EFFECTIVE MODELLING FOR UTILITY OPERATION

J Viyakesparan FCIWEM, MICE, C.Eng, MSc, BSc(Hons) MWH New Zealand Limited

ABSTRACT

Water distribution modeling has been used as a hydraulic tool since the early 1980's. Initially used by Consultants as a tool to provide answers for a number of solutions, but since the late 1980's more and more by Water Utilities as part of their day to day operational business. The initial thought of Water network or distribution models is that they reside with a model keeper within a Water Utility whether in the Leakage section, Asset planning section or Capital works section there are many different thoughts or views for their use within a Water Utility. Generally, they seem to reside with a person or department where the use of such models is seen as a useful tool for the respective job function.

This paper seeks to enlarge the domain for the use of these models within a Water Utility, if anything perhaps enlightens the reader to "think outside the box".

The uses of Water distribution models have evolved beyond expectation in the last five years with the increased computer power available and the accessibility to computers within the work place is common place. With the increased automation of Water distribution models by linking or accessing asset data from corporate Geographical Information Systems (GIS), the value placed on these Hydraulic models can extend beyond just the run of the mill uses.

KEYWORDS

Hydraulics, Modelling, Water Networks, Integration, Efficiency and Added Value.

1 INTRODUCTION

Privatised water companies in around the world are currently battling a whole host of pressures and challenges, not the least of which are the demanding efficiency targets imposed by Regulators. The Regulators exists to ensure that utility customers are neither over-charged, nor under-served for their services. The organisation's most prevalent demand, applicable to all utilities, is the requirement to submit an Asset Management Plan (AMP), detailing each water company's strategy for meeting the regulatory requirements.

In addition to the regulations, water companies and utilities around the world are also facing significant extreme weather conditions, whether by droughts or flooding both of which are tending to occur at greater frequency. Delivery of the required level of service is placed high as a charter within water utilities. So the day-to-day operation of the network is off paramount importance, even more so with the "out sourcing" of such services by the water utilities. This provision of an adequate level of service is required by the customer and even more so with customer expectations of quality for a service they are paying for.

The third variable the water utilities are have to balance against is performing for the shareholder, who expect to see the value of their share increase, by the profit made by the water utility.

Many water utilities in New Zealand have invested a large amount of money in purchasing water distribution software and building network models of their respective water supply systems. Are these network models being used effectively throughout the business?

Figure 1: The balancing act

So how can modelling assist?

- To assess current situations and problematic areas
- Simulations of engineering solutions to test and evaluate costs and benefits
- Investment decisions can be made with more confidence and effectiveness
- The estimated savings in terms of capital and operational efficiencies runs into $M!

2 A SHORT HISTORY OF WATER NETWORKS AND MODELLING

2.1 THE HISTORY OF WATER DISTRIBUTION

Water distribution modeling is the latest technology in a process of advancement that began two millennia ago when the Minoans constructed the first piped water conveyance system. Today, water distribution modelling is a critical part of designing and operating water distribution systems that are capable of serving communities reliably, efficiently, and safely, both now and in the future. The availability of increasingly sophisticated and accessible models allows these goals to be realised more fully than ever before.

2.1.1 HISTORICAL DATES IN WATER DISRIBUTION MODELLING

1500 B.C. - First water distribution pipes used in Crete. The Minoan civilization flourishes on the island of Crete. The City of Knossos develops an aqueduct system that uses tubular conduits to convey water. Other ancient civilizations have had surface water canals, but these are probably the first pipes.

100 A.D. - Roman aqueducts. The Romans bring water from great distances to their cities through aqueducts. While many of the aqueducts are above-ground, there are also enclosed conduits to supply public fountains and baths. Sextus Julius Frontinus, water commissioner of Rome, writes two books on the Roman water supply.

1845 - Darcy-Weisbach head loss equation developed. Julius Weisbach publishes a three-volume set on engineering mechanics that includes the results of his experiments. The Darcy-Weisbach equation comes from this work, which is essentially an extension of Chezy's work, as Chezy's C is related to Darcy-Weisbach's f by

C^2=8g/f. Darcy's name is also associated with Darcy's law for flow through porous media, widely used in groundwater analysis.

