GIS Hydrography Management System for Provincial Waters

Cazzaro Mirco, Boscolo Cegion Nicola

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1   Objective of the Studies

The objective of this project is to develop an information system for hydrography management in the Italian province of Belluno. The system aims to achieve the following goals:

- Know the situation of all the water resources in the province: The system will provide comprehensive information about the water bodies within the province, including lakes and rivers. It will facilitate the understanding of the current state of these water resources.

- Manage inputs of potentially polluting liquids: The system will enable the management and monitoring of inputs that have the potential to pollute the water resources. It will track and control the release of substances into the water bodies to ensure environmental protection.

- Monitor the status of provincial waters: The system will continuously monitor and gather data on the condition of water resources, including parameters like water level, flow, turbidity, temperature, pH, dissolved oxygen, and more. It will enable the province to assess water quality and identify any anomalies or pollution incidents promptly.

- Compliance with European standards: The system will adhere to the relevant European standards for the representation of water networks. It will ensure that the information system follows the prescribed guidelines and formats for accurate and standardized data representation.

By achieving these objectives, the hydrography management system will provide the province with an efficient tool to monitor, manage, and protect its water resources effectively.

2 Analysis of Requirements

2.1 Functional Requirements

- **Import and Export of Data**: The system must support the seamless import and export of data in various standard formats, including shape files. This capability will enable data integration from diverse sources and facilitate interoperability with other systems.

- **Network Update**: The system should allow authorized personnel to update both the geometric and attribute aspects of the water network. It must ensure data consistency by maintaining a comprehensive history of modifications, enabling traceability and analysis of network changes over time.

- **Query System**: A robust interrogation system is necessary, equipped with spatial and alphanumeric filters that can be combined. This will empower users to perform complex queries, extracting relevant information based on specific criteria for data retrieval and analysis.

- **Query Results Export**: Users should have the ability to export query results in compatible formats for further analysis, reporting, or integration with external tools and systems. This functionality enhances data utilization and supports informed decision-making processes.

- **Cartography and Orthophoto Visualization**: The system should provide an intuitive visualization interface, allowing users to overlay cartographic and orthophoto data as a background for analysis purposes. This feature enables the correlation of additional information with spatial context, aiding in decision-making.

2.2 Data Requirements

The system necessitates the following data (with the following charateristics) to fulfill its objectives in the hydrography management system:

- **Required Data**: Comprehensive information regarding water bodies within the province, including spatial attributes (geometry), essential attributes (e.g., name, type), and historical records of network modifications.

- **Data Format**: The system should support multiple data formats for efficient data management and interoperability. Primarily, the system should be capable of working with shape files, which are widely used in the geospatial domain. Shape files provide a standard format for storing both the geometry and attributes of geographic features. This format ensures compatibility with existing datasets and enables seamless integration with other geospatial systems. Furthermore, the system should support commonly used formats for import and export operations, such as CSV (Comma-Separated Values) and GeoJSON (a format for encoding geospatial data in JSON). These formats facilitate data exchange with external systems and enable data analysis using various tools and applications. By accommodating these diverse data formats, the system can effectively handle the information related to the water bodies, ensuring compatibility with existing data sources and promoting data interoperability within the hydrography management domain.

2.3 Nonfunctional Requirements

To ensure the development of an effective hydrography management system, the following nonfunctional requirements must be considered:

- **Use of PostgreSQL DBMS**: The system should leverage the PostgreSQL database management system (DBMS) for efficient data storage, retrieval, and management. The utilization of this reliable and widely adopted DBMS will contribute to the system's scalability and performance. Within PostgreSQL, a powerful plugin for it called PostGIS will be used, so to expand the DBMS capabilities on managing spatial data.

- **Use of FOSS Components**: The system should embrace the use of Free and Open Source Software (FOSS) components during its development. By leveraging FOSS tools and libraries, the system can benefit from community support, cost-effectiveness, and flexibility in customization.

- **Compliance with Applicable Standards**: The system must adhere to applicable national and international standards for hydrography management and data representation. This compliance ensures interoperability, facilitates data sharing, and promotes compatibility with other systems within the domain.

- **Compliance with Rules and Regulations**: The system should conform to all relevant rules and regulations governing water management and environmental protection at both national and international levels. Adherence to these regulations ensures legal compliance and promotes responsible data handling practices.

