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LIGHT RAIN FOR RUNOFF AND DESIGN DEPTH

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Abstract: The disorderly soil occupation without the necessary conservationist practices leads to impacts on the local hydrology and induces the pollution of water resources. This pollution may come from more urbanized areas due to the amount of pollutants drained during the rains. Even moderate precipitations constitute one of the main factors that define pollutant runoff on the surface. These rains have recently been called light rains. Light rains have a lower precipitation height and a higher frequency compared to classic rains of drainage projects, being necessary to define them according to patterns of rain frequency for each region. This study aimed to characterize light rain in the municipality of Piracicaba to establish statistical standards for the frequency of certain precipitation heights. A database provided by the ESALQ/USP automatic weather station, which provides precipitation measurements every 15 minutes, was used in the present study. Light rain heights reached 40.3, 41.4, and 42.7 mm for 100, 90, or 80% frequencies, respectively, which implies the use of return periods of 1.00, 1.11, and 1.25 years, respectively.
Keywords: diffuse pollution, precipitation, return time, Python.

INTRODUCTION

Population growth and increased demand for consumer goods have usually been associated with environmental deterioration. The increase in population and the development of urban areas have led to an increase in impermeable soils and excessive waste generation. This increase is related to the degradation of water resources, a consequence of surface runoff of rainwater, leading the materials disposed on urban surfaces to watercourses (Yang et al., 2016; Zanchin et al., 2021).

Polluting sources stand out among the main problems associated with this human intervention and can be specific or diffuse. According to Oliveira et al. (2018) and Tansar et al. (2022), pollutants can be released into the environment in a specific (concentrated in a certain location) or a diffuse way (distributed), with specific discharges consisting of those released in specific places of water bodies.

Diffuse pollution is defined as the indirect introduction of substances into water or soil as a result of human activity, being dispersed and variable in space and not attributed to a specific origin (Oliveira et al., 2018). Leite et al. (2018) state that diffuse pollution occurs over a vast area and is generally associated with the type of land use and occupation, with surface runoff being an important transport agent.

Recent studies have shown that uncontrolled diffuse pollution begins to gain important space in the literature as defined forms of pollution have been controlled in several countries (Cembranel et al., 2017). Diffuse forms are more difficult to resolve and often cause high levels of pollution in waterways, which are related to their dispersion in space (Batista et al., 2019). According to Leite et al. (2018), the processes and causes of polluting sources, especially diffuse ones, need to be analyzed for their control and study. Thus, analyzing precipitation is essential for the beginning of its study.

Patios on which windrows of filter cake from the sugar and alcohol plants are arranged have a detention basin downstream, responsible for the temporary storage of residues carried by the rains. Currently, there is no sizing criterion for these types of reservoirs, as the influence of rainfall on water quality is difficult to quantify. Pollutants deposited on the surface are carried to the water bodies as the rains occur, being gradually distributed by runoff, and released into rivers (Kuo et al., 2017).

According to Pruski et al. (2015) and

Yoon et al. (2010), pollutants accumulate in urban basins during dry weather, being produced not only by human activity but also by atmospheric deposition. The first rapid contribution when rain occurs after a period of drought consists of removing pollutants from impermeable surfaces, providing them highly concentrated in wastewater (Ahmed et al., 2022).

Precipitation causes an initial wetting on the surface and this layer is infiltrated (Oliveira et al., 2018; Zanchin et al., 2021). The dissolution of deposited soluble elements begins in this phase and runoff begins after passing the wetting phase. These authors state that runoff is associated with the dragging and transport of particles disposed on patios, pointing to associated factors, such as the kinetic energy of raindrops, the runoff speed, and the cohesion of deposits.

This concentration of pollutants is carried by the so-called first flush, which is defined as the first volume of precipitation that is drained. The first flush phenomena are recognized as typical of highly populated and urbanized regions (Damé et al., 2016). The first flush phenomenon can be described as the runoff of rainwater during which pollutant concentration is significantly higher than in later precipitation stages (Beck et al., 2017). As pointed out by Pitt (1999), frequent rainfall events are responsible for most of the runoff of massive discharges of pollutants. Therefore, these events should be used as the basis for water quality control.