1906 - Hazen-Williams equation developed. A. Hazen and G.S. Williams develop an empirical formula for head loss in water pipes. Although not as general or precise in rough, turbulent flow as the Darcy-Weisbach equation, the Hazen-Williams equation proves easy to use and will be widely applied in North America and New Zealand.

1936 - Hardy Cross method developed. Hardy Cross, a structural engineering professor at the University of Illinois, publishes the Hardy Cross method for solving head loss equations in complex networks. This method is widely used for manual calculations and will serve as the basis for early digital computer programs for pipe network analysis.

1938 - Colebrook-White equation developed. Cyril Colebrook and Cedric White of Imperial College in London build upon the work of Prandtl and his students to develop the Colebrook-White equation for determining the Darcy-Weisbach *f* in commercial pipes.

1944 - Moody diagram published. Lewis Moody of Princeton University publishes the Moody diagram, which is essentially a graphical representation of the Colebrook-White equation in the turbulent flow range and the Hagen-Poisseuille equation in the laminar range. This diagram is especially useful because, at the time, no explicit solution exists for the Colebrook-White equation.

1960s and '70s - Earliest pipe network digital models created. With the coming of age of digital computers and the establishment of the FORTRAN programming language, researchers at universities begin to develop pipe network models and make them available to practicing engineers. Don Wood at the University of Kentucky, Al Fowler at the University of British Columbia, Roland Jeppson of Utah State University, Chuck Howard and Uri Shamir at MIT, and Simsek Sarikelle at the University of Akron all write pipe network models.

1970s - Models become more powerful. Although the earliest pipe network models could only solve steady-state equations for simple systems, the '70s bring modeling features such as pressure regulating valves and extended-period simulations.

Early 1980s - Water Quality Modeling First Developed. The concept of modeling water quality in distribution systems is first developed, and steady state formulations are proposed by Don Wood at the University of Kentucky and USEPA researchers in Cincinnati, Ohio.

1990s - Privatization of water utilities. The privatization of water utilities increases significantly as other utilities experience a greater push toward deregulation.

1993 - Introduction of water quality modeling tool. Water quality modeling comes of age with the development of EPANET by Lewis Rossman of the USEPA. Intended as a research tool, EPANET provides the hydraulic engine for several commercial modelling software.

1990 through present. Several commercial software developers release water distribution modeling packages. Each release brings new enhancements for data management and new abilities to interoperate with other existing computer systems.

2001 – Genetic Algorithms. Automated calibration of distribution models moves from being a research tool to a standard modeling feature with the use of Genetic Algorithms.

2001 - Security awareness. Water system security increases in importance and utilities realize the value of water quality modeling as a tool for protecting a water system.

2002 - Integration with GIS. Water modeling and GIS software become highly integrated.

3 WATER UTILITY FUNCTIONS

3.1.1 OVERVIEW

The modern water industry operates sophisticated and costly water and wastewater networks and sewage treatment plants, and typically consumes 1-2% of GDP. It is generally a natural monopoly, and as a result is usually run as a public service by a public utility which is owned by local or national government. In some countries, notably France, the UK and the Czech Republic, the water industry is regulated but services are largely operated by private companies with exclusive rights for a limited period and a well-defined geographical space.

3.1.2 ORGANIZATIONAL STRUCTURE

There are a variety of organizational structures for the water industry, with countries usually having one dominant traditional structure, which usually changes only gradually over time. A typical structure is shown below in Figure 2.

Figure 2: Typical Company Structure

There are also a number of ways in which water companies are owned, typically by those listed below:-

- Local government
- National government - in many developing countries, especially smaller ones
- Private ownership - relatively few examples outside England
- Co-operative ownership and related NGO structures.

The way water companies operate will also vary according to governess, typically as follows:-

- Local government operating the system through a municipal department, municipal company, or inter-municipal company - the most usual structure worldwide
- Local government outsourcing operations to the private sector - an increasing trend since around 1990; around 10% of the industry

- National government operations
- Private sector operating a system it owns.

