Smart Water Networks for Efficiency Gains

Brian E. Heimbigner1*, Mark Bitto2*

1ABB Inc., 4355 Little Falls Drive, Cumming, GA 30041
(*correspondence: brian.e.heimbigner@us.abb.com, 770-625-6704)
2ABB Inc., 29801 Euclid Avenue, Wickliffe, OH 44092
(*correspondence: mark.bitto@us.abb.com 440-585-8120)

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ABSTRACT
Water is a limited resource and requires effort and cost to source, treat, and distribute. Different drivers exist for water utilities to make their distribution systems more efficient: water quantity limitations, water quality limitations, need to be green, state and federal regulations, energy reduction, total operating cost reduction, high water losses and need to improve productivity with smaller staff levels.

Since the goals are to provide water of a safe quality on a reliable basis, it is important for many utilities to be pro-active in monitoring their distribution system leaks & bursts, meter malfunctions, pressure gradient deviation, failed production assets, and other significant changes to the normal network behavior.

Many people (Lord Kelvin, Edward Deming, and Jack Welch) have been credited with “You can’t manage it, unless you measure it.” To be able to monitor and measure the water network, it is appropriate to have a minimum set of tools: zones or district metered areas (DMAs) set up with appropriate flow meters and pressure gauges on mains to capture data, telemetry to transmit data, a GIS to identify locations, and an automation system to accumulate, process and report results. In addition software as a service (SaaS) is available with sophisticated algorithms to cleanse, interpret, compare current data to historical results, and to prioritize the data into actionable business decisions. The presentation covers the elements of a monitoring and action system.

Introduction
A modern day water distribution system may be modern in many respects relative to management and control of the system and some of its physical assets (tanks, reservoirs, pump stations), but still ancient in terms of the physical assets underground. With tight budgets and reduced resources in the current economy, water utilities definitely need to do more with less and have done an excellent job responding to the challenge. However, the continued restrictions on budgets call out for additional solutions and tools to make the operation of the system even more efficient, to reduce costs wherever possible, and to monitor and optimize the resources – both the physical (water lines, pumps, tanks, reservoirs, pressure control devices, flow monitoring meters, etc., as well as the staff and maintenance equipment) and the product resources (clean water for delivery to the customer.)
In optimizing the resources, an item of increasing interest is the reduction of Non-Revenue Water (NRW), not only because it is the main product for the customers, but also because the costs of producing and distributing water is generally more expensive each year due to increases in power, chemical, labor, and other consumable costs.

**Water Loss and Impact on Society**

The United States is one of a number of fortunate countries having vast water resources although they have recently come under pressure due to drought, overuse in certain regions, or industrial/agricultural/municipal pollution. Generally, safe drinking water is delivered right into our homes. Some parts of the world are not as fortunate. It is estimated that between 700,000 to 1,500,000 people in the world do not have access to safe drinking water which results in extensive medical costs and a significant fatality rate, especially among children (estimated at 4,000 children per day). Granted, part of the problem is that about 2.5 million people do not have access to proper sanitation which can lead to contamination of drinking water.

However, for the countries that have made great progress in improving their water treatment and delivery systems, it is pitiful to lose a significant portion of the water in the distribution system. The World Bank has identified reduction of Non-Revenue Water as one of its major goals for water systems in many countries due to relatively high NRW levels and generally very high energy rates in many developing countries. In a number of major global cities, NRW is 20% or greater with some cities NRW reaching over 50%, as shown in Figure 1. Treating and distributing twice the amount of water needed to reach the end user or to correct for non-billing consumes a lot of additional power, labor, and chemicals.

![Figure 1 – Global Non Revenue Water Rates](image-url)
The above relatively high NRW rates appear in cities in many countries considered still developing, but a few (Cork, Montreal, Sao Paulo, Rome) are in developed countries. It is indicative of a couple of things: aging infrastructure and tight capital budgets. The water utilities have different levels of knowledge of their problem, but may not have the funds to solve it nor to keep on top of it. The US scene is not quite so severe, but NRW does still exist as noted in Table 1.

<table>
<thead>
<tr>
<th>City</th>
<th>% Non Revenue Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Philadelphia, PA</td>
<td>31</td>
</tr>
<tr>
<td>Cleveland, OH</td>
<td>29</td>
</tr>
<tr>
<td>Jefferson Parish, LA</td>
<td>24</td>
</tr>
<tr>
<td>Portland, ME</td>
<td>18</td>
</tr>
<tr>
<td>Macon, GA</td>
<td>18</td>
</tr>
<tr>
<td>Memphis, TN</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 1 - Non-Revenue Water Losses in US Water Utilities (US EPA survey 2008)

Since the survey was made five years ago, we understand a number of these cities have made improvements to their NRW numbers, but are still able to gain additional operational savings by further reductions. And many other cities still experience NRW numbers that could be reduced to generate savings.

