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The New Zealand Water & Wastes Association Wairoa Aotearoa

Modelling Special Interest Group

NATIONAL MODELLING GUIDELINES

WATER DISTRIBUTION NETWORK MODELLING

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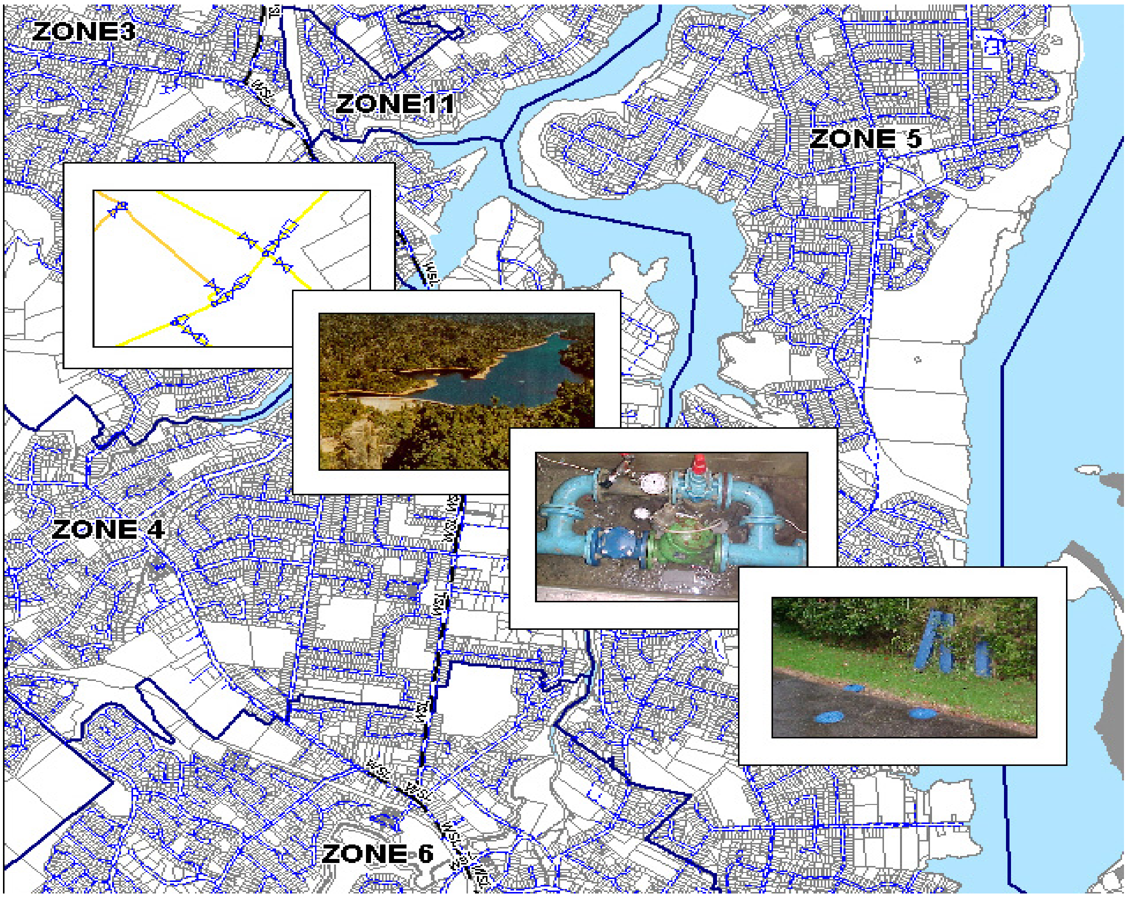

Preface

This document constitutes draft Version 1 Revision 4 of the Water New Zealand National Guidelines Module 2: Water Distribution System Modelling Guidelines. Version 1 Revision 1 of these National Guidelines Module 2: Water Distribution System Modelling Guidelines was published in April 2004.

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Table of Contents

Appendix 1: Acceptable Levels of Calibration

1 Introduction

This document was written to provide a brief overview of water supply modelling activities, intending to present some principles of “Good Modelling Practice”, for people involved in undertaking and managing water supply modelling projects – managers, designers, operational and planning engineers, consultants and others well informed or involved in the running of water distribution systems.

Development and use of water distribution models comprises of many activities and processes. As with any such complex task, it can be managed more successfully and efficiently if it is broken down into its components or stages. The staged approach of managing the modelling of water distribution systems can be presented as shown in Figure 1.1. The process is common for almost any such type of project, regardless of the size of the system and it could be divided into eight characteristic stages, namely:

a) Setting up a new modelling project or Re-establishing the existing,
b) Data Collection, Model Build (or Model Update)
c) Data Verification and Model testing
d) Model Calibration and Validation
e) Model Use
f) Results Interpretation
g) Reports and model documentation
h) Change monitoring and model management

The following should be noted in the management of the modelling process:

a) The key decision which must be made at the very start of the process is whether or not to use the hydraulic network modelling software as the right tool for providing answers to problems faced in managing water distribution systems.

b) If a hydraulic network model is the right tool, running the water distribution modelling project is an ongoing activity, which needs regular model updating and checking if the existing model is still an adequate tool for providing answers to actual requirements.

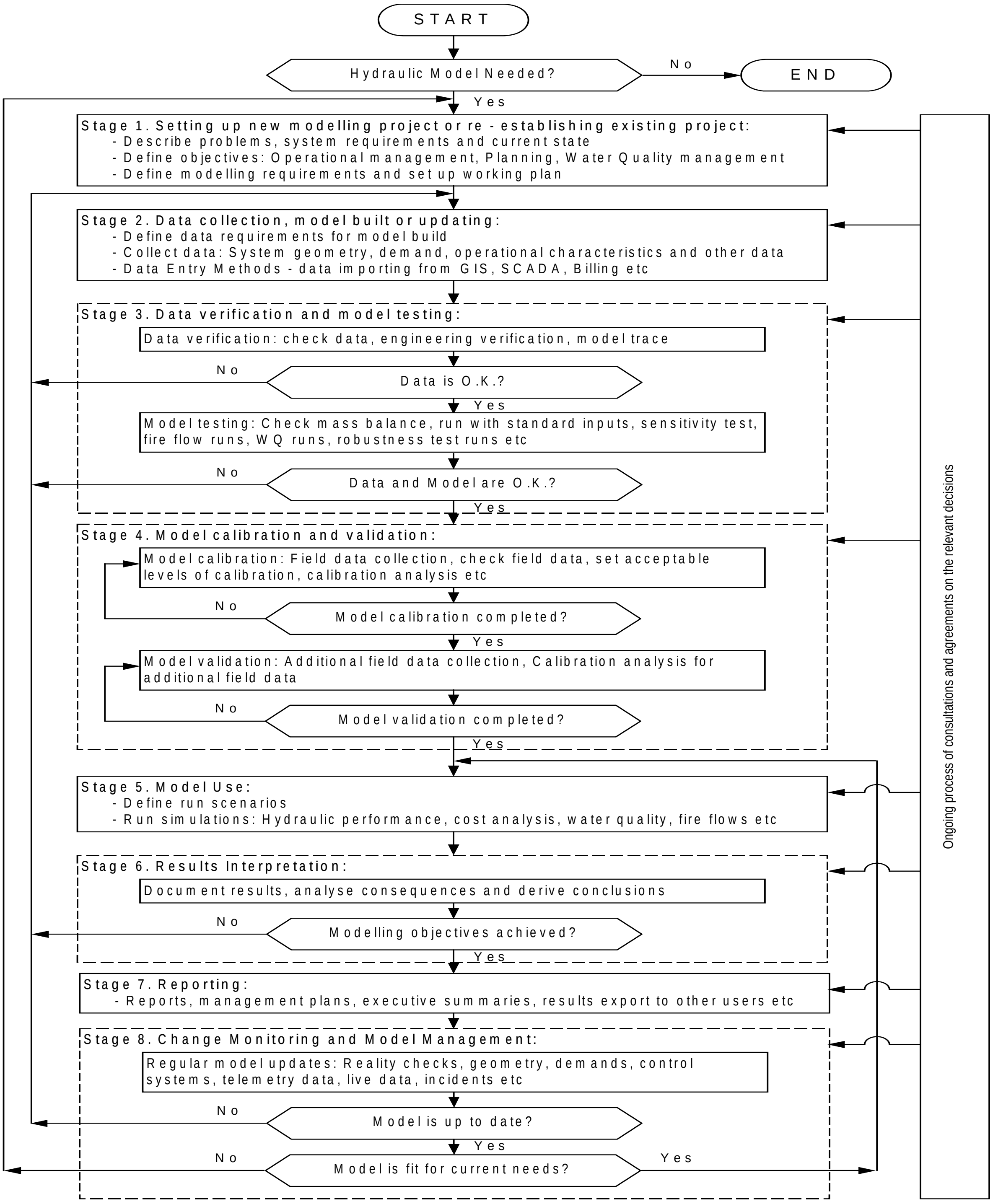
c) The process of the management of the modelling process inherently has many loops and feedbacks from previous steps.

