Engenharia Agrícola

ISSN: 1809-4430 (online)
www.engenhariaagricola.org.br | www.scielo.br/j/eagri

Technical Paper
DOI: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v45e20240143/2025

APPLICABILITY OF HEC-DSSVue FOR MANAGEMENT OF HYDROLOGICAL GAGING NETWORK: A CASE STUDY USING SUB-HOURLY RAINFALL DATASETS FROM SOUTHERN BRAZIL

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KEYWORDS

hydrological data manipulation, sub-hourly rainfall datasets, regular- and irregular-interval time series, software.

ABSTRACT

Hydrological data are typically sequential and often correspond to large datasets, and not all application programs allow their retrieval, storage, and manipulation. This technical article aims to contribute to this subject by reporting the applicability of the Data Storage System of the Hydrologic Engineering Center (HEC-DSSVue) using 5-min rainfall datasets collected from 10 self-recording rain gages (2014–2023) installed in Southern Brazil. Although the HEC-DSSVue is commonly used to integrate databases into other HEC models (HEC-HMS and HEC-RAS), its application in managing hydrological gaging networks remains undocumented. Our methodology comprised six steps conducted within the HEC-DSSVue: i) acquiring all files generated from each hydrological campaign, ii) addressing irregular-interval time series, iii) evaluating file management functionalities, iv) identifying data visualization functionalities, v) assessing mathematical operations, and vi) examining edition and export functions. The main conclusion was that the HEC-DSSVue is a powerful tool for efficiently managing datasets from hydrological gage networks and supporting data manipulation, thereby making routine tasks more efficient and less susceptible to user-introduced errors.

INTRODUCTION

Hydrological gaging provides critical information on hydrometeorological variables gathered from gaging stations. These data are essential for understanding the hydrological behavior of watersheds and for effective water resource management. Gaging stations can be categorized as conventional, automatic, and telemetric stations based on their data gathering, recording, and transmission mechanisms. Conventional stations require manual data collection by observers at predefined intervals, whereas automatic stations rely on data loggers to store information with periodic uploads depending on the capacity of the data logger. Conversely, telemetric stations are equipped with data loggers that store and transmit data in different ways (GPRS and satellites), enabling real-time hydrological gaging. Each type of gaging station produces data in a unique output format, necessitating distinct techniques for data acquisition and manipulation, particularly in hydrological gaging networks with diverse station types.

Hydrological gaging networks generate vast amounts of data, making manual operations impractical because of the frequent need for complex mathematical and statistical analyses. Although general-purpose computer programs, such as spreadsheets, are commonly used, these tools have significant limitations, as they are not specifically idealized for hydrometeorological datasets. The key challenges include i) individualized data manipulation for each gaging station owing to output format variability, ii) difficulties in handling date and time data, iii) lack of tools for irregular-interval time series, iv) absence of visualization tools tailored to hydrological data, v) increased risk of user errors, vi) difficulties in managing time series gaps, vii) difficulties in aggregating data at different time intervals, and viii) a limited range of operations intrinsic to hydrological analysis.

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Area Editor: Fernando António Leal Pacheco
Received in: 8-19-2024
Accepted in: 2-5-2025

Several computer programs have been developed exclusively for hydrological analysis, including HIDRO (ANA, 2002), SisCAH (UFV, 2008), ALEA (UFMG, 2012), SEAF (Cândido, 2003), Hydrognomon (Kozanis et al., 2010), SYHDA (Vargas et al., 2019), and GAM-IDF (Vargas et al., 2023). Although these tools offer valuable functionalities, they often have limitations, as they are tailored for specific file formats, time intervals, or a restricted set of analyses. Consequently, none of these tools were inherently conceived for the comprehensive management of hydrological gaging networks.

The Data Storage System of the Hydrologic Engineering Center (HEC-DSS), which is linked to the US Army Corps of Engineers, is a computer program specifically designed to manipulate hydrometeorological datasets stored in various file formats. According to USACE (2024), the HEC-DSS is a database system capable of storing, managing, and retrieving sequential records, such as time series derived from hydrological gaging networks and paired datasets. The HEC-DSS can be used to transfer hydrological datasets to other HEC tools such as HEC-HMS, HEC-RAS, and HEC-MetVue, which are applied worldwide. The Data Storage System Visual Utility Engine (HEC-DSSVue) developed by HEC serves as a graphical interface based on the Java programming language and is compatible with Windows, Linux, and MacOS (USACE, 2024). HEC-DSSVue allows users to import, tabulate, edit, manipulate, plot, and export datasets in the DSS format. In addition, it has over 60 mathematical functions organized into the following categories: arithmetic, general, time, hydrological, smoothing, and statistical. An important advantage of HEC-DSSVue is its ability to standardize and streamline repetitive tasks related to data manipulation, thereby reducing the possibility of user error. It also provides a framework for the consistent application of hydrological procedures.

Despite its potential, no publications were found in Brazil or internationally that focused on assessing HEC-DSSVue for managing hydrological gaging networks. However, some studies used the HEC-DSSVue to process data for integration with other HEC tools (Bielenki Júnior et al., 2016; Fuaad & Mustafa, 2019). For example, Bielenki Júnior et al. (2016) used the HEC-DSSVue in Brazil to manipulate rainfall datasets and input them into HEC-SSP. Similarly, Fuaad & Mustafa (2019) applied the HEC-DSSVue to Iraq to manipulate streamflow records and derived time series with different time intervals for use in other HEC models.

The Research Group on Hydrology and Hydrological Modeling in Watersheds (RG Hydrology) manages two hydrological gaging networks, including rainfall and other meteorological data as well as stage and streamflow measurement data for watercourses. The main objective of this study was to evaluate the applicability of the HEC-DSSVue for storing, managing, and manipulating rainfall datasets collected from a hydrological gaging network installed in the Pelotas River watershed (PRW). Notably, this study is the first to compare the HEC-DSSVue with widely used spreadsheets from the perspective of managing hydrological gaging networks. These findings provide valuable insights for hydrologists and engineers and contribute to the advancement of data management practices in hydrology.

CASE STUDY: HYDROLOGICAL GAGING NETWORK IN SOUTHERN BRAZIL

The RG Hydrology operates a hydrological gaging network in the PRW, which comprises many gaging stations installed in the drainage area upstream of the Cordeiro de Farias Bridge (PRW-CFB), as illustrated in Figure 1. The municipalities of Pelotas, Canguçu, and Morro Redondo, situated in Rio Grande do Sul State, Southern Brazil, lie partially within this drainage area, amounting to 386 km² (Figure 1). The RG Hydrology is responsible for the acquisition, storage, and management of rainfall datasets collected using self-recording rain gages installed in the PRW-CFB.