3 Starting Situation

In order to provide a comprehensive understanding of the project context, it is important to analyze the starting situation, including the existing technology, available data, and market analysis.

3.1 Technology

The Province of Belluno currently operates an IT sector responsible for managing their Management Information System (MIS) using commercial software and the PostgreSQL database management system (DBMS).

However, a specific Geographic Information System (GIS) application tailored for hydrography management is not currently in place: our task is to develop a customized GIS solution to address this gap and fulfill the province's requirements.

3.2 Exsisting Data

The region Veneto already possesses a topographic database built in accordance with the Italian national standard at the NC5 level. This database provides detailed information about the province's terrain and water features. The data is stored in the ETRF2000 reference system and can be accessed through OGC WMS (Web Map Service) and WFS (Web Feature Service) non-transactional services.

Additionally, orthophotos at a scale of 1:5000, also based on the ETRF2000 reference system, are available for visualization through WMS.

3.3 Market Analysis

Extensive research indicates that there are currently no off-the-shelf or packaged solutions available in the market that adequately address the requirements of the hydrography management system for the Province of Belluno.

This market gap presents an exciting opportunity for our team to develop a tailored solution that precisely meets the province's needs. By creating a custom application, we can ensure the fulfillment of all functional and nonfunctional requirements while complying with the relevant standards and regulations governing water resource management.

3.4 Conclusions

Analyzing the starting situation in terms of existing technology, available data, and market conditions, it is evident that the development of a dedicated hydrography management system is crucial to effectively manage the province's water resources and address the current market gap.

4   Working Hypotesis

The working hypothesis for this hydrography management project is based on careful analysis of the requirements and constraints. It forms the foundation for our approach and solution design. The following aspects outline our working hypothesis:

4.1   Considerations

Our primary focus is to develop a robust and scalable hydrography management system that effectively meets the needs of the Province of Belluno. We understand the importance of adhering to relevant standards and applying best practices in hydrography management. Additionally, we recognize the significance of user accessibility and aim to design the system as a web application, compatible with commonly used browsers such as Explorer, Chrome, and Firefox. We will also incorporate functionalities for specific use cases that may require customization using desktop GIS tools.

4.2   Hypotesis

Our hypothesis is that by implementing a customized GIS web application, integrated with a PostgreSQL DBMS, we can create an efficient hydrography management system that meets the specified requirements. The system will enable the province to document water bodies, manage intakes, monitor water conditions, perform data consultations, and handle citizen alerts effectively. To achieve this, the system will incorporate the following key features:

1. Import and export of data in shape format and other standard formats to facilitate seamless integration with existing data sources and enable data exchange with external systems;

2. Capability to update the network, both in terms of geometric elements and attribute data, while ensuring the historicization of changes. This will provide a comprehensive view of the network's evolution over time;

3. An advanced interrogation system that combines spatial and alphanumeric filters to enable users to perform complex queries. This functionality will allow users to retrieve specific information based on their criteria;

4. Export of query results to allow users to save and utilize the obtained data for further analysis or reporting purposes;

5. Visualization of cartography and orthophotos as a background to enhance the analysis and interpretation of data within the system.

In addition to these core features, the system will address specific requirements within the hydrography management domain. It will enable the province to:

1. Manage intakes effectively by providing information on intake positions and attributes, facilitating the insertion and removal of intakes, and determining the route of pollutants released from intakes;

2. Monitor water conditions by collecting real-time data from water monitoring units strategically placed across the province's waterways and lakes. The system will capture parameters such as level, speed, flow, turbidity, temperature, conductivity, pH, redox potential, dissolved oxygen, *NH4+*, and *CL-*;

3. Support maintenance activities for the control units, generating schedules for periodic maintenance and recording execution details to ensure the continuous and accurate functioning of the monitoring units;

4. Enable data consultation by providing technical offices with the ability to perform combined searches based on spatial and attribute filters, as well as historical queries. The system will support complex queries such as identifying intakes in specific stretches of rivers or monitoring units measuring pH values below 6 within specific time intervals;

5. Handle citizen alerts and facilitate transparent governance by creating a dedicated portal for daily publication of water quality analysis results. The system will include a reporting mechanism for citizens to anonymously report the presence of pollutants in the water, attaching photos and indicating the geographical location. Automatic filtering and relevance scoring of reports will be performed to reduce manual processing. The system will associate each alert with relevant monitoring units and previous alerts within a certain proximity.