d) One of the key characteristics of the process is that these feedbacks make the modelling work an iterative process – not linear as it was traditionally presented.

e) The modelling process should be considered as a process closely linked to other corporate systems, not as an isolated activity. The model’s output provides input and support to many strategic Water Utilities programmes or policies, and the model requires strong linkages with GIS, Telemetry, Water billing and other information management systems.

f) The process requires at various stages, agreements with involved parties, on reached verdicts about the quality of completed work at certain project stages and recommendations prior to commencement of the next stage. Supervision of the project should be continuously run from the beginning of the process by preferably one party based more on a working relationship than on traditional audit control approach.

g) Depending on the size of the distribution systems, models can vary from very simple - with only one water source and a small network, up to very complex systems with multiple sources and sophisticated operating regimes. Although the level of complexity in managing a modelling project varies with the size and complexity of a particular system the principles of the modelling process remain the same.



2 Setting Up The Modelling Project

Setting up of a modelling project comprises the following tasks:

a) Initial assessment
b) Defining the project objectives
c) Defining the project requirements
d) Setting up working plan

2.1 Initial Assessment

One of the first steps in managing water distribution modelling projects is analysing the system concerns. This is where network issues are identified and consideration given to effectively describing the issues. The problem area must be clearly identified, along with primary causes and a suite of solutions identified.

In general terms the problem area could be related to operational, planning or legislative requirements and more recently to water quality management. An overview of problem types in water supply systems, which could be analysed by using the hydraulic network models are presented in Table 1.1.

The overview is given with intention that some common issues could be identified in order to improve the efficiency of modelling application with wider coverage of expected results.

Table 2.1 Types of problems that could be analysed by modelling

Domain	Possible Problem
Operational Management	Developing an understanding of how the system operates
	Training water system operators
	Assessing the level of service
	Assessing the carrying capacity of the existing system
	Assessing the efficiency of current operational management policy
	Assessing levels of pressures at critical points within the system
	Identifying and resolving operational anomalies – closed valves
	Low pressure or high pressure fluctuation problems
	Low fire flow at hydrants - if it is different from expected capacity
	Daily operational use - shutting down a section of the system due to major breaks
	Power outage – impact on pump stations
	Sizing control points – subsystem metering, control valves – PRV, PSV, FCV
	Sizing sprinkler systems – fire service and other
	Assessing the available range of pressure at customer connections
	Real time control of the system

Domain	Possible Problem
Water Quality	Disinfectant residual assessments - levels of FAC throughout the system
	Substance tracking, determination of age of water, water blending from various sources
	Distribution Systems Flushing - velocity and flow assessments, sedimentation trends
	Analysing water quality contamination events
Planning	Identifying the impact of future population growth on the existing system
	Identifying the impact of major new industrial or commercial developments on the existing system
	Identifying key bottlenecks in current and future systems
	Designing the reinforcement to the existing system to meet future demand
	Designing the new distribution system
	Optimising the capital works programme
	Assessing the new resource option
	Assessing the effects of rehabilitation techniques
	Leak control – Reducing losses by lowering maximum pressure
	Demand management – Reducing the pressure related demand by lowering service pressure
	Sizing elements of the system to meet fire service requirements in existing and future systems
	Assessing the value and design of distribution monitoring systems – Telemetry, Data Loggers
	Contingency planning – Answering “ what if “ questions on major outages
Legislative	LTCCP and Water Assessments – Assessing levels of service, Regulatory levels of service reporting, and options for future planning based on community consultations,
	Public Health - Maintaining levels of residual FAC within predefined values.
	Assessing the financial contribution required for new developments
	Fire Service Code of Practice – Water and pressure requirements for fire fighting purposes

2.2 Defining the Project Objectives

Defining the objectives of the modelling project in a transparent way is a vital stage in conducting the overall modelling activities. The objectives must be defined in terms of the type of problems for which a model must provide a useful contribution and answers to these problems. There are traditionally two types of hydraulic network models for water distribution systems which need to be considered as outlined in Tables 2.2 and 2.3 as:

Macro model for analysing overall system mainly for strategic planning or strategic operational management.

Distribution model, which goes into fine detail analysis of the network in some cases even up to the individual houses.

It should be appreciated that in some instances a combination of a strategic and detail model should give the most cost efficient results. This allows detail to be added into macro model only in those areas with problems – critical locations, or where upgrading of the system is required.

Network models can be classified as performing steady state simulations or extended period (dynamic simulations). Data requirements for each type of model are essentially the same, however greater amount of data and some additional types of data – mainly related to defining daily demand patterns are required for dynamic models.

Steady state models use a set of data for a given point in time generally to simulate maximum (or extreme) water demand conditions.

Dynamic models provide an overview of the system behaviour in time for a range of operational regimes. Application examples include: determination of pump capacity, reservoir sizing and positioning, water quality analyses, pressure management modelling etc.

Table 2.2 Macro Model – Strategic Planning

Purpose	TYPICAL MODEL COVERAGE	Typical outputs	Typical benefits	Model complexity
o Bulk conveyance and treatment options o Prioritisation plan for upgrading of trunk mains, major pump stations and reservoirs o Development of detailed planning and investigation programmes o 20-50 year cost estimates for upgrading programmes o Identification of high risk assets o Impact assessment of major regional initiatives	Regional Whole of city Large parts of city	Master plans Operational Management for Bulk Supplier Treatment location options Planning and new construction programmes - prioritised treatment upgrade programme - prioritised trunk main, major pumps or reservoirs upgrade programme	Framework for more detailed studies Prioritisation of future expenditure Assists with consultation Better understanding of future works programmes Inputs to Asset Management Plan, LTCCP, Water Assessment Least expensive Relatively short timeframe to complete	Can vary from simple static type models (inexpensive) to simple dynamic models (more expensive) Simple static models can be done by spreadsheet or with simple hydraulic software Lower requirements in terms of asset data coverage and quality

Table 2.3 Distribution Models – Detail Analysis

Purpose	TYPICAL MODEL COVERAGE	Typical outputs	Typical benefits	Model complexity
o Operational Performance and Assessment o Localised growth scenario planning o Pump station upgrading options o Inter water supply zone transfers assessment o Water Quality Analysis o Valve Managements o Long term upgrading programme development o Impact assessment of any significant proposed development	Large parts of city Water supply zone or sub zone Large Subdivisions	Upgrading strategy - long term upgrading programme for treatment, pipes, pump stations (costs and scope) New Infrastructure Planning Management plans for water supply zones Continual improvement/monitoring	Linkage with renewal planning and prioritisation of renewal programmes Improved confidence level in outputs for cost, nature and extent of works Confirmation of operational problems and identification of previously unknown operational problems Monitoring of trends or net impact of network improvements Problem prioritisation – enables funds to be targeted at areas of specific and urgent need Calibration of model against measured performance gives increased confidence in model output Inputs to Asset Management Plan, LTCCP, Water Assessment	Medium to high level complexity requiring sophisticated software that makes use of time varying data to generate a dynamic model Requires fairly extensive asset data of good quality Requires experienced modellers with good understanding of engineering problems and solutions

Once the objectives are defined the appropriate type of model should be selected based on the relevant project requirements.

