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Experimental and representative watersheds as a training site of qualified professionals in water resources: a case study of Onça Creek Watershed (SP, Brazil)

Bacias hidrográficas experimentais e representativas como local de formação de profissionais qualificados em recursos hídricos: estudo de caso da Bacia Hidrográfica do Ribeirão da Onça (SP)

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ABSTRACT

This study aims to present how continuous and systematic monitoring in representative and experimental watersheds can help form high-level professionals and researchers in water resources, based on a case study of the Onça Creek Watershed (OCW). Through a historical survey of the monitoring network and the scientific studies carried out in the area, we identified people and map their geographical and professional location, to analyze the impact and importance of this area for the water resources community. We identified 90 scientific studies already developed at the OCW, which resulted in 22 masters and 4 Ph.D. students formed, involving another 33 external collaborators. We observed that 85% of the trained professionals continue to exercise functions related to water resources, in public and private institutions, throughout Brazil and abroad. We highlight the importance of financial support from research and development agencies, both for the monitoring network expansion and the training students' scholarships. We believe that the involvement of water resources graduate programs can be a way to increase the number of experimental and representative watersheds monitored in Brazil.

Keywords: Representative watersheds; Water resources training; Onça Creek Watershed; Guarani Aquifer System.

RESUMO

Este trabalho visa apresentar como o monitoramento contínuo e sistemático de bacias representativas e experimentais pode contribuir para formação de profissionais e pesquisadores qualificados em recursos hídricos, a partir de um estudo de caso da Bacia do Ribeirão da Onça (BRO). Por meio de um levantamento histórico da rede de monitoramento e dos trabalhos desenvolvidos na área, buscou-se identificar as pessoas e mapear sua localização geográfica e profissional, a fim de analisar o impacto e a importância desta área para a comunidade de recursos hídricos. Foi possível quantificar 90 trabalhos científicos já desenvolvidos na BRO, que permitiram a formação de 22 mestres e 4 doutores, além de envolver outros 33 colaboradores externos. Considerando os profissionais formados, observa-se que 85% deles seguem exercendo funções relacionadas aos recursos hídricos, em instituições públicas e privadas, espalhadas pelo Brasil e no exterior. Destaca-se ainda a importância do suporte financeiro de agências de fomento e outros órgãos de pesquisa, tanto para a expansão da rede de monitoramento quanto para o apoio aos alunos de pós-graduação. Acredita-se que o envolvimento de programas de pós-graduação da área de recursos hídricos pode ser uma forma de aumentar o número de bacias experimentais e representativas monitoradas no Brasil.

Palavras-chave: Bacias experimentais; Formação em recursos hídricos; Ribeirão da Onça; Sistema Aquífero Guarani.

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INTRODUCTION

Hydrological and hydrogeological monitoring is an important tool for water resources management, both in quantitative and qualitative aspects. Historical data series of different variables allows advances in hydrology and hydrogeology studies, linked to the comprehension of previous phenomena and predictions of future scenarios, besides assisting in decision-making on the water uses (Tetzlaff et al., 2017; Brantley et al., 2017; Bogena et al., 2018). Commonly, such monitoring is performed in experimental and representative watersheds. Experimental basins corresponds to areas up to 4 km^2, where research organizations can manipulate land use, ensuring the homogeneity of physical characteristics. Representative basins includes regions with similar hydrological characteristics, without area limitation and land use manipulation (Toebes & Ouryvaev, 1970; Whitehead & Robinson, 1993; Wang et al., 2014; Villas-Boas et al., 2017; Blume et al., 2017).

Monitoring these areas requires adequate equipment and qualified staff, who are responsible for data collection and devices maintenance (McDonnell et al., 2007; Burt & McDonnell, 2015). In Brazil, such groups are commonly composed of professionals from public institutions linked to the water resources sector, such as National Water and Sanitation Agency (ANA) and Geological Survey of Brazil (CPRM). State agencies and university professors and researchers are another affiliation examples of these professionals. Graduate students (master and Ph.D.) are also involved in these activities, once they can develop their scientific studies in these areas (Cadier, 1996; Rede de Hidrologia do Semi-Árido, 2004; Melo et al., 2020). Considering this period of field training, these students develop specific technical skills, which can become differential features and encourage them to continue a career in the water resources area.

Considering this, we aim to present how continuous monitoring in representative and experimental watersheds can contribute to the training of qualified professionals in water resources. Using the Onça Creek Watershed (SP, Brazil) as a case study, we made a historical survey of the developed research in this watershed and how its monitoring network evolved over the years, highlighting the importance of financial support for continuous monitoring. Then, we seek to identify the former researchers, called here professionals trained at the OCW, their current careers, geographic location, and if they are still linked to the water resources sector, applying their practical experience and contributing to this community.

STUDY AREA: ONÇA CREEK WATERSHED

The Onça Creek Watershed (OCW) is located in the rural area of Brotas municipality, São Paulo state, in southeastern Brazil (Figure 1). This watershed has approximately 65 km^2 of drainage area, being occupied by private properties, where the most common

