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GEOTECHNICAL AND GEOENVIRONMENTAL DATABASE FOR MODELING SEDIMENT GENERATION AND DEPOSITION IN RESERVOIRS OF HYDROELECTRIC POWER PLANTS

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ABSTRACT: The implementation of a database, logically and coherently related, provides a better organization, analysis, correlation, availability, accessibility, and security to georeferenced data. In this sense, a proposal is presented a geotechnical and geoenvironmental database to support research related to modeling sediment generation in erosion and deposition in hydroelectric power plant (HPP) reservoirs, at various scales. Supported by a literature review, the work presents an expository, descriptive, and applied approach. The results demonstrate the structuring of the database, from the requirements definition, the conceptual modeling and physical implementation, the development of metadata and data dictionary, and maintenance tools and other functionalities. The proposal demonstrates benefits, especially by: 1) making it possible to handle a large amount of data; 2) minimizing data loss and redundancy; 3) ensuring data availability and remote access.
Keywords: Erosive processes. Erosion. GeoDatabase. Environmental Modeling.

BANCO DE DADOS GEOTÉCNICO E GEOAMBIENTAL PARA MODELAGEM DE GERAÇÃO E APORTE DE SEDIMENTOS EM RESERVATÓRIOS DE USINAS HIDRELÉTRICAS

RESUMO: A implementação de um banco de dados, logicamente e coerentemente relacionado, provê uma melhor organização, análise, correlação, disponibilização, acessibilidade e segurança aos dados georreferenciados. Nesse sentido, é apresentada uma proposta de modelo de banco de dados geotécnico e geoambiental para subsidiar pesquisas relacionadas a modelagem de geração de sedimentos em erosões e aporte em reservatórios de usinas hidrelétricas (UHE), em escalas diversas. Com base na revisão de literatura, o trabalho apresenta abordagem expositiva, descritiva e aplicada. Os resultados demonstram a estruturação do banco de dados, a partir da definição de requisitos, da modelagem conceitual e implementação física, do desenvolvimento de metadados e dicionário de dados e de ferramentas de manutenção e outras funcionalidades. A proposta demonstra benefícios, especialmente por: 1) possibilitar manusear uma grande quantidade de dados; 2) minimizar a perda e redundância de dados; 3) assegurar a disponibilização e acesso remoto aos dados.
Palavras-chave: Processos Erosivos. Erosão. Banco de dados Geográficos. Modelagem Ambiental.

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BASE DE DATOS GEOTÉCNICA Y GEOAMBIENTAL PARA LA MODELIZACIÓN DE LA GENERACIÓN Y APORTACIÓN DE SEDIMENTOS EN EMBALSES DE CENTRALES HIDROELÉCTRICAS

RESUMEN: La implementación de una base de datos, lógica y coherentemente relacionada, proporciona una mejor organización, análisis, correlación, disponibilidad, acceso y actualización de los datos georreferenciados. En este sentido, se presenta una propuesta para la estructuración de una base de datos geotécnicos y geoambientales para apoyar investigaciones relacionadas con la modelación de la generación de sedimentos en erosiones y aporte en embalses de centrales hidroeléctricas (UHE), en diferentes escalas. Apoyado en una encuesta y revisión bibliográfica, el trabajo presenta un enfoque expositivo, descriptivo y aplicado. Los resultados demuestran la estructuración de la base de datos, desde el relevamiento de requerimientos, modelado conceptual, implementación física, desarrollo de metadatos y diccionario de datos y herramientas de mantenimiento y otras funcionalidades. La propuesta demuestra beneficios, especialmente porque: 1) permite manejar una gran cantidad de datos; 2) minimizar la pérdida de datos y la redundancia; 3) garantizar la disponibilidad y el acceso remoto a los datos.
Palabras clave: Procesos erosivos. Erosión. Base de datos geográfica. Modelado Ambiental.

INTRODUCTION

Until 2012, the Midwest Region was the second most affected by erosive processes in the country, behind only the North Region (UFSC, 2013). From 2013 to the present day, it is the region that holds 50% of the records of damages and losses related to erosive processes, as pointed out by the Civil Defense (MDR, 2021).

Soil erosion processes cause significant negative impacts to the environment, affecting the environmental quality, compromising the socioeconomic aspect, and restricting the land use capacity (CARVALHO et al., 2018). In this perspective, it is worth highlighting the issues related to water availability and power generation, which can be negatively impacted due to the contribution of sediments to hydroelectric power plant (HPP) reservoirs, which can affect the useful volume of stored water (DE ANDADE et al., 2020) and, consequently, the lifetime of the project itself (CARVALHO et al., 2000).

