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DEVELOPMENT AND APPLICATION OF WSC AND PARSHALL FLUMES FOR DATA COLLECTION OF SURFACE RUNOFF

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1 ABSTRACT

The use of spillways, such as Parshall and WSC flumes, are widely used for fluid flow measurement, as in Water and Sewage Treatment Plants, measurement of runoff for agricultural purposes. Thus, it has been used in scientific works in which it is necessary to obtain the flow rate, due to measurement accuracy, ease of construction and operation. Therefore, the objective was to dimension and build flumes like Parshall and WSC, and adjust a mathematical model to estimate the drained flow depending on the height of the depth water in these flumes. The experiment was carried out in the Federal University of Grande Dourados in Hydraulics Laboratory, where flow values for flumes were measured by the volumetric method. The data were subjected to the normality test and regression adjustment for potential function. With the results, a good adjustment of the calibration equation was verified, obtaining high values of determination coefficients for the flumes, WSC (R^2 = 0.98) and Parshall (R^2 = 0.99), the minimum and maximum flows observed were, respectively, 0.039 and 2.23 $m^3 h^{-1}$ for WSC and 0.11 $m^3 h^{-1}$ e 4.44 $m^3 h^{-1}$ for Parshall, meeting the specifications for use in experimental plots with typical weather of the South region of Mato Grosso do Sul State.

Keywords: volumetric method, calibration, flow rate, channel

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DESENVOLVIMENTO E APLICAÇÃO DE CALHAS WSC E PARSHALL PARA COLETA DE DADOS DE ESCOAMENTO SUPERFICIAL

2 RESUMO

O uso de vertedores, como as calhas Parshall e a WSC, são muito utilizados para medição de vazão de fluidos, como em Estações de Tratamento de Água e Esgotos, mensuração de escoamento superficial para fins agrícolas. Assim, vem sendo empregadas em trabalhos científicos em que é necessário obter a vazão de escoamento, devido precisão da mensuração, a facilidade de construção e operação. Diante disso, objetivou-se dimensionar e construir calhas do tipo Parshall e WSC, e ajustar um modelo matemático para estimar a vazão escoada em função da altura da lâmina de água nessas calhas. O experimento foi realizado em Laboratório de Hidráulica da Universidade Federal da Grande Dourados, onde foram medidos os valores de vazão para as calhas pelo método volumétrico. Os dados foram submetidos ao teste de normalidade e ajuste de regressão para função potencial. Com os resultados, verificou-se um bom ajuste da equação de calibração, obtendo valores elevados de coeficientes de determinação para as calhas, WSC (R^2 = 0,98) e Parshall (R^2 = 0,99), as vazões de mínima e de máxima observados foram, respectivamente, 0,039 e 2,23 m^3 h^{-1} para WSC e 0,11 m^3h^{-1} e 4,44 m^3h^{-1} para Parshall, atendendo as especificações para uso em parcelas experimentais com clima característico da região Sul do Estado do Mato Grosso do Sul.

Palavras-chave: método volumétrico, calibração, vazão, canal

3 INTRODUCTION

The action of man in the environment, with the use and occupation of the soil without planning and preservation of water sources, brings a current problem and of great repercussion (APARECIDO; NOVELI; MATOS, 2017). The consequences can be diverse, reducing the rate of water infiltration into the soil, increasing water erosion and silting of rivers with the soil degradation and contamination of surface waters (CONFESSOR; RODRIGUES, 2018). These disturbances are visible in the surface flow hydrographs, which tend to have a shorter time and higher peak discharge (FELICE et al., 2018). Among the main factors of reduction of runoff and loss of soil, is its coverage, which acts to reduce the direct impact of raindrops and their kinetic energy (ALMEIDA et al., 2012).

According to Adviento-Borbe et al. (2018), part of the water incident on the plants, from rains and irrigation, is transported to another location through surface runoff. Thus, the estimation of surface water potential is essential for planning irrigation, water supply and flood control projects (RAO, 2020). The monitoring runoff and rainwater conservation is an issue that has been addressed in several studies (SETHI et al. 2017), however, measurements made with collection containers (tanks) are expensive work, dependent on the collection of accumulated daily volumes. More realistic interpretations of the dynamics of the runoff phenomenon using these procedures are not feasible due to the dynamic nature of rainfall, a phenomenon that triggers it (PORTOCARRERO; ANDRADE;

CAMPOS, 2017).