2.3 Defining the Project Requirements

The modelling project requirements are:

Quality requirements: There are a number of inter-related modelling quality requirements, which should be considered with regard to the quality of the answers to the question posed, particularly with regards to the calibration and runs to be carried out. This may be the most difficult step of the entire process, which needs to be clarified right from the start of the process. However, the quality requirements could be finally determined only during a consultative process involving all stakeholders throughout the modelling process.

Resource and expertise requirements: As for any engineering project, an estimate must be made at the beginning of the project as to what level of resourcing and expertise is required to complete the project. There must be a clear relationship between the scope of the project and required resources including the time, budget, expertise required in order to solve a certain specific problem etc. It is important that the project team members are identified at this stage. Generally the project team consists of three stakeholder groups, namely: water utility, modelling team and external parties.

Software requirements: Several issues related to corporate and technical concerns should be considered in selecting a water network modelling package. Corporate considerations are related to the Water utility's goals, objectives, IT capabilities and constrains, vendor reputation and overall software cost. Technical considerations include a user network size, the user interface, modelling features, the available support and training, data requirements, external required software, hardware configurations etc. Some of the software packages recently developed offer additional capabilities beyond standard hydraulic modelling such as water quality assessments, source blending, travel time determination, energy and power cost calculation, leakage and pressure management, surge analysis, automated calibration, real time simulation, network optimisation etc.

Other requirements: Supplementary requirements may be formulated in some projects such as use of the results from other models, exporting results for use by other models, provision of required data and quality of field tests etc.

2.4 Setting Up Working Plan

Setting up working plan for implementation of modelling project would be developed with focus on the project objectives and necessity for providing all project requirements. This should provide the full model functionality and required quality of project outcomes. The working plan should be set up to more closely define staged developments of modelling activities, its timeframes and all necessary activities, which contribute to its outcome.

The working plans could be set up as short-term plans, whereas annual plans and long term plans are usually for a few years' period. An annual plan should be focused on setting modelling works for the coming year in the form of running various project activities which includes setting up new or updating existing models and their objectives, agreements on justification and quality of end results, specifying all requirements - data, software, resources etc. A long-term plan should be focused on outlining long term modelling goals, activities and resources. It could include planned software upgrade, acquiring additional software packages for advanced hydraulic network modelling, transients analysis, system optimisation, additional water quality analysis, or for setting up links between the model and various corporate systems – SCADA, GIS, etc.

3 Data Collection, Model Build (or Model Update)

3.1 Data Requirements

There are three types of data essential for assembling a water distribution model as outlined in Tables 3.1, 3.2 and 3.3. These are network data, water demand data and operational data.

Network Data

Network data describes all physical components of the water distribution system and defines how those elements are interconnected. Networks are made up of nodes and links. Nodes represent water system features at specific locations and links define relationships between nodes. Network data can include traditional data mainly composed of two primary types – pipe and node data. Network geometry data are now generally available in the Geographical Information System (GIS) format.

Water Demand Data

Water demand data describes two basic components of overall demand – metered or un-metered consumption and water losses from distribution systems. Water demand data is assigned to nodes in the modelled network. Modelling demand (consumption rates) and its distribution throughout the network is one of the key elements of a water distribution model. As such, the spatial distribution of demand and its variation over time must be carefully modelled.

The overall success of a modelling project can depend largely on quality and accuracy of the water demand data available. Other information regarding the network, reservoirs, pumping stations, valves etc can be found and checked relatively easily – but not demand. Moreover the procedures on how to gather all necessary water demand data in a particular system and analyse it and having good confidence in the modelled water demand is still to a certain extent subjective than a clearly predefined process.

The water demand could be modelled by multiplying the average or base demand - billed or assumed consumption plus assessed losses on one side with weighting or daily demand variation factors on another.

There are two basic approaches in defining the average or base demand:

From the bottom – modelling demand by summarising real individual consumption mainly based on water billing records and adding likely level of losses at associated nodes; and

From the top – modelling demand by evenly distributing overall demand to each node.

Planners and designers favour the first, more accurate approach.

Table 3.1 Network Data

Data	Detail	Accuracy	Source
Nodes	Number or name Coordinates, Elevation Type – Network junctions or end points, source of water,	Off GIS, as-built plans, maps	GIS, As-built plans, Operational staff
Pipelines	Initial node, end node Diameter – nominal or internal Length, Material, Construction year Pipe roughness, Minor loss coefficients Water Quality – Reaction rate coefficients: bulk and wall	Off GIS, as-built plans, maps Estimate	GIS, As-built plans, Operational staff Design standards, recommendations, hydraulic textbook Design standards, recommendations, hydraulic textbook
Valves and control equipment	Initial Node, end node Diameter, Length, Roughness coefficients Type – Throttled, NRV, PRV, PSV, PCV, TCV, FCV,	As-built plans	GIS, Control valve database As-built plans
Pumping stations	Initial node end node Diameter of suction and delivery pipe Number or pump, name, pump type Pump delivery rate, delivery head, power Rotating speed, number of stage, efficiency Pump characteristic “Q – H – P curve”, protections Type – Fixed or variable speed pumps	As-built plans	GIS Pump station database As-built plans
Reservoirs	Number or reservoir name Shape and volume Inflow and outflow pipes arrangements Type – Storages, Water Towers	As-built plans	GIS , Reservoir database As – built plans
Zones Boundary	Zone or sub zones boundary lines	Maps	GIS, Contour plans

Table 3.2 Demand Data

Data	Detail	Accuracy	Source
Existing demand	Yearly average or base consumption Type of consumer Level of water losses	Off Billing system	Water Billing System, Sub meter readings Water Balance Sheet Minimum Night Flow
Spatial Allocation	Location of water meters or water users	Off Billing system and GIS	Water Billing System, GIS
Time varying factors	Daily and hourly peaking factors Diurnal curves – Patterns of water use	Off Telemetry or data loggers	Telemetry or data loggers Typical patterns
Future demand	Projected future demand and its allocation	Mesh block or sub zone level	Water Utility or regional planning documents

Table 3.3 Operational Data

Data	Detail	Accuracy	Source
Source node	Hydraulic Grade Line Initial Water Quality, Baseline concentrations and patterns		Operational staff
Pump Station	Pump’s operational regimes – setting points: pressure at node, water level at reservoir, time		Operational staff SCADA
Reservoirs	Water levels ranges – lower and upper operational limits		Operational staff, SCADA
Control Valves	Control regimes, control points, trigger values, throttled valves		Operational staff SCADA,
Zone valves	Locations of permanently closed valves		Operational staff, GIS

Demand variations or weight factor could vary considerably because they are affected by many factors – climate, yearly season, daily consumption pattern for specific customers, day in week, public holidays, type of customers, real losses etc. Possible way for modelling demand variation – peaking factors could be presented according to characteristic demand time scales:

Daily, which varies with consumers' activities over the course of the day usually presented with 24 hour daily pattern for each typical water users

Weekly, which varies from weekend patterns to weekdays patterns, usually presented with a 7-day pattern in summer or winter seasons.

Seasonal, mainly depending on the extent of outdoor water use or seasonal changes, usually presented with 12 seasonal patterns.