4.3 Analysis of Risks and Constraints

We will conduct a thorough analysis of potential risks and constraints that may affect the project's success. These could include technical challenges, data quality issues, resource limitations, and compliance requirements. We will develop mitigation strategies and contingency plans to address these risks and ensure smooth project execution.

5 Preliminary Project

The preliminary project section provides an overview of the hydrography management system project for the Province of Belluno. It covers various aspects, including goals, system functions, databases, technological components, project guidelines, operational aspects, risk management, benefits evaluation, and cost evaluation. This section serves as a comprehensive summary of the project, outlining its objectives, system functionalities, database structure, technical components, implementation guidelines, and assessment of potential benefits and costs. It provides a holistic view of the project's scope and sets the foundation for its successful execution and management.

5.1 Goals

The goals of the hydrography management system project for the Province of Belluno are defined to ensure the successful development, implementation, and utilization of the system. These goals provide a clear direction for our project team and serve as measurable outcomes to evaluate the project's success. The goals can be categorized into two key areas: overarching goals and intermediate goals.

5.1.1 Overarching Goals

- **Develop a comprehensive hydrography management system**: The primary goal of the project is to design, develop, and implement a comprehensive hydrography management system tailored to the specific requirements of the Province of Belluno. The system will enable efficient management of water resources, including the documentation of water bodies, tracking of intakes, monitoring of water conditions, and citizen alert management;

- **Ensure user-friendly access and compatibility**: The system should provide a user-friendly interface accessible through popular web browsers such as Explorer, Chrome, and Firefox. Additionally, it should support specific functionality through customized desktop GIS tools when necessary. Compatibility and ease of use are essential to ensure widespread adoption and efficient utilization by technical offices, internal technicians, and citizens;

- **Adhere to relevant standards and regulations**: The system must comply with applicable hydrography management standards and regulations. It should ensure accurate data representation, support data interchangeability using standard formats, and promote interoperability with other systems in the hydrography management domain.

5.1.2 Intermediate Goals

- Enable efficient data management, so to develop functionality for importing and exporting data in shape format and other standard formats, allowing seamless integration with existing datasets and data exchange with external systems. Implement mechanisms for network updates, both in terms of geometric elements and attribute data, ensuring the historicization of changes to track the evolution of the hydrography network;

- Implement advanced querying and visualization capabilities, so to create an advanced interrogation system that combines spatial and alphanumeric filters, empowering users to perform complex queries for retrieving relevant information. Enable the export of query results and provide visualization capabilities for cartography and orthophotos as a background, enhancing data analysis and decision-making processes;

- Support intake management, so to develop features to enable the identification and management of intakes, including their positions and attributes. Implement functionality for inserting new intakes, removing abandoned ones, and determining the routes of pollutants released from intakes;

- Facilitate water condition monitoring, so to design and implement mechanisms to collect real-time data from water monitoring units strategically located throughout the province. Capture key parameters such as water level, flow, turbidity, temperature, conductivity, pH, redox potential, dissolved oxygen, NH4+, and CL- to enable effective monitoring of water conditions;

- Enable maintenance planning and execution, so to develop functionality to support the scheduling and execution recording of periodic maintenance tasks for the monitoring units. Ensure timely and efficient maintenance to maintain accurate and reliable data collection;

- Enable data consultation and emergency detection, so to implement features that allow technical offices to carry out combined searches, spatial and attribute-based, as well as historical queries to retrieve relevant data. Develop mechanisms to detect and notify relevant personnel of potential emergencies through email notifications triggered by abnormal parameter values;

- Establish citizen reporting and transparency. The aim is to create a dedicated portal to publish daily water quality analysis results and promote transparent governance. Develop a reporting system for citizens to anonymously report pollutants with photo attachments and geographical location indications. Implement automatic filtering and relevance scoring of reports to streamline manual processing and associate alerts with relevant monitoring units and previous alerts.