Given this context, several studies have been developed in order to map and monitor these erosive processes (MORAES, 2016; TAVARES JUNIOR et al., 2018; DEWES, 2019; VILHENA et al., 2019; NASCIMENTO, ROMÃO, SALES, 2020; ROMÃO et al., 2022; SOUZA DIAS et al., 2022) or modeling sediment production and input in the context of watersheds (NGUYEN et al., 2019; SCHLESNER, 2019; DEMARCHI, 2020; BARBOSA, 2021; NUNES et al., 2022) or for specific cases of hydroelectric power plant reservoirs.

Since erosive processes are complex phenomena, multidisciplinary approaches are often used with the support of Geographic Information Systems (GIS) to model the susceptibility and vulnerability of soil to the outbreak and development of erosive processes, seeking to define guidelines and solutions to mitigate or reduce the negative impacts on reservoirs and water bodies. However, it is quite common for the geoinformation used in such models to be restricted to the authors who produced them or to be lost over time, among other issues involving the management, processing, and use of a large volume of data. For this reason, the use of databases is recommended.

The implementation of a structured database ensures the interoperability and quality of data, besides allowing immediate access and the consequent availability of information, as well as the reduction of registration errors due to the data integrity restrictions. This is precisely the justification for this work, which aims to contribute by presenting a methodological proposal for structuring databases that contemplate this theme (sediments) and the specificity of the spatial context (reservoirs of hydroelectric power plants).

In this context, this work brings a proposal for structuring a preliminary Geotechnical and Geoenvironmental Database (GGD) to support research related to modeling sediment generation in erosion and input in hydroelectric power plant (HPP) reservoirs, at various scales.

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Thus, this work has an expository, descriptive, and applied character. After a brief literature review, supported by the literature, the text turns to the demonstration of a database structuring for application in modeling sediment generation and contribution to HPP reservoirs. The conception and implementation of databases aimed at modeling sediment flux has been discussed (BENAUD et al., 2020; BORRELLI et al., 2021), but with little focus on the internal structure of the database, thus making it difficult to replicate its structure. In this sense, we present this work aiming to stimulate the discussion of a storage standard directly related to the theme in question.

At the end of this introduction, it is worth mentioning that this work is linked to a research and technological development project for modeling, at various scales, the generation of sediments in erosion and the contribution to reservoirs of hydroelectric power plants (UHEs), regulated by the National Electric Energy Agency (ANEEL) and financed by Eletrobras FURNAS, which aims to monitor, evaluate, and mitigate the impacts of erosive processes on reservoir edges.

BRIEF LITERATURE REVIEW ABOUT DATABASES

Databases are treated within the areas of computer science and information systems, which, in turn, concern computer technology applied to the organization and display of data and information related to the real world. A database (DB) can be understood as a logical and coherent collection of properly related data, being designed, implemented, and populated with data for a defined group of users, to meet a specific purpose (ELMASRI; NAVATHE, 2005).

The first database mentioned in the specialized bibliography was created as part of the Apollo Project for space exploration of the moon and was developed by the National Aeronautics and Space Administration (NASA), which in 1964 developed a hierarchical file system called the Generalized Update Access Method (OPPEL, 2004).

Over the years, research on databases has been concerned with the support and unconventional applications to computer science and information systems (SCHNEIDER, 1997). It is in this context that geographic databases (GDB) appear, which present spatial attributes, that is, characters that describe objects and phenomena with a specific geographic location.

Lisboa Filho (2001) points out that geographic databases (GDB) differ from conventional databases with respect to the types of data managed. These are no longer only descriptive and take spatial or geometric forms, which may be related to a specific portion of the geographic space. In this sense, a geographic database must meet the following characteristics:

- Spatial Characteristic: refers to the orientation and location in space, the geometry of representation, in point, line, or polygon;
- Non-spatial characteristic: refers to the alphanumeric, pictorial or sound description of the object or phenomenon represented;
- Temporal characteristic: refers to the chronological time of generation and, consequently, the possible "shelf life" of the data. For example, geological, pedological and geomorphological data tend to have a longer shelf life, having its limit of use extended until other more recent and more detailed data are collected. This is quite different when it comes to data such as soil loss, flow and meteorological data, whose use beyond the time of occurrence is restricted to registration, comparison and monitoring purposes;
- Documentary characteristic: this refers to the metadata, which comprise a set of information that is useful for satisfactory knowledge and, therefore, the correct use of the data.