Measuring the water flow in open channels is a basic element for management and there are several methods to calculate the flow rate, thus simplifying the continuous flow monitoring (SAMANI, 2017). The use of flumes, such as the Parshall, HS or WSC type, for example, to assist in the measurement of runoff, appears in several works (PORTOCARRERO; ANDRADE; CAMPOS, 2017; FELICE et al., 2018; TIWARI; SIHAG, 2020).

The flume is a spillway that works in the face of bottlenecks and rebounds that establish for a given section a relationship between the flow and the height of the fluid blade. The system was developed by Ralph L. Parshall engineer in cooperation with the US Department of Irrigation in the 1920s (KHOSRONEJAD et al., 2021) being considered an improved model of the Venturi flume.

The short-necked Parshall flume (opening of the strangled section) has the advantages of simple structures, low prices and high precision, in addition to its application being less dependent on the type, size and inclination of the channel (XIAO et al., 2016). Indirect methods of collecting channel flow are still the most used for irrigation management in the field; especially the use of spillways with such advantages becomes an easy to use measure, with the purpose of guaranteeing adequate water management for the cultures.

In work carried out on slopes with a slope and inclination of 66%, Portocarrero, Andrade e Campos (2017), used Parshall-type flumes adapted with an ultrasonic level transmitter for flow measurement, demonstrating a good alternative for measuring different flow events. Sousa et al. (2016) in a study of micro basins used Parshall flumes to observe the flow through installed sensors in order to measure the elevation of the level and a gap for collecting sediments.

In view of the above, the objective of this study was to dimension, build and calibrate the flumes of the Parshall and WSC type to evaluate the runoff of agricultural areas subject or not to erosion.

4 MATERIAL AND METHODS

The work developed consisted of elaborating WSC and Parshall flumes and adjusting a non-linear model (Potential) to estimate the flow based on the height of the water flow drained by them. The experiments were carried out at the Hydraulics and Hydrology Laboratory of the Faculty of Agricultural Sciences of the Federal University of Grande Dourados, in Dourados / MS. The experiment is located at 22º11’51.6”S and 54º55’57.4” O, with an average altitude of 446 m.

Flumes are devices normally used to conduct flow. WSC flumes are widely used to measure flow in irrigation grooves or channels. The Parshall flume, on the other hand, consists of equipment where its method of quantification is maximum and minimum flow rates in a watercourse. To determine such flow, the size of the opening of the water passage must be defined, denoted by the parameter W (Throat width).

The current standard in Brazil to design the flumes it is NBR / ISO 9826: 2008 (ABNT, 2008), thus, it was used to elaborate the flumes. The sizing of the flumes used in this experiment were made aiming to use them to measure flow to meet flow events between minimum and maximum flow values. For this, the study of rainfall intensity data was carried out (i) for the city of Dourados / MS of the last 10 years, based on data from the weather station of Embrapa Guia Clima Dourados / MS (GUIA CLIMA, 2020), thus obtaining the highest and lowest rainfall intensities, these values being 49.8 and 13.4 mm h^{-1}, respectively. For rainfall intensity values, rains of 1 hour of uninterrupted duration were considered.

For the calculation of runoff, based

on the values of minimum and maximum i (mm h^{-1}), Equation 1 was used. Adopting a C value equal to 0.4 (maximum for land covered with crops) as Chen et al. (2019). We obtained if so, the flows of 5.36 and 19.92 m^3 h^{-1}, for the minimum and maximum runoff in experimental areas of 1000 m² (0.1 ha), respectively.

$$Q_e = \frac{C*i*A}{360} \quad (1)$$

Where:

Q_e: runoff flow, m^3 s^{-1};
i: rainfall intensity, mm h^{-1};
C: runoff coefficient, dimensionless;
A: catchment area, ha.

Thus, the dimension of the parameter W (throat width) chosen was one inch (2.54 cm) where it supports the minimum and maximum flow, respectively, 0.40 m³ / h and 20.41 m³ / h, according to the flow chart for the Parshall flume (Table 1), thus meeting the maximum and minimum flow conditions for Dourados / MS.