Usually, the diffuse pollution that is associated with rain is more important the longer the period of drought that precedes the referred phenomenon, that is, extended drought periods. The accumulation of materials and pollutants in urban regions increases during longer periods of lack of precipitation, as pollutant elimination is controlled by physical processes such as rain associated with the interval of occurrence, intensity, and duration (Kruel et al., 2015). The need generated by analyses of runoff frequency related to diffuse pollution has led to the concept of light rain hydrology, also called small storms (Pitt, 1999).

According to Oliveira et al. (2018), detention basins stand out among the optimal measures for managing diffuse pollution. Pruski et al. (2015) recommended the adoption of minimum intervals of duration of 3, 6, 12, or 24 hours in the hydrological modeling to size these basins.

The so-called light rain hydrology method was developed to estimate the volume of runoff for use in urban and suburban soils for relatively small rainfall events and plan the control and quality of rainwater (Pitt & Clark, 2008).

Different drainage project criteria generally require the examination of different types of rainfall (Pitt, 1999; Pitt & Clark, 2008). Similarly, water quality issues due to rainwater runoff are typically associated with minor storms rather than the project storms commonly used for surface drainage projects (Tansar et al., 2022).

The classification of light rain has variations in different regions, that is, its concept may vary according to certain parameters to be studied and analyzed, with urbanized areas being mainly those with higher concentrations of pollutants. According to Thiemig (2012), rainwater volume is often dimensioned through the concept of light rain, which is defined as a precipitation height greater than 2 mm capable of generating sufficient surface runoff to carry most of the diffuse pollutant load on the surface.

According to Pedron & Klosowski (2008), light rains are defined as rains higher than or equal to 2 millimeters that have a 90% probability of occurring with higher or equal height. They are recommended among the best

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management practices (BMP) for managing diffuse pollution.

In contrast, rains between 13 and 38 millimeters are responsible for about 76% of pollutant discharges in the runoff, being important to be addressed in the study of massive loads of pollutants (Bannerman et al., 1983). Rainfall higher than 38 mm is associated with drainage and accounts for only relatively small portions of annual pollutant discharges. Moreover, pollution control depends on local precipitation, and events with an 80% frequency are recommended to be considered for analysis (UDFCD, 2011).

Therefore, quality control criteria for urban runoff are part of many guidelines for rainwater management. Capturing and treating intense extreme events are recognized not to be necessary, and the most commonly defined target in these guidelines is based on a more frequent distribution precipitation analysis aiming to determine the rainfall volume to be used for the project of reservoirs and detention basins (Rivard, 2010).

Rainfall parameters that fit the literature recommendations are necessary when analyzing the frequencies of precipitation heights, stipulating them according to their return time (Tr). The return time (inverse of the frequency) is necessary to decide the degree of protection given to the population or, in other words, the risk to which the population is subject (Passos et al., 2021; Manke et al., 2022).

According to Yang et al. (2016), pollutants are quickly drained into the water body for rain events with return periods of 2, 3, and 5 years, that is, consist of excessive rainfall. However, the situation is reversed for a return time of about 1 year, that is, the concentration of pollution remains longer in the water body.

This study aimed to characterize the light precipitation in the municipality of Piracicaba based on the process of filtering and separating rainfall data, seeking to establish recommended statistical standards for certain lower precipitation heights, which occur with higher frequency. The focus was given to less intense rains or light rains, which have been frequently used to simulate the displacement of diffuse pollution in urban or agro-industrial patios, such as the compost patios of sugar and alcohol plants in São Paulo.

SUBJECT DESCRIPTION

AREA OF INTEREST FOR CARRYING OUT THE STUDY

This study was carried out in the municipality of Piracicaba, São Paulo State, Brazil, located at a critical point of transition of general circulation currents, with varied climate characteristics. This variability causes two distinct periods: a hotter and rainy period from November to March and a less hot and drier period from May to August (Ferreira et al., 2021).

