Geo-processing Approaches for Urban Water Supply and Drainage Systems' Data Rehabilitation

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***Abstract*—This study highlights the critical importance of accurate and comprehensive physical data in Integrated Urban Water Management (IUWM) and sustainable planning of water resources. Inaccurate or insufficient physical data can directly impact the reliability and sensitivity of planning, making it crucial for administrations to maintain accurate, thorough, and up-to-date data. To achieve reliable simulation results from hydrodynamic models, it is essential to define actual conditions in the model using correct and complete physical datasets. The study proposes a methodology for handling physical datasets of infrastructure systems in a GIS environment to obtain reliable simulation results. Digital and non-digital data from existing infrastructure systems are obtained and transferred to the GIS environment, with subroutines applied as needed to ensure accuracy and completeness. The physical data is then combined into a single database, correcting deficiencies and ensuring upstream-downstream continuity in the hydraulic model structure. With the integration of all physical data into the GIS environment, analysis and queries of geometric and attribute information are carried out for the detection and correction of deficiencies and errors of the system elements. This approach resulted in high-precision planning, detecting and correcting deficiencies and errors of the system elements, and ensuring the upstream-downstream continuity relationship in the hydraulic model structure. This study emphasizes the significance of accurate physical data in the sustainable management of urban infrastructure systems, and the proposed method can be utilized for any level of planning. Accurate and up-to-date physical data is essential for the sustainable management of urban infrastructure systems, and the use of the GIS environment and hydrodynamic models can lead to high-precision planning and reliable simulation results.**

Keywords*—*Water and drainage systems; hydrodynamic modeling; GIS analysis; data accuracy; sustainable water management.

I. INTRODUCTION

Water is a critical resource for human survival, and access to safe and clean water is essential for sustaining public health, environmental integrity, and economic prosperity. Efficiency and sustainability are primary goals of the services obtained by city municipalities and water companies in modern urban areas [1]. Integrated Urban Water Management (IUWM) methods, such as Sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID), and Best Management Practices (BMP) have become increasingly widespread in recent years to achieve the Water-Sensitive City (WSC) goal. These methods aim to minimize the environmental impact of urbanization and improve the resilience of urban water systems to climate change and other stressors. Achieving a WSC requires more than just the implementation of these techniques. The multi-dimensional analysis capabilities of hydrodynamic modeling software must also be used as much as possible in the management and design of water infrastructure.

Model output simulation is a widely used method in modern cities, which can show problematic spots and risks in urban networks with high precision. However, accurate identification of problematic spots and potential risks in urban networks depends on precise, accurate, and up-to-date technical attributes of the entire urban network, which are typically stored in GIS databases [2]. Low input data quality can significantly affect the accuracy of simulation results. Data deficiencies are often encountered in GIS data for a variety of reasons, including converting data from Computer-Aided Design (CAD) or other formats into GIS. In particular, in metropolises, where a significant amount of data is being continuously entered into the system, ensuring data quality that can be used in hydrodynamic models to achieve accurate results is crucial [3]. Without high-quality input data, hydrodynamic models cannot be run without preprocessing, which can lead to deficiencies and errors in the simulation results [4] [5]. To address this issue, the ISO 19114 standard provides guidance for assessing and rehabilitating GIS data quality. The standard for data rehabilitation outlines a five-step process for improving data quality. The first step in the ISO 19114 standard is to assess the quality of the GIS data. This includes identifying any missing or faulty geometries, as well as missing data in the attribute table. Once the data has been assessed, the needs for data quality can be determined. This involves identifying the types of data that need to be improved, as well as the level of accuracy required. The next step is to develop a study methodology for improving the data quality. This involves identifying the appropriate tools and techniques that will be used to improve the data, as well as the resources that will be required to carry out the study. The study methodology will need to be tailored to the specific needs of the project, taking into account the type of data being collected, the level of accuracy required, and the available resources. Once the study methodology has been developed, the study results can be specified. This involves identifying the specific improvements that will be made to the GIS data, as well as the expected outcomes of the study. The study results should be communicated clearly to all stakeholders involved in the project, including water utility companies, city municipalities, and software developers. The final step in the ISO 19114 standard is to check the conformance of the data. This involves verifying that the GIS data has been improved to the required level of accuracy, and that it meets all relevant standards and guidelines. Checking the conformance of the data is essential to ensure that the hydrodynamic models run accurately and that WSC goals are achieved.