5.2   Technological components

Whenever talking about a system in the IT field it is implicit that different technological components (being them more or less interconnected) are required. In the case of the proposal for a Hydrography Management System, meeting the requirements of the customer, two different systems has top be developed: a desktop GIS system and a web GIS system, that are introduced in the following subsections and deeply explored in a dedicated paragraph. After that, software and hardware requirements need to be exploited.

5.2.1   Database

We can consider the database of the system the glue of all the other technological components. Furthermore, the customer already has in his IT sector a PosgreSQL database, that adapts prefectly to the system we want to develop, thanks to his extension *PostGIS* that is suitable for managing spatial ang geographical data. Hence, this component will be used as the base for the developing of our application.

5.2.2   Desktop GIS system

Since is accepted that some of the funtional requirements can be met through a desktop GIS application, and to stay adherent to the non-functional requirement of using FOSS components, the solution found is to develop specific plugins for the *OpenJUMP* desktop application, making use of the *Java™ JTS library*; the plugins built for the system will be packed together with the application and delivered to the customer. Technical support for the installation of the desktop system on customer terminals will be provided.

5.2.3   Web GIS system

The core of the system will be the web application: since it has to deliver to the user GIS capabilities, many components need to be integrated:

- Frontend map management: it is necessary to provide to the users the possibility to use maps through the web app. For this, the OpenLayer JavaScript plugin will be used;

- Background map: it is necessary to display in this plugin a background map of the province: to meet this requirement, OpenStreetMap maps will be used;

- Backend spatial data delivery: it is necessary to deliver to the user (and to display over the OpenStreetMap) the spatial data that the Veneto Region has at disposal: for this, a dedicated Geoserver instance is necessary;

- Frontend implementation: parts of the web application shall be used also from the provincial citizens even on the go from mobile devices. In an optic of usability of the system with any device it is necessary of a full responsiveness of the system over any kind of terminal (smartphones, tablets, etc.) and to better integrate with other public IT systems, the *Bootstrap Italia* template is our implementational choice.

5.2.4   Hardware requirements

To support the functioning of the web application also from the exterior of the provincial organization, because of the active citizenship policy, but also to facilitate eventual and future possibilities of smart working activities of the provincial employees, a concrete possibility is the one of setting up a public private server hosted on the cloud: this possibility can be delivered both from a provate hosting company, with a cost that has to be kept in consideration, or by the availability of some italian server infrastructure, if any. The fact that the customer already owns a PostgreSQL database in their servers, can suggest to use them as hosting machines also for the system, but this can led to security problems since can be that the machines are used also for other purposes, and the data traffic coming from the new system can cause slowdowns of the machine or worse, of the provincial office network. A solution to this can be to keep the data on the legacy database and tunnel the traffic between the new private server and the native machine whenever interactions with database are necessary, or to replicate the data we are interested on on a new instance of PostgreSQL running on the dedicate new private server.

5.2.5   Software requirements

Many softwares needs to be used to set up the system:

- **Operating system**: an operating system has to be installed on the private server: to be stick with the FOSS components requirement, an installation of *Ubuntu server* or *CentOS* can be considered as valid option.

- **Database**: from the considerations derived from previous section, two different approaches can be followed: in case of replication, a fresh installation of PostgreSQL with the PostGIS extension is needed; if this is not considered a valid option, a way to set up a VPN connection between the existing PostgreSQL server and the system' server needs to be setted up.

- **Web server**: a web server capable of delivering web contents, possibly also under SSL certificates, run scripts, and proxy data from other softwares needs to be setted up: for this, the *Apache HTTP server* can be suitable for this requirement.

- **Scripting interpreter**: the logic of the web system will be implemented through *PHP*, a scripting laguage, that needs its interpreter (with the needed extensions) to be setted up properly.

- **Web Map server (WMS)**: a system capable of delivering web maps is needed: for this, *Geoserver* is the best solution available.

- **Web Map server container**: Geoserver is developed as a web application in *Java*. This requires a Java container to run web applications. *Tomcat* is our implementing choice, but a standalone version that includes another container (*Jetty*) can be used.

- **Security**: to better protect the server from malicius trials of intrusion, a firewall software can be installed on the machine. A good approach can be the usage of *iptables*.