Rainfall datasets from 10 self-recording rain gages (model HOBO-RG3-M) that have been in operation since 2014 (Figure 1) were used in this study. These rain gages are installed 1.5 m above the ground and are protected by surrounding fences. This gage is constructed of aluminum and operates according to the tipping bucket principle, such that each bucket tip represents a rainfall depth of 0.2 mm. The equipment is 15.25 cm in diameter and 25.72 cm in height, and weighs 1.2 kg. Each gage is powered by an internal lithium battery placed along with its data logger. Its operating principle is to automatically store date and time stamps whenever a 0.2 mm bucket tip occurs, allowing the determination of rainfall intensities and duration. With a storage capacity of 64 kB, the data logger can hold 25,000–30,000 recorded tips. The rain gages used in the PRW-CFB were programmed to record cumulative rainfall depths every 5 min. Considering the aforementioned configuration and the data logger's capacity, data acquisition can typically be performed once every three months using the HOBOWare software. Although these rain gages are automatic, they do not provide real-time tele-transmission data. Consequently, members of the RG Hydrology conduct field campaigns every two months for data acquisition and maintenance of the hydrological gaging network.

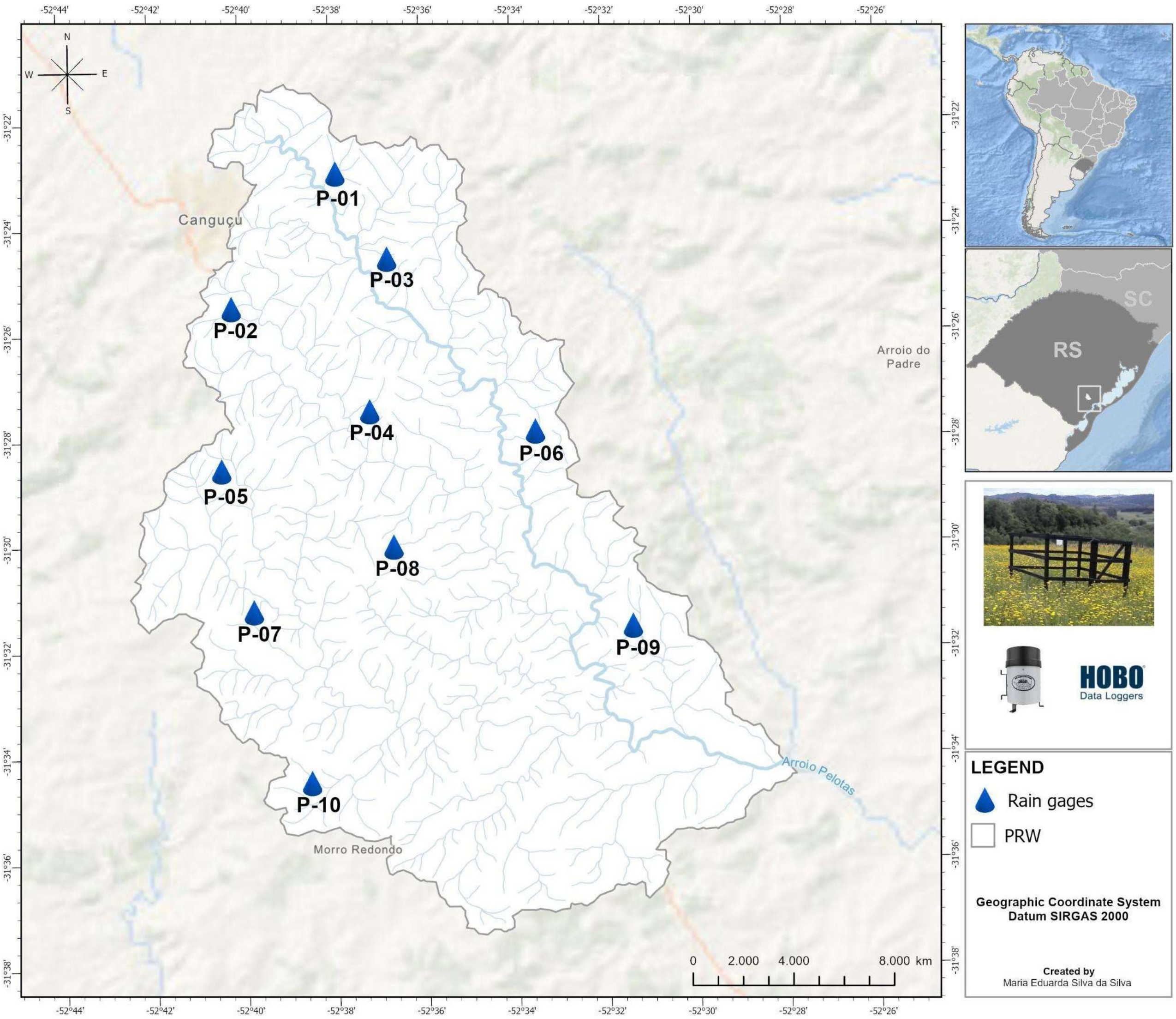

FIGURE 1. Location of the automatic rain gages in the hydrological gaging network situated in the PRW.

HOW WAS THE HEC-DSSVUE APPLICABILITY TESTED WITH RESPECT TO MANAGEMENT OF RAINFALL DATASETS DERIVED FROM A HYDROLOGICAL GAGING NETWORK?

The methodology of this study consisted of six steps developed entirely within the HEC-DSSVue environment: 1) data acquisition considering all the files generated after each hydrological campaign, 2) handling of irregular-interval time series, 3) evaluation of functionalities for file management, 4) identification of data visualization functionalities, 5) assessment of available mathematical operations, and 6) evaluation of edition and export functions. For this purpose, datasets with rainfall depths from 2014 to 2023, including regular- and irregular-interval records, were used.

Step 1 involved acquiring records from all files originated from the hydrological campaigns for the rain gages, which were stored in the RP Hydrology cloud (HOBOware format). Subsequently, these files were opened in HOBOware software, the manufacturer of the rain gages used in this study, and converted into a format compatible with spreadsheets (.csv). Finally, the csv files were imported into the HEC-DSSVue as *Pathnames* using the *"Data Entry → Manual Time Series"* function. In the HEC-DSSVue, each imported file is assigned a *Pathname*, which comprises six *Parts:*

- A-Part: defines the project, river, or watershed name;
- B-Part: informs the location of the gage providing the records;
- C-Part: corresponds to the data parameter;
- D-Part: stores the starting date of the records;
- E-Part: refers to the time interval in which records are organized;
- F-Part: allows users to include additional descriptive information.

Step 2 focuses on identifying a set of operations available in HEC-DSSVue capable of dealing with irregular-interval time series data, that is, when records are not organized according to a unique time interval. Irregular-interval records may arise because of issues associated with critically low battery levels in the data loggers, failure at the moment of recording readings, or errors in the definition of the time interval when reprogramming the data logger.