Wolff et al. (2014) state that the region has tropical trends, that is, mean annual temperatures vary around 20 °C,

reaching a mean of 23 °C in the hottest months of the year and 17 °C in the coldest months. The mean long-term annual precipitation in the region is around 1,280 mm (Alvares et al., 2013).

The municipality of Piracicaba is located at the geographic coordinates 22°42'30" S latitude and 47°38'01" W longitude, with a mean altitude of 554 m. The total area has 1,378 km^2 and the population is estimated at 410,275 inhabitants (Lucas et al., 2018). Figure 1 represents the location of the municipality of Piracicaba in the São Paulo State, Brazil.

Piracicaba is currently a new metropolitan region of the São Paulo State, with around 1.5 million inhabitants and an area of 7,367.88 km^2.

PRECIPITATION DATA

The first part of the study covered the search and selection of data. The data came from the automatic weather station of the Luiz de Queiroz College of Agriculture (ESALQ/ USP), located in Piracicaba-SP, which presents precise data measured every fifteen minutes. This small measurement time was essential for the detail and accuracy of the analyzed data (0.1 mm precision). Figure 2 shows the location of the weather station in the municipality.

Following the first activity, data every 15 minutes between 1997 and 2020 were collected, totaling 24 years. The data from 2021 were disregarded in the analysis due to a lack of complete data.

DATA ANALYSIS

A verification was carried out after collecting the data to find flaws in the chronology or gaps, which can occur mainly in precise and frequent data such as those used in this study. This second stage of the methodology was carried out entirely in Excel® based on an investigation of failures and adjustments. This step was extremely important and fundamental for the subsequent steps.

A spreadsheet was created after analyzing the data and adjusting with essential data such as date, time, and rainfall, formatted in Excel®. All spreadsheets were standardized over a period of 24 years to facilitate interpretation by the used programming language (Python Software Foundation). The Python language was chosen due to the ease of operating a large number of data arranged in a spreadsheet with few command lines. Table 1 shows, as an example, part of the spreadsheet updated with the new database for part of the first day of January 2021, already filtered and filled in.

The entire previous process was defined and thought out for the subsequent stage, which was based on working with the extracted database, checked and adjusted entirely by programming in Python. Python language is used widely by analysts and data scientists, and its programming provides some databases that favor the manipulation of information and can be used to check variables in a certain time interval (Mello & Silva, 2009).

Python version 3.8, provided by Anaconda (2021), was used. The Anaconda platform is one of the most popular worldwide, as it provides a variety of data already pre-installed. Specific software for reading the computational language, the free software PyCharm Community Edition, specific for Python, was used to facilitate access to the programming language and its development.

The process of manipulating data via computational language was initiated aiming at counting and verifying them. Therefore, one event was separated from the other as long as there were 12 hours or more without precipitation relative to the next event. Figure 3 shows the flowchart of the main part of the programming.

The criteria for separating events with a period of 12 hours or more without rain is adopted for light rain events that have a higher frequency than extreme events. Therefore, we considered that there would be maintenance during this interval of at least 12 hours, with cleaning being carried out in the detention basins and exit devices to reduce polluting loads. In addition, as most rainfall records reported in the literature have a minimum duration of 24 hours without rain, considering a period of 12 hours is a practical way to facilitate future studies that use longer intervals.

This criterion of using at least 12 hours also facilitates the design of diffuse pollution control structures, as suggested by Louzada et al. (2018). In this interval logic, these drainage systems must have a final reservoir for rainwater accumulation or a detention