Demand data could be gathered from water billing system, water balance sheet, telemetry, data loggers' files or accepted as typical values and patterns for certain water users from literatures what is less accurate approach.

Operational data

Operational data describes actual operational system characteristics at a given time. Operational data is required to model water levels in reservoirs, status of pump stations and its control policy, settings at pressure regulating valves, control of flow control valves, status of sluice valves – zone valves are closed, etc. Contact should be maintained with operational staff throughout the model assembling and data verification processes in order to ensure that all relevant and updated information including temporary changes to the system are available. Operational data could be generally obtained from Water Utilities operational staff.

3.2 Data Completeness and Accuracy

There are two critical data characteristics in the modelling process – its completeness and its accuracy. Completeness refers to ensuring that all relevant or specified data is collected and accuracy is determined by the correctness of the values used as data. Good practice is to have data as complete as reasonably possible and appropriate for the intended purpose. This data should be closely reviewed and updated to make it more accurate. Data accuracy depends on the purpose and the required accuracy of the model.

Too much emphasis on data checking is usually not cost-effective. In certain cases data accuracy will have very little impact on the accuracy of the model while in other cases it may be significant. A balanced approach between an extensive and too little data checking should be adopted. It is very important that any concerns about data accuracy are adequately documented.

3.3 Model Build - Data Entry Methods

Model can be generally assembled applying some of three basic data entry procedures or some combination between them, depending on then modelling software used. Data entry process can be accomplished in the following three methods:

Manually creating data by typing it into the model, which can be time-consuming work particularly for large systems. This method is rarely utilised for large model builds due to it being resource intensive. It is sometimes used to add small areas into an existing model such as a new sub-division area.

Transferring data between various files by copying and pasting data from one file to another, which sometimes requires some additional manual editing. The source and format of data must be considered to determine the most appropriate data transferring method for a particular situation.

Building up models directly from various files by importing data directly from GIS, water billing and other data source into a model, is recently developed data entry and model building technique.

3.4 Updating the existing model

As the system changes, due to upgrades and new developments, increased demand or operational alternations the model must be kept current. Care should be taken to ensure that all changes to the model are properly documented.

To ensure that an adequate up-dating procedure has been properly set-up the following must be resolved:

a) Who has administrative authority to update the network model

b) How frequently the model will be updated

c) What data source will be used for the updating process

d) Who is authorised to provide the updated data

e) Which data sources are to be used for updating the model

4 Data Verification And Model Testing

After assembling the model, entered data needs to be checked to ensure that potential data errors are corrected and model tested to ensure that it is functioning correctly under conditions that are likely to be subject to in its use.

4.1 Data verification

There are many potential sources of error in data gathering process that concern data accuracy and as such must be corrected. The source of data errors can be related to: network data, demand data and operational data. It is also important to understand how compensating errors may impact network model accuracy.

Network Data Errors

Network data errors include incorrect network data, incorrect network definition or incorrect pressure zone definition. Incorrect network data mainly include erroneous pipe diameter or length, pipe material or construction time and node elevation. Incorrect network definition mainly includes missing or wrongly added pipelines data, inappropriately identified pipelines connectivity, wrongly identified pipe start or end node. Incorrect pressure zone boundaries mainly include wrongly stated location of zone valves – modelling a valve as open when it is actually closed in the field or vice versa.

One way to check data is to use the data sorting and its colour coding capabilities available in many models to quickly identify very large or very small values, which are out of the expected data ranges.

Some software has data checking or graphical capabilities that make it easy to recognise this type of errors. These software have specifically developed data management tools called “engineering data validation” or similar routines with an option to set up an expected range of the network data values so software can automatically spot any data, which probably has wrongly entered values. Additional data verification tools incorporated into some software, is a model connectivity tracing tool for analysing entered pipelines connectivity and zone boundaries isolation from the rest of the system.

Certain network definition errors cannot be identified through data verification process. For example: hydraulic connectivity between crossed pipes, existing of connections between pipes due to temporary built pipes during construction periods which are not present in GIS etc. These errors could be detected and rectified only during the fine model calibration process.

Demand Data Errors

Demand data errors commonly include incorrect overall system demand totals, incorrect node demand, incorrect spatial distribution of demand and incorrect demand variations. Generally, discrepancies in overall system demand could be easily identified because such data is one value data, which should be one of the first items checked. Incorrect node consumption and water loss data occurred when the load for a node is wrong – or distributed incorrectly what is generally difficult to detect. Loading of nodes is based on many factors – type of consumption and its average daily value, correctness of assisted level of water losses if losses are presented as separate demand category, maximum day demand, maximum hourly demand, estimated on lend use and its unmated consumption etc. Manipulation of these data, especially when numerous assumptions are used, is a potential source of errors.

The best approach to avoid errors in this process is to be careful, thorough and to check the work. Generally, if reasonable carefulness is exercised, significant errors can be avoided.

Operational Data Errors

Operational data errors can include erroneous telemetry or data loggers' data, partly or fully closed valves, inadequately defined pump curves, settings at control valves etc. Erroneous telemetry or data loggers' data can affect the accuracy with which pumps, control valves, reservoir elevations, flow rates, residual pressure etc are modelled. It is important that telemetry and data loggers' data are checked and verified prior to its further use. After checking the data – spikes, no available data, constant value, wrongly scaled sensors, communication failures, etc and discus it with operational people, bad data can be spotted and correctly interpreted.

The presents of an unknown partially closed valve in the field - usually forgotten to be open after shutdowns, can make the calibration process difficult. In such cases, additional field investigation should be arranged and valves checked to make sure they are in the proper position.

The use of inadequate pump curves in a model will result in flows that do not match real head. In this case, pump heads can be adjusted, lowered or increased, to produce the desired flow rate.

Compensating Errors

Compensating Errors – sometimes one error can compensate another error, resulting in no apparent error. If the friction coefficients are too high and demand too low the results might be the same as for correct friction coefficients and demand. Good approach for this situation is to be aware of the appropriate level of confidence in the data.

The required degree of accuracy depends on the purpose of the model. Even if all of the data gathered describing the model matched the real system exactly, it is unlikely due to certain mathematical assumptions employed by the software, to make computed pressures and flows absolutely agree with observed pressures and flows. Although general intention is usually for the greatest degree of accuracy as possible, there are practical considerations that require the model to be accepted at some point.

4.2 Model testing

Once a model has been assembled, entered data verified and reasonable confidence that it can be studied in more detail, the model needs to be analysed and tested. Testing a model can vary in nature from very simple to comprehensive analysis depending on the model objectives and other project requirements. The task of model testing procedure is for the network analyst to gain a general impression of whether the model works correctly before commencing the next, time consuming, calibration stage of the process. There are four commonly used basic model testing procedures:

Run with standard inputs is the most common model run test to check if the model performs correctly without any mathematical instabilities, usually based on using so-called standard input data. This is in general running a simple case – day with typical operational regimes and standard demand, of which network analyser knows the exact results in advance. Additional standard runs could be carried out using known fire flow test results or just for assessing distribution of water quality parameters throughout a system.

Global behaviour run needs to be carried out to check whether the model translates any changes in the input or in operational variables into an altered output which describes the behaviour of the system in an expected manner.

Check the mass balances, usually water balance in distribution system – or energy balance needs to be checked in order to ascertain whether there is any discrepancy between system input–output and overall demands.

Robustness test is carried out with extreme values in order to find out which conditions show undesirable model behaviour or model crash. Most of the work involves the choice of a limited number of expected extreme of operational conditions under which distribution system still needs to perform well and running a model using such input.

All model test results must be checked and analysed. If there are any significant differences with some reasonably high degree of correlation, between run results and expected system performance, further investigation needs to be undertaken before undertaking any further work.

5 Model Calibration And Validation

Before any use, the model must be calibrated to establish its credibility and allow decisions about physical and operational developments in the real system to be made with as high a degree of confidence as possible.