In Step 3, the functions in the *Edit* menu are analyzed to assess essential file management operations; the main goal of this step is to standardize datasets and files. The *Merge* function was carefully evaluated as it enables the placement of multiple individual *Pathnames* into a single continuous time series with records between 2014 and 2023. Step 4 corresponds to the appraisal of some data visualization functionalities within the *Display* menu for exploratory hydrological analysis. In this menu, "Tabulate" and "Plot" were explored for their ability to display data in tables and graphs. In Step 5, some mathematical functions available in the HEC-DSSVue (accessible via *Tools → Math Functions*) are analyzed. The goal was to verify their applicability to data handling and management, as well as their advantages over spreadsheet-based methods.

The assessment of tools designed for editing and exporting graphs and tables, enabling the visualization of a complete series for each rain gage or even for all rain gages, is addressed in Step 6. For this purpose, we created and exported pluviograph- and hyetograph-type graphs for the complete series (2014 to 2023), both individually for each rain gage and together for all rain gages. This methodological framework offers a comprehensive assessment of the capabilities of the HEC-DSSVue in managing rainfall datasets gathered from hydrological gaging networks.

ANALYSIS, FINDINGS, AND INSIGHTS RESULTING FROM THE EVALUATION OF THE HEC-DSSVue APPLICABILITY FOR THE CASE STUDY

Data acquisition, file import to the HEC-DSSVue, and its data management philosophy using *Pathnames*

We manually imported 508 raw files in CSV (10 rain gages named P-01 through P-10) resulting from field campaigns conducted between 2014 and 2023 into the HEC-DSSVue. To ensure standardized file management, the *Pathnames* representing the files resulting from each hydrological campaign were individually parameterized by populating *Parts* A, B, C, D, E, and F, such that the same procedure was adopted for the other nine rain gages. The first advantage of the HEC-DSSVue over the other tools lies in its ability to import files containing rainfall data directly from the rain gages used in this study. The files used in this study had a specific format generated by HOBO automatic rain gages. Other hydrology computer programs, such as HIDRO (ANA, 2002), SYHDA (Vargas et al., 2019), GAM-IDF (Vargas et al., 2023), ALEA, and SisCAH (UFV, 2008), do not support the direct import of the analyzed files. Many of these tools were primarily designed to deal with daily Brazilian databases from ANA and/or INMET. For example, SYHDA (Vargas et al., 2019) and GAM-IDF (Vargas et al., 2023) allow imports in a columnar text format with data preprocessed into daily intervals.

After importing all the files, we verified an important advantage of the HEC-DSSVue: its ability to standardize data storage using *Pathnames.* This implies that the HEC-DSSVue project file (.dss) may have a unique *Pathname* or even thousands of *Pathnames*. In practice, a *Pathname* represents a dataset of rainfall depth records obtained from a specific rain gage over a given time window. In other words, the definition of *Pathnames* in *Parts* enables hydrologists to provide an excellent data management strategy and promising alternatives from the hydrology perspective of grouping and analyses. This logic is not used in the other hydrology tools mentioned in the article: HIDRO (ANA, 2002), SisCAH (UFV, 2008), ALEA (UFMG, 2012), SEAF (Cândido, 2003), Hydrognomon (Kozanis et al., 2010), SYHDA (Vargas et al., 2019) and GAM-IDF (Vargas et al., 2023). This is because these tools were not developed for the management of hydrological databases but rather for specific hydrological analyses.

The highest level of the HEC-DSSVue *Pathname* in the context of a hierarchical window is defined as *A-Part*. We defined *A-Part* as the watershed where the hydrological gaging network was installed (PRW) because the RG Hydrology manages datasets from different watersheds. Datasets from 10 self-recording rain gages installed within this watershed were evaluated; therefore, "Pelotas River" was informed in *A-Part*. When considering the rain gage datasets from different watersheds, the hydrologist would simply need to change the name in *A-Part*, thus considerably facilitating the *Pathnames* management. The logic behind *B-Part*, the second management level, was to name it according to the rain gage ID. Under the management viewpoint, all the rainfall depth records with *B-Part* defined as P-01 through P-10 are linked to *A-Part* ("Pelotas River").

A-Part and *B-Part* were conceived in the HEC-DSSVue to organize and manage the datasets. When comparing the HEC-DSSVue file management system with spreadsheets, *A-Part* would probably be a folder corresponding to the hydrological gaging network, whereas *B-Part* would potentially resemble the file associated with each gaging station, containing different sheets populated with data for specific time periods. In this study, there would be a folder with 10 spreadsheet files, each containing several sheets, totaling 508 sheets to be managed. Managing this large number of spreadsheets is challenging, particularly considering that the datasets could come from various rain gages and have different time windows, varying time intervals, and potential gaps. Figure 2 illustrates the organization of *Pathnames* in the HEC-DSSVue *Catalog*, using P-02 as an example. In this study, we created a separate dss file for each rain gage; however, it would be simpler to manage the *Pathnames* of all rain gages in the same dss file. If a dss file is created for each rain gage, the HEC-DSSVue offers a key feature that allows modelers to keep multiple projects open simultaneously, enabling them to drag *Pathnames* of interest from one dss project to others.

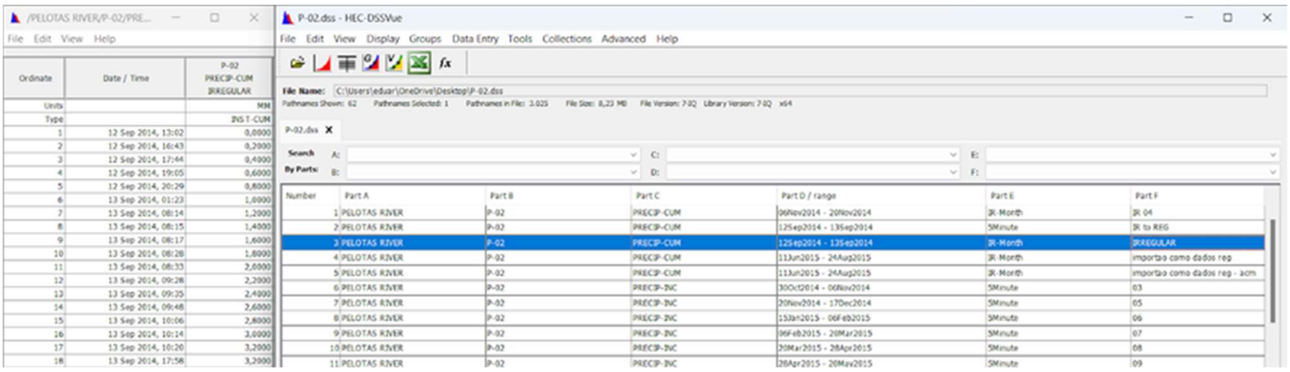

FIGURE 2. Illustration of the *Pathnames* organization in the HEC-DSSVue, using the datasets of P-02 as a reference, along with a representation of irregular-interval time series.

