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Utility Network Management in ArcGIS Pro for the Gruia Neighborhood, Cluj-Napoca

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RESEARCH ARTICLE

Abstract

Geographic Information Systems (GIS) represent a powerful tool for the monitoring and management of utility infrastructure, with growing applications in Romania and internationally. This study addresses the design and implementation of a water supply and sewerage network in the Gruia neighborhood of Cluj-Napoca, developed as a branching system to serve local consumers. Field data were collected using high-precision GPS equipment, while AutoCAD was employed for technical drafting and ArcMap for spatial analysis and cartographic representation. Additionally, ArcGIS Online was integrated to publish interactive maps, enabling real-time access, collaborative use, and on-site data updates. The resulting GIS-based maps provide a comprehensive visualization of network components, support the rapid identification of malfunctions, and facilitate efficient management of infrastructure. By combining advanced geospatial technologies with web-based platforms, this study highlights the potential of GIS to optimize decision-making processes, enhance service delivery, and strengthen urban infrastructure management.

Keywords: GIS; sewerage infrastructure; ArcGIS Online.

INTRODUCTION

The objective of the present project is the construction of a utility network in the Gruia neighborhood, located in Cluj-Napoca, Romania. The network comprises a system of branches through which essential resources - namely water, natural gas, and electricity - are distributed to consumers within the locality. The development of any urban area is intrinsically linked to the existence and efficiency of its utility networks, including those for water supply, sewage, gas, and electricity. The proposed utility network focuses specifically on the water supply and sewage systems of the neighborhood.

Geographic Information System (GIS) models offer broad applicability in monitoring water supply and sewage infrastructure. At both national and international levels, administrative bodies have expanded the implementation of GIS technologies (Kamal & Al-Ameen, 2021). In Romania, for instance, wastewater companies employ GIS applications in various programs dedicated to the analysis and optimization of water distribution systems. In order to streamline the management of utility networks, specialized web pages and interactive maps have been developed - accessible on any device, including those used in field operations.

The utility network is designed to model all components comprising the system - such as cables, pipelines, valves, zones, devices, and circuits -band allows for the realistic simulation of the network's behavior and operational characteristics (Bala & Serban, 2020).

Establishing a utility network enables a series of functionalities, including: the creation and editing of attributes and entities representing various utility equipment; visualization of the interconnectivity among features and components within the network; provision of an operational overview of the current configuration of all dynamic devices; and the analysis of how the network is impacted by real-world events such as storms, service interruptions, or equipment failures (Orgoványi, Szilágyi, & Tóth, 2024).

Online applications incorporate a variety of basemaps, data layers, spatial extents, and navigation tools such as zooming and panning. Generally, the basemaps and associated data layers are hosted and shared through ArcGIS Online. However, maps may also include layers added directly by the user, as well as externally referenced basemaps and layers. Many maps also feature scalable symbols and intelligent styling techniques, which dynamically render spatial data and patterns as users interact with the maps (Chiorean, et al., 2024)**.**

The process of creating maps can be completed in a few fundamental steps, and the resulting maps are accessible via standard web browsers, mobile devices, or desktop-based map viewers. These maps can be shared through direct links, embedded in websites, and employed in the development of web-based applications driven by geospatial data.

The utility network construction took place in the Gruia neighborhood. This area is located in the northwestern part of Cluj-Napoca and is bounded by the railway to the north, Horea Street to the east, General Eremia Grigorescu Street to the south, and Tăietura Turcului Street to the west. Gruia is one of the older neighborhoods of Cluj-Napoca, with a history dating back to before the Second World War.

This study presents a GIS model applied within Cluj County, offering the advantage of a highly detailed representation of the components of the water supply system. The model also enables the extraction of data necessary for redesigning pipelines and complex installations, or for planning rehabilitation works. GIS models can generate thematic maps, work reports, and mathematical models for both design and presentation purposes, all within relatively short timeframes.