Table 1. W parameter and their respective flow rates for flumes of the Parshall type. Dourados/MS, 2019/20.

W (Inch)	**Flow rate (m^3 h^{-1})**		**Flow rate (L s^{-1})**	
	Minimum	**Maximum**	**Minimum**	**Maximum**
1	0.40	20.41	0.11	5.67
2	1.00	51.00	0.28	14.17
3	2.88	193.68	0.80	53.80
6	5.04	397.44	1.40	110.40
9	9.00	907.30	2.55	252.02

Source:http://portaldoprojetista.com.br/funcionamento-da-calha-parshall/, acesso em 10/09/2020

The developed WSC flume, due to the lack of standard information, was built for sizes and flow proportional to that of the Parshall flume. From the choice of the diameter of the throat (W) of the Parshall flume, the determination of the parameters of each section of the flume was carried out, making it possible to carry out the dimensioning and design of the flumes (Figure 1) and later the construction (Figure 2).

Figure 1. Sketch of the design of the WSC flume (A) and the Parshall flume (B), dimensions in cm. Dourados / MS, 2019.

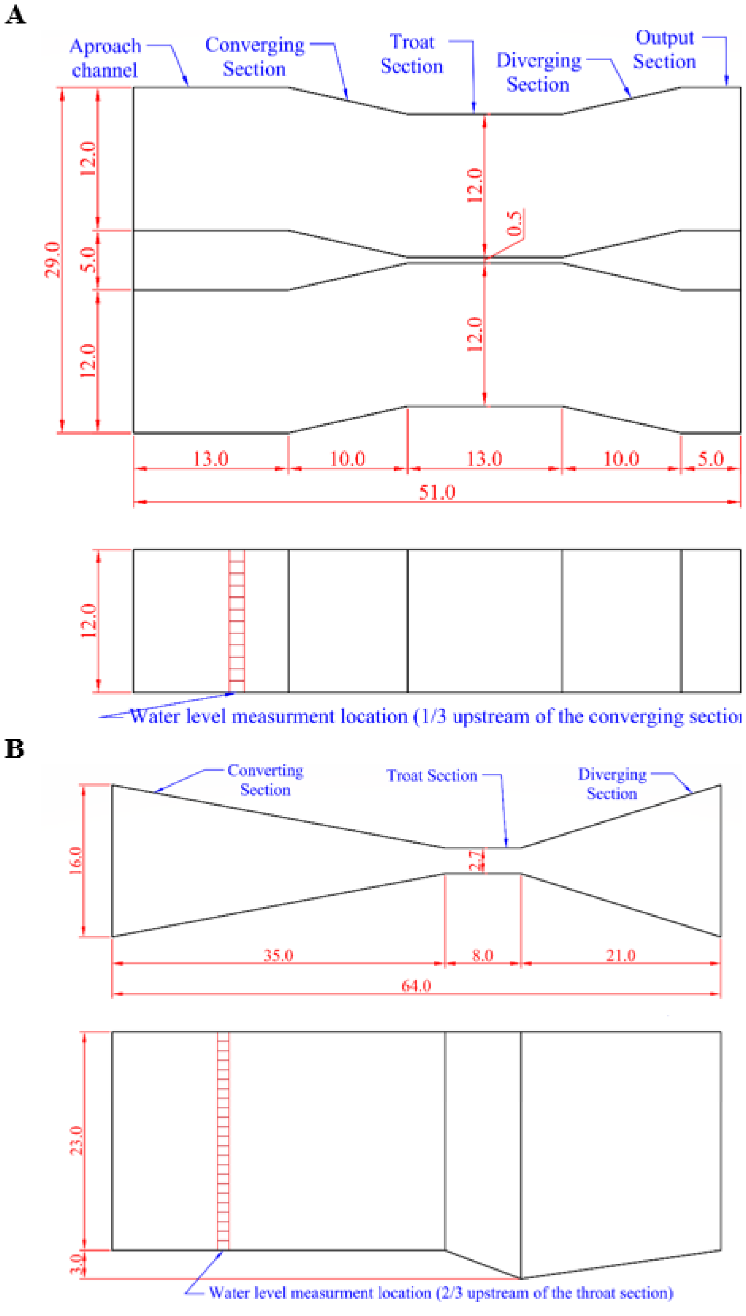
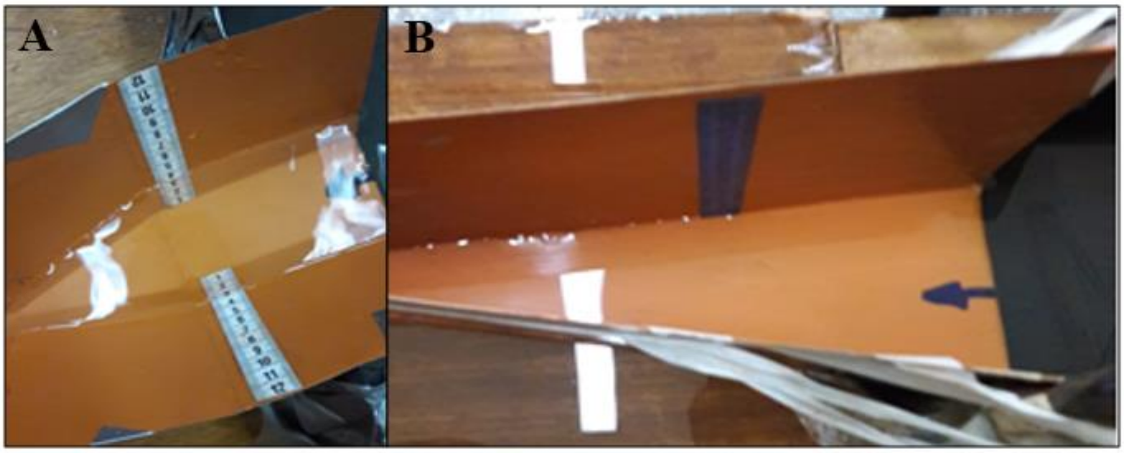