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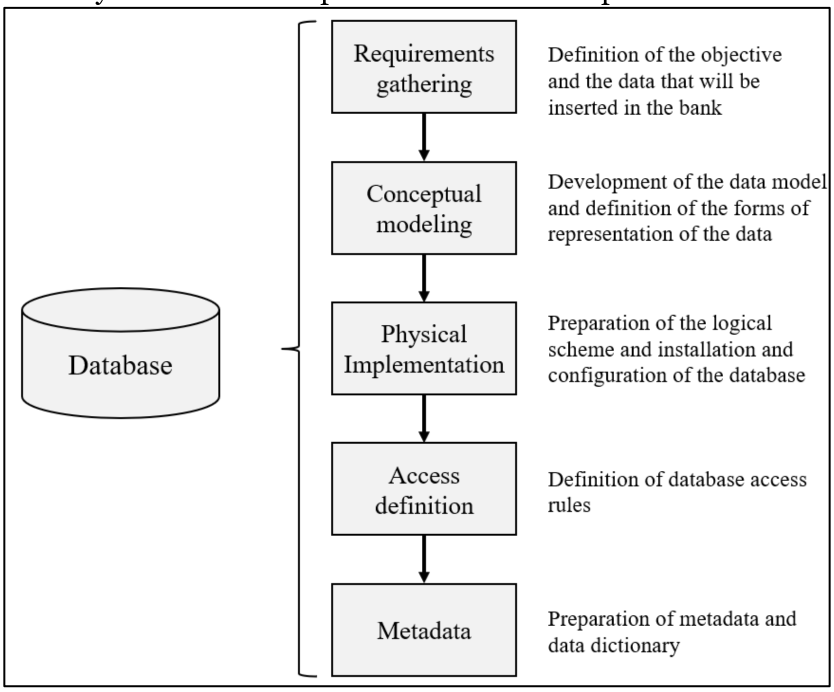
The development of information and communication systems and the advent of the so-called geotechnologies (Remote Sensing, Geoprocessing, Global Positioning Satellite System, etc.), especially after the 1970s, were responsible for the broad development and dissemination of Geographic Information Systems (GIS), focused mainly on the acquisition, storage, organization, access, treatment and representation of georeferenced data and information - a context in which geographic databases play the role of storage and support for access to georeferenced information.

Some initiatives can be pointed out as examples of the various possibilities of conception and implementation of geographic databases, such as for making available various data at the municipal (VIEIRA; TAGLIANI, 2001) or state (BOLFE et al., 2009) scale, or for specific applications, for example, in the management of water resources (LAGO, 2006) or transport infrastructure (GUERRA, 2007), geotechnical data (OLIVEIRA et al., 2021) and in the analysis of environmental vulnerability and sensitivity (CASTRO, 2002; SANTOS, 2005).

METHODOLOGICAL PROPOSAL FOR STRUCTURING THE DATABASE

In the following topics, the steps of the methodological proposal for structuring the database applied to modeling sediment generation at the edge of HPP reservoirs will be presented. The methodology is subdivided into five steps, illustrated in Figure 1.

Figure 1 - Summary of the activities performed in each step of the database structuring.



Source: authors

Requirements Gathering

Considering that the purpose of the database is to support the modeling of sediment generation at the edge of HPP reservoirs, the choice of entities relevant to the theme that should be represented in the conceptual model was made.

The generation of sediments from erosive processes can be analyzed in many ways, so we chose to subdivide the theme into seven axes, each responsible for an approach, theme, and scale. Figure 2 demonstrates the thematic axes defined for the survey of requirements and the implementation of the database.

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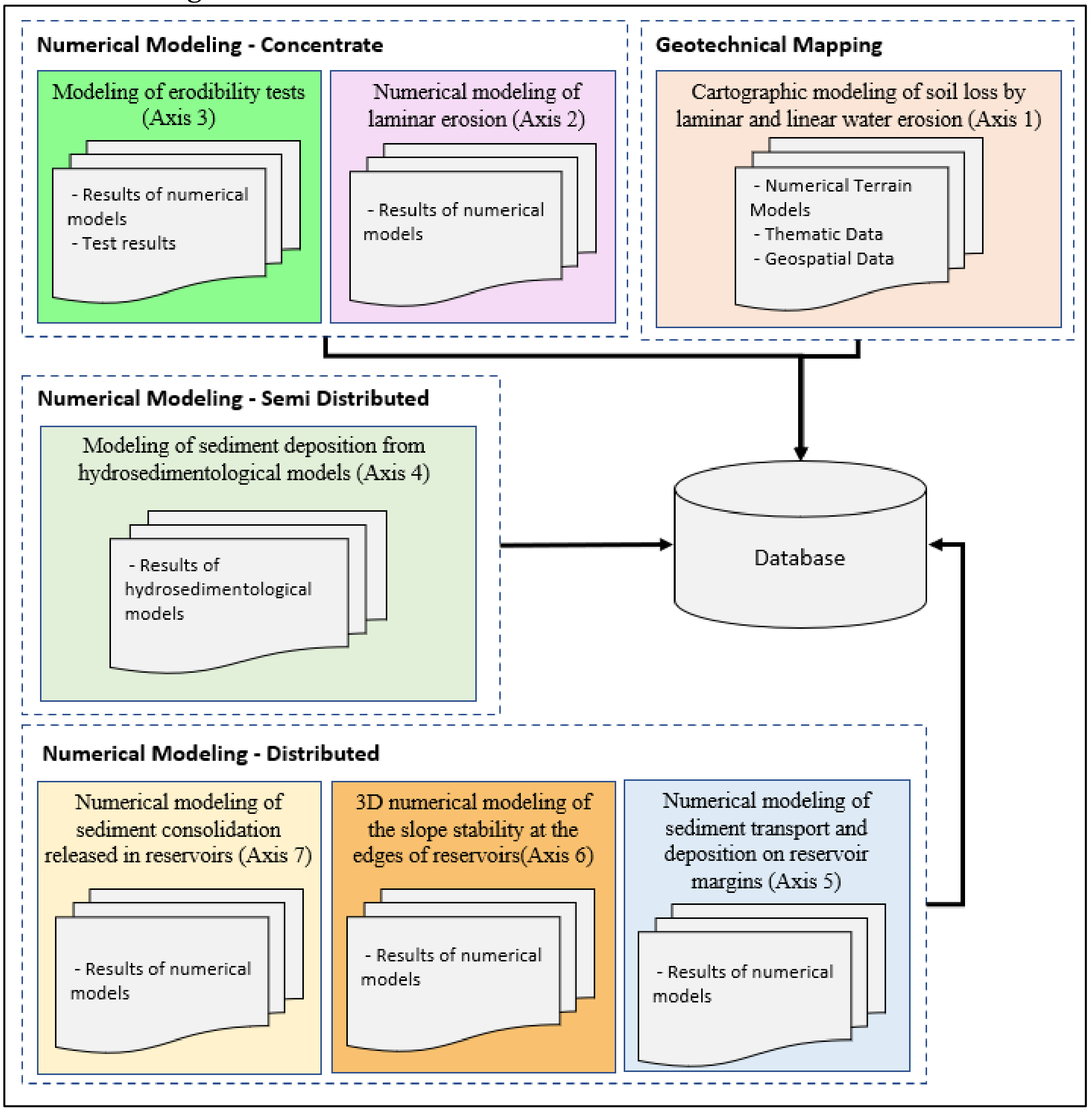
Figure 2 - Thematic axes that define the database structure.