5.2.6 Components' Schema
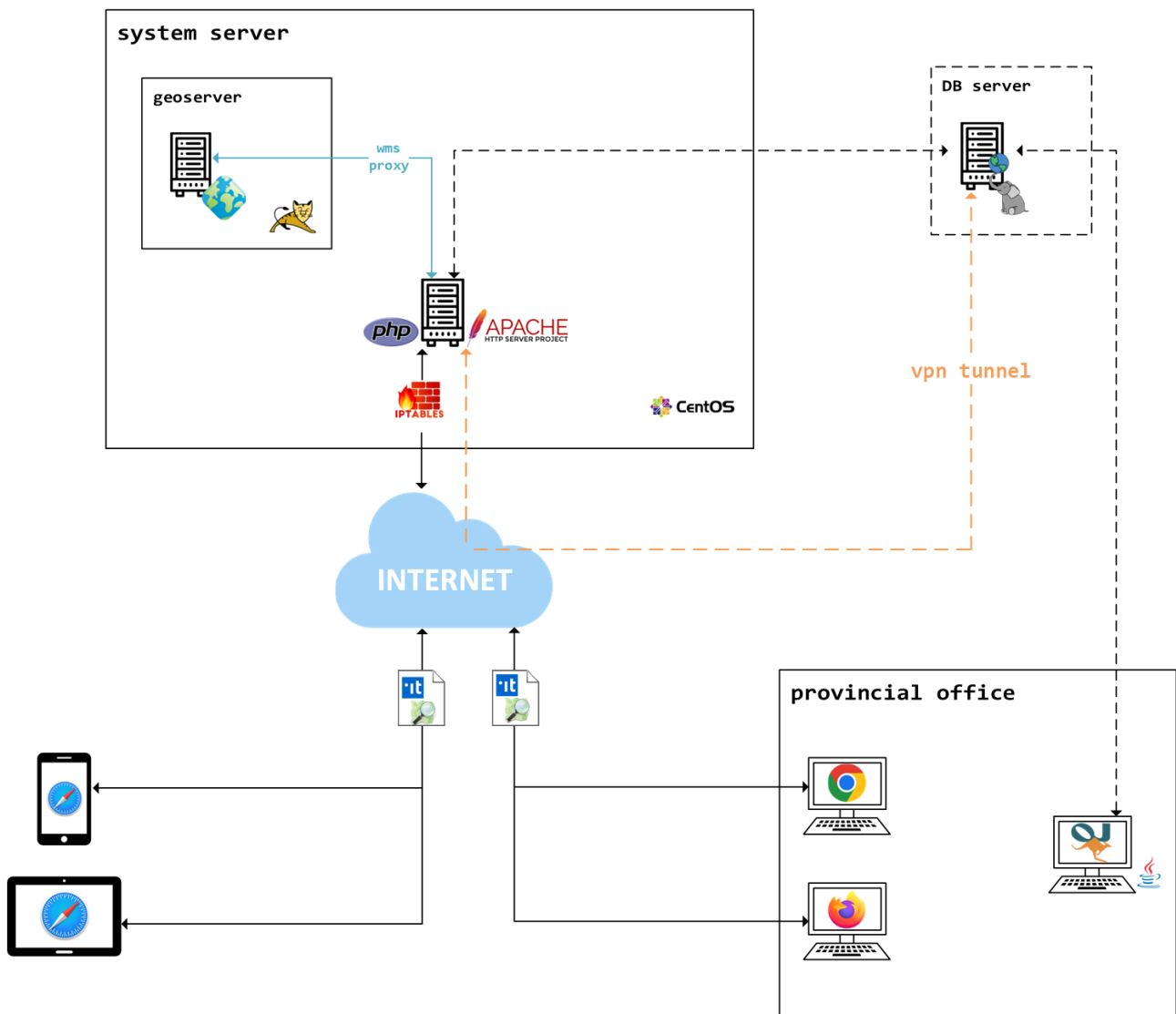
5.3 Functional aspects of the system

The systems are developed in a way that no specific capabilities are required from the users. Anyway, here we present some short explaination of the funtional aspects of both the webapp and the desktop OpenJUMP plugins.

5.3.1   WebGIS application

5.3.2   OpenJUMP plugins

Differently from the webapp, here a specific initial configuration on the user's terminals needs to be setted up. This kind of initial support is by the way provided by our company and so no tutorial needs to be included in this document.