Figure 2. Graduated ruler on the WSC flume (A) and on the Parshall flume (B). Dourados / MS, 2019/2020.



According to Figures 1A and 2A, the flow inlet in the WSC flume has a lower height than the Parshall flume, which implies a water level with a higher height presented in its proportions. The ruler was marked at the end of the first section (2/3 of the entry section), Figure 2B. In the Parshall flume, the ruler was placed 2/3 of the throat (W) (Figures 1A and 2A). All of them following the current NBR / ISO 9826: 2008 standard. To start the experimental data collection process, relating flow rates (Q) in the flumes with their respective water hydraulic head (H), read in the ruler installed in the flumes, it was necessary to build an stabilization tank (Figure 3), in order to mitigate the turbulent flow of water generated by the increased flow provided by the water ducts and not generate interference in the results. In the methodology proposed by Xiao et al. (2016) supply tubes were used which, as the upstream valve was opened, water flowed through the tubes to the stabilization tank, and later to the portable flume. Objective that resembles the elimination of water turbulence generated by increased flow in the present experiment.

Figure 3. Images of the stabilizing tanks of the WSC (A) and Parshall (B) flumes in April 2020. Dourados / MS.

To support the supply of the tank and increase the flow, a polyethylene water tank with a capacity of 750 liters with a 1 ½ ”drawer valve was installed at the outlet, together with the aid of 2 taps connected directly to University water network, which supplied the stabilizer tank. Thus, several flow rates were tested with only the register coupled to the box and with the taps, together or not, for each type of flume studied. At least eight valid flow points were used (the points with errors during the collection were discarded), which during the adjustment distanced much from the others. It was performed three replicates for each point flow, using the mean of the same for the smallest error.

The flow was collected at the outlet of the flume, where the flow after the Parshall and WSC flume was considered, so that there was no error in the collection caused by any leak in the stabilizer tank. The method of obtaining the flow was the volumetric one, where test tubes were used to collect water and a digital timer to measure the period, thus obtaining the volume over time, which corresponds to the flow. Both flumes, studied in this work, the same flow rates were tested, for purposes of comparison between these two types of flumes.