C-Part plays a fundamental role in defining the hydrological variable which will have records stored and analyzed. Almost 100 hydrological, meteorological, and land-use variables are available for use in the HEC-DSSVue (https://www.hec.usace.army.mil/confluence/hmsdocs/hmsum/latest/data-storage-in-hec-dss/descriptors). The other hydrology tools listed in this article, namely HIDRO (ANA, 2002), SisCAH (UFV, 2008), ALEA (UFMG, 2012), SEAF (Cândido, 2003), Hydrognomon (Kozanis et al., 2010), SYHDA (Vargas et al., 2019), and GAM-IDF (Vargas et al., 2023), allow users to deal with information of a much more limited number of variables (generally, only incremental rainfall and instantaneous streamflow). This suggests that the HEC-DSSVue offers greater flexibility for hydrological data manipulation and analysis. Furthermore, *C-Part* enables modelers to specify the hydrological meaning behind the stored records. In this study, all *Pathnames* were defined as *PRECIP-INC*. Therefore, it is expected that the datasets added to the respective *Pathname* correspond to the incremental rainfall depth, that is, the rainfall depth occurring within each predefined time interval. Graphically, these data over time represent a hyetograph. Notably, *PRECIP-CUM* can be used in *C-Part* rather than *PRECIP-INC*, corresponding to the cumulative rainfall depth over time (graphically, a pluviograph). It is also essential to discuss the data type in which the datasets are stored, as specified during the creation of a *Pathname*. The HEC-DSSVue data types were classified as *PER-CUM*, *PER-AVER*, *INST-VAL,* and *INST-CUM,* referring to the period cumulative, period average, instantaneous value, and instantaneous cumulative, respectively. The incremental rainfall depth is defined as *PER-CUM*, as this variable represents the cumulative rainfall depth within a time period. Notably, the correct operation of several HEC-DSSVue functions depends on the appropriate definition of the data type. Because the computer programs used for comparison in this study were generally designed to handle specific Brazilian databases (HIDRO, SYHDA, and GAM-IDF), and not files directly generated by rain gages, these programs only work with incremental rainfall depths corresponding to the PRECIP-INC variable and PER-CUM data type in the context of the HEC-DSSVue.

D-Part refers to the date and time of the first record of the *Pathname*. This is crucial for organizations, because it enables users to split a full hydrological series into several subsets for specific periods. Once a *Pathname* (manual or import) has been created, users can view the start and end dates of the *Pathname* in *Part-D,* making it easier for them to rapidly identify and manage different datasets in the *Catalog*. The HEC-DSSVue requires a nine-character military-style date.

E-Part is also key in the HEC-DSSVue, as it represents the time interval between two consecutive records of the variable being analyzed (incremental rainfall in the present study). During the creation of a *Pathname* using either manual inclusion or automatic import, the HEC-DSSVue determines whether the time interval is constant throughout the records in the dataset. If the HEC-DSSVue identifies that the time interval is not constant, it designates *E-Part* as *IR* (irregular) (Figure 2). The ability to handle regular and irregular time intervals makes the HEC-DSSVue highly applicable in hydrological engineering. Another strength of the HEC-DSSVue is its capability to work with time intervals shorter than one day (e.g., 1 h, 30 min, and 5 min), providing numerous functions to manipulate datasets under these circumstances. In contrast, most hydrological tools are designed to handle only daily datasets, such as HIDRO (ANA, 2002), SYHDA (Vargas et al., 2019) and GAM-IDF (Vargas et al., 2023), further reinforcing the applicability of the HEC-DSSVue in everyday hydrological applications.

Despite the large number of csv-format files imported into the HEC-DSSVue, we observed the advantages of manual import, particularly in cases where the datasets had regular time intervals. Two points of discussion on file imports are pertinent. First, the HEC-DSSVue enables automatic import using functions that support general format files (e.g., xlsx, csv, and txt) and other specific databases that are not applicable to our study (e.g., USGS and SHEF). Notably, automatic import functions for the csv and txt files were not assessed in this study. Second, each csv file from every rain gage for each hydrological campaign was individually imported into the HEC-DSSVue, resulting in a separate *Pathname* for each file. This procedure led to the creation of numerous *Pathnames*. For illustrative purposes, each *Pathname* was used to store rainfall depth records from a rain gage for periods between 1 and 15 weeks.

For future studies related to HEC-DSSVue for similar purposes, we recommend merging all csv files containing datasets from the same rain gage and importing only one file with its complete historical series into the program. This approach would be highly advantageous, particularly when hydrologists need to manage numerous rain gages or multiple gaging networks.

Dealing with regular- and irregular-interval time series in the HEC-DSSVue

After importing a file obtained from a self-recording rain gage and creating the corresponding *Pathname*, the dataset was expected to be temporally organized according to a predefined time interval. The HEC-DSSVue confirms this organization and automatically populates the *E-Part* of the *Pathname* accordingly. When the software recognizes that the records are organized in a unique time interval, it populates the *E-Part* accordingly (from 1 min to 1 year). Conversely, if it detects the occurrence of multiple time intervals, "IR" (irregular time interval) is added to the *E-Part*. In the case of an irregular time interval, the datasets are stored in variable-length blocks (e.g., days, months, years, decades, or centuries). In some cases, we noticed that the rainfall datasets were stored following irregular time intervals, that is, without a constant time interval between two consecutive rainfall depth records. In these cases, the *E-Part* was populated with "IR-MONTH" (Figure 3). From a hydrological perspective, the nonuniformity of time intervals may poses challenges in organizing historical series, performing hydrological analyses, and preparing inputs for hydrological models. Therefore, we evaluated the HEC-DSSVue functions for handling irregular time intervals.

Initially, we sought to comprehend how records were stored when the HEC-DSSVue identified them as being organized according to an irregular time interval. In these cases, the rain gage data logger only recorded the exact moments when the tipping bucket tipped, storing the cumulative rainfall depth over time instead of aggregating the incremental rainfall within predefined time intervals. Two alterations were applied to address this issue: i) replacement of "PRECIP-INC" with "PRECIP-CUM" in the C-Part using the *Rename Records* function (menu *Edit*), and ii) change in the data type from "PER-CUM" to "INST-CUM" (instantaneous cumulative rainfall), directly through *Tabulate* or the *Set Type* function (*Math Functions* → *General*).

After editing C-Part and E-Part for each *Pathname* initially identified with irregular time intervals, we evaluated the applicability of the *Irregular to Regular* function. This function, available under *Tools* → *Math Functions* -> *Time Functions* -> *Irregular to Regular*, is intended for the transformation of an irregular-interval into a regular-interval time series and can be applied in two ways:

- *Interpolation* (fill-in values): This process creates a new regular-interval time series.
- Snap (no fill-in values): This derives a new regular-interval time series by moving data in accordance with the user-specified regular-interval time.

Some arguments can be made when configuring this function for both options (interpolation or snap), thereby broadening its applications in the field of hydrology. For this study, we selected *Snap* because it was better suited to the datasets of the present study. This procedure resulted in a *Pathname* storing cumulative rainfall depths. The next step was to create a *Pathname* compatible with the incremental rainfall depths. We investigated the operators existing in the *"Arithmetic" tab* (*Tools* → *Math Function* → *Arithmetic*). Among them, the *Successive Differences* operator has the necessary characteristics; that is, it computes the difference between two consecutive records and enables either updating the *Pathname* or creating another *Pathname* with the transformed data. After applying this function, HEC-DSSVue updated the data type to *"PER-CUM," i.e.* incremental rainfall depth per time interval (5 min in this case), representing the dataset as a 5-min time interval hyetograph (Figure 3).