For the usual privatization structure of keeping assets public and privatising service operations, there are three major types, in order of increasing risk transfer to the private operator:

- Management contract, under which the private operator is responsible only for running the system, in exchange for a fee (usually performance-related). Investment is typically financed and carried out by the public sector, but implementation may be delegated.
- Lease contract, under which assets are leased to the private operator, who recoups the cost from end users. Investment is typically financed and carried out by the public sector, but implementation may be delegated.
- Concession, under which the private operator is responsible for running the entire system, including planning and financing investment. Concession contracts usually run for 20-30 years.

Therefore increasingly as more and more water utilities tend towards this mode of operation and management of assets, the knowledge of the network assets, the operation and the way it behaves are being lost as individuals with that knowledge leave.

Therefore it is import that water utilities maintain and update their corporate GIS system to hold the most up-to-date information. From these data sets network models can quite readily be produced with the advance in interrogating tools with the software package itself.

Accurate asset records and an understanding of asset behaviour are essential for safe and efficient operations and optimal asset management of a water utility.

GIS and modelling service offerings are geared to help utilities to record and understand their asset infrastructure. With accurate records network models can assist companies to derive greater value from its infrastructure, extend the life of its assets and plan and optimise future system improvements and expansion. With solution experts involved in every stage of asset life, water utilities can maximise profitability and return on investment across the entire asset lifecycle.

Along with the various other corporate databases holding billing data, meter data, financial and operational data, water utilities can automate business processes and improve overall performance via application development, database and data development, systems integration and information technology infrastructure.

Such services allow companies to extract the customized enterprise-wide information needed to support business decisions based on existing GIS, OMS, SCADA and/or CIS data, or the term **“Integrated Network Management (INM)”**. The key objectives of the INM approach are to:

- provide a greater understanding and better control of water network assets
- provide the optimum level of service for customers
- reduce operating costs and risks
- provide capital efficiencies through effectively targeted investment.

This approach is essential to the development of an economic and proactive strategy for network management and the course aims to review the issues relevant to the successful implementation of INM for Water Distribution Network Management. With regard to the place of modelling within INM, true INM looks forward and compares reality with prediction – which means you have to have models to do the prediction. Thus, modelling is an essential part of INM.

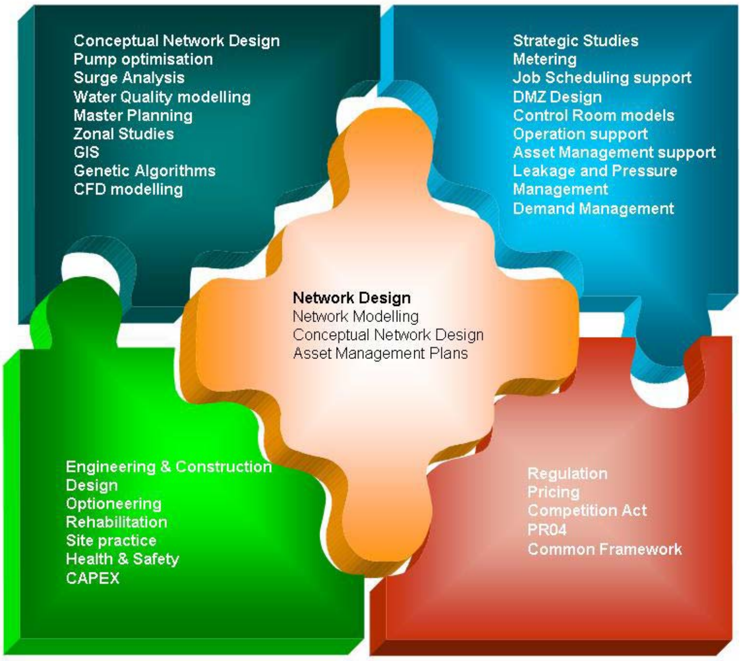
4 WHERE DO NETWORK MODELS FIT IN

Water utilities traditional have less than adequate investment/maintenance of their assets, and are in need of significant capital and operational changes in order to satisfy the ever-increasing standards of customer service. In addition, Network Managers are coming under ever increasing additional pressure, from both regulators and shareholders to manage the networks at least risk and least cost.

4.1 THE JIGSAW

The general puzzle illustrated below in terms of where network modelling has a part to play with the core day to day business. Many of these functions are or may already be carried out within a water utility and in different ways.

