Every drop counts

Increasing the efficiency of water distribution

FREDERIK BLANK, MARKUS GAUDER – Drinking water is a precious but scarce commodity, and is not equally distributed on our planet. With rising world population, water withdrawals are predicted to increase by 50 percent by 2025 in developing countries and 18 percent in developed countries, according to the UN's GEO-4 report. Shortages are further exacerbated by climatic change. One part of the solution lies in implementing new sources of water, treatment capability and in transporting water over longer distances. Another contribution lies in addressing the significant losses that occur in its transport and distribution. The World Bank estimated that leakages account for 32 billion cubic meters in 2006. Particularly in water distribution, losses of up to 50 percent were found to occur in some regions and countries. Reducing losses is not just about saving water but also about saving energy as every drop lost is also a waste of the energy invested in its treatment and transportation (and thus has a price in terms of CO_2 emissions). ABB has developed an integrated water-management solution to reduce these losses in different ways. It supports maintenance by helping locate leaks, but also reduces the volumes lost by optimizing pump pressures, and saves energy and energy costs by scheduling pump operations.

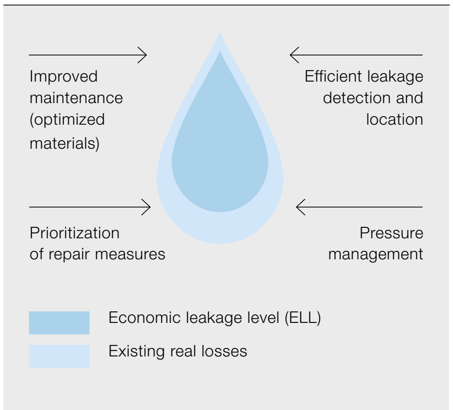
Leaks in water supply networks can be attributed to a variety of causes. Besides ageing pipelines, high pressures are among the main causes for water losses as pressure peaks not only increase water loss at existing damage points, but also cause additional leaks.

Water supply networks are often operated at unnecessarily high pressures to ensure supply at critical points, eg, parts of the network at high altitudes. Inadequate working points for pumps lead to an unnecessarily high energy consumption (and thus CO_2 emissions). Improvements in water supply efficiency can be achieved by the following measures:

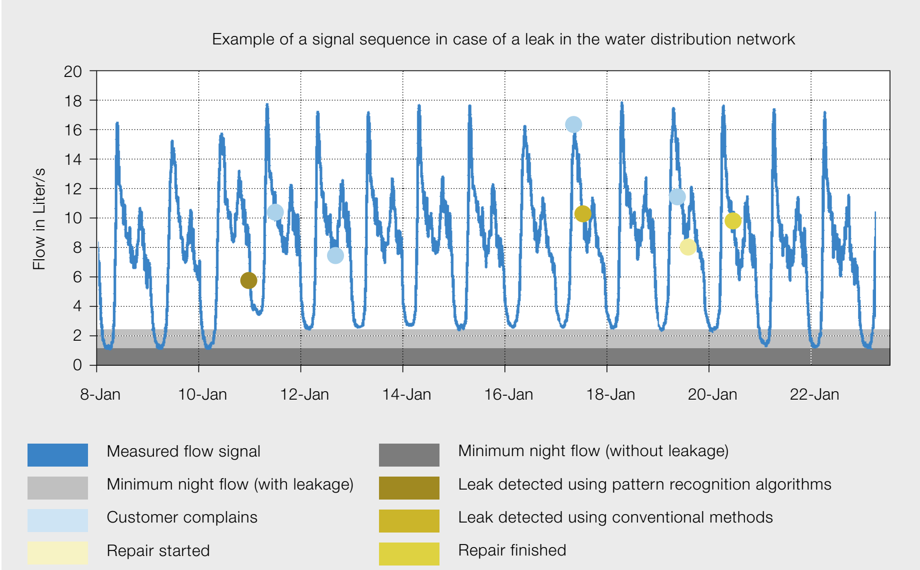
- Leakage management
- Pressure management
- Energy management

Title picture
Water is a precious commodity that is not equally distributed across the planet. The environmental sustainability of water supplies can be raised by tackling wastage of both water and energy (the title picture of this article shows the skyline of Dubai).

