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CHALLENGES OF THE HYDROLOGICAL MONITORING OF SMALL HYDROGRAPHIC BASINS: CASE STUDY OF THE MINEIRINHO STREAM BASIN, SÃO CARLOS (SP, BRAZIL)

L. Angelini Sobrinha[1], L. G. B. Martins[1], R. M. Genova[1], M. V. Galbetti[1], M. M. Mine[1], J. L. B. Brandão[1]
1. *University of São Paulo, Brazil*

ABSTRACT: Acquisition of hydrological data is essential for managing basins and hydrology studies. Implementing a hydrological monitoring network, however, is a complex and unique task.Its planning and implementation involve aspects related to the monitoring objective, the nature of the data, the study area and the available equipment. The implementation is even more complex in urban areas than in rural or mixed basins because the choice of equipment and the selection of installation points present various challenges. These challenges involve subjecting the professionals and equipment to risks or relaxing the technical recommendations so that the task is fulfilled. This article addresses the obstacles and solutions found during the installation of a hydrological monitoring network in the Mineirinho urban stream basin in São Carlos(SP), Brazil. The network has equipment for rainfall, streamflow and water quality monitoring. The selection of points for installation, the choice of equipment and the advantages and disadvantages of the solutions found by the working team are presented.

Keywords: Urban rainfall, urban streamflow, hydrological monitoring.

1. INTRODUCTION

Knowledge about the hydrological regime of a hydrographic basin is of the utmost importance in hydrological studies that serve as a basis for projects in different areas and on different scales. The lack of hydrological data, however, is one of the largest problems encountered by Brazilian professionals. Federal Law no. 9433/1997, which lays out the Brazilian national policy for water resources, recommends that management instruments include a system of hydrological information that is still being developed, which has led to difficulties. The lack of data on large hydrographic basins is still a frequent problem in Brazil, which has many small basins for which a total lack of hydrological data is common.

The acquisition of hydrological data is not a simple task. It can be performed in different ways, depending on the purpose of the data. The nature of the data and the network characteristics drastically change as a function of the type and area of study. For complex hydrological studies, such as studies of water availability and multiple water uses, extensive data series are necessary with relative consistency and spatial representativeness. In these cases, the equipment used has reasonable precision. The equipment mostly consists of cumulative rain gauges and streamflow stations supported by rating curves. For hydrological studies on small scales, such as those related to urban flash floods and other drainage problems, a monitoring network with greater spatial density of rainfall and streamflow stations is needed, in addition to a data series with greater temporal discretization, which is not necessarily long. This makes it necessary to use flow meters and water level recorders with greater precision, and to use rainfall stations equipped with automatic rain gauges. Thus, the implementation of a hydrological monitoring network must be studied case by case, with consideration of the conditions of the study area and the monitoring objectives.

This study examines the planning and implementation process of a hydrological monitoring network in the small urban hydrographic Mineirinho stream basin in São Carlos (SP), Brazil. The network is composed of

4 rain gauges, one flow meter station equipped with a water level recorder, a fixed ADCP (Acoustic Doppler Current Profiler) flow rate meter and a sample collection center for the evaluation of water quality. The monitoring network is designed to survey the hydrological data to study the behavior of the basin with consideration of rain events (rainfall-runoff modeling) and to evaluate the quality of the water runoff (modeling of non-point pollution).

2. LITERATURE REVIEW

2.1 Hydrological Monitoring

Conventional hydrological monitoring of hydrographic basins implies the implementation of a hydrometric network that must be composed basically of equipment that measure the complete hydrological cycle, such as water level recorders and flow rate meters in bodies of water, precipitation (cumulative or automatic rain gauges), evapotranspiration, infiltration, and qualitative parameter meters, among others. Technicians are also necessary for the functioning of the network. They operate and maintain the equipment to keep it safe from damage, etc.

The rainfall and streamflow data, as well as the water quality data, support decision-making related to the use and management of water resources, for public agencies (federal, state and municipal) as well for sanitation companies, non-governmental organizations and the general population (MOURÃO *et al.*, 2009). The success of the monitoring program involves basic questions such as: what (parameters), where (location of monitoring points), when (period and frequency of monitoring) and how to monitor (materials and methods used).Bartram and Ballance (1996) report that it is important to clearly define objectives so that there are no misunderstandings between the members of the technical team. It is also essential to clearly establish the purpose of the collected data.