Source: authors.

Thematic axis 1 is responsible for the cartographic modeling of soil loss by water erosion using geospatial data in Geographic Information Systems (GIS) environment. The axis is also in charge for storing vector and matrix files of environmental information relevant to the purpose of the database. The axis aims to contribute with advances to the understanding of accelerated hydric erosive processes, of their conditioning factors for sediment generation, as well as the resulting impacts on the efficiency and useful life of reservoirs through the mapping of erosive susceptibility and geotechnical zoning.

The numerical modeling of erosion (thematic axis 2) uses a concentrated model to simulate a laminar erosion process under various conditions of flow and bed material, and stores results of the numerical simulations. The information produced by the axis allows a better understanding of the modeled process and, consequently, the adoption of field solutions based on the knowledge of the phenomenon. In this case study, the axis addresses only laminar erosion, but does not prevent its expansion to address other types of erosive processes.

Thematic axis 3, modeling of erodibility tests, uses models focused on diverse types of erodibility tests to understand the final behavior of the process, and is responsible for the execution of laboratory erodibility tests, to obtain parameters for estimating sediment generation in reservoir margins.

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The modeling of sediment deposition via hydro sedimentological models (Thematic Axis 4) addresses a semi-distributed model that uses georeferenced data, but returns tabular information, aiming to estimate the flow and sediment production in different scenarios, allowing the analysis of land use and coverage among other characteristics that influence this process. This axis is responsible for storing climate information such as temperature, evapotranspiration, pluviometry, among others.

Thematic axis 5 deals with the modeling of bank erosion and siltation of reservoirs considering the effect of waves. This axis is responsible for storing bathymetry information, field monitoring results related to the modeling, and the results of numerical simulations related to the axis.

Thematic axis 6 performs three-dimensional stability modeling simulating the distinct phases of reservoir operation, with their seasonal filling and level oscillations and considering usual and adverse weather conditions. This axis is responsible for storing the high-resolution numerical terrain models and simulation results related to slope stability in the modeled areas.

Thematic axis 7 is responsible for storing the results of the numerical simulations related to the numerical modeling of the consolidation of sediments released into the reservoirs and their impacts on the reservoir's usable volume.

Conceptual modeling

A database has its physical structure and the information that compose it based on data models, even if these are not properly documented and represented graphically. However, to ensure the reproducibility of the implementation and the interoperability of the data that compose it, it is essential that the data models are available for reference.

A data model is a set of concepts that can be used to describe data, their relationships, and restrictions (KORTH; SILBERSCHATZ, 2020). Older data models, when used for geographic applications, were restricted to the internal structures of Geographic Information Systems (GIS), a context in which the user was obliged to adapt the spatial phenomena that will be modeled to the structures available in the GIS (Borges et al., 2005), generating models that were more distant from the user's mental model.

The data model must be chosen based on usual requirements such as ease of use, understanding and clarity (BORGES et al., 2001), besides the possibility of mapping the schemas produced for implementation in a Spatial Database Management System (DBMS). The model must meet both the modeling needs and the abstraction of geographic concepts and identification of spatial integrity constraints (BORGES et al., 2001, 2005).