Validation is usually the next step of a two staged model credibility establishing process, used to check the results of the model to simulate an independent – additional set of data not used in the calibration procedure.

5.1 Model Calibration

Calibration is the process of comparing the model results to field observations, and if necessary, adjusting the model parameters until model results reasonably agree with measured system performances over a range of operational conditions. Water Supply model calibration process involves adjustments of the following primary network model parameters: pipe roughness coefficients, spatial distribution of nodal demand, altering pump operating characteristics and some other model attributes until the model results sufficiently approximate actual measured values.

In general, a network model calibration process consists of the following seven basic steps:

a) Understanding the purpose of the model
b) Initial estimate of the model parameters
c) Calibration data collection
d) Evaluating the results of the model
e) Macro calibration analysis
f) Sensitivity analysis; and
g) Micro calibration.

Understanding the purpose of the model

Both the purpose of the model and the associate type of analysis provide some guidance about the type and quality of the collected field data and the acceptable level of tolerance for errors between field measurements and the model results. Models for steady state applications can be calibrated using multiple static flow and pressure data collected at different times of the day under varying operating conditions. On the other hand, models for extended periods require field data collected over an extended period, usually over 24 hours.

In general, a higher level of model calibration is required for water quality analysis or an operational management's study, than for a general planning study.

Initial estimate of the model parameters

The second step in calibrating water supply models is to determine initial estimates of the two primary model parameters that normally have the greatest degree of uncertainty – the pipe roughness coefficients and the spatial distribution of base demand assigned to node.

Pipe Roughness values can be usually used as average values obtained in the literature - directly available in some advanced models or as values directly measured from field tests. Various researchers and pipe manufactures have developed tables that provide estimates of pipe roughness as a function of pipe material, diameter and age. Such tables can be useful for newly constructed parts of the distribution system but for older, particularly metal pipes it is helpful to verify the roughness values based on field testing. Conducting a pipe roughness field test is based on selecting a straight section of pipe (all branched pipes must be closed) and by measuring pressure drop between two points.

Roughness coefficient used in the model, may actually represent a composite value of several secondary factors such as fitting losses, effects of network skeletonisation or losses caused by closed valves not re-opened after some maintenance work.

Distribution of nodal demand or the average base demand is the second major parameter determined in the calibration procedure, which needs to be assigned to network nodes. Initial estimates of nodal demand can be developed using various approaches depending on the nature of available data and how precise they want to be. Initially average estimates of nodal demand can be obtained by identifying the area of influence for each node – Tisane polygons, identifying the type of demand units within the area and multiplying the number of each type of area by an associated demand factor. Alternatively, a more precise approach is to use a water meter record – billed consumption scaled on one day usage with the appropriate meter's coordinates and the type of user for associating real demand to the nearest node.

Calibration data collection

Data that is to be collected for calibration must be identified, compiled, checked and organized so it can be used efficiently and effectively for calibration. Data can be available in a variety of sources and forms including - fire flow test, telemetry system, data loggers' database, supply point meter, pump station and reservoir readings, GIS and billing system, operational data – zone valves, PRV etc are used most commonly in calibration tests.

Fire flow test is normally conducted using two hydrants – one identified as the pressure or residual hydrant for measuring both static and dynamic pressure and the second hydrant identified as flowed hydrant for measuring discharge flow. To obtain sufficient data for an adequate model calibration, data from several fire flow tests must be collected as well as associated system boundary condition and operational regimes data.

Telemetry or Data Loggers' Data in addition to static test data, data collected over an extended period – typically over 24 hours are required when calibrating the dynamic model. The most common type of data is gathered by using the telemetry system from continuously monitoring sites or by data loggers from a single location at a specific point in time, usually over two weeks. Collected calibration data is pump's discharge rate, reservoir's water level data, water meter's flow data, pressure at relevant points water demand patterns data etc.

Water Quality Data. In recent years, both conservative and non-conservative constituents have been used as tracers to determine the travel time through various parts of a water distribution system.

Once data is compiled it must be reviewed, analysed and assessed. Operational data must be reviewed for all major system components pressure and flow at supply points, pump station flow rates and discharge pressure, reservoir elevations, inlet - outlet assembling and drop – fill rates, pressure regulating valve downstream pressure and so on, must be reviewed and assessed.

In collecting data for model calibration it is very important to recognise the significant impact of measurement errors – pressure sensors, water meters or water levels, data accuracy particularly if equipment used for gathering field data have no good regular maintenance and re calibration trace record.

Gathering field data for calibration needs to be arranged during operational regimes similar to planed models run scenarios. It is hardly expected a model to accurately predict flows and pressure for a high stress situation – large fire flows or exceptional high demand if the model was calibrated using data from regimes when the flow and velocities in the pipes were low or less than the measurement error. A good way to minimize this problem is to use data from fire flow test or to ensure the measurement errors have been minimised.

Evaluate the results of the model

Once calibration data is gathered the model can then be evaluated and large discrepancies can be addressed simply by looking at the nature and location of differences between the model result and the field data. The accuracy of the model can be evaluated using a variety of criteria. The most common criteria is absolute or relative nodal pressure differences between results and field data across the system. Additional cooperation for dynamic models are commonly predicted and observed water levels in reservoirs and average pump outs.

Because of the issues of model application, defining a single set of criteria for a universally accepted good level of calibration is very difficult task. From some perspective, a highly desirable accuracy of the model is a maximum deviation of the state variable – pressure, water level, flow rate of less than 10% for most planning applications, while a maximum deviation of less than 5% for most design, operational or water quality applications.

Many professionals agree that a model can be considered calibrated “good enough” when the results produced by the model can be used with confidence to make decisions regarding planning or operational decisions and the cost to further improve the model cannot be justified.

An overview of acceptable levels of calibration of water distribution system, as it is presented in reference 6 is given in Appendix 1.

Macro calibration

Macro-calibration analysis. Identifying and addressing larger discrepancy between modelled and observed behaviour of the system is critical in the calibration process. In the event that measured data differs from the calculated data excessively - i.e. more than 30%, the cause of difference is likely to extend beyond errors of the estimates either the pipe roughness values or the nodal demand and may include – closed or partially closed valves, inaccurately pump curve or reservoir data, incorrect pipe data or network geometry, pressure zone boundary, inaccuracy of operational data etc. The only way to address such errors adequately is to review the data associated with the model.

This first step, referred to as macro – calibration is necessary to bring modelled and observed parameters into closer agreement with one another – usually less than a 20% error, before the final calibration steps are attempted.

Sensitivity analysis

Before attempting a micro level calibration it is helpful to perform a sensitivity analysis of the model to identify the most likely source of model errors. This analysis can be accomplished by varying the different model parameters by different amounts, than measuring the associated effects. By examining such results, the user can begin to identify which parameters have the most significant impact on the model results and thereby identify potential parameters for subsequent micro calibration.

Micro calibration

Micro calibration is the final step in the calibration process. This can be time consuming, particularly if there are a large number of pipes or demand nodes that may require adjustments. There are two types of fine-tuning or micro calibration process. The two primary parameters should be adjusted during this stage – pipe roughness and nodal demand. In addition the pumping characteristics should also be checked and calibrated. In many cases it may be useful to break the micro calibration into two separate steps – steady and dynamic state calibration. In steady state calibration, the model parameters are adjusted to match pressure and flow rates associated with steady state observations. In the dynamic state the model parameters are adjusted to match time varying pressures and flows as well as water levels in reservoirs and flow rates at pump stations.

Micro calibration can be undertaken “manually” or through an automated calibration.

