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GIS AND HYDRAULIC MODELING FOR WATER DISTRIBUTION AND SEWER NETWORKS

BY

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Abstracts: There are thousands of hydraulic models implemented around the world, many of which are linked to GIS. All GIS users can greatly leverage the value of their data by using it to build models quickly. However, these links require more than the wholesale import of raw GIS data into a model. To deliver maximum value, the model needs additional functionality to manage GIS data import and export.

Key words: GIS, hydraulic modeling, waer distribution networks.

1. Introduction

Commercially available models are reviewed with comments on their suitability and to assist in the preparation of the procurement contract a draft model specification has been prepared. In addition a range of GIS options have been assessed together with their links to the network models.

For hydraulic modeling a three stage process is undertaken.

Stage 1 – data collection and model building

Stage 2 – model verification with comparison of observed flow and level or pressure data

Stage 3 – use of the models in investigative and predictive mode

2. Main Use of GIS

The main uses of the Geographical Information System (GIS) in implementing for water distribution networks and sewer networks are:

Data Collection: Conventionally data on networks is collected and stored in paper format. This is not only labour intensive and error prone but makes data retrieval and use very tedious. Using technologies such as GPS and digital cameras, data collection can be faster and more accurate and GIS can provide integration of data. In areas where digital data is not available paper plans can also be scanned and used. For newly developed areas where no data is available aerial photographs or satellite images can be used. It is also possible to use a combination of raster and vector data.

Data Storage: Data on network components can be stored in GIS for spatial querying. The main data that will be stored will be pipe and node locations and characteristics. Pipe data is held in the system in a node and line type format. This is ideally suited to the pipeline type layout with nodes and connecting pipe-work. Data can be input in several ways, either directly onto to the screen, from a digitiser, or from previously captured data that can be read into the database as long as it has a record of its grid co-ordinates and connectivity. The GIS includes an import facility for standard GIS to enable interoperability.

Data Mapping: generating the mapping of water, wastewater and storm water networks for various criteria using GIS makes everyday querying based on specific criteria quick, easy and understandable for engineers. Fundamentally the model presents information, as on a map. But it is an intelligent map in that each item that you can see is supported and described by other data that the user can access by a simple click on the mouse button. There is a great deal of flexibility in the way that data can be used. Background maps in a variety of formats can be supported. The GIS contains a standard database structure to hold all the data that is regularly used for water, wastewater and storm water networks, but the system is not limited to just this data. Any data set can be viewed provided that the information is given either a grid reference or a cross-reference to an item (node or line). With maps and data in the system it is easy to view and interrogate. Information can be viewed selectively, for example with different layers switched on and off as need may be. Or data can be filtered: e.g. only pipes of greater than 100mm diameter can be displayed, or even those greater than 400 mm diameter viewed in blue, and those greater than 200 mm diameter in red. The graphical output can be shown in GIS and other relevant features can also be shown relative to for example, pressure variation. The model output can be overlaid on an aerial photograph of the city and also the location of consumers potentially affected shown. If the population theme is turned on, then the Select feature can select an area of interest highlighting the population at risk.

Analysis: Statistical analysis, data interpolation and spatial statistics to be carried out with in the GIS. Due to the voluminous amount of data that has to be stored in case of water, wastewater and storm water networks the various analysis tools in any standard GIS not only help in Spatial analysis but also in statistical analysis of data sets.

Visualisation: Multimedia data like photographs, videos and 3D panchromatic imagery can be stored as associated data sets to enhance real-life scenarios. This enables site condition assessments for immediate action. Also the visualisation tools in GIS can be used to find patterns and relationships in the huge amounts of data collected like pressure and flow recordings. Also the functions in GIS to plot graphs of the data help the engineers in finding anomalies in the huge data sets that is otherwise impossible to detect. Also 'what-if' scenarios can be generated and effects studied which helps in better and informed decision making.

GIS in Water Demand Modeling and Design: GIS can be used to model hydraulic conditions in spatial terms and can help in design of systems. Performance information is important to network design and in planning. A dynamic, hydraulic, water-distribution model helps to understand the effect of different demands on the network, and allows the informed decisions to be made to allow for future increases in demand. The performance of the network can be tested under extreme conditions. A GIS could establish the actual pressure head in an area based on water network model pressures and actual ground levels and also show the variation during the day.

3. Specification for Network Models and GIS

3.1. Water Network Model

A hydraulic model is a computerized, or digital, representation of a pressured closed pipe potable water supply system. The modeling software predicts hydraulic properties throughout the system: flow, pressure, operational status, tank levels, energy usage, chlorine residuals, water quality, water mixing, etc. The geometry of a hydraulic model is edges and junctions (lines and points). Pipes are represented as edges, and all other features are represented as junctions (connections, pumps, tanks, reservoirs, valves, hydrants, meters, etc.).