Various monitoring programs in Brazil seek to establish clear and concise objectives with the intention of avoiding the “data-rich but information-poor" syndrome (TOLEDO, 2004). That is, if the studies do not have a detailed objective, it is possible to waste much time and resources without achieving the objectives. With the monitoring objectives defined, the study can move on to the planned implementation stage. Basically, hydrological monitoring can be divided into some topics that, together, make up the parameters to be monitored and define the equipment that will be used. In this study, with the objectives of surveying the hydrological parameters for the study of the behavior of a small urban basin considering rain events (rainfall-runoff modeling) and surveying the qualitative parameters of the water for the evaluation of diffuse pollution, the network is composed of: precipitation sensors, water level sensors, and flow rate sensors; and measurement of water quality parameters.

2.2 Rainfall monitoring

For adequate hydrological monitoring, a correct analysis of the spatial distribution of rain precipitation is essential (MARCUZZO et al., 2011). In an urban environment, specifically for studies related to urban drainage, this type of monitoring has some specific characteristics that make the task peculiar because the majority of urban basins are relatively small, generally not larger than several dozen km^2.The order of magnitude of rainfall networks generally shows spatial resolution (distance between equipment) of 100 to 500 meters, potentially reaching up to 5 km, covering a total area of not more than 400 km^2 with a time resolution between 1 and 10 minutes (FLETCHER et al., 2013). The definition of a rainfall network starts with the establishment of a minimum number of points, the selection of installation sites for equipment (rainfall stations) and the definition of the objective. Thus, a network defined for flood warning systems is different from a network established to study the climatology of precipitation in an area (CHAIB et al., 2013).

In general, a rainfall station must be installed according to specific technical recommendations. Among the most important is the installation of the rim receiver of the equipment to a rigorous height of 1.5 meters relative to its base, the requirement for the distant installation of obstacles - the equipment must be at a distance that is double the height of the obstacles - and the search for flat locations with few wind currents (DAEE, 2003). Therefore, for urban areas, each rain gauge must not cover an area greater than 20 km^2 and, if possible, must have its own datalogger (WMO, 1994).In cities, however, many of these recommendations are difficult to fulfill due to the difficulty of finding open, available areas for the equipment in densely occupied regions. Additionally, depending on the educational and social level of the population, there are concerns related to the safety of the equipment that, many times, are superimposed on the fulfillment of other requirements, resulting in installations that conflict with the current technical recommendations.

When the intention is to implement a rainfall monitoring network from an organized set of stations, the stations must be spatially distributed in a uniform manner according to some technical criteria, with the objective of monitoring precipitation over a specific area (MISHRA et al.2011). The same authors also state that a low spatial density in networks of this type leads to errors in the calculation of precipitation that can harm the study. Additionally, according to Bhowmik and Das (2007), the greater the distance from the point of interest to the rainfall station, the lower the representativeness of the data. Thus, in addition to the difficulties of installing rainfall stations in urban areas and making up a rainfall network, one must pay attention to the density and distance between stations so that an effective network is obtained, which provides data with quality that is compatible with the monitoring objective.

2.3 Streamflow monitoring

Streamflow monitoring involves various measurement techniques for variables related to flow such as water levels, velocities and discharges. The rating curve relationship is one of the primary products of a streamflow measuring station. After the acquisition of a series of data on the flow rate and water level, the rating curve makes it possible to establish a relationship between these two variables, so that flow rate may be studied by measuring the water level. This relationship is an important requirement for hydrological analyses related to the dimensioning of hydraulic works, especially in urban basins that have a large number of impermeable areas as a primary characteristic (LINDNER; MILLER, 2012; SCHMIDT; YEN, 2008).

The large percentage of impermeable areas in urban spaces increases the hydraulic efficiency of runoff but decreases the time of concentration of the basin. The decrease of the time parameter, according to Canholi (2005), increases the magnitude of peaks in the flow rate and, consequently, increases problems connected to urban drainage. Additionally, urban rivers have a large quantity of solid waste, primarily during flood waves, when these are carried to the river bed through flash floods. Thus, in addition to the recommendations for the installation of common streamflow measuring stations, in urban areas, this task must consider these factors so that planning and installation occur in an appropriate manner.