Hence, the ISO 19114 standard provides a valuable framework for the rehabilitation of GIS data in the context of IUWM. Following the standard can help to ensure that the technical attributes of the whole city network are kept up-to-date, accurate, and precise. By using engineering approaches to correct deficiencies in GIS data, and by verifying missing and certain system information with field studies, real-condition model results can be achieved. In addition, the successful operation of hydrodynamic models requires precise and complete technical attributes and upstream-downstream relationships of the network. This may require time and financial resources to complete, along with field studies to verify missing and incomplete system information. Nonetheless, correcting and rehabilitating the GIS data through engineering approaches in the GIS environment with site investigation support can lead to the accurate simulation results necessary for modeling a WSC.

The purpose of this paper is to highlight the importance of GIS data quality in hydrodynamic modeling and to discuss engineering approaches to improve data quality in a GIS environment. The proposed method aims to improve the accuracy and reliability of hydrodynamic models and provide more reliable decision support for water infrastructure management and design.

The subsequent sections of this paper are structured as follows: Section II outlines the problems encountered and the methods employed to address them, including a presentation of the methodology. Section III provides an in-depth explanation of the problem and the approach utilized. The methodology is also presented in Section II. Finally, Section IV presents the conclusion of the paper, summarizing the benefits and contributions of this work.

II. Methodology

In the context of hydrodynamic modeling, accurate and complete GIS data is critical for achieving reliable results. This is particularly important for water infrastructure management and design, where incorrect or incomplete data can lead to costly errors and inefficiencies. One common challenge in hydrodynamic modeling is ensuring the continuity of manholes and pipelines in the software. The hydrodynamic modeling software possesses GIS software capabilities, allowing it to represent both wastewater and stormwater lines utilizing point geometry for manholes and line geometry for pipelines. However, in actuality, these manholes and lines are interconnected, and it's necessary to have no gaps between points and lines in the software. Furthermore, since the wastewater and stormwater lines rely on the gravitational movement of water, thus, to address this issue, it is essential to ensure manhole-line-manhole continuity in both plan and profile from the upstream point to the final downstream point. Data deficiency and gaps should be identified and completed according to this principle. To achieve this, classifications can be made to identify problems, such as non-connected lines and manholes with short distances that are not visible to the eye and faulty or missing lines (Figure 1).

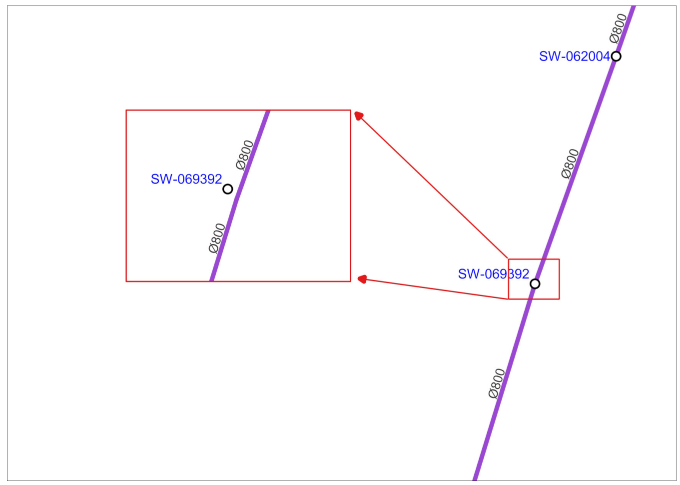

Figure 1. Sample of non-connected point (i.e. manhole) with the lines (i.e. pipes) error.

Non-connected manholes and lines can be caused by issues, such as data loss during the transfer of data from field acquisitions, sensitivity mismatch, and other factors that can disrupt data integrity. Faulty or missing lines may occur due to post-measurement data transfer problems, database errors, and other issues. To overcome these challenges, engineering approaches can be employed to improve GIS data quality in the hydrodynamic modeling process. By addressing these challenges and improving GIS data quality, more reliable hydrodynamic models can be developed, providing better decision support for water infrastructure management and design.

In the preliminary evaluation of the geometric and attribute information in the point (manhole) and line (pipe) layers for the use of the data in hydraulic analysis, in this study, two main problems were identified:

- discontinuity/disconnection (that is not visible) between the pipe and the manhole,
- broken and missing pipelines (on a visible scale).