MATERIALS AND METHODS

Field measurements were performed using the ROVER GNSS RTK South Surveying Galaxy G1C, equipped with an inclination sensor. This device was employed to ensure high positional accuracy during data acquisition, thereby minimizing measurement errors and providing reliable input for subsequent spatial analyses (Teunissen & Montenbruck, 2017).

Modern utilities require access to relevant and actionable information to support increasingly complex networks. Regardless of the industry, utility providers must ensure a safe working environment, deliver reliable services, and maintain a strong focus on customer support. The ArcGIS Utility Network **i**s designed as a next-generation spatial information system that delivers advanced functionality over large datasets at all levels of resolution. Utilities can now leverage the full power of ArcGIS Enterprise, in combination with ArcGIS Pro or ArcGIS AllSource, to provide user-centric tools that enhance communication across the entire organization (Esri, 2024).

A utility network is the core component used by professionals to manage utility and telecommunications infrastructure within the ArcGIS environment. It offers a comprehensive framework of capabilities to accurately model utility systems such as electricity, gas, water, stormwater, wastewater and telecommunications. The utility network is designed to represent all elements that make up the infrastructure such as wires, pipes, valves, areas, devices, and circuits - thus enabling detailed modeling and efficient management of complex utility systems. (Gilbert, et al., 2017).

RESULTS AND DISCUSSIONS

The GIS (Geographic Information System) constitutes the framework that enables the collection, management, and analysis of data. GIS represents a particular case of information systems, which are defined as a “combination of people, procedures, and equipment designed, constructed, utilized, and maintained for the purpose of collecting, recording, processing, storing, retrieving, and displaying information” (Ralston & Reilly, 1992). Accordingly, GIS models present several advantages: facilitating data query processes, reducing working time, lowering maintenance costs, modernizing and rehabilitating systems through the integration of textual and graphical data, simulating mathematical models required for verification calculations, and improving communication with clients and authorities. These benefits are particularly relevant in light of today’s technological advancements (Coroian, et al., 2022).

A Geographic Information System (GIS) is a system that creates, manages, analyzes, and maps all types of data. GIS connects data to maps by integrating spatial information (the location of features) with descriptive information (their attributes and characteristics). This provides a foundation for mapping and spatial analysis, which is applied across scientific disciplines and nearly all industries. GIS assists users in identifying patterns,

relationships, and geographic context. Its benefits include enhanced communication, improved efficiency, and better management and decision-making processes (Wanguba, Siriba, & Okumu, 2024).

Maps serve as the geographic containers for the data layers and analyses that users intend to employ. GIS maps are easily shared, embedded into applications, and made accessible to almost anyone, anywhere. GIS integrates multiple types of data layers through spatial location. Since most data have a geographic component, GIS data typically encompasses imagery, features, and base maps linked to spreadsheets and tabular data (Esri, 2024).

The development of the utility network led to the creation of a corresponding database and a comprehensive dataset that includes the following elements: postal addresses, water meters, water pipes and water service connections, sewer pipes and sewer connections, parcel boundaries and the structure of manholes and water meters (see Figure 1).

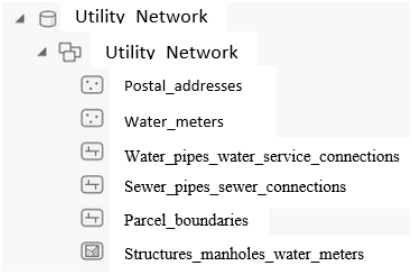


Figure 1. The database structure in ArcGIS Pro.