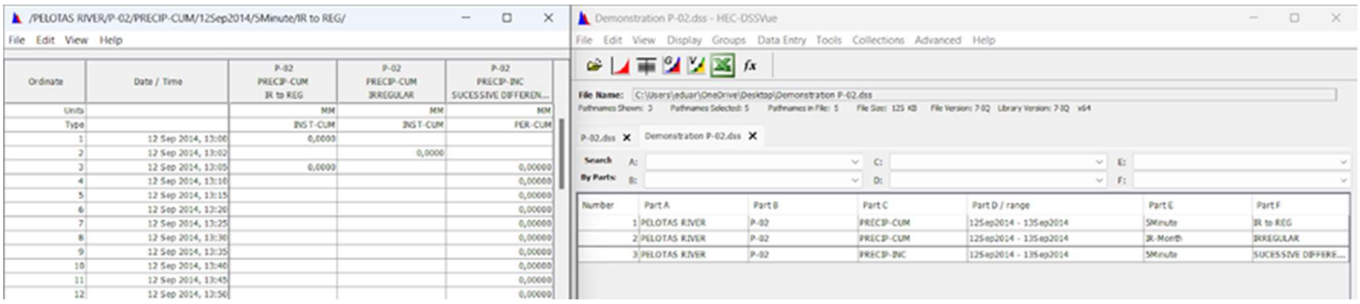

FIGURE 3. Demonstration of the *"Irregular to Regular"* and *"Successive Differences"* functions for P-02.

The transformation of an irregular-interval time series into a regular-interval time series is highly complex and often unfeasible when performed within spreadsheets given their inherent limitations. Obviously, other computer tools make it possible to manipulate irregular-interval records using automatic procedures; nevertheless, they demand that users have minimal programming language skills. For readers interested in programming solutions, R and Python have excellent packages with functions that are appropriate for working at regular and irregular time intervals. The HEC-DSSVue provides a user-friendly and intuitive interface specifically tailored for hydrological data manipulation. This tool was designed to comprehend hydrological time series, and has specific functions for dealing with hydrological issues without necessarily requiring programming expertise. In Figure 3, we demonstrate the conversion of an irregular dataset obtained from P-02 containing records from September 12, 2014, to September 13, 2014. Although the time period used was short, this example highlights the importance of the continuous representation of rainfall depths over time. Such a representation is possible only because of the conversion of irregular -interval records into regular-interval records.

From a hydrological perspective, the example illustrated in Figure 3 represents a classic scenario. Users are frequently confused by the fact that, depending on the organization of rainfall records, they may seem to indicate some missing values instead of no rainfall in the determined time intervals. This task would have been practically impossible to perform using spreadsheets, and the hydrology tools mentioned in this article do not provide functionalities for dealing with irregular-interval hydrological datasets. For instance, the tools described in UFV (2008), Cândido (2003), Vargas et al. (2019), and Vargas et al. (2023) cannot process irregular-interval records because they were primarily designed to work with national hydrological databases such as those from ANA, which consist exclusively of regular-interval data.

Exploring HEC-DSSVue functionalities for grouping datasets

All the *Pathnames* corresponding to each rain gage were merged into a single *Pathname* applying the *"Merge Time Series"* function. Practically, the 76 *Pathnames* initially created for P-01 with records from 2014 to 2023 were grouped into one *Pathname*. The same procedure was applied to other rain gages. This function was useful for merging all datasets in the HEC-DSSVue, allowing for more efficient file management, particularly when they were intended to be used in conjunction with hydrological models. In terms of data manipulation and consistency analysis, users can identify rainfall depth records in a time series with incorrect values by assessing all the hyetographs. For instance, a 5-min rainfall depth of 100 mm for a given rain gage, whereas the other time intervals are populated with no rain or with too low depths, can be flagged as an anomaly. Discrepant values were visually identified using hyetographs. In contrast, the use of spreadsheets makes it difficult to search for discrepant values in numerous rows and columns.

Hydrologists frequently aggregate hydrological time series data into different time intervals for various purposes. It should be emphasized that transforming a time series into different time intervals requires the original time series to be organized with a regular time interval. Although this task may seem straightforward, it can be time-consuming if an adequate tool is not used. The HEC-DSSVue has an interesting operator: *Change Time Interval* -, under *Math Functions → Time Functions.* According to USACE (2024), the data type assigned to the *Pathname* (INST-VALUE, INST-CUM, PER-AVER, or PER-CUM) dictates the application of interpolation or extraction. Considering that the data type in *Pathnames* for this study was set as *PER-CUM*, the *Change Time Interval* function computed the cumulative rainfall value for the new time interval (USACE, 2024). This task has been recurrent for hydrological studies. For example, after merging all the *Pathnames* created for a specific rain gage into one *Pathname* containing the complete 5-min rainfall depth time series, we may need to transform this time series to a different time interval, such as 1 h, for input into a hydrological model. This example highlights the applicability of the *Change Time Interval* function. Among the hydrological tools mentioned, SYHDA (Vargas et al., 2019) offers the capability of transforming records from one time interval to another. However, its minimum supported interval is 1 day, which limits its use in studies requiring finer temporal resolutions.

Exploring data visualization functionalities in HEC-DSSVue

Many data visualization functions grouped under the *Display* menu are available in the software. In this study, we focused on evaluating the applicability of *Tabulate* and *Plot* functions, which can be used to tabulate and plot records from one *Pathname* or multiple *Pathnames* simultaneously.

For example, consider the complete rainfall time series obtained after merging several *Pathnames*, as described in Section *Exploring HEC-DSSVue functionalities for grouping datasets*, for the rain gages named P-01, P-03, P-04, and P-06. When the *Pathnames* of interest are selected in the HEC-DSSVue *Catalog*, the *Tabulate* function enables viewing and editing of all the corresponding datasets in a vertical scrolling window (USACE, 2024). These records were chronologically organized using a date and time stamp along with the measurement unit and data type (Figure 4). This is a significant advantage, as modelers can visually compare all selected datasets over time with respect to missing values, magnitude, and seasonality. This function allows the tabulation of datasets characterized by different time intervals and data types, aligning them along the same date and time columns. For instance, rainfall and streamflow datasets with different time intervals and periods can be tabulated together, and the HEC-DSSVue can distribute records over date and time accordingly. This capability of the HEC-DSSVue is incomparable to spreadsheet software and the previously mentioned hydrology tools (ANA, 2002; UFV, 2008; UFMG, 2012; Cândido, 2003; Kozanis et al., 2010; Vargas et al., 2019; Vargas et al., 2023) with respect to data visualization and management, making it an excellent option for hydrological analyses from a regional perspective.