According to USDIBR (2001), the location of installation of a streamflow station must have the following characteristics: easy access for installation, maintenance and operation; it must not cause errors in the reading due to hydraulic phenomena; and it must be a safe area for instruments and operators. The equipment must be easy to install and calibrate, it must be adaptable to different operation conditions, it must be capable of measuring variations of the flow rate in short time intervals and it must be resistant to impacts from coarse materials and have a reasonable cost. In summary, the location of the installation must have a stable cross section, and the equipment must be capable of effectively recording flood waves in an adequate time.

Among the primary instruments used in Brazil for the measurement of the flow rate, floats, acoustic meters, current meters and tracers are some of the most important tools. The flow rate obtained by using floats is a flow velocity calculated from the displacement of a floating object and multiplied by the area of the section. The method is useful because of its simplicity and the lack of sophisticated equipment; however, it has low precision and cannot be automated (ALMEIDA JUNIOR et al., 2010). Acoustic meters (ADCP - Acoustic Doppler Current Profiler) perform indirect measurement of water velocity using the Doppler Effect. These instruments are efficient and show good precision, making information available in real time; however, they require specialized labor and have high acquisition costs (RIOS et al.2011). Acoustic meters are divided into fixed and mobile types. The fixed type requires a stable section for fixation; it does not require operators during measurements, and it can be used in small channels, irrigation channels and pipes. Mobile devices are used for the determination of flow rate in rivers and lakes; however, they require operators during measurement (RIOS et al., 2011).

Current meters provide indirect measurements of runoff velocity. The number of rotations of the helix of the device is converted into a flow rate. This is the most popular instrument for the measurement of flow rate in rivers due to its good precision and accessible cost. However, this device has some limitations: the calibration of the equipment can be lost due to the wear of the helices and internal rolling; it is necessary to obtain measurements in different vertical lines along the cross sections to estimate the flow rate; technical knowledge and experience are required by the operators; the devices cannot be automated and boats are needed when the measurement occurs in rivers with large flow rates (CHEVALLIER, 2003; RIOS et al.2011). Additionally, there are operational difficulties with the use of current meters when the water velocity is very high because high flow turbulence hinders the stabilization of the equipment. For measurements of flood waves in urban areas, the use of current meters is inappropriate due to the time required for the measurement of the flow rate and the device fragility to shocks with coarse materials.

Finally, the tracer method is based on the dilution of a chemical product of known concentration in a determined section of the river. The principle consists of continuously diluting the product so that its concentration is measured in a downstream section. The flow rate of the body of water can be determined by the continuity equation. The restrictions of the method are that the chemical product used as a tracer must not react with existing impurities or be harmful to the fauna or flora; the flow rate must be sufficiently turbulent to cause total dilution and the cost of the product can make measurement impractical (PORTO; ZAHED FILHO; SILVA, 2001).

For the measurement of water levels in streamflow stations, staff gauges or automatic water level sensors can be used. These have been used for a long time and can be of various types, such as float, bubble, laser or ultrasound water level sensors or pressure transducers. For urban areas, only electronic sensors are viable for various reasons: reduced size, good precision, ease of installation and use and, currently, they still have the advantage of ease of acquisition due to their reduced cost. Of the electronic equipment, pressure transducers are particularly useful. They come in two types: those that directly compensate for atmospheric pressure through the use of a vented cable, and those that require later compensation by the operator, based on readings from a barometric sensor.

2.4 Water quality monitoring

The choice of parameters to be analyzed in a specific study must consider the study objective, the particulars of the studied basin and the available resources (GOMES, 2004). The following must also be considered: the ease of monitoring the parameter, the availability of historical data, possibilities for simulation of the pollutant through qualitative models and the representativeness of the parameter as an indicator of the pollution source and processes that occur in the water course (LARENTIS, 2004).

Magina *et al.* (2007) emphasizes the importance of adapting the location for measurements, highlighting the following properties: equal distance between other monitoring points that make up the network, the safety for the equipment and protection against vandalism, accessibility and safety for the technician responsible for maintaining the equipment under any climate and hydrological conditions.