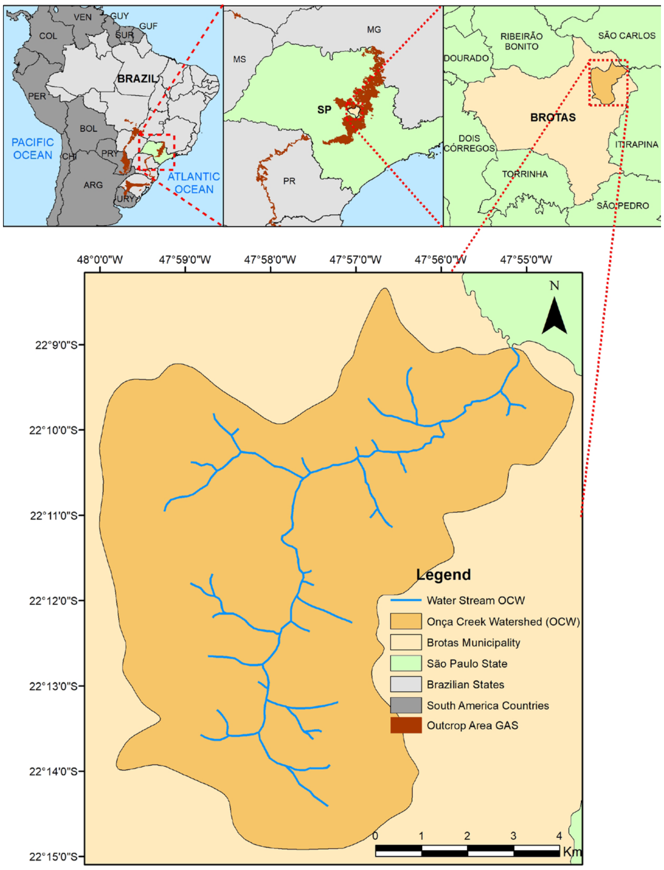

Figure 1. Onça Creek Watershed location: (a) at the context of Brazilian territory; (b) at the context of São Paulo State and the outcrop areas of Guarani Aquifer System; (c) at the context of Brotas municipality and the central region of São Paulo state; (d) drainage area and water stream of OCW.

land uses/ land covers of the state are observed: sugarcane, citrus, eucalyptus, pasture, and remaining areas of Cerrado Biome, a woody savannah (Figure 2). The interest in monitoring is related to its location, which is a Guarani Aquifer System outcrop area. There, studies have been developed to quantify groundwater recharge for better understanding this system, which has national and international importance (Gastmans et al., 2010; Richts et al., 2011; Hirata et al., 2020; Hirata & Foster, 2021).

According to Köpper-Geiger climate classification, the OCW is located in a humid subtropical climate (Cwa). This climate is marked by dry winters and rainy summers, especially from October to March. OCW has a annual mean rainfall of approximately 1500 mm and a mean air temperature of 21.6 ºC (Cabrera et al., 2016). Considering the soil pedological classification, OCW is covered mainly by an ortic quartzarenic neosol, with sandy texture in the entire profile (Coutinho et al., 2020). Other types of soils are also founded at the OCW (Figure 3). In terms of elevation, this watershed has values varying from 643 to 842 meters above sea level (Figure 4), with an average slope of 7.6 m km^{-1} (Meira Neto et al., 2011).

The representative watershed implementation began in 1972 from a cooperation between the University of São Paulo (USP) and the Water and Electricity Department of the State of São Paulo (DAAE/SP) (Contin Neto, 1987). In the 1980s, a research project supported by the São Paulo Research Foundation (FAPESP) enabled the first physical characterization of the region and hydrological cycle components assessment (Mattos et al., 1984; Preto Filho, 1985).

A systematic and continuous monitoring was implemented in early 2004, after an interruption during the 1990s. Nowadays, we measure groundwater levels, streamflow, and collect meteorological data. This monitoring is carried out by USP, through the Computational Hydraulics Laboratory of São Carlos School of Engineering (LHC/EESC). This watershed has been making possible the training of masters and Ph.D. students, linked to the Graduate Program in Hydraulic Engineering and Sanitation (PPGSHS/USP). As a result of this training, several scientific studies related to hydrology, water resources, and the Guarani Aquifer have been developed.

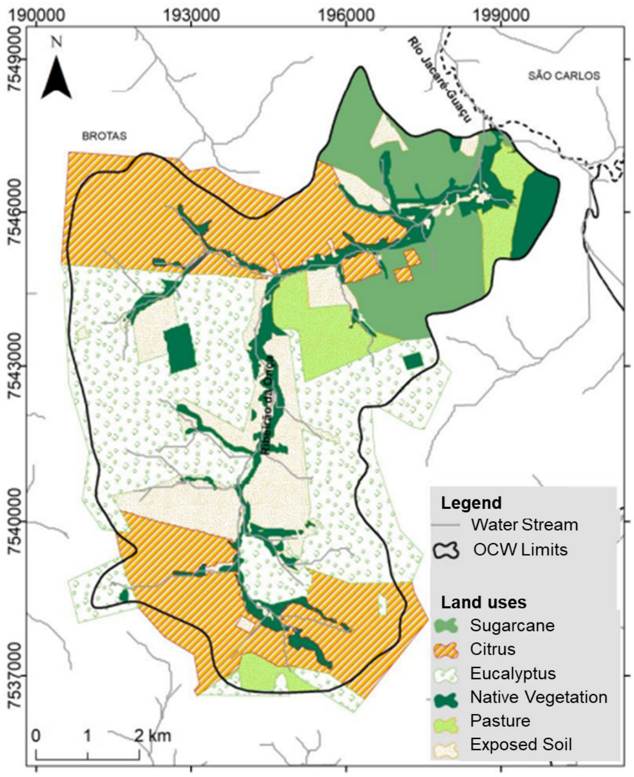

Figure 2. Land uses at the OCW, mapped in 2017. Since then, there have been no significant changes [Source: Adapted from Coutinho (2019)].

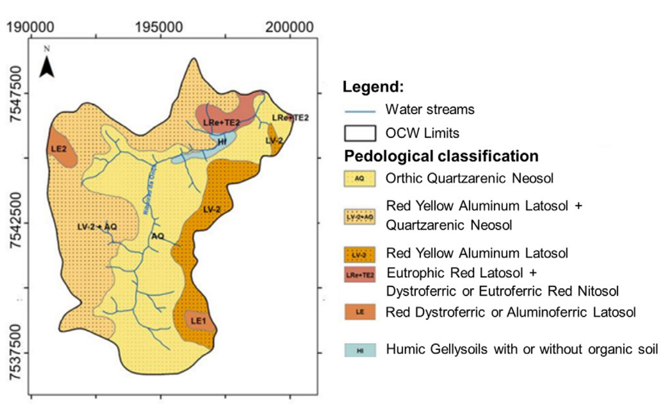

Figure 3. Soil pedological classification at the OCW [Source: Adapted from Coutinho (2019)].