Figure 3: The" puzzle"



A water utility will need to understand the purpose to which integration is required and the operational and financial drivers that determine the direction of integration the different management systems into one seamless way of reporting.

The three distinct functions tend to be (i) planning and engineering, (ii) operational and (iii) corporate and business needs. The problems and limitations of all the existing management systems need to be assessed before hand.

Common limitations found generally are listed below:-

- Billing data difficult to extract on an area basis
- Multiple conversion requirements
- Time consuming
- Need for manual intervention
- Subject to currency of data
- Room for error because of translation needs
- Telemetry in different formats

- Varying reliability and frequency of data on telemetry
- Operational changes input manually
- Varying quality of reports
- Missing data
- Not all changes recorded.

The impacts of one or more of the above can have are:-

- Reliability and frequency of data affects Engineering Design (Pump specification, pipeline sizing etc
- Inaccurate data prohibits accuracy of Forecasting and hence planning
- Speed of information turnover not adequate to satisfy operational needs
- Reactive decision due to speed, not enough Management information tools for proactive approach
- Distorted Global view of all components hence misleading overall picture; not appropriate for good Business and Corporate Planning and Decision
- Sporadic and ineffective Feedback.

4.2 THINKING OUTSIDE THE BOX

In order for water utilities to embrace the change they face, the whole conceptual model of how business streams communicate within the utility need to be assessed and adapted to suit the requirement. Benefits that are possible include:-

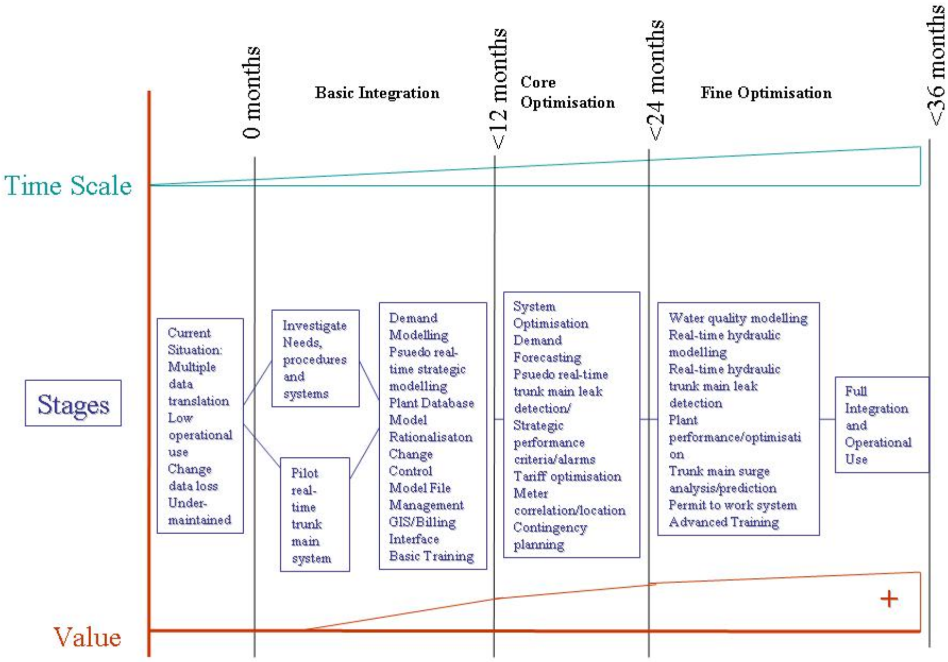
- Rapid response to events (bursts/Water Quality/Blending etc)
- Efficiency in Operation (Power costs/purchasing, Targets, Storage Maximisation, Pump scheduling)
- Proactive Management of Operations
- Short and Long term Planning
- Targeting Maintenance Areas
- Feedback-leading to cyclic efficiency
- Enhanced customer service

This is not a straight forward change management idea, it takes time one company took eight years from concept to implementation. Depending on the size of the utility, area of operation/coverage and number of data management systems this time scale can vary. The example is shown below in Figure 4 shows a typical time line through the process that may be required.