In addition to tabulating the records, datasets can be visualized as plots. In this case, if the modeler selects the *Pathnames* of interest in the HEC-DSSVue *Catalog,* the *Plot* function allows users to view the data in a plot format (USACE, 2024). The strengths of the HEC-DSSVue with respect to the *Plot* function are as follows:

- The HEC-DSSVue automatically creates a viewport for each data parameter (*C-Part*) and measurement unit identified among the selected *Pathnames*, plotting all datasets (*Pathnames*) with the same variable (*C-Part*) and an identical measurement unit in the same viewport.
- The software allows users to arrange several viewports together, thereby facilitating the simultaneous visualization of rainfall and streamflow datasets.
- Users can define a time window for plotting records from a given set of *Pathnames*, meaning that they are not required to plot the complete time series contained in the selected *Pathnames*.
- Plot properties generated by the HEC-DSSVue are highly customizable.

For illustration, by selecting the *Pathnames* indicated in Figure 4 and using the *Plot* function, the HEC-DSSVue generates a graph displaying rainfall data from all the selected *Pathnames.* Because these *Pathnames* store incremental rainfall depths (defined as *PRECIP-INC* in *C-Part*) in millimeters, the HEC-DSSVue automatically creates a hyetograph-type graph (stepped-type line). The HEC-DSSVue ensures that some plot properties vary based on the *C-Part* established in *Pathname*. A hyetograph-type graph was generated because C-Part was set as *PRECIP-*

INC and the HEC-DSSVue had a stepped-type line defined as the default line style for this hydrological variable (Figure 4). An impressive characteristic of the HEC-DSSVue is that it allows users to redefine the line style for the variable of interest (*C-Part*). The strengths associated with data plotting make the HEC-DSSVue a valuable supplementary tool compared to the application programs described by ANA (2002), UFV (2008), UFMG (2012), Cândido (2003), Kozanis et al. (2010), Vargas et al. (2019), and Vargas et al. (2023).

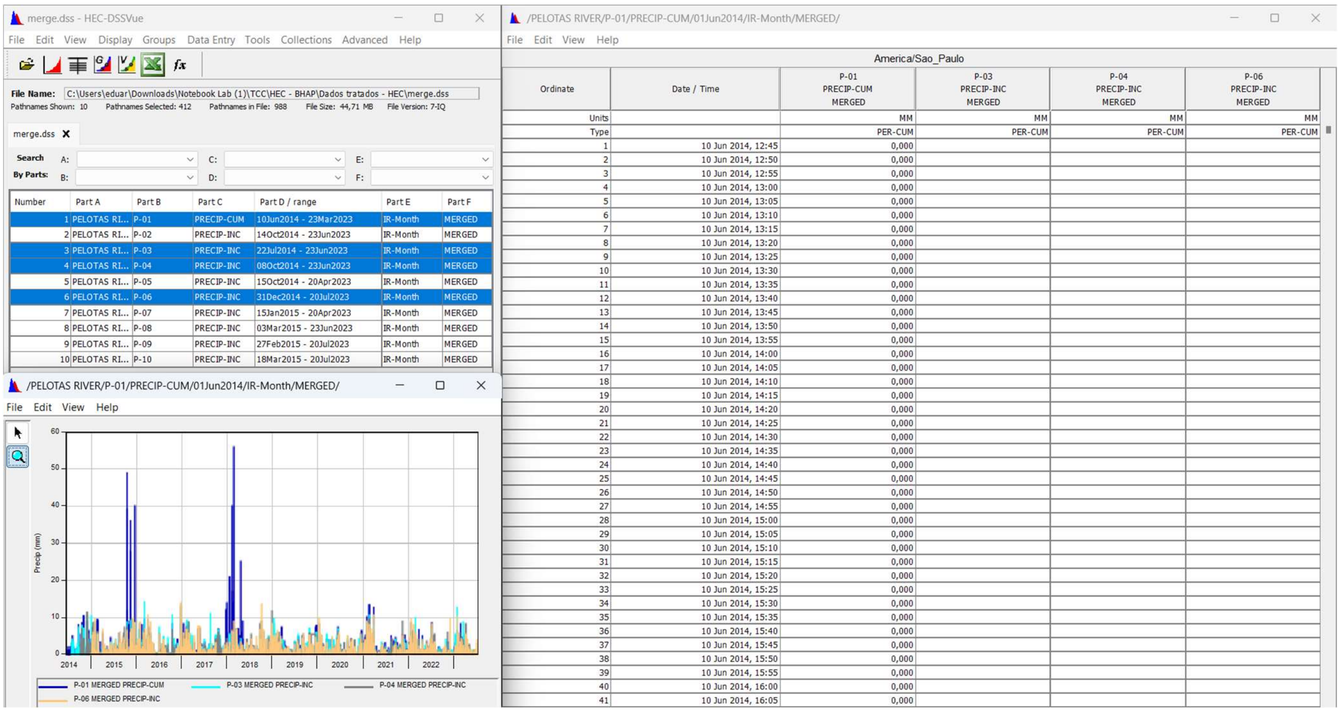

FIGURE 4. Visualization of tabular and plot data from the datasets derived from P-01, P-03, P-04, and P-06.

Applicability of some HEC-DSSVue mathematical functions

The strengths of the HEC-DSSVue for data manipulation using its mathematical functions *Tools → Math Functions,* were demonstrated based on the time series derived from the series-grouping step. The HEC-DSSVue comprises over 60 mathematical functions grouped by similarity and purpose in the following tabs: *Arithmetic*, *General*, *Time Functions*, *Hydrologic*, *Smoothing*, and *Statistics.* We assessed only the functions available in the *Arithmetic*, *General*, and *Time Functions* tabs because the functions in the *Hydrologic* and *Smoothing* tabs were beyond the scope of this study.

The *Arithmetic* tab has general functions capable of adding, subtracting, multiplying, and dividing, either with a constant or a dataset, as well as several important functionalities whose applications are intrinsic to rainfall data manipulation for regular- and irregular-interval time series. These include *Accumulation*, *Successive Differences*, and *Time Derivative.* The *Accumulation* operator can be used to convert rainfall depth records organized in increments (incremental rainfall) into accumulated rainfall depths; this function allows hydrologists to transform a hyetograph into a pluviograph. The reverse procedure can be performed through the *Successive Differences* operator, which results in an output dataset with the *"PER-CUM"* data type if the original dataset is defined as the *"INST-CUM"* data type. Finally, the *Time Derivative* operator calculates successive differences per unit of time. When considering rainfall depth per time interval (*Successive Differences*), the use of the *Time Derivative* operator returns the average rainfall intensity per time interval, characterized by *"PER-AVER"* data type. Some of these functions were used in Section *Dealing with regular- and irregular-interval time series in the HEC-DSSVue* for dealing with irregular-interval time series. The use of these important functionalities in a hydrological context is illustrated in Figure 5.