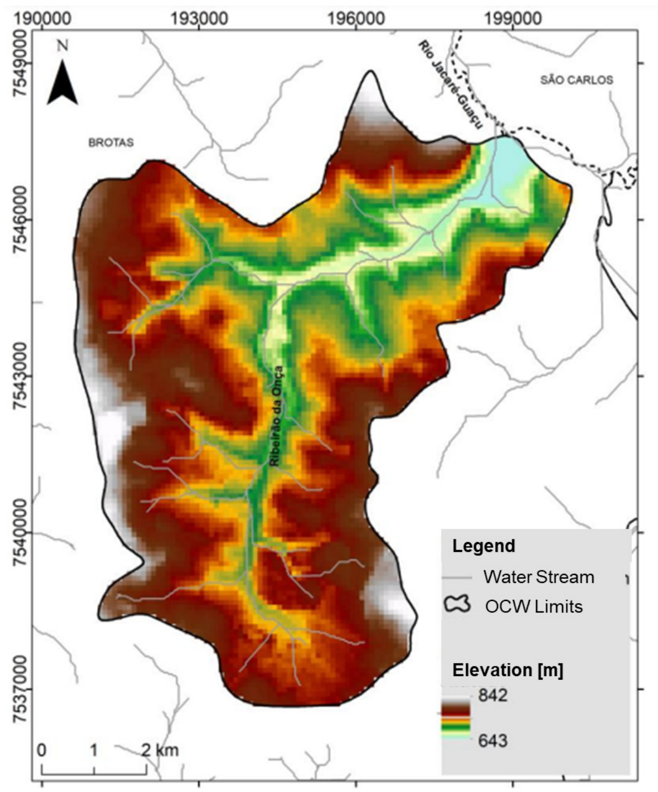

Figure 4. Digital Elevation Model (DEM) of the OCW [Source: Adapted from Coutinho (2019)].

In 2022, OCW completes 18 years with continuous monitoring. This period is longer than the average of the monitored watersheds in Brazil, which is around 12 years (Melo et al., 2020). During this period, research projects funding enabled the monitoring network expansion, aiming to investigate different hydrological variables and to contribute for new studies in the area, related to groundwater recharge, evapotranspiration, precipitation, and how changes in land uses and land covers can influence the hydrological cycle. Currently, the OCW has 35 monitoring wells, 3 streamflow gauges, and 3 automatic meteorological stations, which collects data of precipitation, air temperature, air humidity, solar radiation, and sensible heat flux in soil (Figures 5-6). Also, data from the climatological station of the Water Resources and Environmental Studies Center (CRHEA/USP) can be used, once this station is located near the study area and has data available since 1980.

MATERIALS AND METHODS

The methodology of this study was divided into four stages (Figure 7). The first step consisted of gathering the scientific studies developed at OCW, which included papers published in journals, dissertations, theses, and studies presented at conferences. From this survey, three other analyzes were carried out: mapping the evolution of the watershed hydrogeological monitoring network; the geographic and professional mapping of the people trained at OCW; and the creation of a word cloud with the most common terms found in the English abstracts of papers, theses and dissertations. Each of these steps will be detailed in the following topics.

Survey of scientific studies developed in OCW

The identification of the scientific studies developed at OCW was carried out by consulting the following databases:

- USP Theses (Universidade de São Paulo, 2022), USP institutional repository. In this platform, it is possible to obtain digital versions of dissertations and theses developed in the Institution graduate programs. The terms "Ribeirão da Onça", "Guarani Aquifer System" and "Onça Creek" were used to search for studies of interest. Filters related to the institutional unit ("São Carlos School of Engineering") and the department ("Hydraulics and Sanitation") were applied.
- Curriculum Lattes (Conselho Nacional de Desenvolvimento Científico e Tecnológico, 2022) of professors from PPGSHS, who developed studies in the OCW, considering the existence period of the program created in 1970.
- Web of Science, Scopus and Google Scholar journal platforms. The terms "Ribeirão da Onça", "Guarani Aquifer System" and "Onça Creek" were used again. It was necessary to cross-reference the data obtained from these platforms with the studies and authors found in the other two aforementioned research sources, in order to guarantee coherence and compatibility between the identified studies.

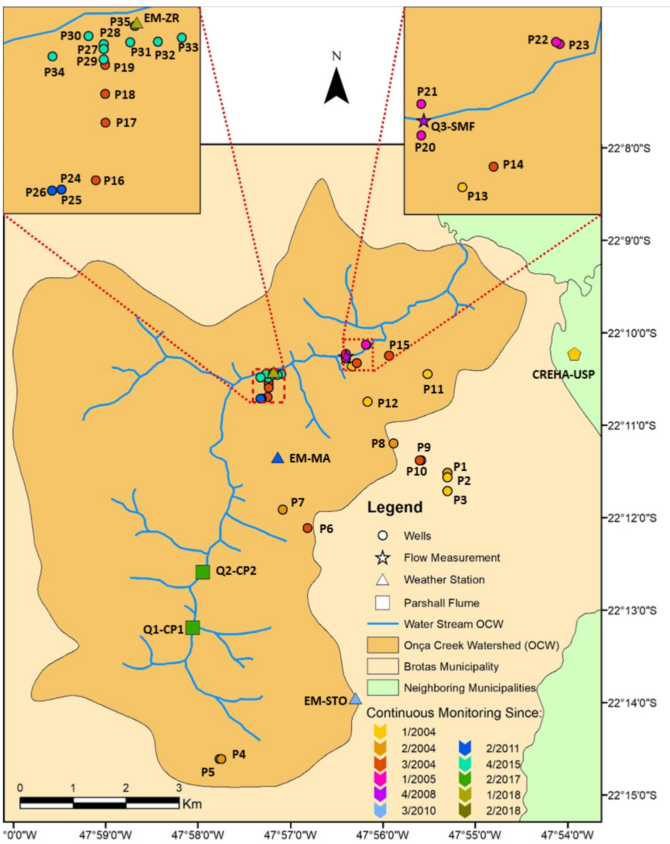

Figure 5. Onça Creek Watershed instrumentation map. The letter P indicates the monitoring wells, the letter Q indicates the streamflow gauges and EM indicates the automatic meteorological stations. The colors indicates when each monitoring device was implemented.