For the time and frequency of collection, CETESB (2011) reports that the best solution is to use equipment that continuously records changes in quality. If this is not possible, however, the definition must be made based on information and data that are already available or based on preliminary surveys, whenever possible (CETESB, 2011). The sample size can be determined based on statistical calculations, assuming a normal distribution for the quality variable and random and independent samples (CETESB, 2011).

There are various types of equipment available for collecting water samples:surface samplers (stainless steel bucket, retractable arm collector, bathyscaphe, multiparameter probe, sequential automatic samplers); depth samplers (van Dron and Niskin bottles, Schinder-Patalas trap, water pump, plankton net); bottom samplers (Ekman-Birge grab, Petersen and van Veen Grab, Ponar grab, Shipek grab, tube sampler or corer, rectangular dredge, delimiters, manual net); artificial substrate (baskets with rocks, float with blades); natural substrate (devices for passive and active fishing) (CETESB, 2011).The choice depends on the type of material that is needed for collection, on the period of collection and primarily on the resources available for acquisition. Collection, transport, handling and preservation of samples represent sensitive stages in which small oversights can compromise the representativeness of the samples (SILVA *et al.*, 2013). Thus, the choice of location, collection logistics and the training of operators are essential for the success of the procedures.

Despite the large portion of studies that follow all of the recommendations for implementation of a monitoring network, Toledo (2004) finds that there are still frequent reports of problems found in this stage, which range from the elevated costs of implementation to the absence of trained technical personnel to manage the information. The author emphasizes that the lack of definition in the monitoring objectives has been shown to be the primary cause of the abandonment of many programs because the costs make it impractical to continue projects that do not show satisfactory results in a short period of time.

3. STUDY AREA

The Mineirinho stream basin is located in the city of São Carlos, which is situated in the central region of the State of São Paulo, Brazil, approximately 240 km from the capital of the state. The municipality covers an area of 1,141 km^2, with 67.25 km^2 being urbanized, which corresponds to 6% of the total area. The current population is approximately 220,000 inhabitants. The climate is highland tropical, with rainy summers and dry winters, with the hottest average temperature of the month greater than 22ºC.The average annual precipitation is 1,512 mm (PMSC, 2014). The Mineirinho stream is a tributary of the Monjolinho River and has an area of approximately 6 km^2 and a perimeter of 10.8 km. The total approximate length of the stream is 4 km, and the difference between the elevations of the basin is 81 m (APRÍGIO, 2009). An illustration of the location and an image of the Mineirinho stream basin are shown in Figure 1.

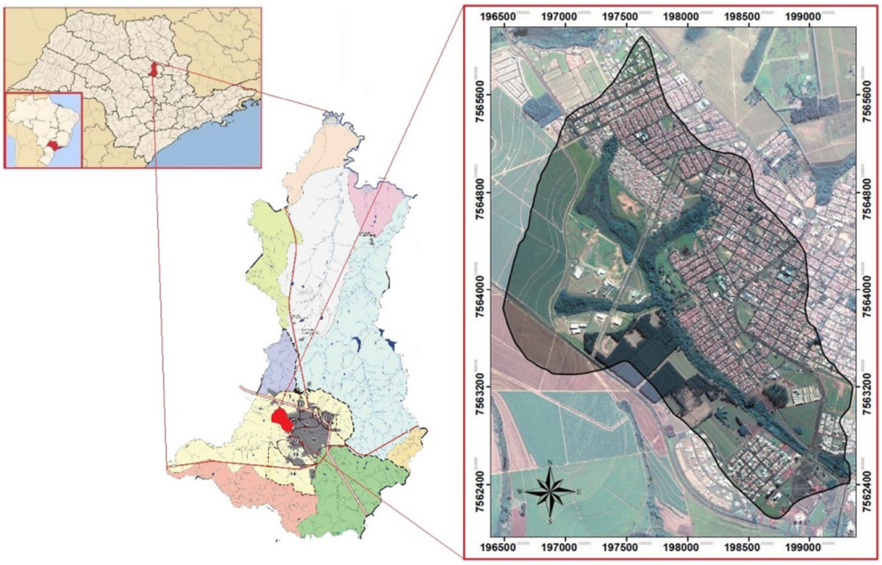

Figure 1: Study Area: Mineirinho Stream Basin

The basin has four springs, of which two are located in the residential neighborhood Santa Angelina, with one of them being its primary spring. The other two springs are located within area 2 of the campus of the