After the creation of the National Spatial Data Infrastructure (NSDI), the National Commission of Cartography (CONCAR) proposed a data model based on the model Object Modeling Technique for Geographic Applications (OMT-G), but unfortunately it does not include the theme of this research project. However, to ensure future geoinformation interoperability, the OMT-G model will be used in the development of the conceptual model. More information about the OMT-G model can be obtained in Borges et al. (2001; 2005), Borges, Davis Jr. and Laender (2005).

Figure 3 shows the class diagram containing the minimum necessary entities that should compose the proposed database to subsidize the modeling of sediment generation in erosive processes. The conceptual model shows the diverse types of geospatial information chosen with their respective geometric primitives and spatial relationships to support the purpose of the database, contemplating all seven thematic axes.

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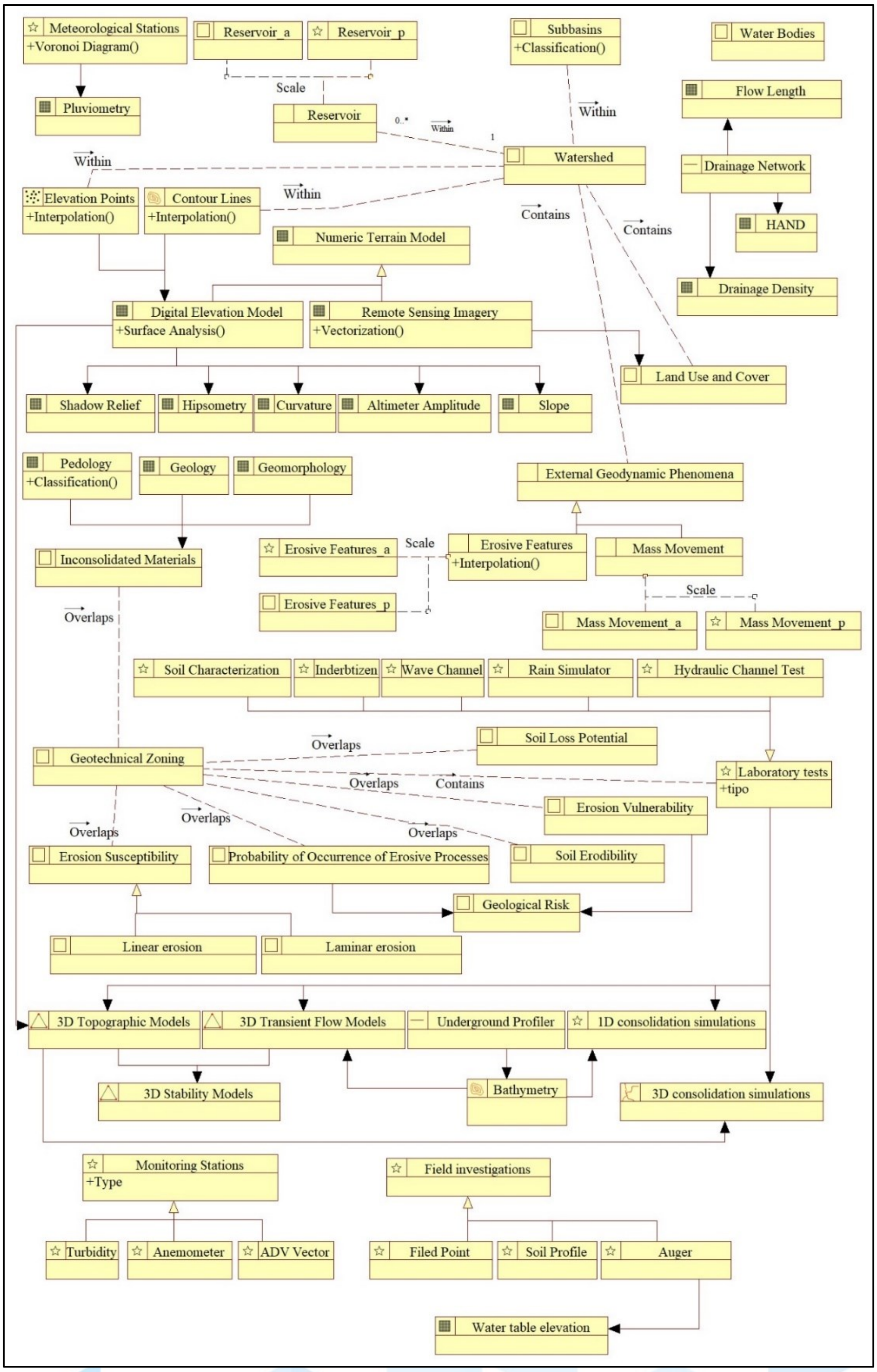
Figure 3 - Diagram containing the classes that compose the database.