Subsequently, the trough calibrations were continued. For this purpose, the volume at the end of the chute ($V_{outflow}$; m^3) and time (T - hours) were measured, obtaining the flow rates (Q - m^3h^{-1}). At the same time, the heights of the blade (H - meters) in the flumes were observed, providing a vertical ruler in them. In the Parshall flume the ruler was placed 2/3 of the throat (W) and in the WSC channel the ruler was placed 1/3 of the first fold (Position 1), in the first section of the channel (Figures 1 and 2). The height of the water depth (H) is also known as the hydraulic load of the flumes. The calibration data for both flumes were subjected to the F variance and data normality test, following the steps below.

1) Separation of data by flumes (Parshall and WSC), aiming to correlate the construction parameters with variations in hydraulic head (H) and flow rates (Q);

2) Application of the Anderson-Darling test to verify that the data were adjusted in the Normal Distribution;

3) F test for variances, in order to find possible differences between the data, and then, to make it possible to choose the appropriate T tests;

4) T test of two samples to check if there were differences in the obtained repetitions.

Finally, with the adjusted flow rates data (Q) and their respective hydraulic head (H), in the flumes, the curves of Q as a function of H were plotted for each flume. To the data collected from Q and H, the nonlinear regression model of a potential function, Equation 2, was adjusted to estimate Q in function of H, for each type of flume.

$$Q = a * H^b \quad (2)$$

Where:

Q: flow rates, m^3s^{-1};

a, b: parameters of the equation, dimensionless;

H: Height of depth water or hydraulic head, m.

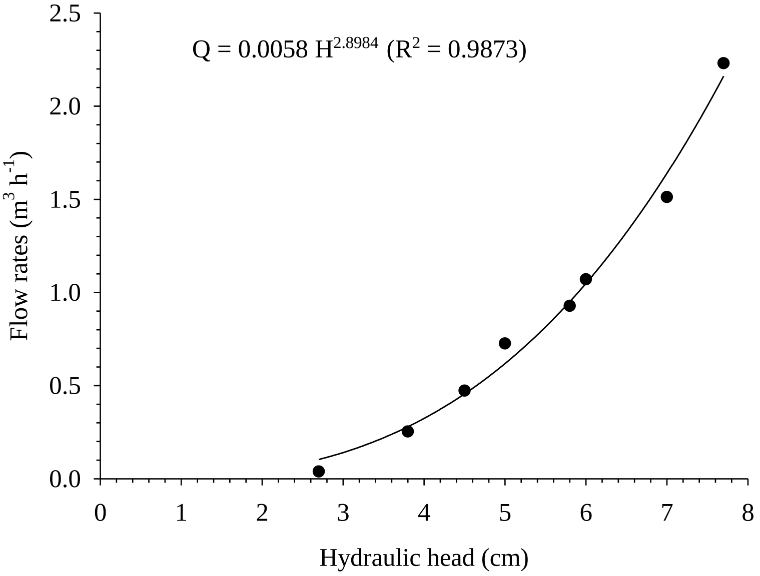
The potential regression model was adjusted using the Sigmaplot® Software, and the statistical tests were applied using the MS Excel® spreadsheet.

5 RESULTS AND DISCUSSION

All data were submitted to the Anderson-Darling test showing normal distribution. The flow data obtained for calibration of the Parshall flume showed different variance ($P < 0.05$) in the data between flow rates (Q) and Hydraulic head (H), with T test without differences between the means [P (T <= t) = 0.96] at the 95% significance level. In the WSC flume, the flow averages showed different variances between Q and H at 95% confidence (P <0.05), with T test without differences between the means [P (T <= t) = 0.97].