University of São Paulo (Universidade de São Paulo) in São Carlos (BENINI et. al., 2003). According to Tarpani and Brandão (2009), the land-use of the soil of the basin in 2007-2008 is divided in the following manner: 40% is urbanized area, 15% is used for sugar cane cultivation and Pinus; 20% of the area is composed of fields and/or pastures; 15% is composed of exposed soil and 10% is riparian vegetation that borders the streams and springs. The soils are composed of yellow red latosols, deep and dystrophic in the interfluves, and hydromorphic soils of the types Gleysol and Organosol, permanently saturated or intermittent with the water table near the surface (BENINI, 2005).

4. RESULTS

Next, the results are shown for the choice of equipment and its spatial distribution, along with other factors related to the implementation of the hydrological monitoring network of the Mineirinho stream basin. The results are summarized in two figures; the first one shows the location of the equipment in the study area (Figure 2), and the second shows the equipment that makes up the monitoring network (Figure 3).

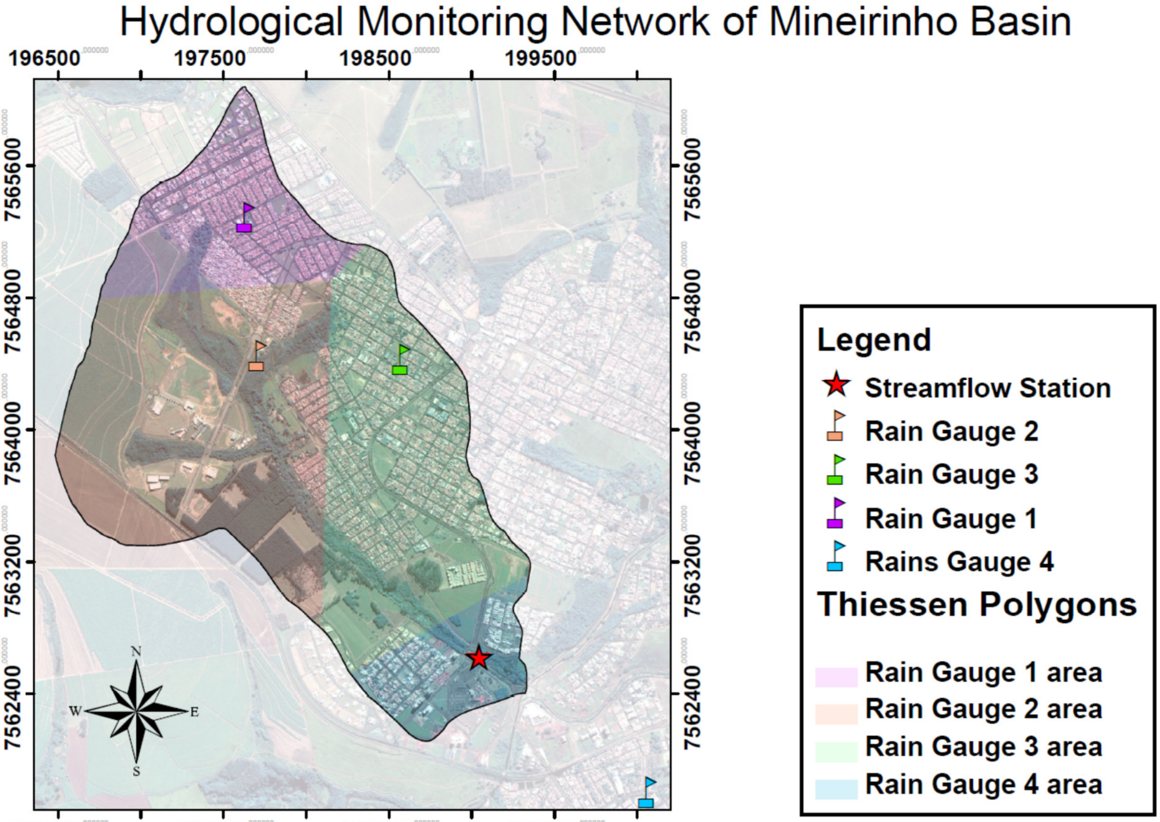

Figure 2 – Location of the stations that make up the monitoring network of the hydrographic Mineirinho stream basin.