The way forward:-

- Water utilities are moving toward customer focus, using an integrated approach
- Application of real-time technology to satisfy customer and business needs
- Traditional management and operational approach will ensure Water Utilities survive
- Integration will ensure that the Water Companies THRIVE

Figure 4: Time line example of implementation



5 AREAS OF BUSINESS INTEGRATION

The following section describes some areas in which network models have been used to integrate a water utility process to achieve a benefit to a water utility. As with all investigations the quality of data is essential to the output of reliable results that that is within acceptable confidence levels.

The examples given below highlight recent or current areas of concern with a number of water utilities. They exemplify finance, ageing assets and operation of assets.

5.1 PUMP SCHEDULING ENERGY MANAGEMENT

Energy costs generally constitute the largest expenditure for nearly all water utilities worldwide, consuming as much as 65 percent of their annual operating budgets. The price of electricity is also rising at a far higher rate than labor costs making it likely that it will become the dominant cost in production and distribution of water in the near future.

The primary goal of an energy management system for a water utility is therefore to save energy costs for pumped water. The ability to measure those savings is important. Calculating the return on investment in energy management is required to determine the pay back period. One of the greatest avenues for energy cost savings is improved scheduling of daily pump operations.

Pumps in particular consume approximately some 80 percent of all the electricity used by the water industry. It is therefore financially important to ensure that

- individual pumps operate efficiently
- they are fit for purpose
- pump usage is optimised

However, it is not realistic to look at pump optimisation in isolation, there are numerous inter-relations between different elements of the network, which have to be taken in to account if a complete, robust and workable solution is to be provided.

Principal Driver = Utilities need to reduce Power and Chemical costs as part of an overall driver to lower operational expenditure

5.1.1 CASE STUDY SCOTTISH WATER GRAMPIAN STRATEGIC NETWORK

A water utility in the UK wanted to understand what kind of energy savings were achievable by optimising the pump schedule used to control the flow of water between source and storage and make use of cheaper night time tariffs. The principal aims of the methodology were:-

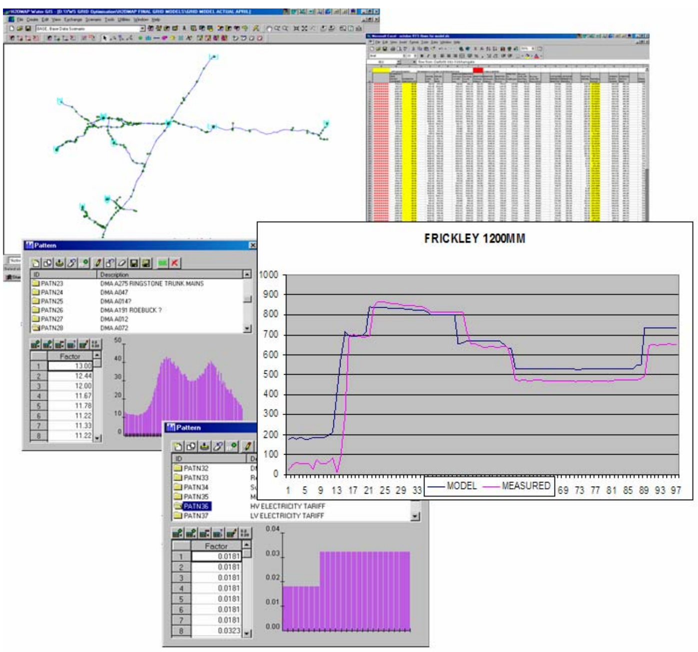
- To generate an accurate strategic model of the system to be studied
- To set this model up with the required data to both reproduce the hydraulic behaviour of the real network, and to generate accurate figures for the costs of operation on example days selected from the historical data available
- To use these costs as the benchmark with which to evaluate alternative operating strategies – developed with the aid of optimisation applications.

The use of either an existing strategic model, or if no model exists or it is out of date then a GIS extract can be imported and rapidly converted into a working strategic model.

With the physical model in place, the next step is to identify, import and apply the measured data (Flows, Pressures, Levels) required to define the boundary conditions and provide the calibration reference data i.e. run the model on recent, real data. Data sources included:

- Historical Telemetry Data
- Logger Data

Figure 5: Model to Optimised Schedule



Example days are selected on the basis of the most complete data availability and the measured demand data is imported into the model as Patterns and applied to the correct nodes. Pump switching in the model is defined as per the pump operation records for the selected days and Reservoir profiles for the selected days also stored as Patterns.