The identified problems are classified and resolved according to the developed algorithm explained in detail below.

A. *GIS Data Quality Improvement Approaches*

The obtained data have been subjected to two types of geoprocessing analysis and evaluation in GIS applications.

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a) Spatial Analysis

- Intersect analysis
- Near analysis
- Select by location
- Select by attribute
- Buffer

b) Topological Analysis

- Point-Line Relation Topological
- Must be Covered by Endpoints
- Must be Covered by Line (Snap, extend, trim)
- Point-Point Relation Topological

The spatial analysis was employed to conduct intersection analysis in order to obtain information about the manholes that were in contact with the lines. Proximity analysis was used to transfer information on manholes located within a certain distance to the line database. Various analyses, such as connected/not-connected and coverage, were carried out using the Select by Location tool. The identification of related lines and manholes was accomplished through the Select by Attribute tool, which involved a comparison of the attribute tables. The topological analysis of the data involved checking whether the line and manhole layers were complementary to each other. The analysis verified the presence of manholes at both ends of the line and the existence of a line touching the manhole. Through the use of geoprocessing algorithms, such as ”Spatial Analysis” and ”Topological Analysis” in the GIS environment, physical disconnections and numerous deficiencies of the same type, which could not be detected visually, were identified.

These approaches have resulted in improvements to both the point and line layers, correcting errors on a scale that may not be visible to the naked eye. The main errors and shortcomings have been categorized as follows:

Point (Manhole) Layer:

- Non-connected points with the line
- Missing points (manholes) at the start or end of the lines

Line (Pipe) Layer:

- Pipes that are a continuation of each other but whose ends do not touch each other
- Duplicate lines
- Missing data and errors that are visible at the line layer, such as the case of missing and disconnected collector lines or the case of missing discharge lines.

B. Disconnected Lines and Missing data (Visible errors)

In some cases, certain lines in the GIS database may not accurately represent their real-world counterparts. This can occur due to a variety of factors, including difficulties with fieldwork and challenges in properly adding geometry and attribute data for older lines. Additionally, issues may arise when attempting to convert CAD data of existing lines to the GIS environment. These conversion problems can result in missing data and errors in the GIS database, which can lead to inaccuracies in the hydrodynamic models. To address these issues, engineering approaches have been employed in a GIS environment with the oversight of local administration controls. Corrections were made to the GIS database to improve the accuracy and reliability of the input of these data into the hydrodynamic model through careful inspection and analysis to identify errors that were missed. This process has involved a combination of techniques, including manual updates to the GIS database and the use of geoprocessing algorithms to identify and correct issues.

III. PROPOSED SOLUTIONS

In the analysis results, several error types are commonly observed. To ensure proper control and tracking of analysis and queries performed on the GIS database, it is recommended to create a new column in the attribute table and record the corresponding operations. The different types of errors and their respective arrangement methods are discussed below:

1. Disconnection of points and lines: This error occurs when a line is missing in the upstream-downstream route (Figure 2). To address this issue, the missing lines are completed to establish the upstream-downstream relationship up to the discharge point. The completion process takes into account estimated information about the systems, topographical bases, and current maps obtained in one-on-one meetings with administrative units.

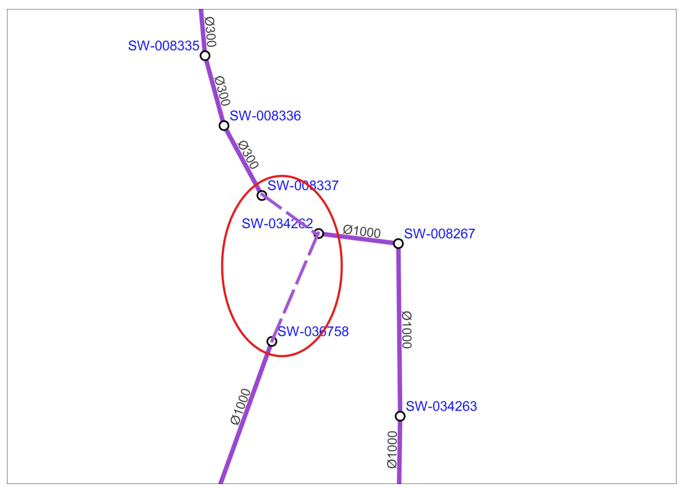


Figure 2. Sample error of the disconnection of points and lines (i.e., disconnection of manholes with lines).