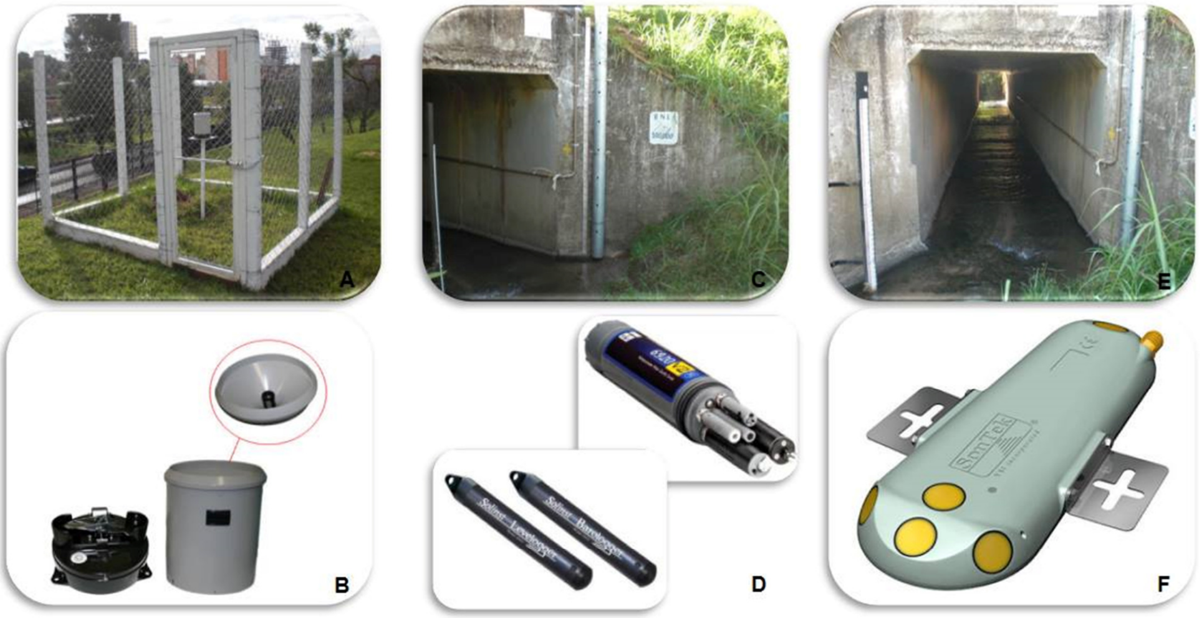

Figure 3 – Details of the network and its equipment:(A) protection fences for rain gauges; (B) tipping bucket rain gauge; (C) protection tube for the pressure transducer and multiparameter probe; (D) pressure transducer, barometer and multiparameter probe (above); (E) location of installation of the flowrate meter; (F) fixed ADCP type flow rate meter.

4.1 Rainfall gauging

Because the rain gauging network is related to the monitoring of urban flooding, it was configured to record data from intense rains. Thus, tipping bucket rain gauges with mini-dataloggers powered by built-in batteries were used (Hydrological Services, Model TB4, Figure 3B).These are small devices with wireless displays that are relatively inconspicuous. The measurement of the intensity of precipitation by these devices is performed by recording the time at which 0.2 mm are accumulated (referring to one tipping), thus permitting a more appropriate time resolution for the study to be adopted later. Because the study area is small and the purpose of the data is to support a study about rainfall-runoff modeling, there was no need to monitor in real time. For this reason, the equipment did not need to have telemetry systems. For the rain gauging network, 4 rain gauges were installed to cover the study area with a satisfactory spatial resolution:1.5 km²/sensor on average. However, the choice of installation sites and their spatial distribution in the study area posed a challenge of unexpected complexity.