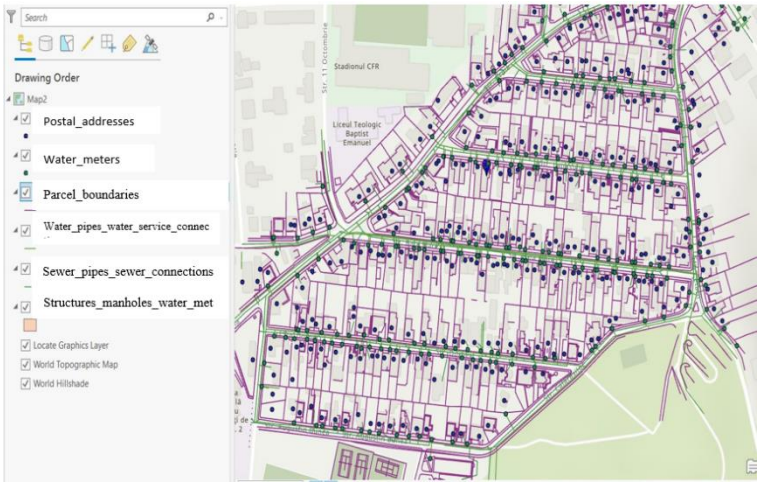


Figure 2. Implementation of utility network elements using the *Street basemap.*

The organization of the database within the ArcGIS Pro environment—emphasizing the spatial and attribute data linked to utility network components—is illustrated (Figure 1). After georeferencing the relevant database elements, they were integrated into ArcGIS Pro to enable various queries and spatial analyses supporting the assessment of the utility network (Figure 2).

ArcGIS Pro offers a wide selection of basemaps that can be chosen based on the intended analytical or visualization purpose. For instance, the Streets basemap is depicted (Figure 2), while the Imagery basemap is shown (Figure 3). To improve data visualization and facilitate clearer interpretation, a utility network map was developed, incorporating water pipes and service connections—displayed in blue—and sewer pipes along with sewer connections—displayed in red (Figure 4). GIS technology enables the assignment of specific attribute fields to each created layer.

The Water Meter Manholes layer includes the following attributes: manhole condition, which specifies the physical condition of each manhole (e.g., flooded, damaged, broken, cracked, etc.), the number of meters, postal number, diameter, and additional details. The Sewer Pipes and Sewer Connections layer contains attribute fields such as distributor, length, pipe type, operational condition (functional or defective), and location (street name).

The sewer connection refers to the segment of the public sewer network that links a user's internal sewage system to the public sewer infrastructure, including the inspection chamber. The inspection chamber is a structural component of either the wastewater or stormwater collection system and forms part of the public sewer infrastructure. It represents the initial element of the sewer network in the direction of flow and is typically positioned at the property boundary, most often within private property.

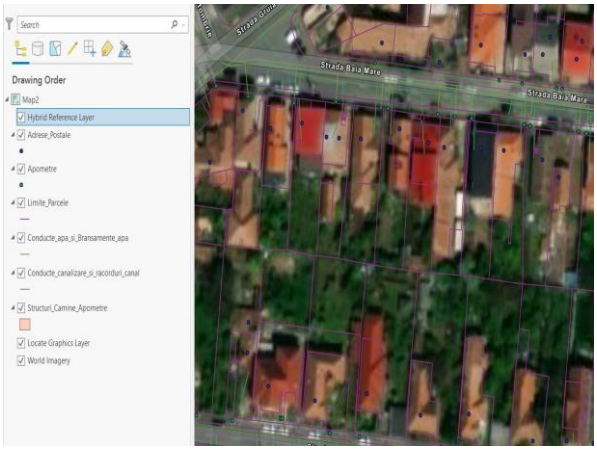


Figure 3. Database displayed using the *Imagery* basemap.

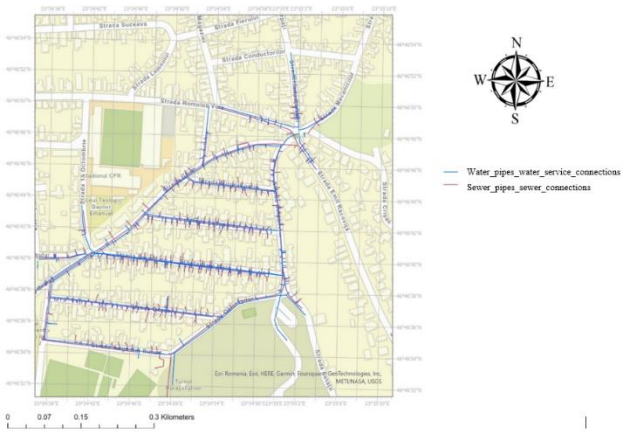


Figure 4. Water and sewer network layers.