2. Missing discharge lines: This error refers to lines that lack an outlet line extending to the final discharge point (Figure 3). To resolve this issue, the line is extended from the last manhole to the discharge point, vertically connecting it from the shortest distance. The diameter of the last pipe is considered, and if the discharge point is a stream, the bottom elevations of the stream are taken into account. If the discharge point is a lake or sea, the slope of the previous line is considered.

3. Indeterminate cross-section dimensions of lines: This error occurs when cross-section dimensions are undefined or empty in the attribute table. The deficiency is completed by assuming that it is the same size as the previous line.

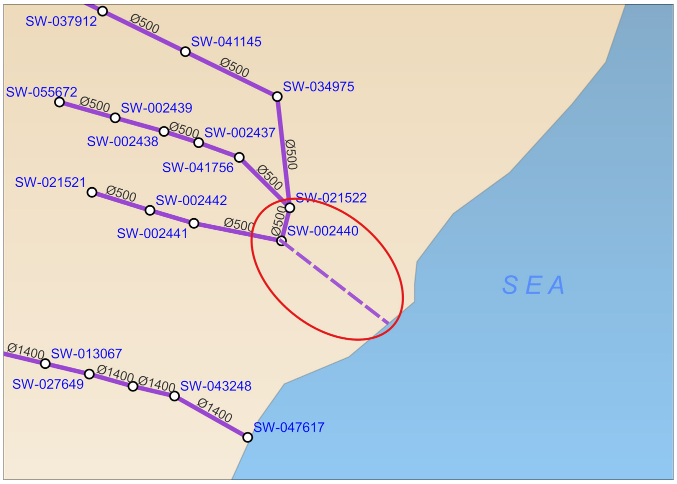


Figure 3. Sample error of the missing discharge line.

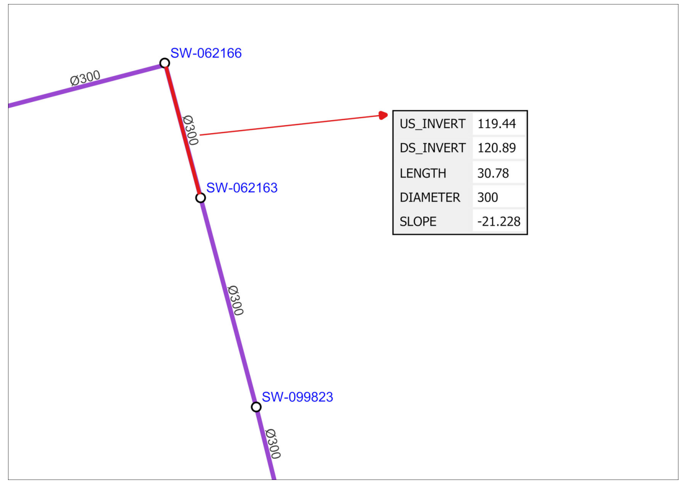


Figure 4. Sample error of the reverse slope of the pipeline.

4. Line elevations not defined: This error represents lines that are not determined, defined as 999.99, or as the same as manhole ground elevations. To address this error, the deficiency is completed by considering the flow levels of the previous/next pipe and manhole. If information is lacking for more than one manhole and/or line, the nearest manhole and/or lines with available information were used.

5. Undefined ground level in manhole: This error refers to manhole floor levels that are undefined or defined as 999.99. To complete the missing data, the Digital Elevation Model (DEM) is used.

6. Manhole ground level and base level being equal: This error occurs when the manhole floor level is incorrectly the same as the ground level. To resolve this issue, the ground level is first checked on the digital elevation model, and then the completion method #4 is applied.

7. Pipe ridge elevation > ground elevation: This error occurs when the pipe ridge elevation is above the ground. If the drain line is acceptable, no further action is required. Otherwise, the flow level and diameter compatibility at the beginning and end of the pipes is checked. If these conditions are not met, the ground level is checked, and the arrangement is made accordingly.