Early on, it was found that the study area had few points that met all of the technical recommendations. The available points, for the most part, were within private areas or lands with difficult access. It was decided to broaden the areas that could receive the stations, permitting that they were part of local networks outside of the study area. Because of the bureaucratic ease of obtaining permission for installation, one of the stations was implemented on of the campus of the University of São Paulo (Rain gauge 2). Two devices were installed in public areas: a municipal health center (Rain gauge 3) and a public school yard (Rain gauge 1). To cover the area downstream of the basin, a station was installed at an industrial site located to the southeast (Rain gauge 4).Thus, for an area of approximately 6 km², 4 stations were installed, with a density of equipment that is very satisfactory for the objectives of the monitoring network and fulfills the recommendations of the World Meteorological Organization (1994), which specifies a maximum coverage of 20 km² per rain gauge station for urban areas. The difficulties encountered in obtaining permission for installation of the equipment are emphasized. In the public school, the installation depended on a didactic agreement. That is, the team agreed to explain the functioning of the equipment to the students. For the health center, an official letter was sent to those responsible for the area and, after a certain period of time, the installation was authorized. In the industry, after sending an official letter, 4 months were need to make a location available for the installation and to set the details of the visits for data collection.

After the devices were installed, although they were in relatively secure locations, the equipment received protective fences to impede vandalism or to avoid accidents that could damage the equipment. The implementation of the rain gauging network in the study area is considered satisfactory, with the primary advantages being the spatial resolution of the equipment and the reliability of the equipment. The primary disadvantages are the time necessary to obtain permission for installation, the less than satisfactory spatial distribution, the risk of damage to the devices and the need for frequent, in-person data collection.

4.2 Streamflow measuring

For the flow station, the chosen area was a culvert situated at the intersection of the avenues Bruno Ruggiero Filho and Parque Faber. The location is characterized by being close to the stream mouth and having a large free area around it, which favors the installation of a camp to support field work.Because the location is at the intersection of two access routes with the presence of businesses, such as two upscale residential parks and a shopping mall, the action of vandals is discouraged due to the high flow of people and the policing of the region.

The location chosen is a concrete culvert with a square cross section of 2.5 meters on a side of length 32 meters, which characterizes the cross section as stable. The culvert has a waterfall on the downstream end, creating adequate hydraulic conditions for the measurement of flow rate, so that hydraulic phenomena such as backwaters or hydraulic jumps do not occur.

To acquire water level data, a level meter was installed consisting of a pressure transducer (Figure 3D), which records the pressure exerted by the water level, and a barometer (Figure 3D), which records the atmospheric pressure. Both of the devices were installed immediately upstream of the culvert in a six-inch galvanized steel tube (Figure 3C) to protect them during extreme events. The tube was perforated along its entire length with one inch holes to avoid the formation of negative pressure and consequent alterations in the measurement of the water level. The two devices were connected to steel cables with steel hooks on the tip, attached to a screw passing into the inside of the tube with the upper extremity closed. A staff gauge was installed on the side of the tube (Figure 3C).

Because there was a section showing high velocities due to the increase of the efficiency of flow caused by the channeling, the choice of possible equipment for measuring the flow rate was restricted. A fixed ADCP automatic flow meter, model IQ Plus from the manufacturer Sontek (Figure 3F), was chosen and installed in the middle of the culvert. Despite the relatively high costs for acquisition and training of personnel, the equipment was easy to install and remove; and it shows a hydrodynamic form, interfering as little as possible with the flow lines. The device records the flow rate data, water depth (essential parameters to establish the rating curve), velocity of flow and other parameters related to the quality of the reading. Despite being simple, sandbags were needed for the installation of the device to divert the water from within the culvert, and an electrical generator was needed to provide power for the electrical tools. A duct for passage of the energy and data collection ADCP cable was required.

Another feature of the location is the presence of extreme conditions during flooding, characterized by high velocities and an excess of solid wastes and sediments, with tree trunks not being uncommon. To prevent the device from being hit by these materials or covered by solid wastes during the flood waves, a small protective grid was installed one meter upstream of the device, so that it would not attenuate or interfere with the acoustic signal, the accumulation of sediments or the disturbances of the flow lines.

To facilitate data acquisition for the flow rate and to avoid vandalism and robbery, a small concrete box was installed outside of the culvert to cover the battery and protect the data reading terminals of the ADCP. Because the concrete box was partially buried, it provided discretion and convenience to the operation.

Operation of the installation requires constant maintenance. Within the culvert, the wastes stuck on the grate are removed – composed for the most part of leaves, small sticks and plastic bags –the integrity of the ADCP is verified. In the concrete box, data collection is performed, and the charge available in the battery is verified (exchanging it for a charged battery if there is a need).Additionally, the equipment is calibrated. The equipment remains in continuous operation, even without rainfall, so that there is no need for field visits prior to rainy events. It is emphasized that the maintenance is performed every two or three days, independent of the occurrence of these events. The equipment performs the flow rate measurements from a minimum water depth of approximately 10 cm. Water depth in the culvert, outside of rainy events, is normally below this limit.