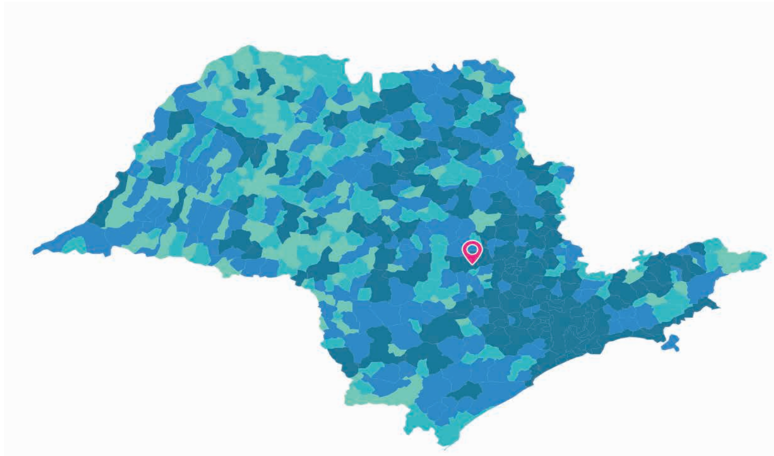

FIGURE 1. Location of the municipality of Piracicaba in the São Paulo State, Brazil. Source: IBGE (2021).

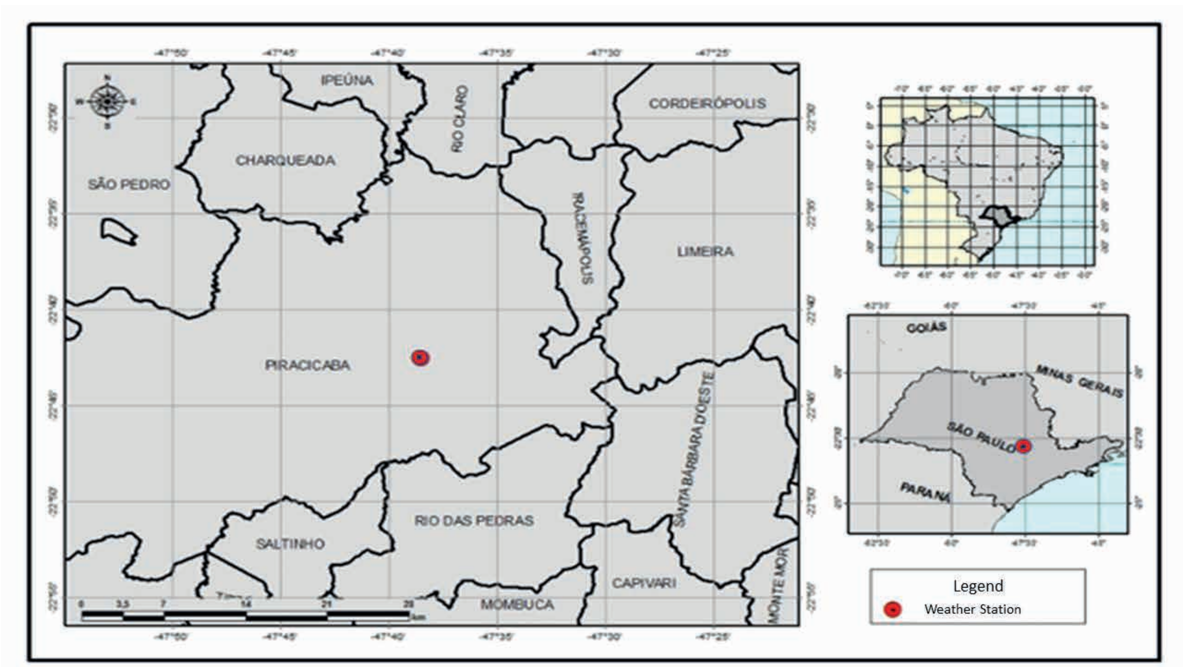

FIGURE 2. Location of the weather station in the municipality of Piracicaba, São Paulo State, Brazil. Source: The authors (2021)

Date	Time	Rainfall
01/01/2020	00:00:00	0
01/01/2020	00:15:00	0
01/01/2020	00:30:00	0
01/01/2020	00:45:00	0
01/01/2020	01:00:00	0
01/01/2020	01:15:00	0
01/01/2020	01:30:00	0
01/01/2020	01:45:00	0
01/01/2020	02:00:00	0
01/01/2020	02:15:00	0
01/01/2020	02:30:00	0
01/01/2020	02:45:00	0
01/01/2020	03:00:00	0
01/01/2020	03:15:00	0
01/01/2020	03:30:00	0
01/01/2020	03:45:00	0
01/01/2020	04:00:00	0
01/01/2020	04:15:00	0
01/01/2020	04:30:00	0
01/01/2020	04:45:00	0
01/01/2020	05:00:00	0

TABLE 1. Part of the new database systematized from data from the automatic weather station exemplified for the beginning of January 1, 2020.