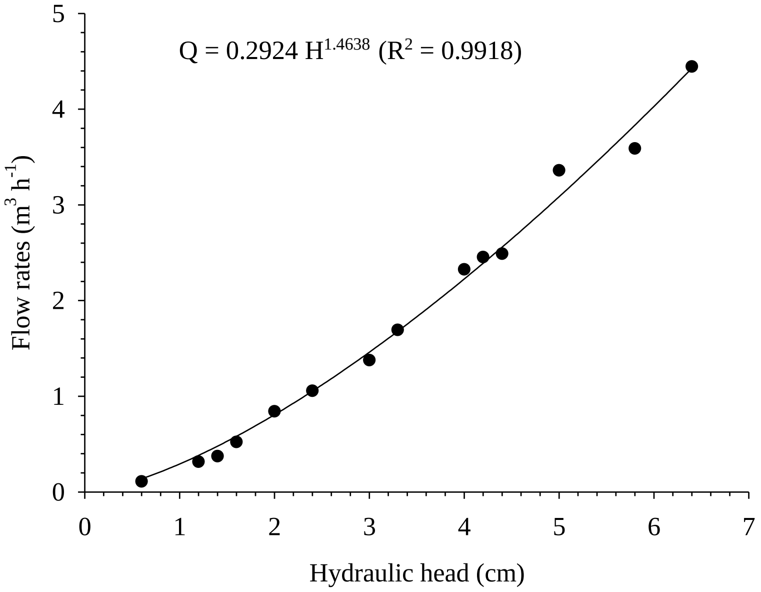
The calibration of the WSC flume was obtained with eight valid points of observation of the volume per time (flow rates - Q), presenting adjustment with a high value of determination coefficient (R^2 = 0.96), as shown in Figure 4. The flow data showed low standard deviation (σ = 0.0002), being homogeneous and little dispersed. Thus, the calibration showed a good fit with a high coefficient of common determination in well performed calibration works (SANCHES et al., 2020), in which it points an R^2 = 0.99 in a calibration of soil instrumentation.

Figure 4. Average calibration curve of the WSC flume. Dourados, 2020.



The minimum and maximum flow rates in the WSC flume were 0.039 and 2.23 $m^3\ h^{-1}$, respectively. However, in runoff work on ramps, Portocarrero, Andrade e Campos (2017) used ramps of 44 m^2 (11 x 4), so the flume would absorb up to a precipitation of 126.7 mm h^{-1}. This value is higher than the 10-year data average for Dourados (i = 49.8 mm h^{-1}), making the flume suitable to receive flows from experimental plots.

Figure 5. Average calibration curve of the Parshall flume. Dourados, 2020.



The minimum and maximum flows in this calibration correspond, respectively, 0.11 m^3h^{-1} and 4.44 m^3h^{-1}. Through the calculation of $Q = C*I*A / 360$, taking into account the same previous data of the WSC flume, with infiltration coefficient of the terrain C = 0.4 (high flow), and considering a contribution area equal to 44 m^2, concludes the maximum precipitation that the system can collect is 252.6 mm h^{-1}.

In the Parshall flume calibration performed by Xiao et al. (2016), in which velocity was correlated with flow depth, a correlation coefficient of 0.98 was found, a value that corroborates the study. Finally, the discharge generated a potential depth equation similar to the proposed study.

Commercial Parshall flumes despite having the same throat diameter “W”. The maximum could be related to the maximum height profile of the flume collection, which in the present flume is 0.23 m. However, in the minimum flow, from three companies Digiflow (2020), Alfamec (2020) and Incontrol (2020) have flows of 0.4; 0.5 and 1.0 $m^3 h^{-1}$ in 1 inch W diameter. Even though they are not exact 1” (2.7 cm W) as shown in Figure 1.a), the calibration of the trough made must be carried out, thus avoiding subsequent reading errors.

The adjustment equations ($Q = 0{,}0058H^{2{,}8984}$ and $Q = 0{,}2924H^{1{,}4638}$)potential of the flumes with good adjustments, was also the method of choice in 4 calibrations made by Costa et al. (2005), in which the authors observed adjustments with high determination coefficients (R2 = 0.99), showing the potential pattern as the most appropriate method.

The maximum flow points diverged dramatically between the flumes, even though they were placed under similar conditions.

The WSC was 2.23 m^3h^{-1} while Parshall was 4.44 m^3h^{-1}. This may be due to the structural differences between them, despite similar sizes, they are different flumes, according to flow work, the differences in the data fundamentally depend on the method chosen, as well as the precision (ZHOU et al., 2019). In such a way, the Parshall flume presented a greater $R^2 = 0.99$.

6 CONCLUSIONS

The developed flumes presented good calibration adjustments for their potential adjustment.

The Parshall flume showed a better fit with a higher determination coefficient.

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