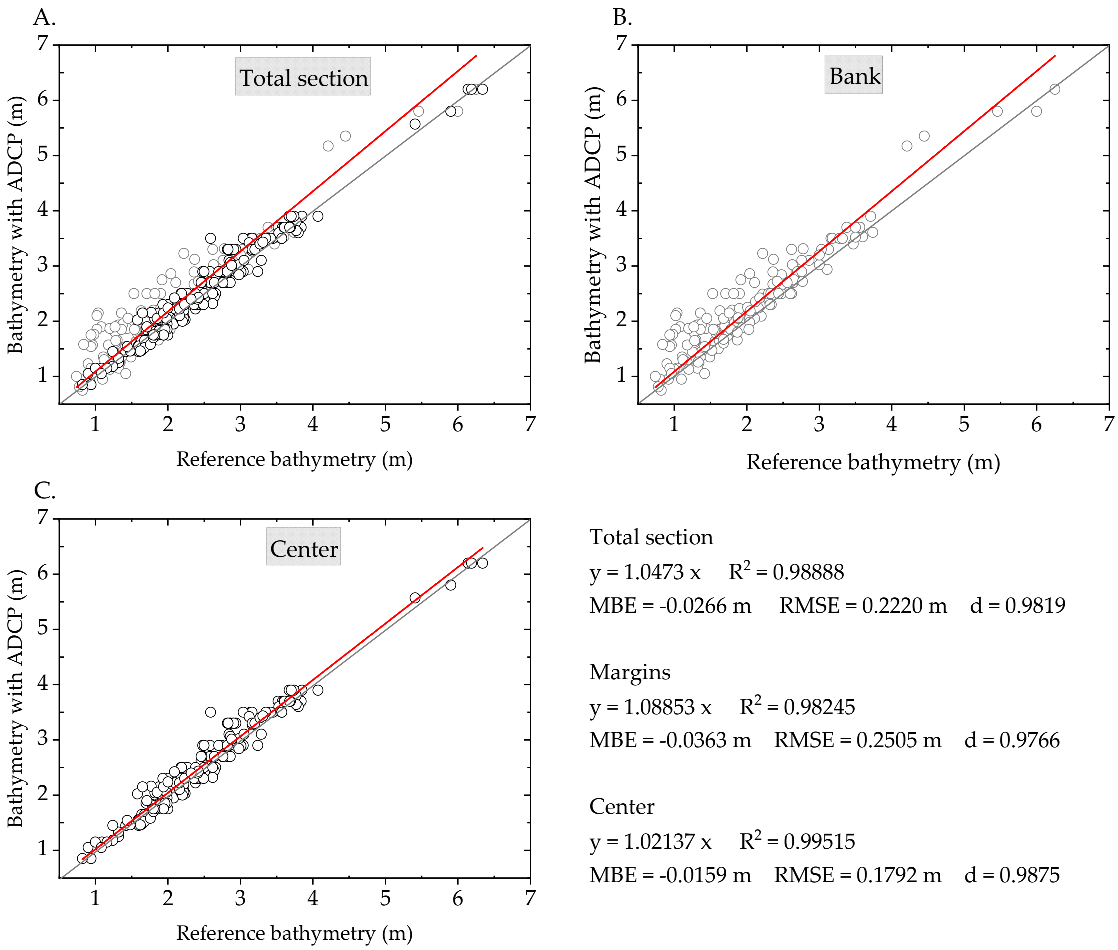


Figure 13. Linear estimation equations and their statistical performances of the depth measured by the reference method about the depth obtained by the ADCP in different measurement positions in

the five transversal sections of the hydrographic sub-basins of the Teles Pires River, Mato Grosso, Brazil.

4. Discussion

The hydrodynamics of natural and perennial channels depend on several factors, whether natural (type of soil) or anthropogenic (land use), the water seasonality of the region in which the watershed is located [10,24], as well as its physiographic characteristics, such as the area and density of the drainage network, the shape, slope and sinuosity of the channel that influence the generation, volume, speed and direction of the surface runoff flow [25,26] and in the production and transport of sediments [5].

In the evaluated cross-sections, the predominant vegetation cover on the margins is native vegetation (Figure 13). The density of the vegetation cover [27] and the type and physical-hydric characteristics of the soil control the dynamics of water and sediments in a watershed [7,26] influenced by the precipitation and evapotranspiration components, impacting the storage (infiltration and retention) of water in the soils of the watersheds [28].