1 Building blocks of a comprehensive leakage management strategy



2 Sequence flow of a measurement signal with a leak



The occurrence of a leak can be seen at the beginning of the sequence (the flow measurement signal does not return to the lower dashed line during the night). Using the standard process, the problem could not be identified before 18 January. The corresponding repair order was issued and carried out on 20 January. The solution using signal models, which was installed in parallel, already identified the problem on 11 January so that an earlier intervention would have been possible.

Leakage management

A comprehensive leakage management strategy must generally consider different aspects. Active leakage management aims at minimizing both the occurrence of new damages and existing leakage flows by optimized pressure management. Passive leakage management detects and locates additional leaks at an early stage and thus supports maintenance planning. The latter thus focuses on the relatively small leakage flows occurring in the background rather than larger pipe bursts that can be identified and located relatively quickly due to their obvious impact. It is estimated that only 10 percent of the water losses in well-monitored and controlled networks are caused by larger pipe burst whereas the largest part of the losses are due to the many smaller leaks that are difficult to identify and locate.

Reducing the real water losses to an economically acceptable level – the so-called economic level of leakage (ELL) – requires targeted and coordinated measures in the following four functional areas:

(1) leakage detection and location
(2) pressure management
(3) improved system maintenance, eg, by using optimized materials, and
(4) prioritization and implementation of repair measures → 1.

Pressure peaks not only increase water loss at existing damage points, but also cause additional leaks.

A complete elimination of water losses is not feasible from a practical and above all from an economic point of view. The absolute minimum requirement, however, should be that losses are reduced to an economically acceptable level.

In leakage management, distribution networks are subdivided into so-called leakage or pressure-management zones, with an appropriate leakage detection and evaluation as well as pressure regulation being implemented in every zone.

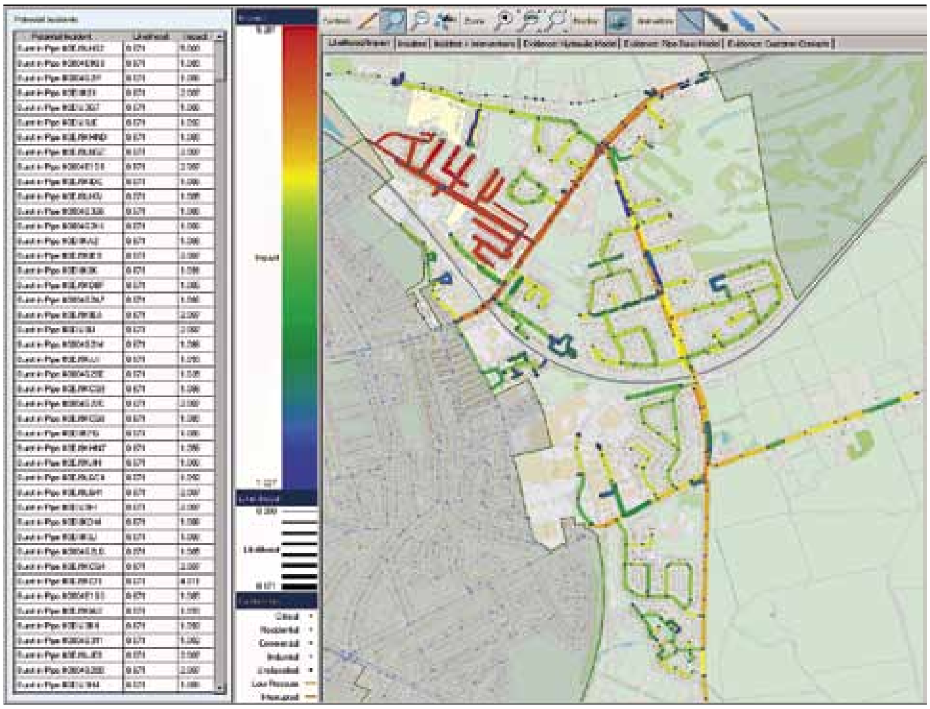
An approach followed by ABB builds on a continuous analysis of flow and pressure data. Using pattern recognition techniques, neuro-fuzzy and statistical methods, models are generated that predict the signal values that can be expected as a result of activity on the network (such as valve settings and pumping). If measured values (or sequences of values over a longer period) deviate from these predictions, an alarm is generated. The use of self-learning methods allows the solution to regularly adapt to the operational changes in the supply network.