Source: The authors (2021)

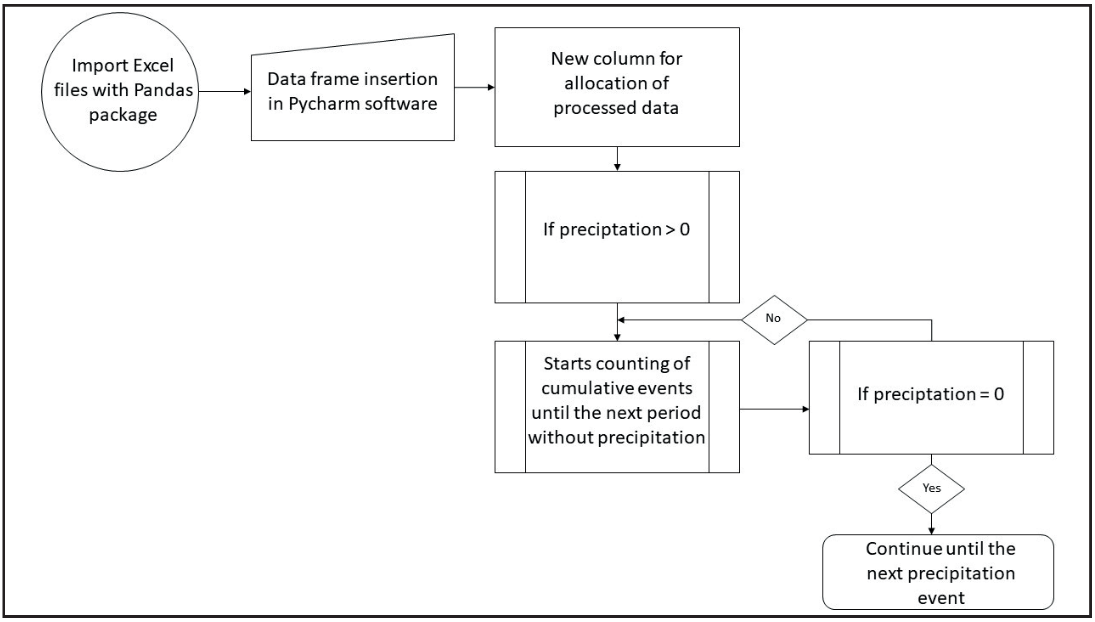

FIGURE 3. Main flowchart part of the software developed in Python aiming to obtain light rain in Piracicaba, São Paulo State, Brazil.

Source: The authors (2021)

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basin, which is used as a temporary reservoir for a period lower than 24 hours.

Filtering was developed directly in Python once the analysis time was defined by counting the period of 12 hours or more without rain before restarting the count, as the amount of pollutants is concentrated in longer periods of drought (Leite et al., 2018). Therefore, mixing drought factors and the fact that the maintenance of the detention reservoir can be carried out within a period of 12 hours, the number of events was counted.

The criterion of counting every 48 lines or more without precipitation was used for the computational language, as the analyzed data had information every 15 minutes, being equivalent to the period of 12 hours or more, thus counting one event.

After this count, the results were converted into an Excel® file directly from the Python directory. The sum and counting of events higher than 2, 5, 10, 15 mm and so on up to 50 mm was performed in Excel®.

An exploratory analysis was performed to start manipulating the results by calculating the mean, median, minimum, maximum, and standard deviation of the number of events counted.

The last analysis consisted of the graphical representation by plotting the precipitation as a function of the stipulated return times, covering a series of 24 years of data. For this purpose, the data were placed in descending order and the empirical frequencies of occurrence with higher or equal heights were calculated (Passos et al., 2021). The data were separated with this formulation, and a spreadsheet with the number of events in the interval, the total value, and the empirical probability of each rain height being equaled or exceeded and its respective return time, that is, the inverse of the frequency, was created in Excel®.