The hydrographic sub-basins studied are predominantly rural (Figure 13). The survey of water availability in their watercourses is still developing. However, the Caiabi River (fluviometric station 2) has flow records by the hydrometric reel between 5.95 and 16.14 $m^3 s^{-1}$ from December/2018 to February/2020 [29]; these values are similar to those observed in the present study (Table 6).

Several methods and techniques can measure flow in watercourses, the choice of which depends on the hydrodynamic and morphological characteristics of the cross-section, the desired precision and accuracy, the availability of equipment, the type and configuration of the equipment and the operator experience [13,29,30]. The acoustic method by Doppler Effect (ADCP *RiverRay*) proved to be statistically safe for measuring net flow in the different hydraulic conditions of the cross-sections evaluated in the present study about the reference method (windlass).

For the ADCP *RiverRay*, the total measurement time, time per vertical, the number of transect pairs and the number of verticals per transect (Table 7) depended on the hydraulic characteristics of each hydrological section (Table 6), which in turn depend on the dry and rainy seasons in the region. The minimum total measurement time to obtain the net flow in rivers of the Teles Pires River basin mainly depended on the width and flow velocity, as it was evident in the present study that the wider cross-sections and greater flow velocity of the surface runoff required a smaller number of pairs of transects to complete the minimum time of 720 s required by the *USGS* (Table 7), but with similar measurement times between the cross-sections of the Caiabi rivers (fluviometric station 1), Celeste, Renato and Preto river.

The statistical quality of the flow measurements must also be considered to establish the total measurement time and the minimum number of pairs of transects since they depend on the quality of the variables obtained during the field measurement. In the present study, based on the uncertainty estimate at 95% confidence, a range between 2 and 5% of measurement uncertainty was established, considered a good quality measurement.

With the increase in the number of pairs of transects and the total flow measurement time from the pre-established time of 720 s, the uncertainty estimate decreased by up to 0.5% (Figure 21). Klema et al. [31] report that the longer a transect is measured, the more accurate the net flow estimate will be; this reinforces the greater influence of the total measurement time in reducing measurement uncertainty than the greater number of measured transects.

The greatest differences in net flow measured by the evaluated methods occurred in the cross-sections with higher flows, such as Renato and Celeste (Tables 6 and 7). Despite these differences, the ADCP *RiverRay* showed satisfactory statistical performance for measuring flows in rivers with different depth ranges (0.43 to 6.34 m) and widths (7.80 to 31.30 m) of the cross-sections studied (Table 6), in addition to continuously detailing the hydraulic behavior of these sections throughout the year.

As for the bathymetric survey, the ADCP measured the lowest depth value (0.65 m) near the bank, a difference of 0.22 m about the depth measured by the metal rod (0.43 m) in the same cross-section vertical. This shows the limitation of the ADCP when applied to sections with depths below

0.40 m, and that, in this case the equipment performs extrapolations and interpolations of areas close to the unmeasured margins to estimate depth and velocities of solids in suspension and calculates the total net flow.

In the bathymetric survey, despite finding depths with greater mean deviations and scattering near the margins, when the grouping in total section by reference and acoustic methods, it did not negatively affect the quality of the measurement, resulting in a good fit of the equation, and therefore, the bathymetric survey carried out by ADCP *RiverRay* considering the entire section is adequate to measure the net flow (Figure 24).

The differences observed between the measured values of flow and depth of the cross-section by the different measurement methods may be associated with the level of detail of the measurement between the equipment and the displacement of the cross-section (~2.5 m) for measurement with ADCP. In addition, this ADCP allows measuring moving bottom and extrapolating hydraulic variables of areas not measured by the equipment that may have contributed to such differences, however not significant. These issues can be better explored in future work.

The fact that the ADCP overestimated the depths at the margins may be associated with the transducer frequency. For the acoustic method by the Doppler Effect, the accuracy of a net flow measurement depends on the frequency of the transducer, the mode of operation and the type of acoustic processing [13,32]. ADCP *RiverRay* features automatic setup and adaptive measurement methods to optimize ADCP performance for measuring water velocity, turbulence level and depth, a flat surface *phased-array* transducer with wider beam angles, making it more accurate for the bathymetric survey in shallow to deep rivers (0.4 to 60 m), and updated software [22,32].