If additional data including maintenance information, customer feedback (eg, telephone calls) and weather data are made available to the system, these can also be taken into account in the analysis. The consideration of such additional data can increase the error detection rate and further narrow down the geographic area to be considered when searching for a damaged section. The on-site search can then use appropriate (eg, acoustic) leakage detection devices in a targeted and hence more efficient manner.

This approach allows changes to be recognized very quickly and permits a proactive planning of maintenance measures. Overall, problems can be dealt with before the customer supply is actually affected. The approach requires neither extensive modeling of the water supply network nor assumptions regarding the configuration. The system runs automatically and trains itself continuously → 2.

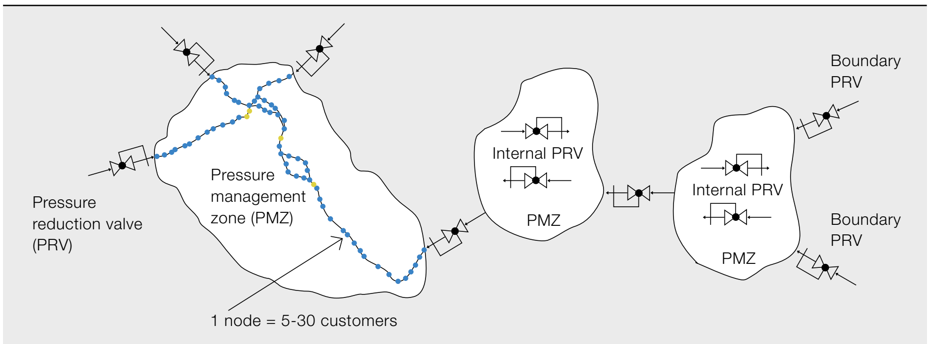
On the basis of hydraulic network models, a fault-tree analysis, and correlating current and historic data, a risk indicator can be calculated for each individual pipe segment. This value indicates the probability that the identified leak has occurred in a particular pipe segment and evaluates the leak's potential impact on the supply. This data helps narrow

3 Decision support system showing a likelihood/impact map



Color coding and line thickness are used as indicators of likelihood and impact of a leak. Source: Exeter University, UK

4 Cascading management zones with the corresponding pressure control elements (actuators)



A characteristic feature of the management zones are multiple inlet and outlet points allowing systematic control of the pressure within the respective zone.

down the location of the leak and can be used to prioritize maintenance activities ➔ 3.

Pressure management

The pressure management zones discussed above are usually controlled by means of pumps or control valves ➔ 4. The ABB pressure-management solution uses a hydraulic model of the zones to be optimized and a prediction of the consumption at the various nodes. Mathematical optimization methods are used to calculate the optimum pressure at reference valves and pumps for a future time horizon (eg, the next 24 hours).

Operational requirements such as ensuring the minimum required pressure at the highest point of the pressure management zone are taken into account by the formulation of mathematical constraints. The reference values are then implemented on each actuator (pump or valve).