A model 24 hour simulation is then run to represent the real network on the example day. Real Data and Model Data (i.e. flow profiles and reservoir level profiles) are compared to verify that the model is reproducing the behaviour of the actual network.

In order to calculate the accurate cost of operating the network on the selected example days, the correct seasonal electricity tariffs that apply to the pumping stations in the system need to be entered into the model.

It is important at this point that the pump scheduling uses the pump efficiency and performance data as the basis for selecting pumps. Therefore, the better the data relating to the pumps present in the network, the more robust the pump selection process and the more accurate the predicted energy savings.

Each WTW has a cost per cubic meter of water produced, based principally upon the chemicals used in the treatment processes. Although the cost of operation can include manpower, waste disposal etc. It is dependant upon the data collected by the utility. These operating costs are incorporated into the model either:

- By totalising the output from each works in the model and multiplying by the corresponding operating cost
- Or by entering the cost directly into the pump scheduling module.

The pump scheduling module uses Genetic Algorithm (GA) based routines to evaluate multiple possible pump operating combinations. The results of each iteration are assessed in terms of the calculated energy costs and ability to meet the user defined constraints that have been imposed.

These constraints take the form of :-

- Reservoir target levels at end of simulation period
- Minimum pressures to be maintained
- Maximum flows not to be exceeded
- Pumps available
- Maximum number of pump switches etc.

At the end of the run, the least cost solution that meets the defined constraints is selected as the output result. The output is in the form of a summary of results and the pump control patterns used in the successful solution.

The new pump controls generated by the scheduler module are exported back to the hydraulic model and a new 24 hour simulation is run. A hydraulic check is then made of the model performance, this case example generated savings as tabulated below in Table1.

Table 1: Example Savings

Max Power Cost Saving %	**Min Power Cost Saving %**	**Max kWh Saving %**	**Min kWh Saving %**
12%	**8%**	**6.6%**	**6%**

5.2 DISCOLOURATION

Discoloration of potable water supplied to customer taps is one of the biggest causes of water quality related customer complaints. At present, understanding of the fundamental processes that cause discoloration is limited and the modeling of events unfeasible.

In recent years the Drinking Water Inspectorate (DWI) in the UK has been more concerned about discolouration and dirty water incidents and associated levels of complaints received from the public. Accordingly, the DWI has introduced new guidelines for Water Utilities to report any event that might cause alarm to customers. The DWI expects that Companies act in a careful manner and, by use of best practice, reduce the risk of discolouration.

5.2.1 CASE STUDY SOUTHERN WATER DISTRIBUTION NETWORK

Southern Water's objective is to minimise the risk of discolouration. In order to do this more effectively they propose to carry out the same risk assessment they currently practise at zone level, but at the District Meter Area (DMA) level.

The current Southern Water interim assessment for risk of discolouration considers the following categories.

- Treatment
- Mains Deposits
- Structural Condition
- Mains Capacity
- Operational Measures
- Previous History
- Complex Operation

Current industry research has many references relating to discolouration, including Boxall *et al,* (2001), Seth *et al* (2003), Abell *et al* (2002). Current trend is that discolouration rarely originates from treatment works in England and Wales and is believed to originate as a result of in-system processes, with events triggered by changes in the hydraulic regime within the network.