The Water Pipes and Water Service Connections layer includes the following attribute fields: functionality, material, distributor, status, location and pressure. A service connection is the part of the water supply network that provides the link between the public distribution system and the internal water network of a property or building. Each service connection serves a single user.

The Water Meters layer includes the following attribute fields: diameter, type and postal number. Water meters are devices used to record the amount of cold and hot water consumed monthly, ensuring that users are billed only for the quantity they use. Over time, the internal components of water meters wear out, leading to a decline in measurement accuracy. The typical lifespan of a water meter ranges between 10 and 15 years.

The Postal Addresses layer includes the following attribute fields: house number and street. Each water manhole is assigned a specific location (street and house number), which is essential for accurately identifying the manhole's position in case maintenance or intervention is required.

The Parcel Boundaries layer includes the following attribute fields: type and length.

To improve the analysis of the database, several classifications were performed to support the management of the utility network.

The spatial distribution of water meter manholes in the Gruia neighborhood, organized by postal code, highlights the arrangement of infrastructure along the street network. Classifying streets based on the number of pipelines is essential for utility management, as it allows for the precise identification of pipeline intersection points, which are critical in the event of system malfunctions or failures (Figure 5).

Subsequent stages involved conducting a series of database analyses designed to enhance the examination of the utility network. These analyses not only supported a more comprehensive understanding of the system's structure and performance but also ensured the availability of specific and relevant information in the event of infrastructure malfunctions, thereby contributing to effective management and timely decision-making.



Figure 5. Distribution of water meter manholes.

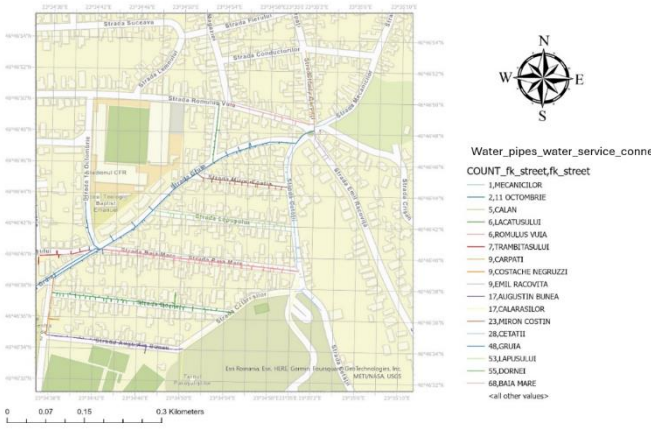


Figure 6. Classification of water pipes by street and pipe count.

A map displaying the classification of water pipes by street and their respective counts is shown (Figure 6). Each category is represented using a distinct color. As indicated in the legend, for example, Lacatusului Street contains 6 water pipes, while Gruia Street contains 48. This classification is essential for quickly identifying the relevant streets and postal addresses where a potentially affected manhole may be located in the event of a malfunction.

The classification of water pipes based on their year of installation and corresponding quantities is illustrated (Figure 7). Each installation year is visualized using a different color. According to the legend, 26 pipes were installed in 2013, only 2 in 2002, and as many as 312 pipes in 1905. Maintaining records of pipe counts by installation year is crucial for identifying and locating older infrastructure, which is significantly more susceptible to failure due to material aging and degradation.

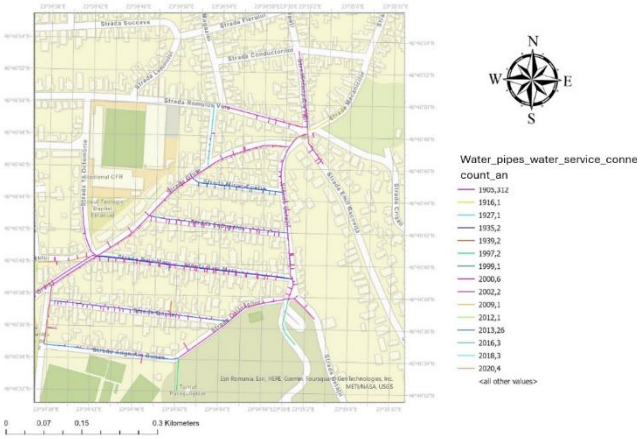


Figure 7. Classification of water pipes by installation year and quantity.