Manual calibration is a trial and error process, applicable to skeletonised networks, generally involves the modeller supply estimates of pipe roughness values and nodal demands within predefined ranges, conducting the simulation and comparing predicted to observe performance. If the agreement is unacceptable, then a hypothesis explaining the cause of the problem should be developed, modifications made to the model and the process repeated again. The process is conducted iteratively until a satisfactory match is obtained between modelled and observed values. If no satisfactory match can be obtained, then further site investigations are usually made to identify the reason of discrepancy

Automatic Calibration is a simulation technique based on the idea of solving one or more calibration factors through the addition of one or more network equitation. Various optimisation techniques can be used to successfully solve calibration. Lately, genetic algorithms seem to offer a good technology for automatic calibration.

5.2 Model Validation

Once a model is calibrated to match a given set of field data, the user can gain full confidence in the model by validating it, using additional sets of field data under different operational conditions. In performing validation, system demands, initial conditions and operational regimes need to be adjusted to match the conditions at the time the additional field data set was collected.

6 Model Use

The final step in the analysis process is to determine under which circumstances the model needs to be used and carrying out appropriate model runs

6.1 Simulation Runs Plan

Once the model has been calibrated and the network analyst is sufficiently confident of its operation i.e. that the model can be used for considered applications. At this stage it is appropriate to set up a simulation runs plan, describing the exact implementation – the model run scenarios. The plan should usually define combinations of:

a) The calibrated version of the model to be used

b) Periods of the simulation run

c) Existing and future demand and operational conditions

d) System reinforcement options

e) Analysed system parameters

f) The way of presenting run results

Defining the scenarios for model runs requires close cooperation with the Water Utility. The run scenarios that need to be carried out should be roughly discussed earlier – in stage 1, but now when the model is ready to be applied, the final arrangements must be reconsidered and further detailed. It is important that distinctions are held between the stakeholders and any issues should be finally determined and documented. Before defining a list of model run scenarios it may be useful to make a series of initial runs in advance for providing the first indications about the results domain.

6.2 Simulation Runs

This activity is the next step in the running of the modelling project. Immediately following the model runs, the results must be verified to any extremes, ranges of model output, unexpected results or indication of numerical errors. At the same time, it must be determined whether all the planned run scenarios have been performed and whether they have been done in a sound way.

7 Results in Interpretation

Defining the exact interpretation of the results is an important activity. The results should be presented in a transparent way, not only as a set of final values and graphs but also, more importantly, under which conditions they were calculated. A good approach is to first describe the results without attaching them to any conclusions, consequences or statements. The results should be grouped using thematic templates.

7.1 Describe results and conclusions

The results should be compared to itself, results obtained using other models or with results from any available similar investigations. Any un-anticipated results must be discussed and supplemented with possible explanations.

The conclusions must be drawn only from the calculated results and directly linked to the project objectives.

7.2 Check project objectives and analyse the consequences

In this project stage – operation validation of the overall modelling project, the modelling project objectives – questions must be answered, whether the model procedures have achieved project objectives or not. Consequently the project objectives may have to be adjusted but not before the modelling process has been fully completed. This decision may impact on the overall project objectives as well as on the entire modelling process. This can cause additional workload and, as a consequence, add an extra cost to the project.

8 Reports and Model Documentation

The results of the model are very rarely used in their original form for presenting final project outcomes to shareholders and policymakers. The results need to be translated into a policy supporting conclusions mainly as simple answers on complex questions that were set up in the project objectives. Therefore a key task of producing the final reports is to translate models' results and conclusions not only as professionally justified but also as a transparently formulated document easily understood by non-professional people.

8.1 Reports

A typical report consists of the following topics: project objectives, description of study area, description of model composition, description of analysed scenarios, modelling results, conclusions and recommendations. Project summary in general or executive form should be included into the report.

The level of detail contained in the final report may vary depending on applied procedure and the project's objectives. A more detailed and more formal report is necessary when a consultant is engaged.

8.2 Model Documentation

In order to provide essential information to future users of the model as well as for auditing purposes the model should be properly documented. This documentation is not to be confused with the reporting requirements, which require fewer details. The following should be considered as a minimum model documentation requirement:

a) Model objectives

b) Model assumptions

c) Data description

d) Model build description

e) Model calibration description

f) Model updating and administering procedures

9 Change Monitoring and Model Management

Model management has a critical role in the successful implementation and ongoing development and use of a water distribution system modelling project. It is important for water utilities to accept that use of a good model is the core asset management tool to assist asset managers and other stakeholders in an efficient provision of water services.

Further developments should introduce additional modelling tools such as optimisation techniques, cost analyses, transient flow analyses etc., which are widening modelling inputs and supports to water utility programmes and policies. Consequently the scope of the modelling project management could be quite extensive. It is important to keep in mind the basic modelling tasks as these are generally presented in Figure 1.1.

Network modelling, once started is an ongoing (never-ending) process. Considerable time and effort is required to build a good model. Water utilities must realize that maintenance of a created good model is just as necessary as maintenance of any other asset. It should be understood that there is no end to future utilization of the model as a multipurpose design tool and its further implementation in various programmes will be increased over time.

Analysing resource requirements on regular basis – staffing and budgeting, strengths and weaknesses of modelling activities, must be part of the overall process. Taking adequate actions – the process improvements, having ongoing staff training programmes on both formal and informal methods, engaging experts for carrying out some specialized modelling work, purchasing additional software modules, support packages or computer hardware should be part of ongoing project management activities.

9.1 Change Monitoring and Model Maintenance

Monitoring the modelling project changes, created by Water Utilities as defining some additional project objective or due to ongoing system alternations at network, demand or operational regimes, must be closely followed up and appropriate action must be taken.

Current model must be examined regularly - can it still provide sufficiently good answers on all additional stated objectives and permanently up dated against any system changes. If capabilities of the existing model are such that it can not ensure providing sufficiently good answers, the overall modelling procedures need to be revised and adequate – up dated modelling process to be set up.

Model maintenance is critical to ongoing successful model implementation and use. Poorly maintained model - updating model's data can result in erroneous conclusions, considerable duplication of efforts and decreased use of the model. To ensure adequate model maintenance, some issues must be addressed including:

Data updating – who and when will update the network, operational and demand data. The frequency of updating should be specified – usually annually after high water demand season and for maintaining proper calibration procedures.

Directories and file naming – Model directories and file naming conventions must be establish to facilitate identification of the model that is developed. The method of describing the purpose of the model and naming the directories and files should be developed simply in an easily recognisable manner, so that the user can easily recognise what it is and can use it in further applications with high confidence.

Data security – Model data sets must be protected so that they can not be changed by any unauthorized person or disrupted by any hardware failures. The model files must be regularly saved and stored as back up copies as well as regular updating of the data by administrative authorities.

Since considerable time and effort are required to compile data, data must be recognized as an asset of the organisation and must be continuously maintained to retain their value and the model credibility.

9.2 Accountabilities and Process Coordination

Accountabilities are facilitated through periodic overall process reviews and staged agreements on conclusions and recommendations at critical process activities, prior to commencement of the following activity.

Periodic process reviews include formally examining the modelling goals, effectiveness of running various process activities and measuring progress at selected time intervals. Modelling goals must be regularly examined to determine it these are still applicable to the goals of the water utility and the overall project to be kept on course. Progress must be measured and any source of difficulties should be noted. These sources can include over ambitious project requirements, software that does not perform to expectations, personal conflicts or overconfidence, inadequate staffing or training, lack of available data etc. Once the source of the problem is identified, timely action must be taken to solve it.

If a consultant has been employed to produce the model agreements at critical stages a particular verdict must be reached in a more formal way, between involved parties prior to commencement of the following activity. Appropriate consultation needs to take place, conclusions about competition of certain activity made and recommendations for the further activities must be reached between involved parties at the several critical stages of the process. One of the key factors in successfully running the modelling project is in providing good communication with all involved parties i.e.– the decision making person, asset management operational and planning staff, consultant, GIS people, more based on mutual trust than on classical project management relationship.