Applying the acoustic method by the Doppler Effect with the ADCP *RiverRay* is a viable alternative to measure the net flow of natural rivers with depth between 0.4 and 6.5 m and width between 7.80 and 31.50 m. However, care must be taken in applying this equipment when the hydrodynamic and morphological characteristics of the cross-section are not known; it is advisable first to seek to know the hydraulic conditions of the watercourse to choose the adequate ADCP configuration for such conditions. In addition, the total flow measurement time must also be considered to obtain measurements with good accuracy and precision.

Future work will make it possible to compare methods and techniques for measuring flow in natural rivers with low depth (up to 6.5 m) in the Cerrado-Amazon transition region, taking into account other geomorphological and physiographic characteristics of the watershed, in addition to analyzing the seasonality of the watersheds flows during the region's water regime. Evaluate measurement methods and techniques that optimize human and financial resources and reduce fieldwork time when there is an alternative (non-substitutive) and safe method for surveying and monitoring water and sediments of natural water bodies.

The increase in water demand for irrigation and watering of animals in this region of the Brazilian agricultural frontier requires knowledge about the availability of water to supply the agribusiness sector with the maintenance of environmental safety, and therefore not only the need for measurements of in flow loco, but also the need to seek to optimize this survey based on comparisons of measurement methods, as carried out in the present study.

Other studies report the importance of evaluating measurement methods and techniques and flow and bathymetry [31–39] to define the most appropriate method for measuring and/or estimating surface runoff, as well as knowing the dynamics and availability of water resources, to provide tools that support the management of land use and conservation of available natural resources.

5. Conclusions

Measurement with ADCP *RiverRay* is accurate for obtaining the net flow and depth in shallow cross-sections (up to 6.5 m) of hydrographic sub-basins of the Teles Pires River. Comparisons with the reference method (fluviometric windlass) still need to be evaluated in other shallow rivers with different hydraulic and geomorphological characteristics, to optimize and increase the statistical security of measurements in the field.

The increase in the total measurement time greater than 720 s with the use of ADCP *RiverRay* influences the reduction of uncertainty in estimating the net flow in shallow cross-sections (up to 6.5 m) of hydrographic sub-basins of the Teles Pires River. Determining the total measurement time and pairs of transects to obtain measurements of flow depends on the hydraulic characteristics of the watercourse.

Author Contributions: data collection, writing, methodology, formal and statistical analysis and figures - D.R.B.; data collection and laboratory analysis - R.S.D.P., M.A.B.A., C.C.M. and C.J.S.; data collection, review, editing, supervision, and financial support—A.P.d.S. and F.T.d.A. All authors have read and agreed to the published version of the manuscript.

Funding: This study was financed by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brazil (CAPES) and the Agência Nacional de Águas e Saneamento Básico (ANA), Finance Code—001 and Process 88887.144957/2017-00. The authors wish to thank the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for their support with scientific initiation grants and a productivity grant (Process 308784/2019-7).

Data Availability Statement: Study data can be obtained upon request to the corresponding author or the first author, via e-mail. The data are unavailable on the website as the research project is still being developed.

Acknowledgments: We thank the Federal University of Mato Grosso, specifically the PPGCAM and PPGFA. The authors also thank all the students and professors of the Tecnologia em Recursos Hídricos no Centro-Oeste" research group (dgp.cnpq.br/dgp/espelhogrupo/2399343537529589, accessed on 26 September 2023). The authors would also like to thank the owners of the farms that allowed and supported the collection of samples, with the following highlights: i) in Vera-MT: Fazenda Vó Maria, Agropecuária Taguá, Fazenda São José and Fazenda Jaboticabal; ii) in Claúdia-MT: Fazenda Continental, Fazenda Aremisa III and Agropecuária Bedin. To the 3rd Comarca de Justiça Cível de Sinop for the CBH Monitora Project's financial support and the Comitê dos Afluentes da Margem Direita do Alto Teles Pires.

Conflicts of Interest: The funders had no role in the study's design, in the collection, analyses, or interpretation of data, in the writing of the manuscript, or in the decision to publish the results.