4.3 Water quality measurement

For monitoring the water quality of the basin, the sample collection point is the same point as the water level measurement point (Figure 3C).The operational procedures are based on the "National Guide for the Collection and Preservation of Samples" ("Guia Nacional de Coleta e Preservação de Amostras"), published by the CETESB (2011). For this, a multiparameter probe was used (for *in loco* measurements) and the collection of samples is manual. The collections will be performed in the rainy and dry periods.

The 6920V2 probe (YSI brand)was the equipment chosen for *in loco* monitoring of water quality. It has four sensors, which measure conductivity/temperature, dissolved oxygen (DO), pH, redox potential and turbidity. The equipment is powered by long-life batteries, and it is equipped with automatic cleaning sensors and anti-encrustation components for long sampling periods (CLEAN, 2014).

Based on the guidelines of the USEPA (1993) for characterization of non-point pollution in urban areas, the following parameters are monitored: Nickel, Chromium, Cadmium, Zinc, Copper, Lead, Total coliforms, Total Phosphorous, Total Nitrogen, Oils and Greases, BOD, COD, Total Solids, Total Suspended Solids - to be analyzed in a specialized and certified laboratory, according to the ISO standards (International Organization for Standardization) – pH, Turbidity, Temperature, Electrical Conductivity and DO, to be collected in the field through the aforementioned probe. The choice of the point of collection of the water quality samples took into consideration the factors defined by Magina *et al.* (2007). Regarding the control and validity of the data, recommendations from the same author were also adopted (operational procedure for maintenance and calibration).

The methods selected for collection and evaluation of water quality have been satisfactory up to this point. However, some procedures may be cited that showed disadvantages during the field campaigns. In the manual collections, it was necessary for at least two operators to be present near the banks of the stream during rainy events, which exposes the operators to risks such as rapid water level rises and unstable banks, sometimes during night collections. In the automatic collections, the equipment has a low number of sensors, which makes the analysis of many quality parameters in the laboratory necessary (increasing the monitoring costs), and there are operational difficulties during rainy events and a need for a minimum water depth for adequate collection of the samples. Therefore, even if all of the precautions and observations of the safety standards are observed, the acquisition of these data is still a great challenge.

Five solutions were found for these obstacles: the acquisition of complementary equipment (sequential automatic collector) for the collection of samples and later analysis in the laboratory, the damming of the body of water to increase the water level in dry periods and keep the probe in the vertical position during use, the monitoring of weather using meteorological radar for optimization of timing the shifts of the collection team, the performance of collections during the day without leaving the equipment alone and analysis of the technical viability of the installation of waiting bottles for monitoring the rainy events full-time.

CONCLUSIONS

The data obtained from the hydrological monitoring network serve as a basis for decision-making in public policy. The data help to guide creation of urban zoning policies and the establishment of guidelines and priorities for investments in infrastructure related to urban drainage and water resources. For the society that commissions and uses the data, they provide a return on investment in infrastructure, primarily in the form of hydraulic works and other mitigating actions.

Despite its importance, when dealing with hydrological monitoring in an urban environment, there are many difficulties and challenges to overcome in the implementation of a network, as described in the article. In general, it was necessary to relax the standards for installation and operation of the various monitoring equipment because, in urban areas, stringent requirements may make their installation impossible.

Ensuring safety of the devices during operation and choosing appropriate locations was an arduous and difficult task. This choice took into consideration the safety of the operators (in all of the monitoring stages) and the instruments (vandalism and/or theft).The agility of the installation of the network depends also on the good will of the public agencies and the private companies to obtain the necessary permission for the installation of the equipment in areas under their responsibility.

In conclusion, the experiences obtained through the installation of existing monitoring networks and the characteristics of the studied area provide information that can sometimes supersede the technical recommendations. Finally, each monitoring network has unique properties, and there is no single model for their implementation. The implementation strategy may depend on the study area, the monitoring objectives, particulars of the available locations for equipment installation and the financial resources involved.

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