Ongoing project coordination requires communication between the involved parties to get the right people together to focus on the problems and solutions. Coordinating activities could be arranged as formal and informal – more appropriate in the case of running “in-house” model development. Coordination needs to establish and maintain good professional working relationships usually between the following three stakeholders: water utility, modelling team and external parties’ representatives.

Water utility stakeholders include several departments that provide support to network modelling or expect results from the modelling project. These are: corporate and asset management, IT department, customer service, GIS, water billing department etc.

The modelling team mainly consists of asset management staff such as – planning, operations, maintenance, engineering, water system analysts, modellers or other staff usually directly responsible for the modelling project.

External parties may include water user representatives, community bodies, industrial organisations, experts in the areas of concern, consultants, software vendors etc.

The requirements and concerns of affected individuals must be coordinated within the water utility and communicated to the appropriate person.

10 Project Management

Project management is a process of techniques that enables its practitioners to perform to their maximum potential within the constraints of limited resources – point and case for the requirement of this process is on a computer modelling project. Modelling projects are notoriously difficult to deliver due to the vast qualities of data, the high level of technical expertise and the numerous opportunities for something to go wrong, given these first two factors.

The following doesn't aim to replace formal project management training; it is purely aimed at providing some tips in the management of water distribution modelling projects, which have been learnt from a number of managers of modelling projects.

a) Understand the project objectives and task / cost breakdown and stick to it.
b) Understand the limitation of the data available and software and be realistic on their impact on (1) above.
c) You will not be able to deliver a perfect job, so focus on project outcomes. Be prepared that tasks may have to changed or repeated to suit the available data and/or resources.
d) Keep the communications between the provider and the client open, frank and regular.
e) Programme peer reviews throughout the process and not at the end – make sure the peer reviewer's scope of work is focused and adds value.
f) As the project manager, don't get caught up in the detail of the modelling – recognise difference between what is interesting and what is important.
g) Expect variations and budget appropriately, project costs don't generally creep, they jump. A contingency fund is a good idea.
h) Consistency of methodology for multiple, like projects.

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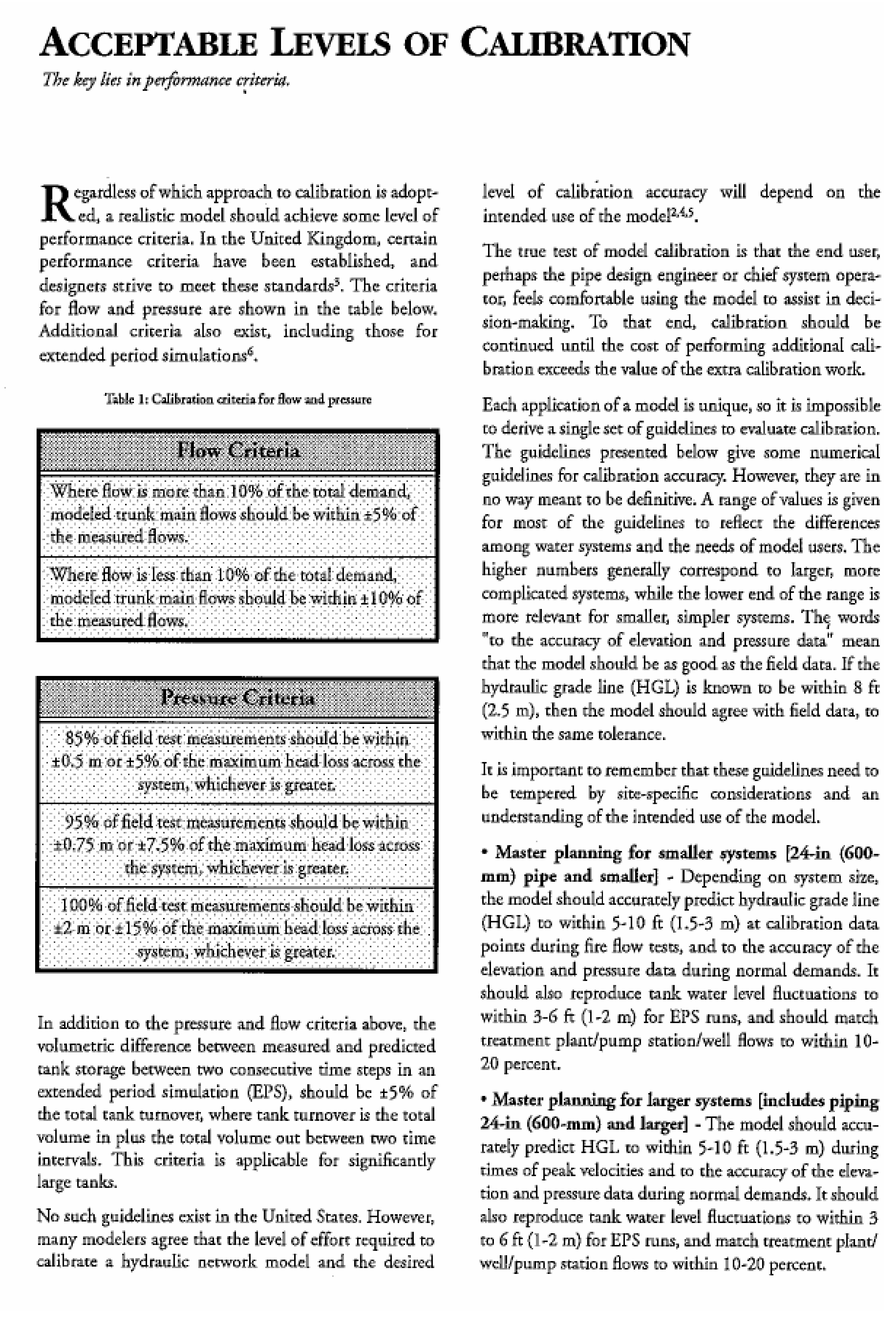


ACCEPTABLE LEVELS OF CALIBRATION

The key lies in performance criteria.

Regardless of which approach to calibration is adopted, a realistic model should achieve some level of performance criteria. In the United Kingdom, certain performance criteria have been established, and designers strive to meet these standards[3]. The criteria for flow and pressure are shown in the table below. Additional criteria also exist, including those for extended period simulations[6].

Table 1: Calibration criteria for flow and pressure

Flow Criteria
Where flow is more than 10% of the total demand, modeled trunk main flows should be within ±5% of the measured flows.
Where flow is less than 10% of the total demand, modeled trunk main flows should be within ±10% of the measured flows.

Pressure Criteria
85% of field test measurements should be within ±0.5 m or ±5% of the maximum head loss across the system, whichever is greater.
95% of field test measurements should be within ±0.75 m or ±7.5% of the maximum head loss across the system, whichever is greater.
100% of field test measurements should be within ±2 m or ±15% of the maximum head loss across the system, whichever is greater.

In addition to the pressure and flow criteria above, the volumetric difference between measured and predicted tank storage between two consecutive time steps in an extended period simulation (EPS), should be ±5% of the total tank turnover, where tank turnover is the total volume in plus the total volume out between two time intervals. This criteria is applicable for significantly large tanks.

No such guidelines exist in the United States. However, many modelers agree that the level of effort required to calibrate a hydraulic network model and the desired level of calibration accuracy will depend on the intended use of the model[2,4,5].