References

1. Stinghen, C.M.; Mannich, M. Overview of critical basin management in Brazil. *Rev. Gest. Água da América Latina* **2022**, 19, e13. DOI: https://doi.org/10.21168/rega.v19e13
2. Paiva, R.C.D.; Chaffe, P.L.B.; Anache, J.A.A.; Fontes, A.S.; Araújo, L.M.N.; Araújo, A.N.; Bartiko, D.; Bleningers, T.; Amorim, P.B.; Buarque, D.C.; Carlotto, T.; Collischonn, W.; Detzels, D.H.M.; Fan, F.M.; Formiga-Johnsson, R.M.; Kobiyama, M.; Mannichs, M.; Marques, G.; Michel, G.P.; Oliveira, D.Y.; Oliveira, P.T.S.; Pinheiro, A.; Ruhoff, A.; Siqueira, V.A.; Tassi, R.; Zanandrea, F. Advances and challenges in the water sciences in Brazil: a community synthesis of the XXIII Brazilian Water Resources Symposium. *Rev. Bras. Recur. Hide.* **2020**, 25, e50. DOI: https://doi.org/10.1590/2318-0331.252020200136
3. ANA (Water National Agency). Topobathymetric and geodetic surveys applied in the National Hydrometeorological Network (NHN). Available online: https://rigeo.cprm.gov.br/xmlui/handle/doc/22628 (accessed on 10 May 2021).
4. Lapola, D.M.; Silva, J.M.C. Da; Diego R. Braga, D.R.; Larissa Carpigiani, L.; Ogawa, F.; Torres, R.R.; Barbosa, L.C.F.; Ometto, J.P.H.B.; Joly, C.A. A climate-change vulnerability and adaptation assessment for Brazil's protected areas. *Conserv. Biol.* **2019**, 34, p. 427-437. DOI: https://doi.org/10.1111/cobi.13405
5. Sekharan, S.; Samal, D.R.; Phuleria, H.C.; Chandel, M.K.; Gedam, S.; Kumar, R.; Sethi, V.; Supate, A.R.; Karmakar, S. River pollution monitoring over an industrial catchment in urban ecosystem: Challenges and proposed geospatial framework. *Environ. Chall.* **2022**, *7*, 100496. DOI: https://doi.org/10.1016/j.envc.2022.100496
6. Peixoto, R.A.O.; Pereira, C.E.; Salla, M.R.; Alamy Filho, J.E.; Nishimura, A. Determination of the liquid and solid discharge ratio and analysis of factors influencing the dynamics of sediment transport in the Jordão river Watershed (UPGRH-PN 1). *Eng. Sanit. Ambient.* **2020**, *25*, 921–931. DOI: https://doi.org/10.1590/S1413-4152202020180137
7. Wang, X.; Zhao, X.; Zhang, Z.; Yi, L.; Zuo, L.; Wen, Q.; Liu, F.; Xu, J.; Hu, S.; Liu, B. Assessment of soil erosion change and its relationships with land use/cover change in China from the end of the 1980s to 2010. *Catena* **2016**, 137, 256-268. DOI: https://doi.org/10.1016/j.catena.2015.10.004
8. Berihun, M.L.; Tsunekawa, A.; Haregeweyn, N.; Tsubo, M.; Fenta, A.A.; Ebabu, K.; Sultan, D.; Dile, Y.T. Reduced runoff and sediment loss under alternative land capability-based land use and management