Finally, considering that several rainfall heights with a return period of less than 1 year were generated, we decided to perform an adjustment to a simple logarithmic function instead of using a classic probability distribution function.

RESULTS

Statistical information for the rainfall data from the automatic weather station referring to the period from 1997 to 2020, with measurements of rainfall heights in the range of 2 to 5 mm, 5 to 10 mm, 10 to 15 mm, and so on up to higher than 50 mm, were the initial basis of this study.

The first analyses measured the descriptive statistical data of the number of events found per year in the intervals of the respective rainfall heights, as shown in Table 2.

A total of 2,568 events larger than 2 mm were recorded in the period of 24 years, which means an average of 107.0 events per year. Rain events with a lower rain height presented a higher number of occurrences per year and in the period of 24 years analyzed. On the contrary, events with higher rain heights occurred with significantly lower frequency. According to Rivard (2010), selecting the number of total rainfall events and the average amount of rainfall over the years can also be a way to obtain a deeper analysis of the different categories regarding the generated precipitation volumes. Moreover, rains that have a lower limit of 25 mm have been adopted in many guidelines related to drainage and management of rainwater (Rivard, 2010).

Rivard (2010) conducted studies in the city of Milwaukee (United States) and observed that most events have a lower rain height, classifying them as: (i) very frequent rainfall events (< 10 mm); (ii) common rains (< 14 mm and < 22 mm); and (iii) intense events (≥ 32 mm), corresponding to less than 5% of precipitation events. Generally, very small events can be considered infiltrated and

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Interval of rain height (mm)	Total number of rain events in 24 years	Average number of rain events per year	Median of the number of rain events per year	Standard deviation of the number of rain events per year	Minimum value of the number of rain events in a year	Maximum value of the number of rain events in a year
2 to 5	932	39.13	40	5.14	30	47
5 to 10	611	25.63	25	4.07	15	33
10 to 15	362	15.25	16	3.21	9	20
15 to 20	233	9.79	10	3.15	3	15
20 to 25	154	6.42	6.5	2.69	2	12
25 to 30	95	3.96	4	2.39	1	10
30 to 35	62	2.63	2	1.61	0	6
35 to 40	44	1.83	1.5	1.55	0	6
40 to 45	28	1.21	1	1.25	0	5
45 to 50	18	0.71	0.5	0.86	0	3
>50	10	0.46	0	0.72	0	2

TABLE 2. Descriptive statistical data on the number of rainfall events recorded per year and the total period (1997–2020) for the Piracicaba weather station.

Source: The authors (2021)

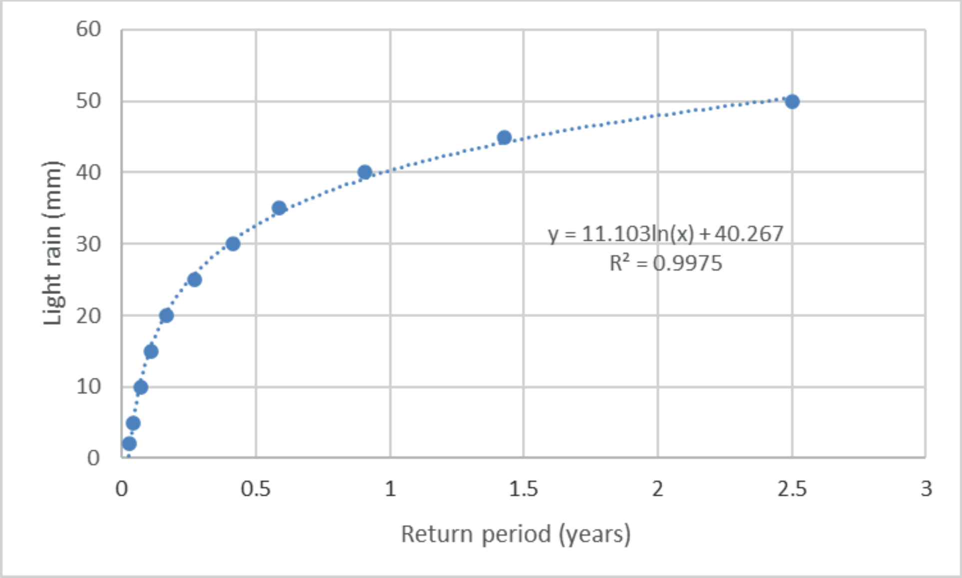

FIGURE 4. Light rains as a function of the return period (Tr) for Piracicaba, São Paulo State, Brazil, with empirical logarithmic adjustment.