In detail the water network modeling software shall:

- Comply with international standards
- Be user friendly and usable by users with limited modeling expertise
- Permit any type of pipe network to be modelled such as trees, loops, grids or any combination
- Model all water network ancillaries including pumping stations, inline pumps and hydrophores, ring mains, valves, fire hydrants etc
- Allow for multiple pipe types
- Calculate water demands from basic data
- Automatically generate a network model from the model data base
- Calibrate the model based on observed data
- Accurately model flows and pressures

- Produce isometric, plan and elevation schematic views of the pipe network with background mapping
- Manage current and historical model network versions, maintaining full details of each modification made to the network geometry and control data, and providing version ID's, date stamps and modeller details for a comprehensive audit trail
- Allow for water leakage to be modelled
- Allow for steady state, extended period, water quality under extended period conditions and transient flow simulations
- Allow for fire flow analysis
- Produce model outputs that can be directly input GIS
- Produce easy to read inclusive reports.

3.2. Wastewater Network Model

A hydraulic model is a computerized, or digital, representation of a closed pipe wastewater collection system together with pressure mains from pumping stations. The modeling software predicts hydraulic properties throughout the system: flow, water levels, surcharge, operational status, wet well levels, storm water overflows, energy usage, water quality, etc. The geometry of a hydraulic model is edges and nodes (lines and points). Pipes are represented as edges, and all other features are represented as nodes (manholes, pumping stations, overflows, etc.).

In detail the waste water network modeling software shall:

- Comply with international standards
- Be user friendly and usable by users with limited modeling expertise
- Permit both free flow and surcharged flow conditions
- Model all wastewater network ancillaries including pumping stations, bifurcations and overflows etc
- Allow for multiple pipe types
- Calculate waste water discharges from basic data
- Automatically generate a network model from the model data base
- Accurately model flows and water levels
- Produce isometric, plan and elevation schematic views of the pipe network with background mapping
- Manage current and historical model network versions, maintaining full details of each modification made to the network geometry and control data, and providing version ID's, date stamps and modeller details for a comprehensive audit trail
- Allow ground water infiltration to be modelled
- Allow for dry weather flows, water quality and storm flows
- Produce model outputs that can be directly input into GIS

- Produce easy to read inclusive reports.

3.3. Storm Water Model

A hydraulic model is a computerized, or digital, representation of a closed pipe or open channel storm water collection system together with storm rainfalls and inflows. The modeling software predicts hydraulic properties throughout the system: rainfalls, storm inflows, flows, water levels, surcharge, etc. The geometry of a hydraulic model is edges and nodes (lines and points). Pipes and channels are represented as edges, and all other features are represented as nodes (manholes, storage ponds, outfalls, etc.).

In detail the storm water network modeling software shall:

- Comply with international standards
- Be user friendly and usable by users with limited modeling expertise
- Permit both free flow and surcharged flow conditions
- Model all storm water network ancillaries including inlets, pumping stations, storage ponds and overflows etc
- Allow for multiple pipe types
- Calculate storm rainfalls
- Include catchment and contributing areas and runoff factors
- Calculate storm inflows from basic data
- Automatically generate a network model from the model data base
- Accurately model flows and water levels
- Produce isometric, plan and elevation schematic views of the drainage network with background mapping
- Manage current and historical model network versions, maintaining full details of each modification made to the network geometry and control data, and providing version ID's, date stamps and modeller details for a comprehensive audit trail
- Produce model outputs that can be directly input into GIS
- Produce easy to read inclusive reports.

It should be noted that most wastewater models include the facility to simulate the behaviour of a storm water networks by including modules for storm rainfall analysis and catchment and contributing area data. In fact in older areas, most nominally separate wastewater networks have significant storm flows and most storm water networks carry wastewater flows.

3.5. GIS

The GIS software must be able to import the water and sewer network data for use in mapping and presentations and have the facility to introduce, edit, spatial analyze, visualise and print the water and sewer data and model results.