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Given the existence and updating of preexisting information, and the possibility of latest information arising from the several types of modeling in different formats and from the

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different approaches to the thematic axes, it was decided to elaborate a class diagram of the OMT-G model that can be expanded as the database is implemented, if necessary.

Physical implementation

This step covers the definition of the standard in which the data is organized and stored in the database, through the elaboration of the logical schema and, at installation, the configuration of the Database Management System (DBMS).

The database management system chosen was PostgreSQL Version 11.17 (PostgreSQL Global Development Group, 2021) which is a powerful open-source object-relational database with over 30 years of active development, earning it a strong reputation for reliability, feature robustness, and performance. PostGIS Version 3.0.1 (POSTGIS, 2021), a spatial extension to the PostgreSQL object-relational database, supports geographic objects and allows spatial queries. The physical implementation was done via pgAdmin version 5.4, an open-source tool for the administration and management of the PostgreSQL database.

In the logical scheme were defined the standards of naming fields and tables and performed the normalization of the tables to eliminate, or at least minimize, the redundancy in the database and definition in the types of attributes (text, numeric, date, geometry, and others) and spatial reference system (datum), where appropriate.

The schema will not be discussed, because different solutions can be adopted depending on the DBMS used in the implementation of the database, however, it should be noted that the entire structure should be documented and made available through data dictionary and metadata.

Access Definition

For better quality control and information security, users with distinct levels of permissions were created. For each thematic axis a user was created that belongs to the group of users with permission to alter the structure of the database related to its thematic, destined only for schema maintenance.

Two general users are available, an edit user associated with the edit group and a query user associated with the query group. The edit group is allowed to edit any record intended for the person responsible for quality control of the database while the query group is allowed to select any data in the database. Each thematic axis also has an editing group user for each thematic with permission to edit any record related to its thematic, allowing better control of edits in the database.

The levels of permission were necessary because the database is used by a multidisciplinary team, composed of faculty researchers, graduate students, and undergraduate students linked to scientific initiation, and the highest level of access and permissions was intended for faculty members with greater expertise and experience.

Figure 4 shows an example of users and groups with their respective permissions. In the illustration, theme axis 1 data can be selected by all users except users in the schema group not related to theme axis 1. The general edit user and the theme axis 1 edit user are allowed to select, update, delete, and insert records in the layer.

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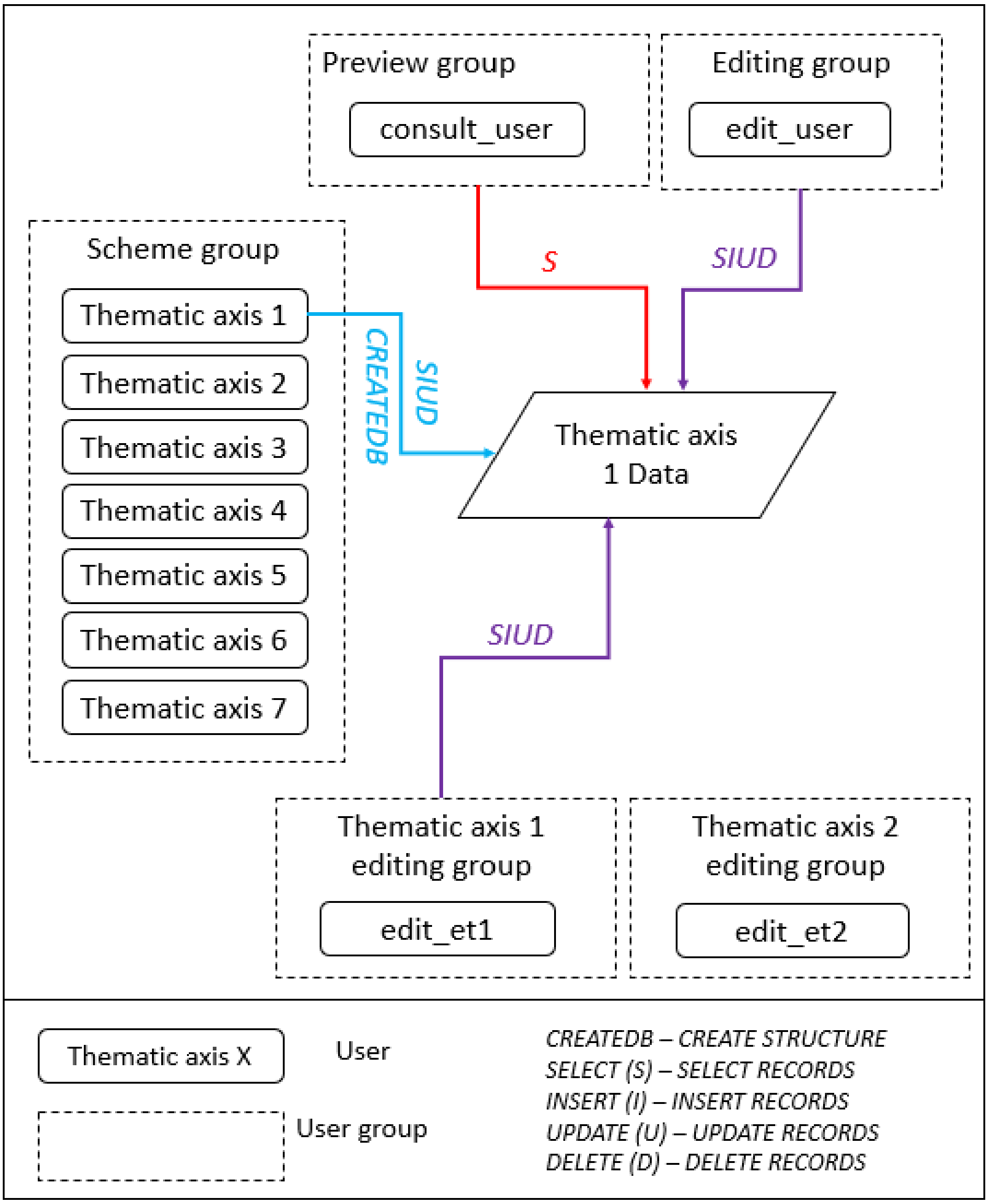
Figure 4 – Example of user structure defined for the database.