**Drivers for Smart Water Networks (SWN)**

When water is plentiful and relatively inexpensive, as it has been in the US, a higher water loss can be accepted. Often in the past the cost of the fix has exceeded the value of the benefits. However, in certain regions of the US this is no longer true. Due to extended droughts in large sections of the US, new industry demands in regional areas (such as the shale oil/gas formations), and increasing state regulations on water loss the need to have a SWN has increased. Another factor making a SWN appealing is the need to further optimize the O&M function at a water utility due to reduced staff and budgets.

**Benefits of Smart Water Networks**

Smart Water Networks can provide many benefits other than just NRW reductions:

- Analysis & detection efficiency of water distribution network and components
- Increased availability of system
• Improved visibility
• Operations optimization
• Energy savings
• Increased compliance
• Early warning of problems and actions, resulting in reduced customer complaints
• Enhanced planning for long-term capital programs and short-term O&M activities

Elements of a Smart Water Network

A Smart Water Network is comprised of five layers, including (1) the water utility’s infrastructure (pipes, pumps, storage facilities, pressure reducing valves, etc.), (2) the sensing devices (flow meters and pressure data loggers), (3) the collection and communication devices (remote transmission units providing data transmission via multiple choices), (4) the brains of the system – the Supervisory Control and Data Acquisition System (SCADA) collects and processes the data, and finally (5) a data fusion and analysis program containing algorithms and mathematical formulas to cleanse the data and convert the raw data to actionable knowledge. The SWN is enhanced by having a Geographic Information System (GIS) integrated with the SCADA system, so that when an abnormality in the distribution system is detected and identified, its precise location can be displayed (with the exception of the piping network, which will not generally be tagged in the GIS). However, with data from other surrounding physical infrastructure a good approximation of the location of a failed pipe can be made.

Since the Physical Layer or infrastructure is whatever it is, we will move onto level 2, Sensing and Control. In order to be most effective it is not only necessary to equip the distribution system with flow meters and pressure loggers on the distribution mains, but also to sub-divide the entire system into smaller sub-systems often referred to as District Metered Areas (DMAs). The purpose of the DMAs is to
provide a manageable size of an area from which detections of abnormalities in the system (leaks, bursts, breaches, pressure deviations from norm, and malfunctioning main meters, pressure reducing valves, flow valves, pumps, or storage units) can be identified, quantified, and acted upon in a more efficient manner than a distribution system without a SWN.

A DMA is depicted below in which the common physical features are noted, including the larger zonal boundaries and their meters and valves as well as the DMA boundaries with their associated meters and valves.

Layer 3 has to do with the collection of data and transfer from the field back to the SCADA system. This can be accomplished in many ways: leased phone lines (expensive), leased cell phone connections (expensive), radio waves or wide area internet. If the field units were only going to wake up infrequently to send the data, the phone line or cell phone connection might work. However, for the Smart Water Network it is desired to be transmitting data on a near-real time basis. Thus the use of radio or internet is preferable. Some cities are installing private internet for use by city first responders and other emergency groups that often can be available for municipal water utilities also.
Layer 4 is Data Management and Display and relies on the SCADA system, which must be capable of spanning large geographic areas, aggregating data from many different sources, process and store large amounts of data, provide control of the network, and send operator commands and instructions to a disparate set of network devices and equipment. It is not only about the quantity of sensors and related data, but also about the quality of data. Also aspects of compatibility and inoperability must be considered when system landscapes are defined and set-up, which will determine the efficiency of operations. Through integration of standard communication protocols, such as OPC, Modbus TCP, DNP3.0, IEC870-5-101/013/104, and IEC61850, the SCADA can easily integrate both locally and geographically distributed devices including Process Control Units, Remote Terminal Units (RTU), Programmable Logic Controllers (PLC), and Intelligent Electronic Devices (IED). The SCADA system needs to be flexible and functional to easily adapt to the requirements of small applications to large, multi-site distributed SCADA architectures. Intuitive navigation as well as context and situation sensitive data and information access are among the most relevant needs for operators to be able to handle an increasing amount of data and alarms. The context-sensitive aspect menus of the SCADA allow operators and engineers to share information and navigate intuitively. With user-specific information presentation, easy navigation to data, and alarm management based on EEMUA 191 guidelines, the SCADA delivers reliable and consistent water network operations.

Figure 5 – Supervisory Control and Data Acquisition System
The adequate visualization of data using ergonomic Human Machine Interfaces (HMI) is another important element to be considered. Depending on the need, the visualization can happen through high performance network schematics, trends, alarms lists or other applications such as integrated GIS with cross-navigation capabilities. Such integration allows visualization temporal and spatial data within the operational environment (using definable and configurable different layers of depiction by the GIS) and thus provides for easy access to information required for tactical decision making.