Figure 6. Images of the OCW instrumentation and the monitoring team working: (a) Well 19 (P19 at Figure 2); (b) Well 26 (P26 at Figure 2) with manual level verification in progress; (c) Well 9 (P9 at Figure 2) with manual level verification in progress; (d) Riparian Zone Automatic Meteorological Station (EM-ZR at Figure 2); (e) Monte Alegre Automatic Meteorological Station (EM-MA at Figure 2); (f) Santo Ignacio Automatic Meteorological Station (EM-STO at Figure 2) with data collection in progress; (g) Parshall Flume 1 (Q1-CP1 at Figure 2); (h) Parshall Flume 2 (Q2-CP2 at Figure 2); (i) Santa Maria da Fábrica stream gauge (Q3-SMF at Figure 2), with a hydrometric current-meter in use.

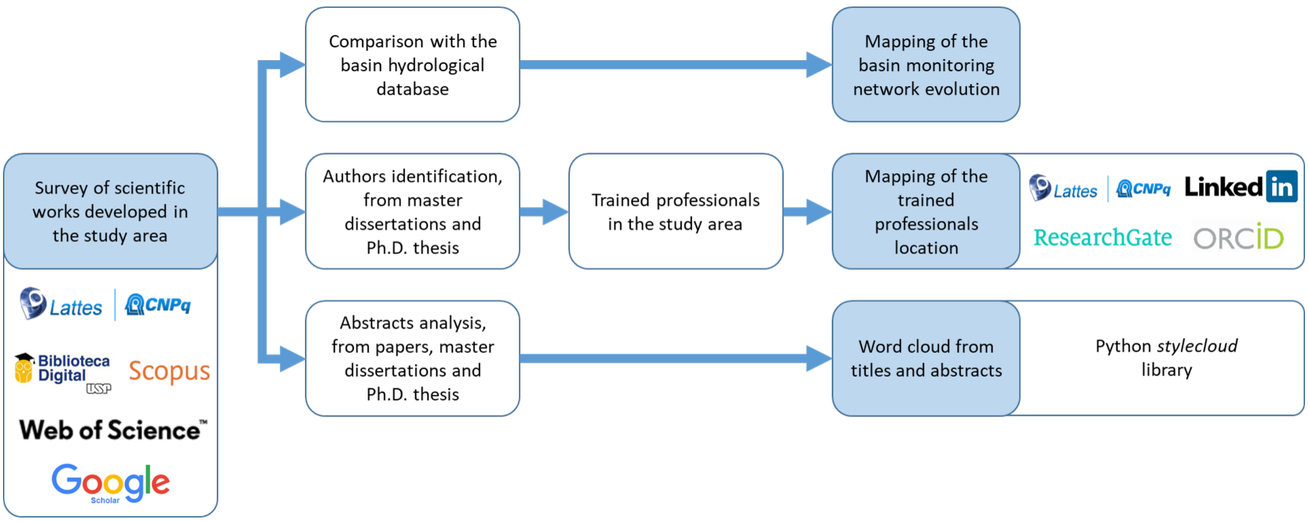

Figure 7. Methodology scheme of this study. From the survey of scientific studies developed at the OCW, we derive the main results linked to this study (blue squares at this figure). The data sources used are indicated with their logos.

From the collected data, it was possible to tabulate a study list divided in four basic categories: dissertations, theses, papers published in journals and studies presented at conferences, which include complete papers, extended abstracts and abstracts published in proceedings. These data made it possible to verify the temporal distribution of the studies, especially after the beginning of the continuous monitoring in the watershed, in addition to supporting other stages proposed in this paper.

Mapping of the watershed monitoring network evolution

The scientific studies found in the previous stage, together with the LHC/EESC internal database, allowed the evolution mapping of the watershed monitoring network. Thus, this step aimed to show the installation progress of monitoring wells, streamflow gauges and meteorological stations at the study area and the respective data availability in each of the monitored locations. Also, we highlighted the financial support provided by different funding agencies, which made this evolution possible.

Mapping of the trained professionals location

From the list of scientific studies identified, the authors of theses and dissertations developed at OCW were called professionals trained in the watershed. This classification consider that these people obtained their degrees through studies developed at the OCW and also because they have direct participation at the OCW continous monitoring during their formation time. So, they gain practical experience with field activities. As examples, we can cite the data acquisition and the assembly and maintenance of the instrumentation. The skills developed can not be measured numeracally and could be a reason for a carrer continuity at the water resources sector. These professionals were mapped, in geographic and professional aspects, by consulting open curriculum platforms, such as Curriculum Lattes, Research Gate, Orcid and LinkedIn. This survey resulted in: the position currently held by the professional; which type of institution (public or private) he/she is linked to; whether the professional has pursued an academic or non-academic career; if he/she has a career linked to water resources or to another area of knowledge; and what is the current geographic location of the professional. Then, we observed if there is a direct relationship between the academic training of the professional, carried out at OCW, with its respective current career, and its present geographical distribution, whether it is in Brazilian territory or abroad.

Word cloud from titles and abstracts

Finally, a cloud of recurring words in the studies carried out at OCW was created. For this, the abstracts and titles of scientific papers, dissertations and theses identified in the survey realized in the initial stage of this paper were analyzed. It must be pointed out that only the studies available for access on online platforms were analyzed, which coincide with the period of OCW continuous monitoring (from 2004 onwards). We used the abstracts in English, because these are requirements for academic publications, regardless of the predominant language of the scientific study.