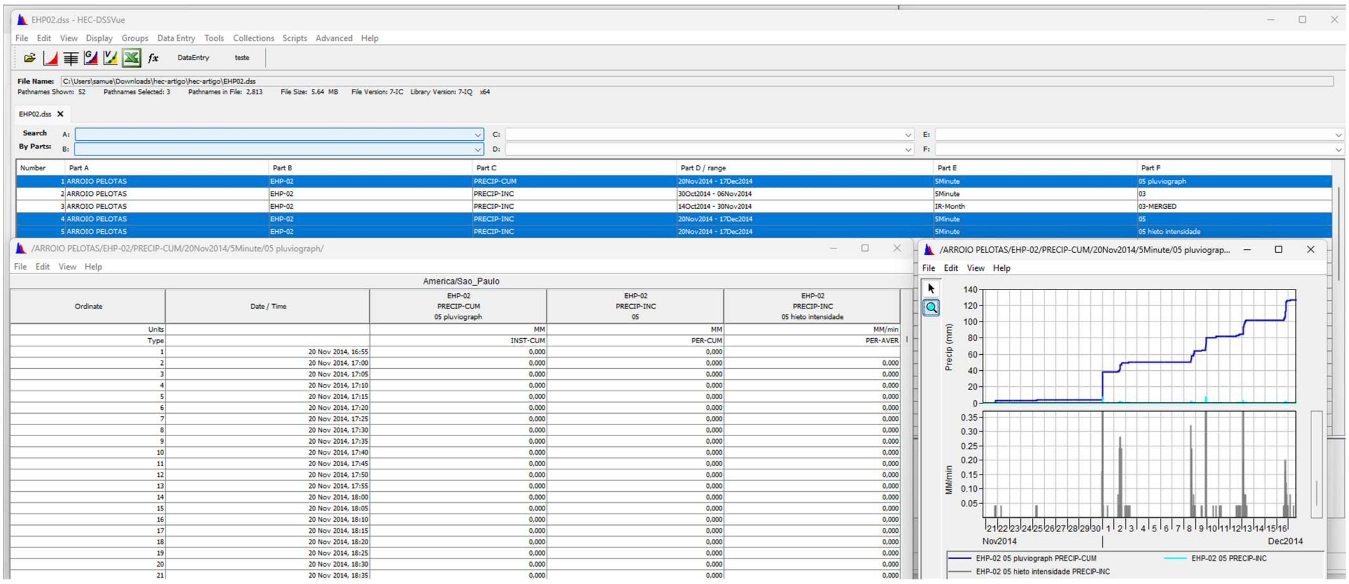

FIGURE 5. Using tabular data and plotting to visualize accumulated rainfall depths in millimeters (derived from the *Accumulation* function) and rainfall intensities in millimeters per minute (derived from the *Time Derivative* function) obtained from incremental rainfall depths in millimeters (hyetograph) observed for P-02.

The *General* tab includes several useful operators such as *Units Conversion*, *Set Units, Set Type*, *Round to Nearest Whole Number*, *Truncate to Whole Number*, *Round Off*, *Estimate Missing Values*, *Replace Specific Values*, *Screen Using Maximum and Minimum*, *Screen Using Forward Moving Average*, *Merge Time Series*, *Merge Paired Data*, and *Generate Data Pairs*. Two operators were used in this study: *Set Type* and *Merge Time Series*. The *Set Type* operator modifies the data type defined in the *Pathname* (*PER-AVER*, *PER-CUM*, *INST-VAL,* or *INST-CUM)*. According to USACE (2024), this function was not designed to convert data to a newly defined data type; instead, it changes the data type label when the datasets (*Pathnames*) are incorrectly labeled. This occasionally occurred in this study, primarily after applying functions that generated new *Pathnames*. Users can identify the data type defined for each *Pathname* directly in the tabular data, as illustrated in Figure 4 (see the second row in the table derived from the *Tabulate* function), or directly in the form presented after accessing the *Set Type* function. The *Merge Time Series* function is widely used and is discussed in Section *Exploring HEC-DSSVue functionalities for grouping datasets*.

The following functions are available in the *Time* function tab: *Min/Max/Avg… Over Period*, *Copy in Time*, *Shift in Time*, *Change Time Interval*, *Irregular to Regular*, *Regular to Irregular*, *To Irregular using Pattern*, and *Extract Time Series*. These functions are useful for manipulating time series, which are frequently necessary in the field of hydrology. The *Irregular to Regular* and *Change Time Interval* functions were evaluated in this study. The *Irregular to Regular* function was discussed in detail in Section *Dealing with regular- and irregular-interval time series in the HEC-DSSVue*.

Editing and exporting datasets

The HEC-DSSVue provides functionality to edit datasets directly within tables. Once the *Pathnames* of interest have been selected, users can access their datasets by clicking the *Tabulate* button and then navigating to *Edit* → *Allow Editing* or to *Edit* menu → *Tabular Edit*. In Figure 6, readers can visualize five *Pathnames* simultaneously in a table in the edition mode. In this mode, non-editable table cells are displayed in gray (USACE, 2024), indicating that users cannot edit the *Ordinate* and *Date/Time* columns. The records, *Units*, and *Type* can be edited easily and independently. These changes can be saved in their own *Pathname* under editing or saved as a new *Pathname* if the user wishes to preserve the *Pathname* with the original data.

In the edition mode, functions such as *Cut*, *Paste*, *Insert Rows*, and *Delete Rows* are available from the Edit or context menus (accessed by right-clicking on the table cells) (Figure 6). These options allow users to modify and delete existing records, and include new records. These editing functions are essential and highly effective for refining datasets after importing them into the HEC-DSSVue. Similar editing functions are not commonly found in other hydrological tools, such as those described by ANA (2002), UFV (2008), Vargas et al. (2019), and Vargas et al. (2023).

Users can easily export datasets displayed as tabular data whenever they wish by clicking on the *File* menu and then *Export*. In this case, the HEC-DSSVue exports in the form of a text file, which can then be opened in other computer programs, such as Microsoft Excel. Additionally, users can export the datasets contained in the selected *Pathnames* directly as xlsx files by navigating to Data *Entry* menu → *Export* → *Excel* (or *Excel Export (Beta))*, as depicted in Figure 7. These export commands are particularly useful for sharing datasets with HEC-DSSVue non-users who require a time series to perform hydrological analyses or as inputs for mathematical models.