Figure 8. Classification of water manholes by number of water meters.

A map illustrating the classification of water manholes based on the number of water meters they contain is provided (Figure 8). As shown in the legend, there are 13 manholes containing two water meters, one manhole housing six meters, and 251 manholes with a single water meter, among other variations.

The classification of water manholes according to their physical condition is shown (Figure 9). Based on the legend, the map indicates 9 flooded manholes, several with broken covers, and 34 that require cleaning.



Figure 9. Classification of water manholes by condition.



Figure 10. Classification of sewer pipes by type.

This classification is highly relevant, as water manholes are frequently subject to various defects caused by weather conditions, improper placement, or human interference. Mapping these conditions enables the precise localization of defective manholes, which are marked on the map using distinct colors corresponding to their condition.

A map illustrating the classification of sewer pipes by type is provided (Figure 10). As indicated in the legend, the dataset includes 38 stormwater (pluvial) sewer pipes and 339 wastewater (domestic) sewer pipes, each represented using distinct colors according to their classification.



Figure 11. Ownership classification of pipes: parcels vs. Sidewalks.

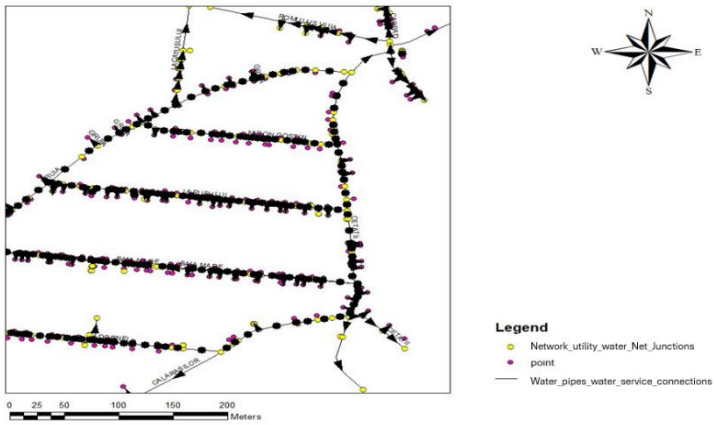


Figure 12. Water utility network.

The spatial distribution of sewer pipes, categorized by their location in relation to property parcels or sidewalks, is shown (Figure 11). According to the legend, 5.547 pipes are located within private parcels, while 320 are situated beneath public sidewalks, with each category represented by a distinct color on the map. This classification is essential for understanding accessibility challenges—pipes within private properties are typically more difficult to access for maintenance or repair, whereas those under sidewalks are more readily reachable.

Using the created database, a water utility network was generated through the predefined Network Utility tool in ArcMap (Figure 12). This enabled the simulation of water flow distribution from main lines along each street to individual properties.

A simulated failure scenario is illustrated (Figure 13). Two barriers were placed to isolate the points of failure—one positioned at the intersection of Mecanicilor, Romulus Vuia, and Carpați Streets, where the defect occurs, and a flag used to identify the affected streets. The Find Loops tool from the Utility Network toolbar was employed to detect the components connected to the flagged segment that form closed loops (i.e., segments inaccessible from multiple directions). In the resulting map, the streets impacted by the malfunction are highlighted in red. Such applications are essential for planning and carrying out emergency interventions effectively.