For this cloud creation, it was used the "stylecloud" library from Python language. As input data, the algorithm demands the texts to be analyzed in a "string" format. The words appear in proportional size to the number of repetitions (frequency) in which they were found in the analyzed texts. Words with high frequency, which are not relevant, such as "the", "and", "or" were excluded from the cloud creation. This made it possible to highlight the most addressed themes in the studies developed at OCW.

RESULTS AND DISCUSSIONS

Survey of scientific studies developed in Onça Creek Watershed, Brazil

The scientific production, identified in our survey, was grouped into four categories: scientific papers, Ph.D. theses, Master dissertations, and conferences proceedings (Figure 8). We highlighted the production after 2004, when the systematic monitoring started. Studies in progress or scheduled for late 2022 were also included in the survey.

We identified 90 scientific studies developed at OCW, in which 23 were papers published in national or international journals, 22 master dissertations, 4 Ph.D. theses, and 41 conference proceedings. These researches contributed to the training of 26 high-qualified water resources professionals, in addition to the contribution of 33 external collaborators from other Brazilians or foreign institutions.

Annually, at least four scientific studies are produced at OCW (average of 4.5), likewise considering each category individually, there is at least one national or international paper per year (average of 1.15), one master dissertation (average of 1.1) and two conference proceedings (average of 2.29). The scientific production is satisfactory, considering the challenges related to the implementation of a systematic hydrological monitoring network and the subsequent collected data consolidation. It is evident that the maintenance of such values depends not only on the monitoring continuity but also with its expansion and new research development.

Considering the fieldwork-dependence of water resources studies, it is common the occurrence of peaks in publication numbers per year, due to the planning and implementation of an experiment, data collection and analysis, besides the publishing editorial procedure. The entire process can be time consuming, however in the long-term usually produces good outcomes. Moreover, the continuity of the master candidates in the research group, as Ph.D. candidates, can allow them to work better on their data, producing more and better results, which can increase the number of publications in the subsequent years, as can be seen in Figure 4 between 2011 and 2015. Conversely, when the candidate starts a new activity, usually non-academic, the publishing process may be affected or even compromised. In addition, the admission of new candidates also increases the human resources available for monitoring, data analysis, and publishing. In the period 2020-2022, the COVID pandemic showed its effect in the studies published

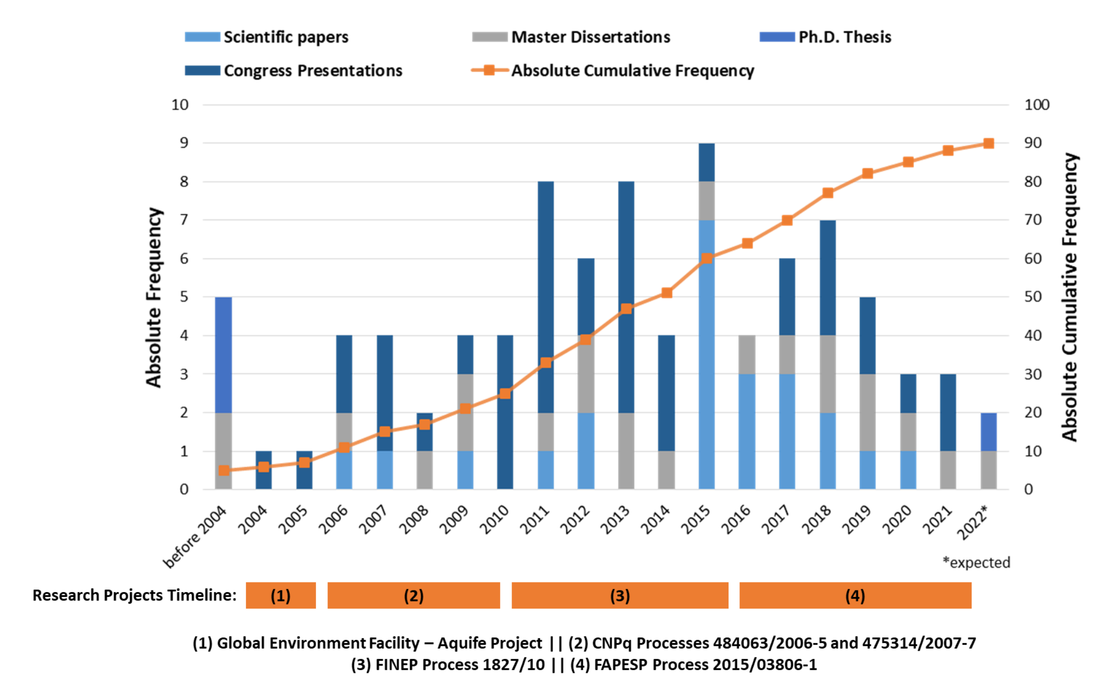

Figure 8. Results of the scientific studies survey, that have OCW as study area. The bars are divided by categories, considering the type of study published. The orange line indicate the absolute cumulative frequency, over the years. The research projects timeline is also shown, indicating the funding agencies support over the period of continuous monitoring.

at the OCW, as we can observe by the reduction of publications. Even though the monitoring team kept the field activities with all possible care regarding the pandemic time.

Mapping of the OCW monitoring network evolution

We can note the monitoring network evolution due to the instrumentation expansion and the hydrologic/hydrogeologic time series for each monitoring site investigated at OCW until the present day (Figure 9 combined with Figure 2). Previously to 2004, some monitoring sites were already installed in the area, such as 12 monitoring wells (P1 to P12) built in context of the initial researches developed at the area (Contin Neto, 1987; Pompeo, 1990; Queiroz, 1991; Milani, 1992), and that are still used in the current monitoring network.