Source: authors

To create the structure a PostgreSQL extension, "pd_sediments", was elaborated. This extension is responsible for creating the default structure of schemas, groups, users, and permissions, being necessary only to adapt the permissions for new users or new data. To create the user structure on another machine it is necessary to copy the files "pd_sedimentos--0.1.sql" and "pd_sedimentos.control" to the folder C:\Program Files\PostgreSQL\11\share\extension. Before running the extension, it is necessary to create a database that will receive the structure.

The data can be accessed using the database manager pgAdmin or using QGIS by adding a connection providing the connection name of choice, host, port, the database name, and user and password, as exemplified by Figure 5. In this way, the database can be accessed

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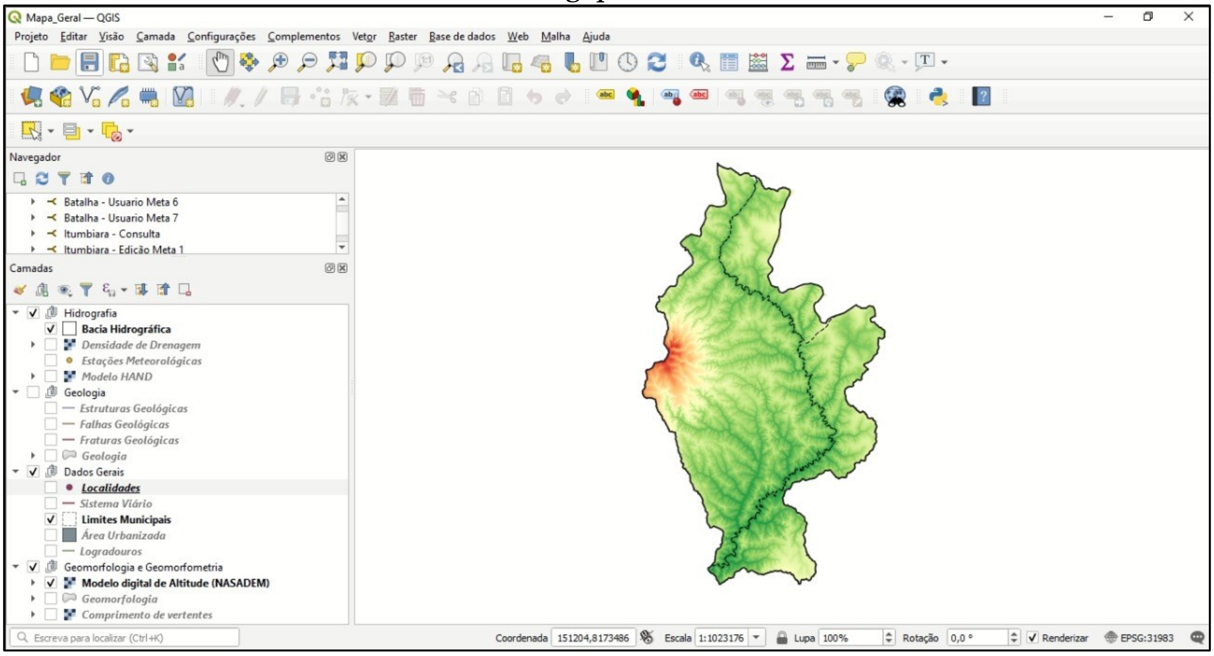
remotely, contributing significantly to data exchange and joint analysis, especially in the context of the social isolation imposed by the first years of the new coronavirus pandemic.