8. Two lines output from one manhole: It means that there are two lines downstream of the manhole. (When a collector divides into two or more branches, the flow calculations become more complex, and as a result, some modeling software may not be capable of solving such situations)

Arrangement method: If the capabilities of the modeling software used can solve this situation, it is used exactly, otherwise, it is reduced to a single line.

9. Reverse slope of the lines: The elevation of the stream on the upstream side of the line is lower than that on the downstream side (Figure 4).

Arrangement method: Correction for deficiencies no. 4, 6, and 7 is applied on reverse sloping lines, otherwise, it is accepted as is.

10. Zero-slope lines: These are the lines with equal stream elevations upstream and downstream (Figure 5).

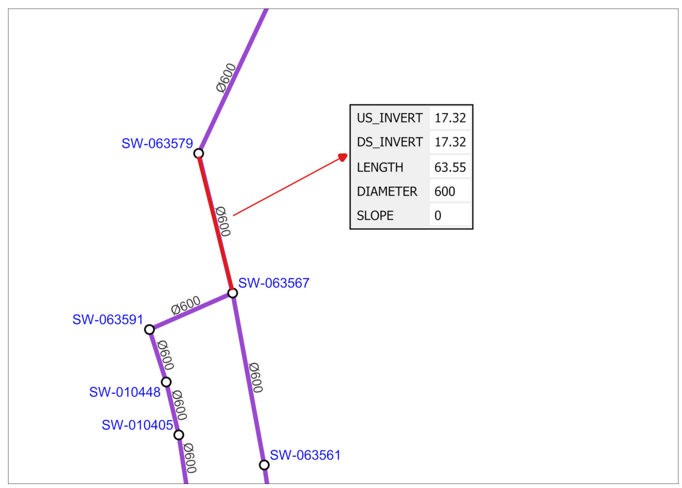


Figure 5. Sample error of the equal flow levels of the pipeline.

Arrangement method: Correction for deficiencies 4, 6, and 7, such as reverse slope lines is applied, otherwise, it is accepted as is.

11. Single lines: Usually refers to culverts and road crossings.

Arrangement method: Since single lines with large cross-sections are usually produced at road crossings, there are no upstream and downstream lines. Therefore, they are not considered as part of the collector system.

12. Multiple points at close range represented by a single manhole: Large cast-in-place manholes represented by multiple point objects with the same characteristics.

Arrangement method: If this manhole definition is made as 2 or 3 points, these points are arranged to be defined with a single point for the hydraulic model base.

13. Small section lines between large section lines: Small section lines connecting two large section lines (Figure 6).

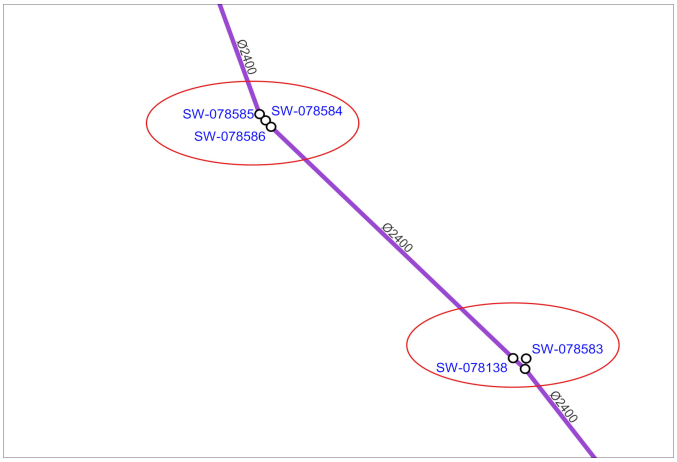


Figure 6. Sample error of the multi-point display at near-distance of cast manholes.

Arrangement method: The section size compatibility is checked by examining the entire line. In this context, if the difference between the dimensions is large, the diameter is considered large; otherwise, it is preserved.

14.Repeating or crossing lines on the same route: It is the situation where there are lines of different or the same size on the same axis or road (Figure 7).