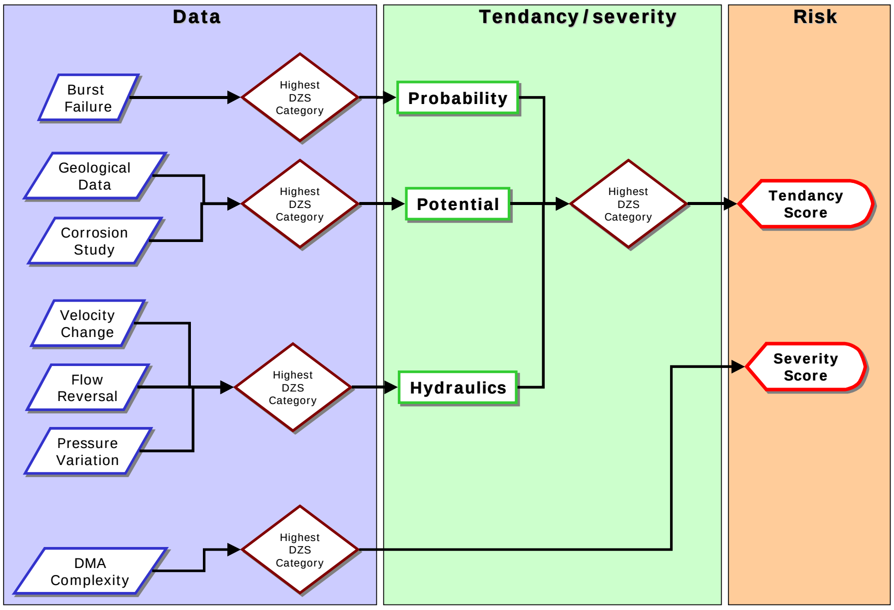
The research provided by the above authors was considered for Southern Waters strategy to carry out the risk of discolouration using a more analytical approach. For this Stage, the analysis and scoring all ready in use in a DZS Needs study will be used.

The current DZS Needs Studies can only provide hydraulic simulations of events over 24 hours under Average Day Demand (ADD) conditions. The results provided are "observations". The "risk" element is provided by the probability and impact per event that needs to be assessed.

Generating an initial concept for this Stage pass, "risk" is a combination of "tendency" and "severity". With the current data available, the "tendency" was ranked looking at the potential, likelihood and hydraulics of the assets and operation. The "severity" at this stage is hard to define and it is proposed that DMA complexity (from the Operational Review) is used as an initial indication.

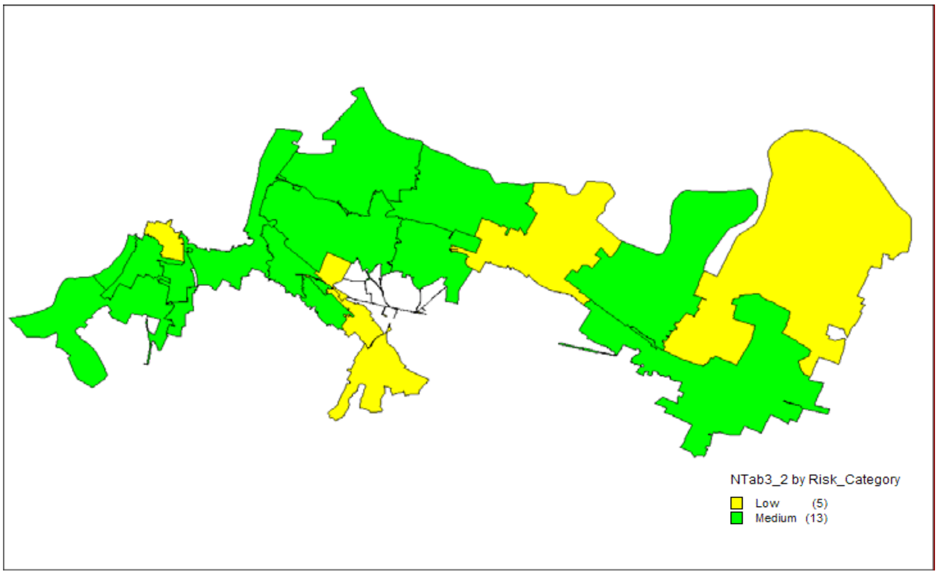
Analysing results are expected to define an initial risk banding that satisfies Southern Water requirements. Figure 6 illustrates the information that links to the process.

Figure 6: Discolouration Process Diagram



Using this approach and using network models. The results of the level of service, pipe material and velocity results can be used to produce thematic maps of high risk areas as shown below in Figure 7.

Figure 7: High Risk DMA Discolouration Map



5.3 VALVE CRITICALITY

The aim of the "Valve Criticality" project undertaken by Thames Water, UK is to identify critical valves within the Company's water supply network, in terms of their potential impact on the customer levels of service, either when they are shut or fail to shut, during planned or emergency work.