options in a sub-humid watershed of Ethiopia. *J. Hydrol. Reg. Stud.* **2022**, *40*, 100998. DOI: https://doi.org/10.1016/j.ejrh.2022.100998
9. Gu, X.; Lin, C.; Wang, B.; Wang, J.; Ouyang, W. A comprehensive assessment of anthropogenic impacts, contamination, and ecological risks of toxic elements in sediments of urban rivers: A case study in Qingdao, East China. *Environmental Advances* **2022**,7, 100143. DOI: https://doi.org/10.1016/j.envadv.2021.100143
10. Almeida, W.S.; Carvalho, D.F.; Pereira, F.A.C.; Rouws, J.R.C. Sediment production and soil water infiltration under different simulated rainfall characteristics. *Rev. Bras. Eng. Agric. Ambient.* **2019**, *23*, 572–578. DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v23n8p572-578.
11. Sousa, M.M.M.; Palácio, H.A.Q.; Andrade, E.M.; Ribeiro Filho, J.C.; Moura, M.M.S. Determinant pluviometric characteristics of sediment transport in a catchment with thinned vegetation in the tropical semiarid. *Rev. Caatinga* **2020**, *33*, 785–793. DOI: https://doi.org/10.1590/1983-21252020v33n322rc
12. Wenzel, D.A.; Uliana, E.M.; Almeida, F.T.; Souza, A.P.; Mendes, M.A.S.A.; Souza, L.G.S. Physiographic characteristics of the medium and upper Teles Pires River sub-basins, Mato Grosso, Brazil. *Rev. Ciênc. Agroamb.* **2017**, 15, 123-131.
13. Collischonn, W.; Dornelles, F. Hydrology for engineering and environmental sciences. 2ª Ed. review – ABRH: Porto Alegre Brazil, 2015; 336p.
14. Gamaro, P.E.M. *Acoustic Doppler flow meters*. Itaipu Binacional: Foz do Iguaçú, Brazil, 2012. 164p.
15. Mueller, D.S. extrap: Software to assist the selection of extrapolation methods for moving-boat ADCP streamflow measurements. *Computers Geoscience.***2013**, 54, 211-218. DOI: http://dx.doi.org/10.1016/j.cageo.2013.02.001
16. Lopes, T.R.; Zolin, C.A.; Mingoti, R.; Vendrusculo, L.G.; Almeida, F.T; Souza, A.P.; Oliveira, R.F.; Paulino, J.; Uliana, E.M. Hydrological regime, water availability and land use/land cover change impact on the water balance in a large agriculture basin in the Southern Brazilian Amazon. *J. South Am. Earth Sci.* **2021**, 108, 103224. DOI: https://doi.org/10.1016/j.jsames.2021.103224
17. Zolin, C.A.; Paulino, J.; Silva, M.E.; Magalhães, C.A.S.; Almeida, F.T.; Souza, A.P.; Mingoti, R. Soil and water losses under crop-forest integration and in soybean-corn succession. *Pesq. Agropec. Bras.* **2016**, *51*, 1223–1230. DOI: https://doi.org/10.1590/S0100-204X2016000900022
18. Uliana, E.M.; Souza, L.G.S.; Silva, D.D.; Souza, A.P.; Almeida, F.T.; Araújo, H.B. Hydrological regionalization of flows for the médium and upper Teles Pires River – MT, Brazil. *Rev. Cienc. Agrar***. 2016**, 59, 333-338. DOI: http://dx.doi.org/10.4322/rca.2240
19. ANA (Water National Agency). Survey of agriculture irrigated by central pivots in Brazil. National Water Agency, Embrapa Corn and Sorgo 2nd ed. Brasília: ANA, 2019. 47p.
20. Souza, A.P.; Mota, L.L.; Zamadei, T.; Martim, C.C.; Almeida, F.T.; Paulino, J. Climate classification and climatic water balance in Mato Grosso state, Brazil. *Nativa* **2013**, *1*, 34–43. DOI: http://dx.doi.org/10.14583/2318-7670.v01n01a07
21. Santos, I.; Fill, H.D.; Sugai, M.R.V.B.; Buba, H.; Kishi, R.T.; Marone, E.; Latert, L.F. *Applied Hydrometry*; Instituto de Tecnologia para o Desenvolvimento: Curitiba, Brazil, 2001; 372p.
22. MapBiomas. MapBiomas Collection 6.0: Land Cover and Land Use Maps. 2020. Available online: https://mapbiomas.org/ colecoes-mapbiomas-1?cama_set_language=pt-BR (accessed on 7 July 2022).
23. Mueller, D.S.; Wagner, C.R.; Rehmel, M.S.; Oberg, K.A.; Rainville, F. Measuring Discharge with Acoustic Doppler Current Profilers from a Moving Boat (ver. 2.0, December 2013): U.S. Geological Survey Techniques and Methods, book 3, chap. A22, 2013. 95p. DOI: http://dx.doi.org/10.3133/tm3A22
24. Souza, A.P.; Silva, A.C.; Tanaka, A.A.; Uliana, E.M.; Almeida, F.T.; Klar, A.E.; Gomes, A.W.A. Global radiation by simplified models for the state of Mato Grosso, Brazil. *Pesqui. Agropecu. Bras.* **2017**, 52, 215-227. DOI: https://doi.org/10.1590/S0100-204X2017000400001
25. Souza, N.S.; Souza, W.J.; Cardoso, J.M.S. Hydrological characterization and influence of the land cover on Fêmeas River flow parameters. *Eng. Sanit. Ambient.* **2017**, 22, 453-462. DOI: https://doi.org/10.1590/S1413-41522017155279
26. Santos, L.L.; Ribeiro, V.O.; Diodato, J.O. Morphometry Of Hydrographic Basins Placed In The Urban Area Of Dourados – Ms, Brazil. *Rev. Esp. Geogr. em Análise***,** 2019, 46, 75-87. DOI: http://dx.doi.org/10.5380/raega.v46i3.67039
27. Carvalho, A.C.P.; Lorandi, R.; Di Lollo, J.A.; Collares, E.G.; Moschini, L.E. Hydrological response of hydrographic subbasins in the Piracicaba River Basin - Southeast Region of Brazil. *Soc. Nat.* **2022**, 34, e63522. DOI: https://doi.org/10.14393/SN-v34-2022-63522
28. Mendes, N.G.S.; Cecílio, R.A.; Zanetti, S.S. Forest Coverage And Streamflow Of Watersheds In The Tropical Atlantic Rainforest. *Rev. Árvore* **2018**, 42, e420204. DOI: http://dx.doi.org/10.1590/1806-90882018000200004
29. Almeida, W.S.; Panachuki, E.; Oliveira, P.T.S. De; Menezes, R.S.; Sobrinho, T.A.; Carvalho, D.F. Effect of soil tillage and vegetal cover on soil water infiltration. Soil & *Soil Tillage Res.* **2018**, 175, 130-138. DOI: http://dx.doi.org/10.1016/j.still.2017.07.009
30. Simioni, C.F.; Almeida, F.T.; Zolin, C.A.; Uliana, E.M.; Souza, A.P.; Marque, A. Solid discharge in a microbasin of the Amazon region. *Cienc. Nat.* **2021**, *43*, e73. DOI: https://doi.org/10.5902/2179460X64223