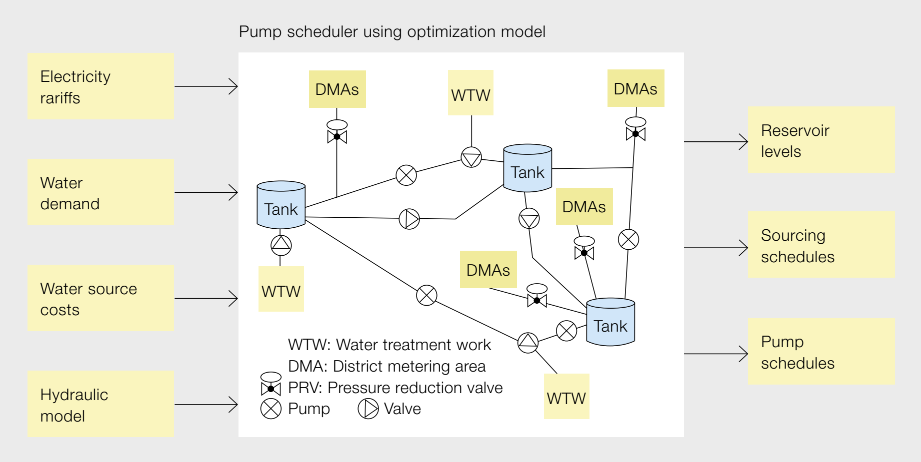
Previous pressure management systems rely on a simple local control of the pressure control elements based on predetermined approaches, possibly varying over 24 hours or being flow-controlled. If the water consumption curves change only very little from one day to the next, the time- or flow-based control schemes configured in the valve remain valid

5 Energy accounts for a large part of water costs

Drivers	Energy's share of operating costs
Pump stations	up to 60 %
Desalination plants	up to 40 %
Water treatment plants	up to 45 %
Wastewater treatment plants	up to 50 %

The largest part of the energy used in water-supply networks is consumed by pumps. Energy accounts for 40 to 60 percent of the operating costs.

6 Schematic representation of the inputs and outputs of the energy management solution



throughout the defined 24 hour time period. In this context it should be noted that this type of pressure control is mainly suitable for pressure management zones with only one inlet.

The situation is different when the water consumption curves vary from day to day, when multiple actuators are involved in controlling the pressure within the zone or when strong interactions with other pressure management zones exist. In such cases, the pressure reference values must be adapted to the respective operating situation. In such a system, the pressure management is implemented on two levels: Besides the local control, a higher-level reference value generation for the individual actuators is required in order to define the optimum pressure reference values. In addition to the reduction of water losses caused by leaks, this strategy helps prevent water hammering and oscillations in the water network. The higher-level pressure control is based on appropriate simulation models, consumption predictions and real-time data provided via the control system.

The higher-level pressure control is integrated in the control system and has access to its functions and data inventory. This does not only allow the result of the higher-level pressure control to be forwarded directly to the connected actuators but also its visualization as a trend or in an integrated geographic information system (GIS). In addition, the pressure reference values can be generated in real-time taking into account the current condition of the system.

Energy management

The largest part of the energy used in water-supply networks is consumed by pumps. Energy accounts for 40 to 60 percent of the operating costs (considered over a period of 20 years) → 5. ABB's pump optimization solution thus seeks to deliver savings in terms of both energy and cost.

As input parameters it uses a hydraulic model of the water supply network and pump characteristics (efficiency curves) as well as current and predicted (over a period of 24 hours) water consumption data and power tariffs. From this it creates a pump schedule containing detailed information for a future time horizon defining which pump is to be operated when and at which operating points. It defines not only the start-up and shut-down points of the pumps but also their speeds (when variable speed pumps are used). The optimization seeks to operate the pumps as close to their maximum energy efficiency points as possible. At the same time, the filling of reservoirs is no longer based on such rigid rules as "if reservoir level too low, switch on pump 1". Instead, the optimization algorithm takes into account the entire optimization horizon of, eg, 24 hours and seeks to fill the reservoirs when the electricity costs are low.

The pump schedules are generated by cyclic calculations and are continuously updated in the information management system.

The pump schedules are generated by cyclic calculations and are continuously updated in the information management system. The integration of the scheduling solution into the control-system environment allows the generated schedules to be applied directly and immediately. Before they are applied, the results can be visualized, for example in the form of trends → 6.