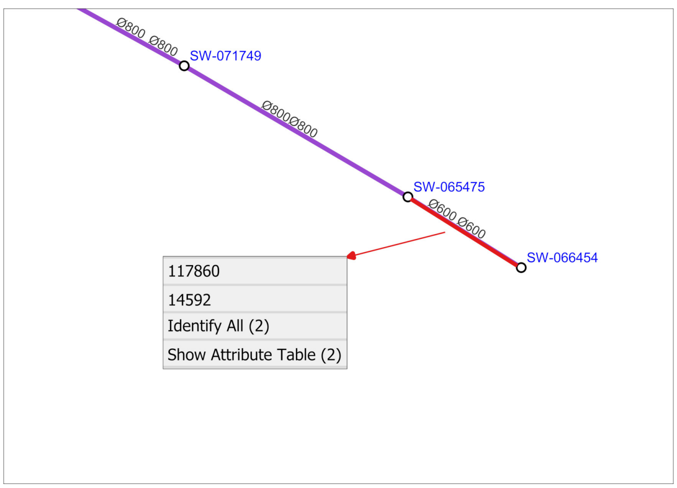


Figure 7. Sample error of repeating or crossing lines on the same route.

Arrangement method: If there are lines starting from the same upstream point, manufactured on the same axis, on different dates, and cut in different diameters and discharged to the same point, the larger diameter line or the newly constructed line is preserved.

To overcome the problems experienced during the transfer of planning from the CAD environment to the GIS environment, it may be advantageous to use middleware that we develop ourselves. The Autolisp platform, which is Autocad's macro development interface, stands out with its widespread awareness and capabilities.

Figure 8 shows the algorithm to convert an infrastructure plan in an Autocad file to an Excel sheet of manholes, along with their attribute information using the AutoLISP Visual Basic code.