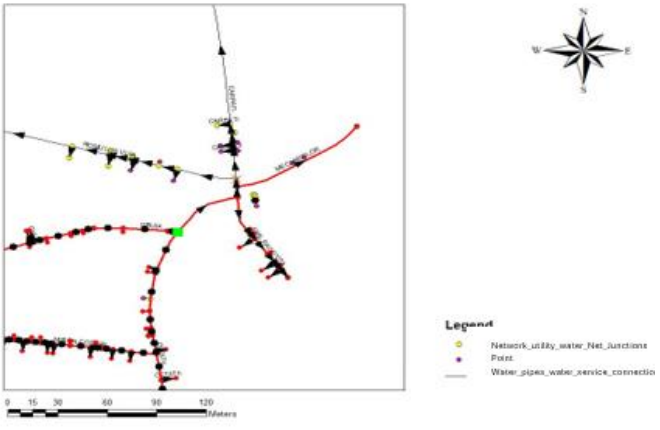


Figure 13. Find Loops between two barriers.

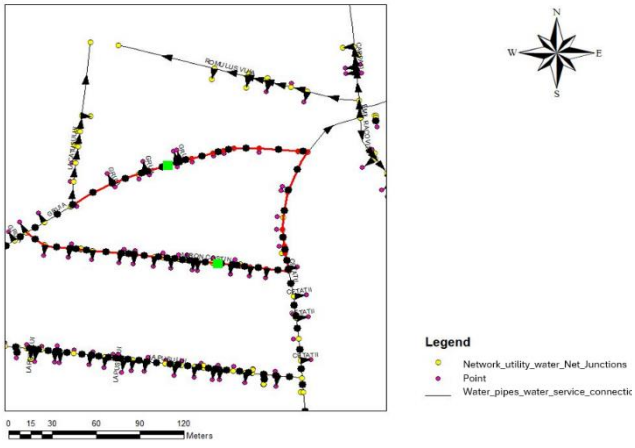


Figure 14. Find Path between two failure points.

Another important example in the management of a utility network is the identification of the connected pipes located between two failure points. As shown in Figure 14, two potential failure points - highlighted in green - were selected: one located on Gruia Street and the other on Miron Costin Street. As a result, the pipes connected within the affected section of the network were identified and are highlighted in red.

Web pages can be created using ArcGIS Online, which helps users gain new insights and improved details through interactive data exploration. Various cartographic styles, data-driven visualizations, and intuitive analytical tools can be used to extract valuable location-based information.

The first online application, which represents the developed database and its core functionalities—such as a legend, layer control, field coordinate display, and basemap selection is shown in (Figure 15). This application is powered by ArcGIS Online, providing access to a wide range of integrated tools and features.

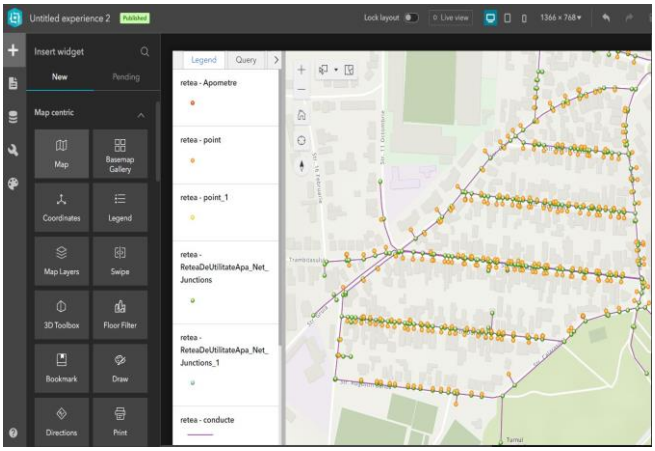


Figure 15. Interface for creating the online application.

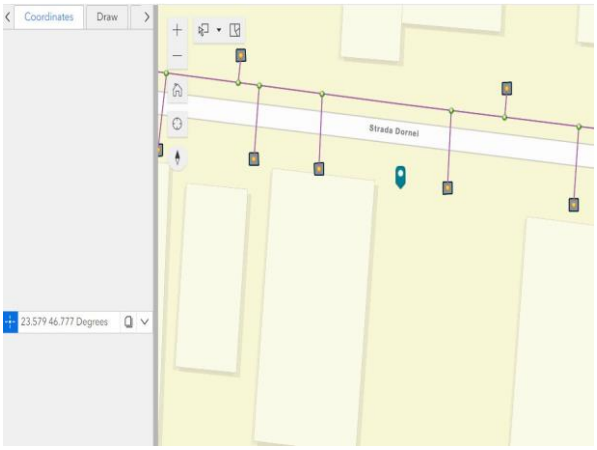


Figure 16. Online application accessed in the field.