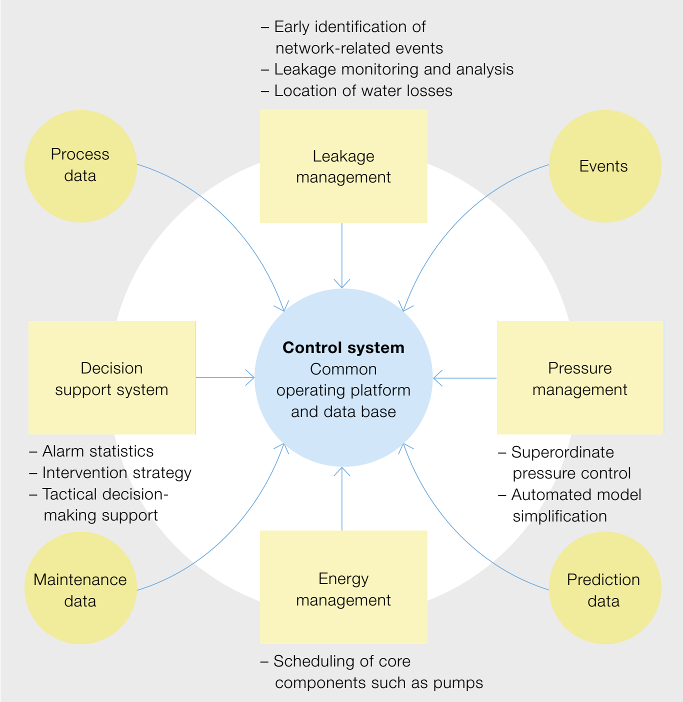
A critical aspect of pump scheduling is the computing time required to calculate optimum pump schedules. To reduce this time and make sure that the results are delivered within a reasonable timeframe, ABB has developed a model simplifier that can automatically reduce the hydraulic model to the essential elements without compromising the required model accuracy or falsifying the hydraulic results. While other solutions on the market require special models that have to be adapted and adjusted to changing network structures, the simplifier developed by ABB automatically processes hydraulic simulation models that can be changed, adapted and calibrated directly by the operator.

The aspect of integration

The applications mentioned above already exist and are being used by water suppliers in different variants. However, these software solutions and IT systems have mostly evolved over time and consist of partly incompatible and not-fully integrated components, preventing optimal data and information flow. The previous sections have shown that the topics of leakage management, pressure management and energy management are closely interlinked, influence each other and are partially based on the same data.

The integration of the aforementioned modules and additional applications in a control system-based user environment enables further efficiency gains. Here, ABB pursues the approach of an integrated water management system which enables a modular structure and the

7 Example implementation of the integrated water management approach



8 The geographic information system (GIS) is fully integrated in ABB's control system

combination of the solution approaches described above.

A schematic representation of the integrated water management approach including its core components is shown in → 7. The system is characterized by a comprehensive, near real-time view on the water supply network, a common user guidance based on a GIS, and the linking of individual applications on the basis of a common data base. Any information, be it of technical or commercial nature, can be retrieved in a context-related and processed form, allowing a detailed view on the condition of the supply network.

ABB has developed a model simplifier that can automatically reduce the hydraulic model to the essential elements without compromising the required model accuracy or falsifying the hydraulic results.

Visualization

Depending on the objectives, an adapted representation of relevant data and information may be necessary. Besides visualizations such as process graphics, which are provided by control systems as standard, the integration of a GIS into the control system environment provides significant added value. GISs are very common among water suppliers, and are used, among other purposes, for planning and network control. From the GIS, the functions of the control system can be accessed in an object- and context-dependent way, while the control system is supplemented by GIS-typical functions such as zooming, panning and decluttering. Temporal and spatial data can also be represented in the same view → 8.

A comprehensive solution

Value-added applications such as those presented above support a sustainable and efficient operation of water supply networks. The application of real-time simulation and optimization contribute to making network operation manageable in complex network topologies. Pressure management and pump scheduling are two important examples. The use of technologies, for example from the area of statistical signal analysis, allows early identification of changes in the network operation and facilitates intervention before customers become affected by a lack of pressure or even the interruption of their water supply. In the area of visualization, the integration of a geographic information system into the control system environment allows a combined representation of geographic and time-based data (such as process data, alarms or simulation results) in real-time and hence a deeper insight into the current state of the network. The approach described in this article supports the development towards a sustainable and efficient operation of water supply networks.

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