31. Vilanova, M.R.N.; Balestieri, J.A.P. Quality Analysis Of Streamflow Data Obtained By Acoustic Profiling. *Rev. Árvore* 2013, 37, 531-538.
32. Klema, M.R.; Pirzado, A.G.; Venayagamoorthy; S.H.; Gates, T.K. Analysis of acoustic Doppler current profiler mean velocity measurements in shallow flows. *Flow Meas. Instrum.* **2020**, 74, 101755. DOI: https://doi.org/10.1016/j.flowmeasinst.2020.101755
33. Boldt, J.A.; Oberg, K.A. Validation of Streamflow Measurements Made with M9 and RiverRay Acoustic Doppler Current Profilers. *J. Hydraul. Eng.* **2016**, 142, 04015054. DOI: 10.1061/(ASCE)HY.1943-7900.0001087
34. Gamaro, P.E.M.; Gomes, B.M.; Maldonado, L.H.; Rodrigues, M.F.C. Analysis of Continuous Flow Series Obtained in Real Time Using Different Techniques with Static Doppler Acoustic Devices in the Piracema Channel of Itaipu Binacional: Almost Rectangular Channels and Trapezoidal Channels. R*ev. Bras. Recur. Hidr.* **2013**, 18, 33-42.
35. Farina, G.; Alvisi, S.; Franchini, M.; Corato, G.; Moramarco, T. Estimation of bathymetry (and discharge) in natural river cross-sections by using an entropy approach. *J. Hydrol.* **2015**, 527, 20-29. DOI: http://dx.doi.org/10.1016/j.jhydrol.2015.04.037
36. Výleta, R.; Valent, P. Adcp Discharge Measurements on The River Danube: Post-Processing and Correction of Data. *Slovak J. Civil Eng.* **2019**, 27, 7-13. DOI: 10.2478/sjce-2019-0002
37. Bjerklie, D.M.; Fulton, J.W.; Dingman, S.L.; Canova, M.G.; Minear, J.T.; Moramarco, T. Fundamental Hydraulics of Cross Sections in Natural Rivers: Preliminary Analysis of a Large Data Set of Acoustic Doppler Flow Measurements. *Water Resour. Res.* **2020**, 56, e2019WR025986. DOI: https://doi.org/10.1029/2019WR025986
38. Huang, H. Estimating the Calibration Error–Caused Bias Limit of Moving-Boat ADCP Streamflow Measurements. *J. Hydraul. Eng.* **2020**, 146, 06020006. DOI: 10.1061/(ASCE)HY.1943-7900.0001736
39. Gentil, W.B.; Ramalho, F.L.; Braga, C.C.; Barcelos, A.A.; Cabral, J.B.P. The Bathymetric Diagnosis of the Hydroelectric Power Station from Caçu – GO. *Rev. Bras. Geog. Físic.* **2021**, 14, 1541-1558, 2021. DOI: https://doi.org/10.26848/rbgf.v14.3.p1541-1558
40. Lagogiannis, S.; Dimitriou, E. Discharge Estimation with the Use of Unmanned Aerial Vehicles (UAVs) and Hydraulic Methods in Shallow Rivers. *Water* **2021**, 13, 2808. DOI: https://doi.org/10.3390/w13202808