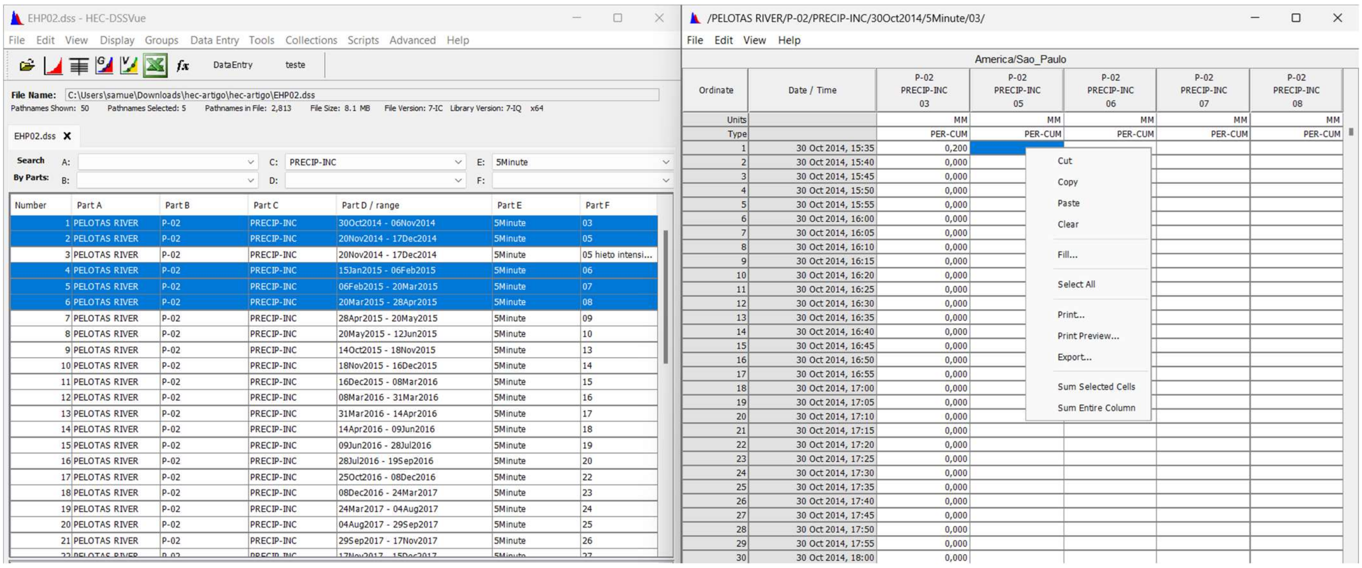

FIGURE 6. Illustration of five *Pathnames* selected and in edition mode in tabular data.

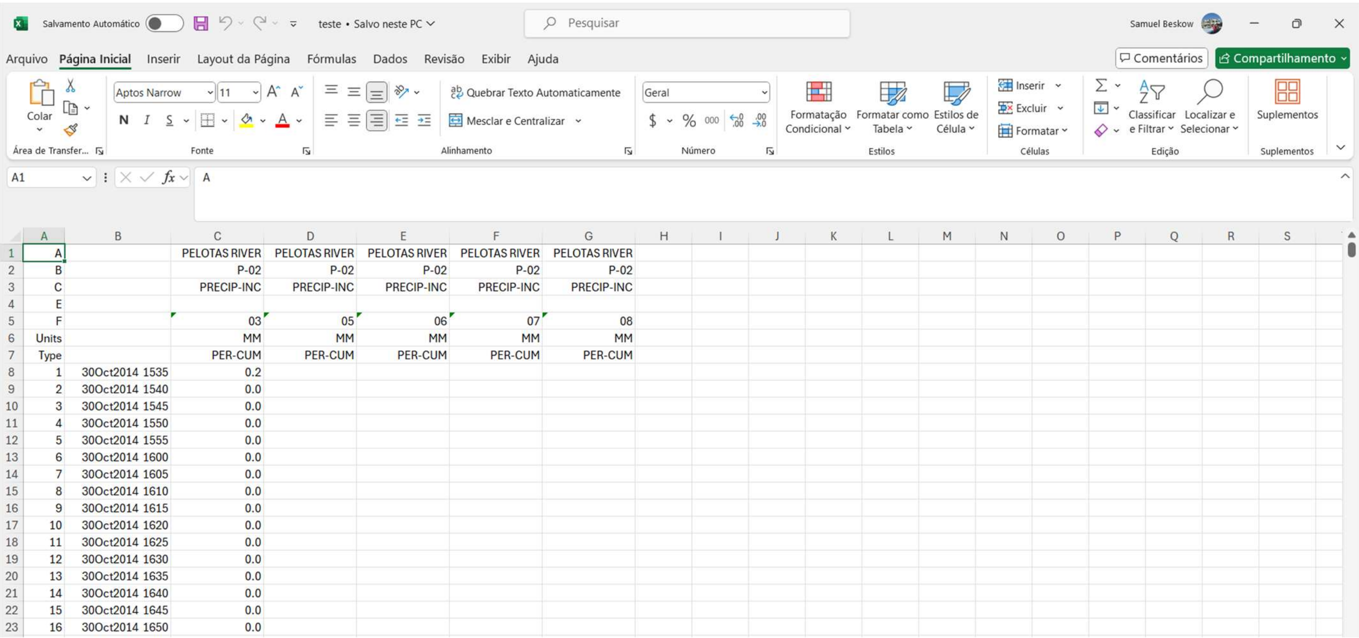

FIGURE 7. Datasets stored in the selected *Pathnames* after being exported in Microsoft Excel format.

CONCLUSIONS

The main conclusions of this technical article are:

- The HEC-DSSVue provides several useful import functionalities and an efficient data management structure based on *Pathnames* within a project, which is compatible with the needs of rainfall datasets.
- Many robust commands are available in the software to manipulate irregular-interval time series, which are common in rainfall datasets, and to convert them into regular-interval time series.
- The HEC-DSSVue allows users to handle multiple time series obtained from the same rain gage and group them into a single series.
- Modelers can specify the hydrological meaning of the records stored in the HEC-DSSVue.
- The data type (*PER-CUM*, *PER-AVER*, *INST-VAL*, or *INST-CUM*) dictates how the HEC-DSSVue commands work and interact with datasets, indicating that the software is optimized for hydrological data manipulation.
- The software offers a broad range of commands to manipulate sub-daily datasets, which are common in hydrological analyses; however, most application programs do not provide such possibilities.
- Datasets of interest can be visualized individually or jointly, either as plots or in tabular form, providing an excellent alternative for hydrological analysis from a regional perspective.
- Rainfall data manipulation in HEC-DSSVue can be performed using many mathematical functions grouped by similarity and purpose under different tabs, particularly those available in *Arithmetic*, *General*, and *Time Functions*.

- Users can edit existing rainfall records, include new records, or delete records after importing the datasets into the HEC-DSSVue.
- The export commands allow users to generate text and xlsx files, which are useful for sharing datasets with HEC-DSSVue non-users who require time series for hydrological analysis or input into mathematical models.

FUNDING

- Edital FAPERGS 09/2023 Programa Pesquisador Gaúcho, Termo de Outorga: 24/2551-0001199-4
- Chamada CNPq Nº 09/2023 Bolsas de Produtividade em Pesquisa, Termo de Outorga: 316122/2023-8
- Edital FAPERGS 06/2024 - Programa de Pesquisa e Desenvolvimento Voltado a Desastres Climáticos, Termo de Outorga: 24/2551-0002118-3

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