Figure 6 – Integrated GIS Functions into SCADA System
Within Layer 5, Data Fusion and Analysis, data are then processed via mathematical and statistical algorithms specifically developed for handling complex and noisy water network data. The resulting information or knowledge is often not obvious or trivial from the input data as collected. As this layer is the most distant from the physical layer, requiring the most sophisticated intermediary data integration and analysis, this layer is also the least developed in today’s SWN. However, promising emerging technologies are available to drive a distribution system towards a true “Smart Water Network (3). One of the most promising is that of the TaKaDu Service as a Solution (SaaS) cloud-based technology⁴. When integrated and “sitting on top of” the SCADA system, the SaaS technology can utilize the information gathered by the other four layers, allow input of external data such as weather or major events in the region that could affect water consumption, and any planned utility activities that could affect components of the distribution system.
The SaaS can cleanse the data prior to evaluating current conditions compared to past historical norm data. Cleansing is a process in which complex and noisy water network data are evaluated with advanced mathematical and statistical algorithms to establish the “normal” behavior of each network element and the network as a whole and compare it in real-time with current network behavior. Any deviation or anomaly in the system is captured from the data and presented in a user-friendly format as actionable alerts that can be prioritized by the system analyst/operator, create action items distributed to the team, activate monitoring of the progress of the deviation and its fix, and (via the historian in the SCADA) cause storage of all of the information on the deviation and its resolution for future consideration for long term planning based on knowledge of the assets’ failure history.
Once an event (i.e. leak, burst, DMA cross-over, pump failure, etc.) is identified, hydraulic and mathematical processes are applied to establish the event’s exact type, time, location, and magnitude. The event is assigned to an “owner” within the water utility who is then notified via a multitude of interfaces (computers, smart phones, radios, etc.). A typical dashboard for a single event is shown below and is generally available to all system users. This provides a good example of system integration between the telemetry, SCADA, field instruments (flow meters and pressure gauges), and the analytic software program operating on a cloud server. The event is then tracked, based on priority, until it is resolved. The event data will be accessible from the Historian function of the SCADA system.
The dashboard below is a depiction to represent a weekly, monthly, or annual report beneficial to a supervisor or manager to view summary information, as she may be more interested in the DMAs’ performance from period to period than the individual events. This dashboard indicates the problematic DMAs and her team’s performance. This type of report can be used to identify DMAs in which additional Capital budget should be applied to replace the aging and failing infrastructure. The supervisor can still drill down into the historical data of the individual events to determine how the service/maintenance team responded, period of time to respond, whether any citizens reports were made prior to or after the first identification of the event and other useful information.
Summary

A number of drivers are affecting the water sector, including regional scarcity of water, regional drought conditions, increasing regulations, scarcity of human and physical infrastructure resources in annual budgets. A Smart Water Network can help to reduce Non-Revenue Water, but also do much more including reducing energy costs, improving customer services, complying with regulations, making a commitment to a greener utility operation, increasing overall operational efficiencies, and extending the life of the utility’s infrastructure. Each water utility is unique and to properly assess the cost/benefits ratio of a SWN requires an evaluation of the specific distribution system, existing infrastructure, topography, regulatory conditions, and company policies/goals/objectives. To help out with this evaluation, it is possible to set up a pilot(s) DMA in the system and gather data over a period of time to simulate the operation of a distribution system divided up into multiple DMAs. This will help to better define how a SWN might work for the utility and identify some of the challenges to setting up the multiple DMAs. The ultimate goal of a Smart Water Network is to provide the utility with better and perhaps more data, but in a very user-friendly form after it has been run through the SaaS to change data into knowledge.
List of Acronyms:

DMA – District Metered Areas
DMZ – District Metered Zones
Event ID – Event Identification
GIS – Geographic Information System
HMI – Human Machine Interface
IED – Intelligent Electronic Devices
NRW – Non Revenue Water
PLC – Programmable Logic Controller
RTU – Remote Terminal Units
SaaS – Software as a Service
SCADA – Supervisory Control and Data Acquisition system
SWN – Smart Water Network
US EPA – United States Environmental Protection Agency

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Author’s Biographies:

Brian Heimbigner has over 25 years of projects and applications experience in the water sector in municipal water and wastewater, electrical power generation, pulp & paper, chemical production, and mining. Mr. Heimbigner has a BSChE and a MBA, both from the University of Washington.

Mark Bitto has over 25 years experience in I&C for various types of plants in the municipal water and wastewater, electric generation, and industrial sectors. His experience has spanned all types of major automation and various types of instrumentation. Mr. Bitto has a BSChE from The Ohio State University and a MBA from Cleveland State University.