The consequence of each valve operation can be measured in terms of the number of properties being disconnected or receiving an unacceptable level of service (e.g., low pressure). An additional benefit of the project is increased knowledge on the system operation, which will enable maintenance and replacement work to be prioritised to the most critical valves.

5.3.1 CASE STUDY THAMES WATER VALVE CRITICALITY MODELLING

As it is not always obvious which valves are the most critical within a water supply network, the decision was taken to make the assessment using an all mains hydraulic model of each water pressure zone. However, with many thousands of valves to analyse, each requiring separate model runs, even a small zone could take over a week to analyse using conventional modelling software.

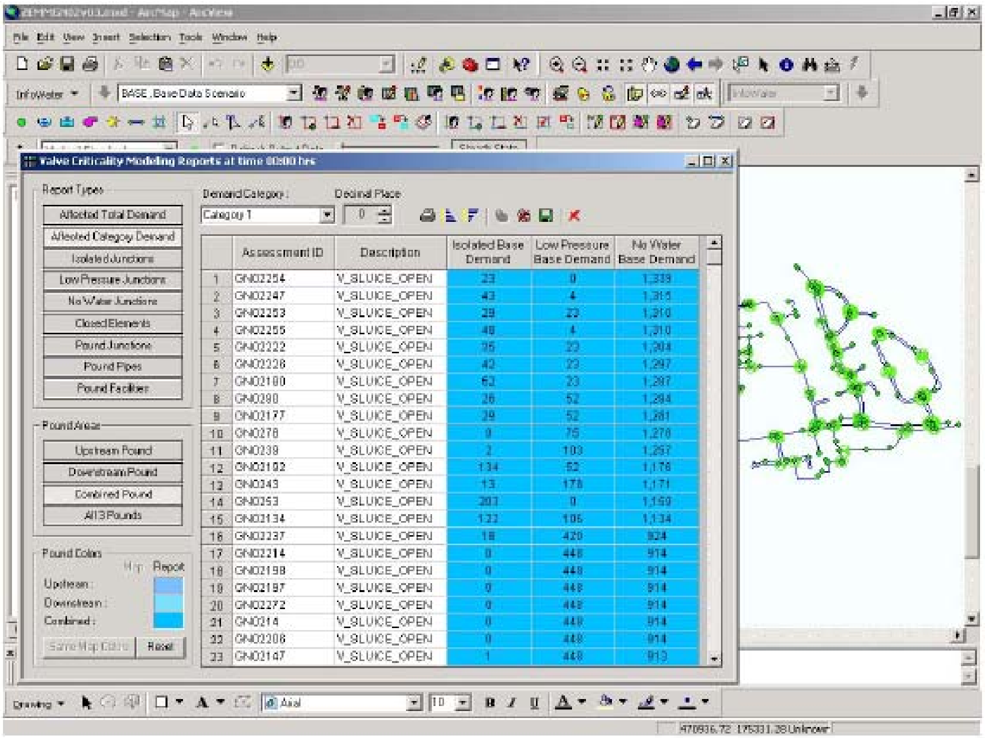
A decision was therefore taken to enhance one particular modeling software to automate the process so that thousands of valves could be analysed in one batch of model runs. A careful specification of the output results was required to avoid vast quantities of data being produced.

Network trace techniques were used to identify each section of the network to be closed in, and the next available valve, should the targeted valve fail to close.

The Valve Criticality Modeling (VCM) module was subsequently released to users (Figure 8). This now enables the user the capability to assess the criticality of the many thousands of valves within major supply networks, enabling maintenance and replacement to be targeted to critical valves. The module will help Utilities develop an optimal investment regarding infrastructure maintenance, minimising the impact on customer levels of service and improving knowledge on the operation of the network.

The tool is being developed alongside a risk assessment module, which assesses the impact of valve operation on water quality within the network.

Figure 8: Illustration of output showing properties without water



6 CONCLUSIONS

There are many more uses that these network models have been used for which are too numerous t for a paper of this kind. However, from what has been presented should give utilities to rethink the valve of the investment already made to build and operate network models.

There are efficiencies to be made that will add value to the business as a whole, these will vary from utility to utility where priorities vary.

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