Considering only the groundwater monitoring network, more significant interventions were made in 2004, 2005, 2011, 2015 and 2016, due to implementation of 22 new monitoring wells (P13 to P34), which contributed to coverage expansion. However, four of them were deactivated (P1, P7, P11, P20), due to obstructions caused by acts of vandalism and other unknown actions, thus having shorter data series (Figure 5). In addition, 16 monitoring wells are provided with water level datalogger, set to daily or sub-hourly resolution, according to their location at the watershed.

The Onça Creek streamflow monitoring began in late 2008 with the implementation of *Santa Maria da Fábrica* stream gauge (Q3-SMF). In this site, stream stage is measured with an automatic and manual gaging station; the first one is provided with an automatic water-level datalogger and a stilling well in the river bank, which yield stage record each 10 minutes. The second is a non-recording gauge which requires manual observations in a local staff gauge. In addition, stream discharge is measured every 15 days (or monthly in pandemic context) based on conventional current-meter method, using a hydrometric current-meter. In 2017, another two streamflow gauge stations were installed within OCW, Q2-CP2 and Q1-CP, provided with a Parshall flume and two water-level datalogger each, which allows them to measure and store the streamflow every 15 minutes.

Previous to 2010, all the meteorological data were traditionally obtained from CRHEA/USP, due to the complete time series and lack of other nearby stations. Since 2010, meteorological data from *Santo Ignacio* Meteorological Station (EM-STO) were also available, despite its interruption between 2013 to 2018, when the station was temporarily deactivated. In early 2011, *Monte Alegre* Meteorological Station (EM-MA) was installed, having currently the longest time series available within the watershed. Finally, in late 2018 the Riparian zone Meteorological Station (EM-ZR) was the last installed at OCW, in order to represent the microclimate and support specific researches of such a peculiar environment.

The monitoring network expansion in OCW was only feasible due to funding agencies and other institutions, which have been supporting research projects developed over the past 18 years of systematic monitoring. We highlight the financial resources provided by Global Environment Facility (Aquife Project), between 2004 and 2005; by the National Council for Scientific and Technological Development (CNPq - Processes 484063/2006-5 and 475314/2007-7), between 2006 and 2010; by the Brazilian Innovation Agency (FINEP, Process 1827/10), between 2010 and 2016; and FAPESP (Process nº 2015/03806-1), between 2016 and 2022.

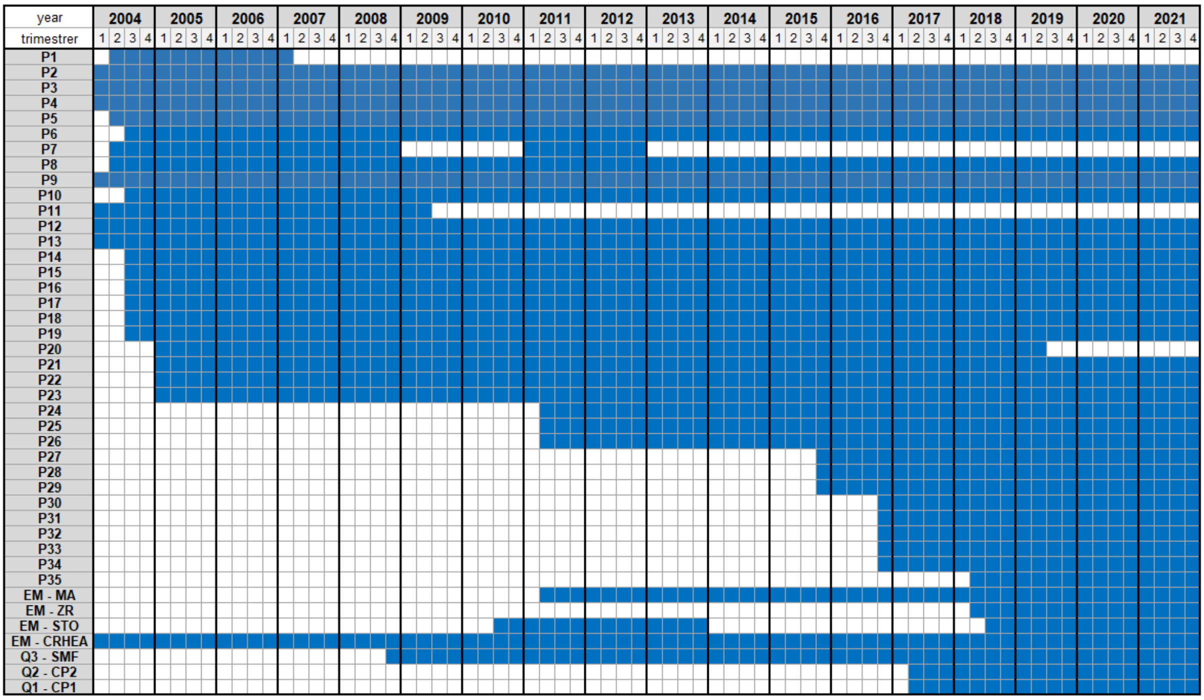

Figure 9. Time series length of OCW monitoring devices. Each year is divided in fourth trimesters. Blue cells indicates periods when the device is on and has data available. White cells indicates periods when the device is off and has no data available.

Other financial support that is also essential for research projects continuity and to the training of new water resources professionals is provided through graduate scholarships (master and Ph.D.), obtained by funding agencies like CAPES, CNPq and FAPESP. Additionally, USP and LHC/EESC institutional support are also important in this context.

Mapping of the trained professionals location

Here, we present the geographic location of all the 26 professionals trained in OCW, their respective career (academic or non-academic), current occupation (linked or not to water resource) and what kind of institution they work (public or private). The results in a Sankey diagram (Figure 10) shows that more than half of the alumni continued in academic careers (54% of the professionals), working as professors, researchers or even continuing their training at another academic institution. The remaining pursued a non-academic career (46% of the professionals), as an engineer or in other positions. We can note a balanced distribution among academic or non-academic careers, thus indicating a wide range of opportunities for water resources professionals.