The application can be accessed directly from the field, as shown in (Figure 16). It can be used on any device, making it particularly useful for fieldwork, and allows the analysis of various data such as water meters, pipelines, and other related infrastructure. The layers contained within the database accessible and editable through the attribute table are illustrated in (Figure 17).

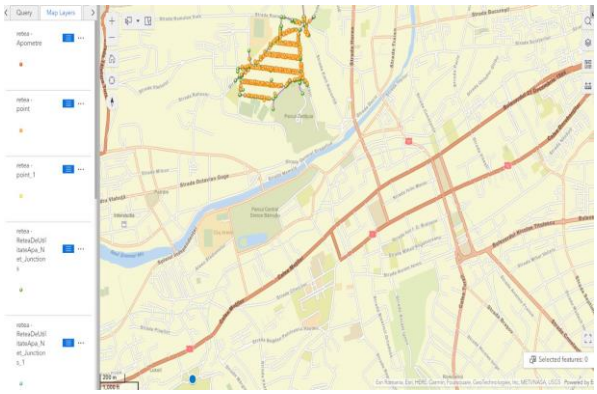


Figure 17. Layers with update data.

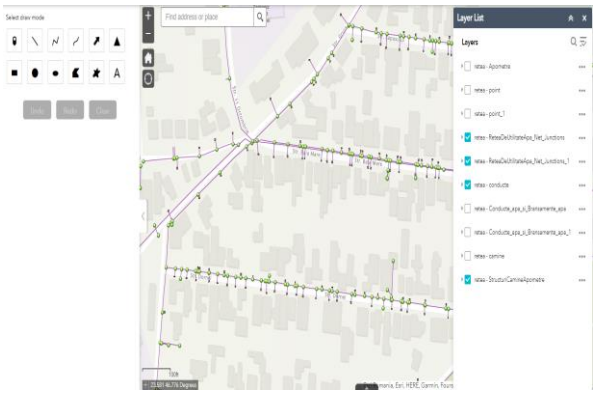


Figure 18. Web application developed according to the utility network.

Another capability provided by Esri is the development of customized applications containing tools tailored to the specific objectives of each user. Using these widgets, a web application was created to support utility network operations in the field. Functionalities include selecting/deselecting relevant layers, determining the user's location, and inserting new features based on field conditions (Figure 18).

CONCLUSIONS

The results of this study highlight the significant potential of Geographic Information Systems (GIS) in the modeling, analysis, and management of utility networks, using ArcGIS Pro and ArcGIS Online as integrated platforms. The systematic structuring of spatial and attribute data enabled the development of a geodatabase capable of supporting advanced spatial analyses and decision-making processes. The classification and spatial distribution of network components, such as pipes and manholes, by location, year of installation, and

physical condition provided a detailed understanding of the infrastructure's current state. These outputs are critical for identifying sections of the network most vulnerable to failure, prioritizing maintenance interventions, and improving the overall reliability of the system. Simulation tools integrated within the ArcGIS Utility Network environment, including flow direction and failure scenario modeling, proved to be highly effective for assessing the impact of system malfunctions. The ability to trace and isolate affected segments enables more precise emergency planning and optimized resource allocation. Furthermore, the deployment of web-based GIS applications through ArcGIS Online enhanced data accessibility and field level interaction. These tools support collaborative workflows, real-time updates, and mobile data collection key features in the context of modern utility network management. The synergy between desktop and web-enabled GIS environments constitutes a strategic foundation for improving the efficiency, adaptability, and intelligence of utility network management practices.

Author Contributions: I.C., L.A. Conceived and designed the analysis and contributed data or analysis tools; F.C., D.F. Collected the data; R.S. Performed the analysis; A.R., S.S Wrote the paper.

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Conflicts of Interest

The authors declare that they do not have any conflict of interest.

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