Figure 5 - Example of the query connection showing the water mirror information from different dates being queried in the database.



Source: authors

Metadata and Data Dictionary

For all the information inserted in the database, compiled, or produced, it was adopted the Profile 2.0 - Profile of Geospatial Metadata of Brazil prepared as reference by the Brazilian Institute of Geography and Statistics (IBGE, 2021). It is recommended as minimum information: title, summary, purpose, date of the data, type of special representation, special resolution or scale, thematic category, lineage and responsible for the data. The data dictionaries (Table 1) should minimally contain the column names, data type, description and, where applicable, length, precision, scale, domains, spatial or semantic constraints.

Table 1 - Example data dictionary of a hypothetical table from an administrative boundary.

Name	Type	Length	Accuracy	Scale	Description	Restrictions
la_pk	Integer	-	-	-	Primary key	Primary key
la_name	Varchar	50	-	-	Name of the Federation Unit	Nullity
la_area	Numeric	-	6	2	Area (km²)	Nullity
la_per	Numeric	-	6	2	Perimeter (km)	Nullity
geometry	Geometry (Polygon , SRID 31983)	-	-	-	Geometry	User defined

Source: authors.

Maintenance and functionalities

When creating the "pd_sediments" extension, besides the users and schemas, some functions were also developed to optimize the development of the work. There is a table in the public schema "tb_dicionary_data" that has a structure to store the meaning of the columns of all the tables in the database. When executing the function "public.retrieve_data_dictionary (schema_name text, table_name text)" the data dictionary is retrieved being composed of this table, if it is filled, and of the information in the database system. This function only returns some information if the information producers fill it.

The function "public.enable_tracking (schema_name text, table_name text)" creates the columns "data_edit" and "user_edit" and enables the trigger on the layer and every time something is changed, the user and date are logged. The "public.disable_tracking (schema_name text, table_name text)" disables the trigger on the layer that logs the user and date and does not remove the "data_edit" and "user_edit" columns.

The function "public.create_permissions()" assigns standard permissions to query and edit groups for all tables. This function is extremely important because when inserting new tables via QGIS, PostGIS Shapefile Import/Export Manager it is necessary to execute this function to adjust the permissions since PostgreSQL only assigns the default permissions for tables created via PL/pgSQL.

The backup and maintenance routine are automated by python code version 3.7 in the QGIS python environment that runs as Windows tasks every day at specific times.

CONCLUSION

The modeling of sediment generation and input can be conducted in different scales and methods, as it reflects a complex, multivariate and dynamic process. In the case of sediment flux to hydroelectric power plant reservoirs, other aspects come into play to be considered in the modeling, such as wave action, slope stability, and sediment thickening in the water body.

Therefore, it is important to define alternative representations and relationships of real-world aspects to simulate the generation, input, and behavior of sediments in HPP reservoirs. For example, some external geodynamic phenomena are best represented by points at small scales, but at larger scales the use of polygons is recommended. Furthermore, there is the combination of attributes that tend to trigger erosive processes and intensify the generation and contribution of sediments, and that must be evaluated in view of their magnitudes, relationships, and scales.

Thus, the database has shown great benefits to the conduct of the research project and technological development to which the work is associated, because it allowed the handling of a large amount of updated data in a single platform, thus ensuring the integrity of the information.

Although the database was implemented in a local network, it was possible to configure it so that the data can be accessed remotely through geoservices, expanding interoperability among producers and consumers of geoinformation and supporting multiple views and a wide diversity of analyses and correlations. In addition, by ensuring that the data will be readily available to all project members, there was a significant reduction in redundancy, loss and/or corruption of data.

With the intention of technology transfer before the research and technological development project regulated by the National Agency of Electric Energy - ANEEL and financed by Eletrobras FURNAS, there is the perspective that the database will be passed on and can be maintained by the state company's professionals, through training and supervision.

Finally, it is worth noting that for the proposal to be easily adapted to other objectives and themes, the conceptual model was developed independently of the specifications of the

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programs and computers, and it turns to a simplified but consistent representation of how the user understands and visualizes in the real world the modeled entities. The chosen model, OMT-G, proved adequate (as expected, since it is the model adopted by the NSDI) to obtain representations of geospatial data related to modeling sediment generation in erosive processes at reservoir edges.

The proposed model is a simplified version to enable the presentation in this paper, but it is easily expanded. The classes erosive features and mass movement, for example, can be subdivided into the categories known in the literature either in the conceptual model or during the physical implementation to improve understanding or data storage. The subdivision is also valid for the classes field investigations and tests, laboratory tests, and monitoring stations.

In this work we used the DBMS PostgresSQL, but the proposed model serves as a reference for the physical implementation in any DBMS and new classes can be inserted if necessary. The use of free open-source software is recommended because it does not imply license acquisition costs and because there is a large community working on the development of these programs. The extension created in PostgreSQL allows rapid replication of the proposed structure on any computer with a compatible version of the program.

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