In detail the GIS software shall:

- work within very large and/or multiple drawings
- integrate data from various sources and formats (e.g. ESRI Shape files, MapInfo TAB);
- provide multiple users access to the same drawing concurrently
- combine geo-referenced raster imagery with drawings
- view CAD data
- support global projections and co-ordinate systems
- perform data collection functions
- link external databases to the drawing elements
- Allow for operational time series data to be stored and interrogated
- Allow for video data to be displayed
- perform spatial analysis (buffers, spatial query, overlay, etc.)
- produce thematic maps
- enable user to create point, line and area topologies
- hyper-link map elements to pictures, sketched drawings, documents
- export to a wide range of industry standard formats (min. ESRI shape, AutoCAD dwg and dxf)
- printing maps

4. Collected Data

It is anticipated that a water and sewer company will collect the following data:

4.1. Water Supply

- Raw water flows and water quality
- Flows to supply with water quality and pressure
- Flows, pressures and water quality in supply system
- Pump hours run and power consumption
- Reported low pressures and supply failures
- Reported leaks and bursts
- Meter consumption records (Bulk and individual)
- Pipe data observed during repairs and connections
- New pipe data

Table1
Data for Water Network

Mapping
Street location plan
Topographical map with contours
Census data map
Detailed water network plans with catchment areas
Land use plans
Levels along water distribution mains
Utility plans (Electricity, gas, telephone, cable, heating and sewerage)
Demand Data
Population data by area
Population projections
Water supplies
Major water users (location and volumes)
Water Network Data
Schedule of pipes with size, depth, material and age
Schedule of junctions with connectivity
Schedule of valves with location, size, material and age
Operational data (leakage & bursts)
Flows from treatment (average and peak)
Leakage
Ancillaries
Pressure valves, operating limits, size, material and age
Pumping stations (size, levels, pump data)
General
Pressure data
Flow data
Repair data
SCADA data
Capital and operational cost data

4.2. Wastewater

- Inflow to treatment plant including spilled flows and water quality
- Reported surcharged sewers and blockages
- Reported sewer collapses
- Sewer data observed during repairs and connections
- New sewer data

Table 2
Data for Wastewater Network

Mapping
Street location plan
Topographical map with contours
Census data map
Detailed Sewer Network plans with catchment areas
Land use plans
Levels along sewer line
Utility plans (Electricity, gas, telephone, cable, heating and water supply)
Demand Data
Population data by area
Population projections
Water supplies
Major water users (location and volumes)
Industrial discharges
Sewerage Data
Schedule of manholes with size, depth, cover level, material and age
Pipe data with length, diameter, invert levels material and age
Sewer connectivity
Operational data (flooding, blockages & collapses)
Flows to treatment (DWFs and peak)
Dry weather flows
infiltration
Storm flows
Ancillaries
Storm overflows (dimensions and levels)
Pumping stations (size, levels, pump data)
Reservoirs (sizes and levels)
General
CCTV data
Flow data
Repair data
Capital and operational cost data

4.3. Reports of Flooding

- Reported surcharged sewers and blockages
- Reported sewer collapses
- Reports of sewage overflows
- Sewer data observed during repairs and connections

• New sewer data

Table 3
Data for Storm Sewer Network

Mapping
Street location plan
Topographical map with contours
Detailed Storm Sewer Network plans with catchment areas
Land use plans
Levels along drain lines
Utility plans (Electricity, gas, telephone, heating, industrial and domestic waste water and water supply)
Rainfall Data
Depth-Area-Frequency curves
Design storms
Storm rainfalls during flooding
Rain gauges and Thiessen polygons
Storm Sewerage Data
Schedule of manholes with size, depth, cover level, material and age
Pipe data with length, diameter, invert levels, material and age
Sewer connectivity
Operational data (flooding, blockages & collapses)
Details of outfalls to river
Dry weather flows
Storm flows
General
CCTV data
Flow data
Repair data
Capital and operational cost data

4.4. Utility Mapping

• Electric supply network
• Gas network
• Heating pipe network
• Telephone cables
• Cable TV network

5. Conclusion

The key parameter in selection of software is the ability of the GIS and database to store all of the water supply and wastewater network data together with the operational data, so that all of the separate types of data are integrated without extensive customisation by GIS analysts.

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REFERENCES

1. Smith T., *Integrated Urban Drainage Lessons from the Birmingham Pilot.* Conf. WaPUG, Birmingham, 2007.
2. Tamasauskas H., Larsen L.C., Mark O., *Using GIS in Water Supply and Sewer Modelling and Management,* Danemarca, 2006.
3. Tomic S., *Developing Hydraulic Models Using GIS.* Geospatial Solutions, 2006.
4. Zang T., *Application of GIS and CARE-W Systems on Water Distribution Networks in Skarholmen in Stockholm.* Master's of Sci. Th. in Geoinfornatics, Stockholm, 2006.

GIS ŞI MODELARE HIDRAULICĂ A REŢELELOR DE ALIMENTARE CU APĂ ŞI CANALIZARE

(Rezumat)

Există sute de modele hidraulice implementate, mult edintre ele fiind integrate cu GIS. Valoare datelor utilizate de GIS creşte prin contsruirea rapidă a modelelor. Această integrare presupune mai mult decât importul datelor. Pentru a lucra la adevărata valoare, modelul are nevoie de funcţii suplimentare pentru managementul datelor GIS.