Considering their current occupation, in most cases they remained in water resources (85% of the professionals), whereas 15% changed to a different expertise area, highlighting that despite the balanced career distribution, there is a tendency of continuity in water resources, both academic or non-academic careers. This fact could suggest a direct relationship between the practical training, through field activities linked to the monitoring routine, and the alumni current expertise area. Those 15% graduates, who followed a different area, currently work in the oil and gas industry, in insurance companies, in project management, and teaching in information technology.

The public sector employs a large part of the graduates trained in OCW (Figure 10). More than three-quarter (77%) hold a position in a public institution, such as universities, research institutes, state or federal autarchies, besides municipal water and sewage departments. A possible explanation for this result is the financial stability and solid career plan offered by the public sector, becoming attractive to the former researchers. The other 6 professionals (23%) are currently working in private institutions, such as consultancy or engineering companies, insurance, and own business.

We also mapped the geographical distribution of OCW trained professionals and their current occupation (Figure 11). Naturally, most of them are located in Brazil, scattered in 16 different cities, with a special concentration in São Carlos/SP and São Paulo/SP. This is explained because the first city is the training location of these professionals. The second one is the economically-richest Brazilian city, which employs a large number of highly qualified professionals. Besides São Paulo state, where we found professionals in Campinas and São José do Rio Preto, other 8 States - Mato Grosso (Tangará da Serra), Mato Grosso do Sul (Campo Grande), Santa Catarina (Florianópolis), Paraná (Foz do Iguaçu and Pato Branco), Espírito Santo (Vitória), Bahia (Salvador), Ceará (Fortaleza) and Paraíba (Areia) - were destinies of OCW formers researchers, spread in 11 cities. In Colombia, there are two native alumni working as university professors that returned to their homeland (Montería and Santa Marta) after their graduate period in USP.

The geographical distribution assessment is not a simple task, because there is a subjectivity and several determining

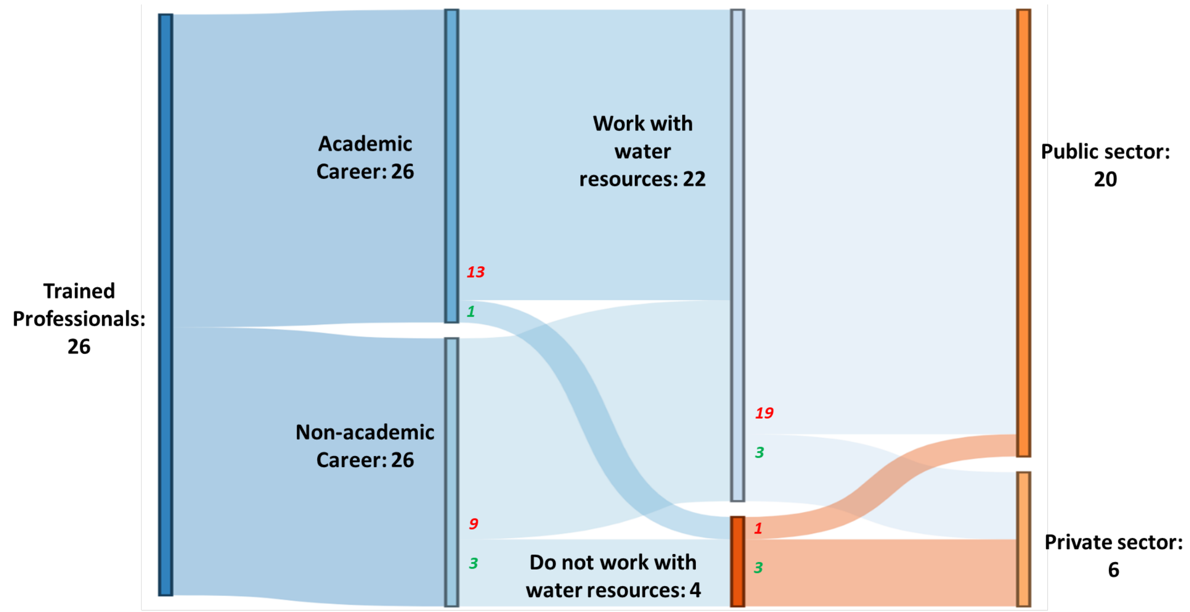

Figure 10. Careers distribution of the professionals trained at OCW, indicating the type of career (academic x non-academic, in first column), the relation between the carrer and the water resources area (in second column) and the sector which the professional is linked (public x private sector, in third column).

Figure 11. Geographical distribution of the professionals trained at the OCW. We can observe the presence in four regions of Brazil and also in another countries of South America.

factors that affect the professional choice, like family homeland and compatible financial opportunities. As one of the most prestigious universities in South America, USP reaches and attracts candidates from all over Brazil and other countries. This fact encourages people to move from their homelands to graduate in a recognized university. Eventually, those professionals return to their original places. Furthermore, some opportunities are restricted to a specific location, as some public tenders in federal or state universities, causing them to move from São Carlos and from their hometown. Both scenarios contribute to the spread throughout the national territory.

Word cloud from titles and abstracts

The most recurring terms from OCW studies titles and abstracts, published from 2004 onwards, compiled into a word cloud (Figure 12). Some of them are bigger than others, due to the frequency in which these words appear. Following, we choose some of the most frequent terms to explain their use in OCW studies.