Source: The authors (2021).

Statistical parameters	Value
Correlation coefficient (r)	0.9987
Nash-Sutcliffe efficiency (NSE)	0.9975
Percentage of bias (PBIAS)	–0.0030
Willmott agreement index (d)	0.9994

TABLE 3. Performance indices of the logarithmic model used in the light rain adjustment.

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indicated for groundwater recharge (Pangle et al., 2022). In contrast, common events are the most used for designing water quality control structures (Conceição et al., 2018; Aguiar et al., 2019; Lu et al., 2022).

Consistency can be observed between the analyses carried out by Rivard (2010) and those obtained in this study, which had a percentage of occurrence of 4.7% for rainfall in the range of 30 to 35 mm in the municipality of Piracicaba, for example. The analyses carried out by Rivard (2010) reached a value of 5%.

According to UDFCD (2011) and Pedron & Klosowski (2008), the project rainfall of the rainwater collection system to control diffuse pollution can be obtained by correlating the rainfall for dimensioning the reservoirs with frequencies (if higher or equal) of 80 or 90%.

Rains to control diffuse pollution were obtained according to the graph in Figure 4.

Figure 4 shows the ratio of precipitation as a function of Tr. It allows stipulating the project rain for its respective Tr value. Thus, the light rain that best fits the design of future structures (Figure 4) according to Yang et al. (2016) (Tr = 1.0 year), considering the sources of diffuse pollution, should have a height slightly higher than 40 mm (exactly 40.267 mm, according to logarithmic adjustment).

Table 3 shows the performance indices of the logarithmic adjustment. The performance can be considered very good for all indices (Moriasi et al., 2015).

According to UDFCD (2011) and Pedron & Klosowski (2008), the project light rain can be obtained by correlating the heights with frequencies of occurrence higher than or equal to 80 and 90%, respectively. This criterion implies the use of Tr values of 1.25 and 1.11 years, which provide heights of 42.7 and 41.4 mm, respectively, by the logarithmic equation.

The obtained values are slightly high compared to the suggestions by Bannerman et al. (1983) and Rivard (2010), who suggest heights from 13 to 38 mm and 25 to 32 mm, respectively. Thus, Tr values a little lower than those adopted may be more realistic for a sub-humid tropical region, such as Piracicaba. It means that laboratory and field experiments must be carried out to validate and adapt the methodology adopted in this study.

CONCLUSIONS

a) The applied frequency study methodology for the definition of light rain was well suited to the raised historical series, as well as the comparative analysis between the occurrence of events by height interval for each year and the cumulative for the 24 years of duration of the precipitation series.

b) Light rains fit well to a logarithmic function and occur more frequently compared to more intense rains, which are usually used in surface drainage.

c) Most consulted authors (Yang et al., 2016; Pedron & Klosowski, 2008; and UDFCD, 2011) presented similar suggestions for estimating light rain, namely, the use of return period values of 1.00, 1.11, and 1.25 years, obtained from total series of rainfall data.

d) Considering the adjustments and the sources of recommendations, these return period values can be used for the Piracicaba region and imply the use of project rainfall of 40.3, 41.4, and 42.7 mm to control diffuse pollution, respectively, if no significant future climate variations occur in the region.

e) The light rain characterization carried out for the municipality of Piracicaba can be useful for the design of detention basins to control diffuse pollution, such as those existing downstream of composting patios of sugar and alcohol plants. However, there is a need for future experimental evidence of rain heights obtained in the region to validate the proposed methodology.

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