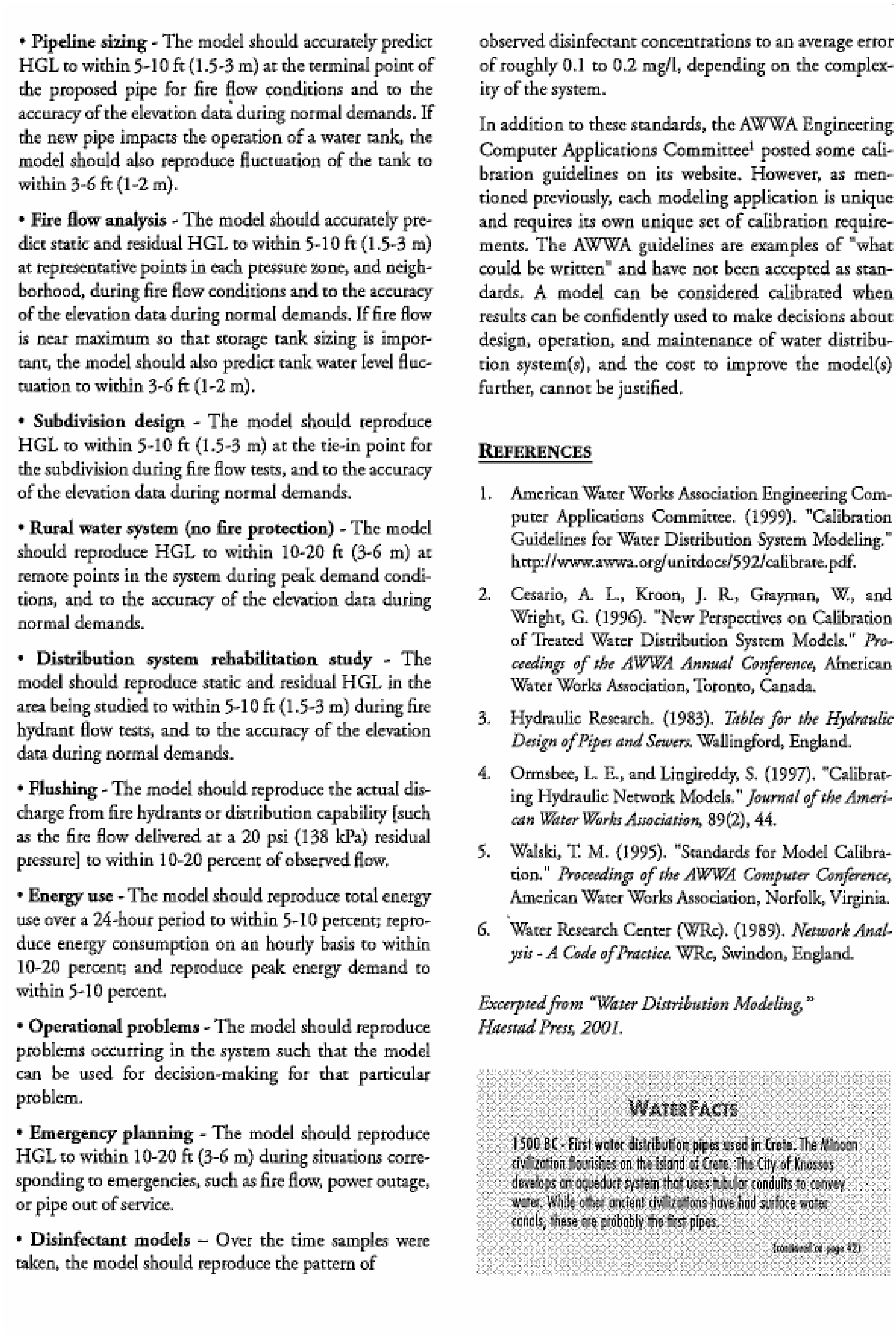
The true test of model calibration is that the end user, perhaps the pipe design engineer or chief system operator, feels comfortable using the model to assist in decision-making. To that end, calibration should be continued until the cost of performing additional calibration exceeds the value of the extra calibration work.

Each application of a model is unique, so it is impossible to derive a single set of guidelines to evaluate calibration. The guidelines presented below give some numerical guidelines for calibration accuracy. However, they are in no way meant to be definitive. A range of values is given for most of the guidelines to reflect the differences among water systems and the needs of model users. The higher numbers generally correspond to larger, more complicated systems, while the lower end of the range is more relevant for smaller, simpler systems. The words "to the accuracy of elevation and pressure data" mean that the model should be as good as the field data. If the hydraulic grade line (HGL) is known to be within 8 ft (2.5 m), then the model should agree with field data, to within the same tolerance.

It is important to remember that these guidelines need to be tempered by site-specific considerations and an understanding of the intended use of the model.

- **Master planning for smaller systems [24-in (600-mm) pipe and smaller]** - Depending on system size, the model should accurately predict hydraulic grade line (HGL) to within 5-10 ft (1.5-3 m) at calibration data points during fire flow tests, and to the accuracy of the elevation and pressure data during normal demands. It should also reproduce tank water level fluctuations to within 3-6 ft (1-2 m) for EPS runs, and should match treatment plant/pump station/well flows to within 10-20 percent.

- **Master planning for larger systems [includes piping 24-in (600-mm) and larger]** - The model should accurately predict HGL to within 5-10 ft (1.5-3 m) during times of peak velocities and to the accuracy of the elevation and pressure data during normal demands. It should also reproduce tank water level fluctuations to within 3 to 6 ft (1-2 m) for EPS runs, and match treatment plant/well/pump station flows to within 10-20 percent.



- **Pipeline sizing** - The model should accurately predict HGL to within 5-10 ft (1.5-3 m) at the terminal point of the proposed pipe for fire flow conditions and to the accuracy of the elevation data during normal demands. If the new pipe impacts the operation of a water tank, the model should also reproduce fluctuation of the tank to within 3-6 ft (1-2 m).

- **Fire flow analysis** - The model should accurately predict static and residual HGL to within 5-10 ft (1.5-3 m) at representative points in each pressure zone, and neighborhood, during fire flow conditions and to the accuracy of the elevation data during normal demands. If fire flow is near maximum so that storage tank sizing is important, the model should also predict tank water level fluctuation to within 3-6 ft (1-2 m).

- **Subdivision design** - The model should reproduce HGL to within 5-10 ft (1.5-3 m) at the tie-in point for the subdivision during fire flow tests, and to the accuracy of the elevation data during normal demands.

- **Rural water system (no fire protection)** - The model should reproduce HGL to within 10-20 ft (3-6 m) at remote points in the system during peak demand conditions, and to the accuracy of the elevation data during normal demands.

- **Distribution system rehabilitation study** - The model should reproduce static and residual HGL in the area being studied to within 5-10 ft (1.5-3 m) during fire hydrant flow tests, and to the accuracy of the elevation data during normal demands.

- **Flushing** - The model should reproduce the actual discharge from fire hydrants or distribution capability [such as the fire flow delivered at a 20 psi (138 kPa) residual pressure] to within 10-20 percent of observed flow.

- **Energy use** - The model should reproduce total energy use over a 24-hour period to within 5-10 percent; reproduce energy consumption on an hourly basis to within 10-20 percent; and reproduce peak energy demand to within 5-10 percent.

- **Operational problems** - The model should reproduce problems occurring in the system such that the model can be used for decision-making for that particular problem.

- **Emergency planning** - The model should reproduce HGL to within 10-20 ft (3-6 m) during situations corresponding to emergencies, such as fire flow, power outage, or pipe out of service.

- **Disinfectant models** – Over the time samples were taken, the model should reproduce the pattern of observed disinfectant concentrations to an average error of roughly 0.1 to 0.2 mg/l, depending on the complexity of the system.

In addition to these standards, the AWWA Engineering Computer Applications Committee[1] posted some calibration guidelines on its website. However, as mentioned previously, each modeling application is unique and requires its own unique set of calibration requirements. The AWWA guidelines are examples of "what could be written" and have not been accepted as standards. A model can be considered calibrated when results can be confidently used to make decisions about design, operation, and maintenance of water distribution system(*s*), and the cost to improve the model(*s*) further, cannot be justified.

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WATERFACTS

1500 BC - 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. While other ancient civilizations have had surface water canals, these are probably the first pipes.

(continued on page 42)