- **Model:** Mathematical and computational models are commonly used in hydrology and water resources studies as an important tool for better understanding the water dynamics in different physical compartments within the watershed. Several studies were developed in OCW applying hydrologic models to build a rainfall-runoff model for the watershed. Examples are JAMS (Jena Adaptable Modeling System) (Ribeiro, 2012) and SWAT (Soil and Water Assessment Tool) (Meira Neto, 2013). Melo (2013) and Coutinho (2019) applied a different type of model, the SPA (Simulation of Process Aquifers) which is an interface of numerical finite elements to simulate groundwater flow. Melo (2013) also used Global Climate Models to predict

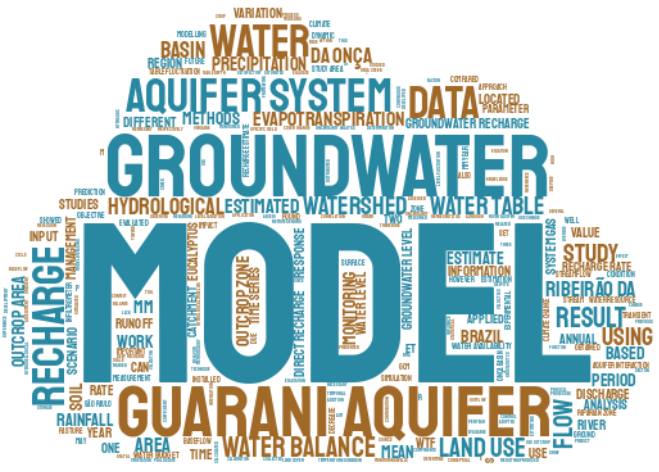

Figure 12. Word cloud generated from the studies identified at the bibliographic survey. Larger words are the most frequent in the texts analyzed.

the water-table behavior under different global climatic changes scenarios in the Guarani Aquifer System outcrop. Not only consolidated models were applied in OCW, but also conceptual models like those developed by Garcia (2016) and Calixto (2020). Furthermore, these models come to complement the systematic monitoring in the OCW, as an efficient way to use the collected data, which had the direct participation of the researchers involved.

- **Groundwater; recharge; groundwater recharge; water-table; water balance; Guarani Aquifer; Aquifer System; outcrop area; outcrop zone:** The study area is located in an outcrop zone of Guarani Aquifer System, becoming a potential recharge area for this important aquifer. Initial studies sought to understand the relation between the water cycle within the OCW and the GAS deep recharge. Barreto (2006), Gomes (2008), and Lucas (2012) applied water balance techniques in the watershed seeking to estimate the deep recharge considering it as a residual component. They also applied the Water-Table Fluctuation method to estimate the groundwater recharge in the unconfined aquifer, due to its simplicity, requiring only water-level and specific yield data.
- **Data; precipitation; evapotranspiration; flow; land use:** In general, these words are terms related to some water cycle components, that are commonly used in hydrology and water resources studies, such as those developed in the study area (Maldonado, 2009; Ponton, 2017; Rosa, 2018; Carvajalino, 2019). In addition, the OCW area is mainly occupied by private rural properties, with agricultural and livestock land use that directly influence hydrologic variables over time, and must be monitored (Lucas, 2012; Martins Filho, 2014; Mattos, 2015; Alcantara, 2018).

Main findings and future perspectives

The studies realized at the OCW, during these 18 years of continuous monitoring, contributed to a better comprehension of the recharge mechanisms of the Guarani Aquifer System, the behavior of each hydrological component, and its influence on the watershed water budget. The increase of the data available and the expansion of the monitoring network allowed:

- the estimation of deep recharge and subsurface storage variation at different times (Wendland et al., 2007; Melo et al., 2015b; Wendland et al., 2015);
- to see the influence of land use and land cover in the hydrological cycle and how the management of agricultural areas in the watershed can reduce the direct recharge expected in an outcrop area of an aquifer (Lucas & Wendland, 2016; Mattos et al., 2019);
- the application of Global Climate Models (GCM) to observe the effects on water table and on recharge estimatation, which showed a reduction on water availability under most scenarios (Melo et al., 2015a; Melo et al., 2017);
- specific modeling experiences to better understand the watershed response to different inputs and the relation between precipitation, groundwater recharge and baseflow (Machado et al., 2016; Meira Neto et al., 2018; Gómez et al., 2018);
- the application of geophysical techniques, which helped to improve the watershed conceptual model, in terms of different hydraulic conductivity regions and boundary conditions (Coutinho et al., 2020).

In future trends and perspectives, our research group expects to maintain the long-term monitoring actions at the OCW and expand the instrumentation available. Therefore, we await new scientific contributions to the hydrology and hydrogeology field, especially linked to groundwater and Guarani Aquifer System. Also, training of qualified professionals in the water resources area will be possible. Research agencies' support is essential with long-term projects and scholarships for master's and P.hD students.

Considering the research in progress at the moment in OCW, we highlight the themes that could generate scientific contributions in the short and medium term. Studies related to:

- evapotranspiration in riparian zones and its relation with groundwater and surface water levels;
- the use of temperature as a natural tracer to investigate groundwater-surface water interactions, with the unprecedented application of distributed temperature sensors (DTS) in tropical areas;
- the development, calibration, validation, and field application of low-cost sensors to monitor different hydrological components;
- the consolidation of 18 years of hydrological data and its publication in a public repository, allowing external collaborations and analysis.

All these themes are in the spotlight of hydrology and hydrogeology science (Blösch et al., 2019; Chaffe et al., 2022) and the structure available in OCW can for sure contribute with answers for these open questions.

CONCLUSIONS

This study aimed to highligth the importance of experimental and representative watersheds for training qualified professionals in water resources, based on the case study of the Onça Creek Watershed (SP, Brazil). This watershed is located in the outcrop area of the Guarani Aquifer System, being a study site of this groundwater reserve. Despite the first surveys in the 1980s, continuous monitoring in this watershed has been carried out since 2004, completing 18 years in 2022. Since then, we found 90 scientific studies already developed at OCW, which contributed to training 22 master and 4 Ph.D. students. Most of these professionals continued to perform functions related to water resources in public and private institutions, spread in various locations in Brazil and abroad. Such results indicate how practical experience in experimental and representative watersheds can favor continuity in this knowledge area.

This monitoring work, linked to a university and a graduate program in the water resources field, can be a way to stimulate the increase of hydrological monitoring throughout Brazil. The financial aid of research agencies is essential for these activities, considering project funding and graduate scholarships. This support can also assure the expansion and maintenance of hydrological and hydrogeological monitoring equipment.

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