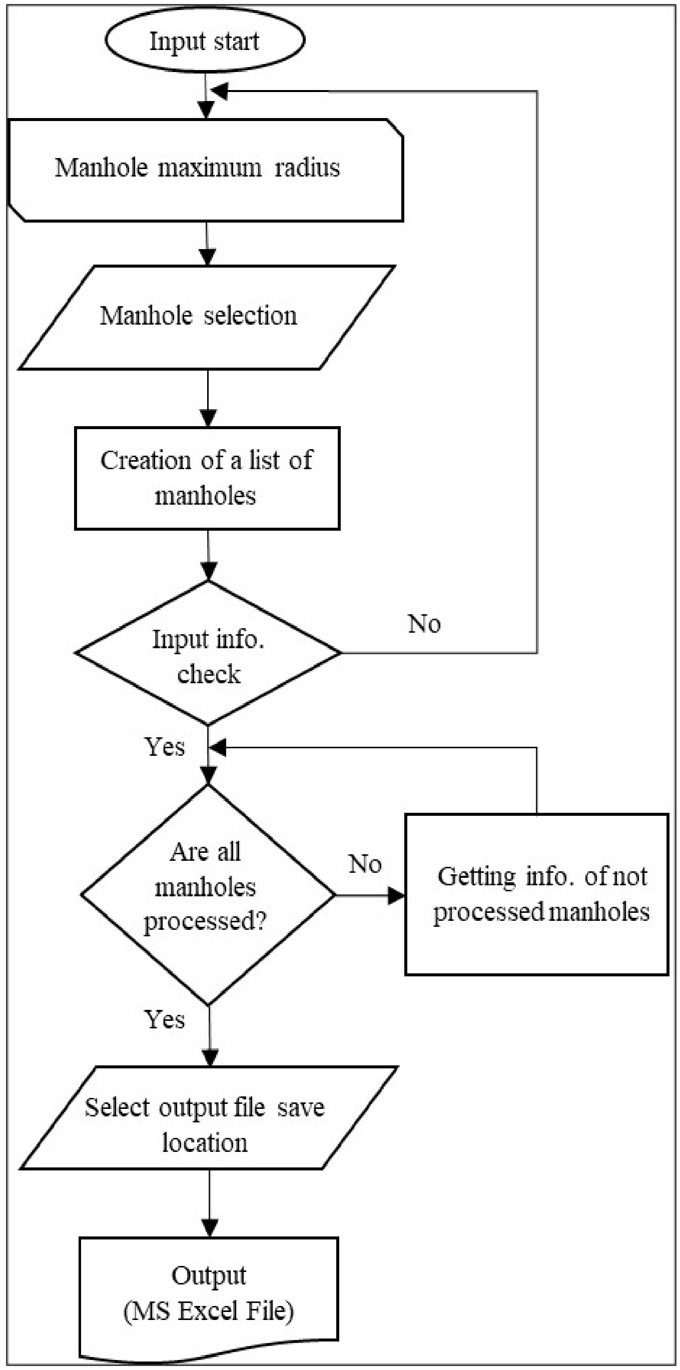


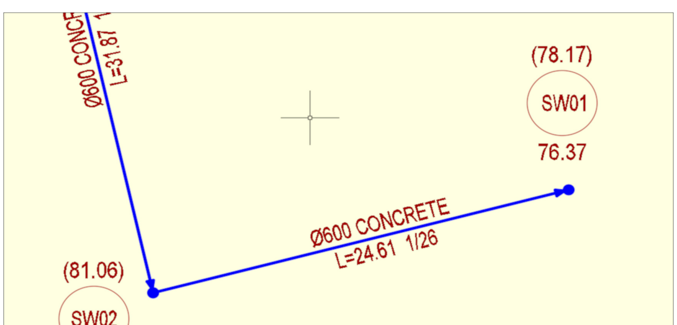
Figure 8. Flowchart to convert an Autocad file to an Excel sheet of manholes.

The algorithm presented here extracts essential information from manholes in a sewer network using the AutoLISP Visual Basic code. Specifically, the code captures the coordinates of the manholes from the center of the circle, as well as their respective manhole numbers, ground elevation, and flow elevation information from the texts written on the manhole.

The explanation of each step of the algorithm is provided below.

1- Start Lisp: The program starts by invoking Lisp.
2- Get User Input ”Enter the maximum manhole radius”: This step prompts the user to enter the maximum manhole radius that is required for the separation of manhole and label circles.
3- Get User Input ”Select Manholes”: This step prompts the user to select the manholes for which data needs to be exported to an Excel file.
4- Creates a list from manhole circles: This step creates a list of manhole circles that have been selected in step 3.
5- Suitability check for the Radius and Selection inputs: This step performs suitability checks for the maximum manhole radius and the selected manholes. If the input values are not suitable, the program returns to step 2. If the input values are suitable, the program proceeds to the next step.
6- Are all manholes processed? (Loop): This step checks whether all the manholes have been processed in a loop. If all manholes have been processed, the program proceeds to step 7. If not, the program extracts the X, Y coordinates, manhole number, ground level, and manhole invert level from the manhole label texts and proceeds to the next iteration of the loop.
7- Select a location for save data to an excel file: This step prompts the user to select a location to save the data to an excel file.
8- Write Manhole data list to Excel file: This step writes the list of manhole data to the Excel file that has been selected in step 7.

Figure 9 shows the sample of the extracted information and transferred to an Excel file. The the output file can be easily converted to a GIS shapefile format, allowing for efficient data analysis and further processing in the GIS environment.



MANHOLE NO	X	Y	GROUND LEVEL	INVERT LEVEL
SW-SW03	405017.066	4544708.005	82.05	80.46
SW-SW01	405031.404	4544644.793	78.17	76.37
SW-SW04	405024.464	4544675.894	82.05	80.46
SW-SW02	405031.404	4544644.793	78.17	76.37

Figure 9. Example of transferring manholes CAD data to excel with Autocad Visual Basic lisp.

IV. Conclusion

The proper design and modeling of urban water supply and drainage systems are essential for urban planning and infrastructure development. Effective hydrodynamic modeling requires careful consideration of multiple factors, such as data collection, model setup, calibration, and validation. Accurate data collection is essential for developing a reliable model, and it involves the use of appropriate data quality improvements approaches, such as data cleaning, filtering, and normalization. The editing and arrangement of data help to ensure the quality of the model and avoid errors. The correction and validation of input data are also critical stages that enable the model to represent the real-world system accurately. This requires a thorough understanding of the hydraulic and geometric properties of the system components and the use of appropriate software tools to model and analyze the system’s behavior. The presented guidelines and data quality improvement methods in this paper provide a useful framework that helps to ensure the accuracy and completeness of the data used in the modeling process. Furthermore, the use of middleware, such as Autocad Visual Basic code can streamline the data transfer process between different software environments and facilitate the integration of data into a GIS platform. GIS tools and algorithms provide a range of benefits, such as data visualization, spatial analysis, data editing, and the ability to integrate multiple data sources. This integration enables efficient visualization and analysis of the urban water supply and drainage system’s behavior and performance, aiding decision-making processes related to system design and management.

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