EVALUATION OF SMART WATER INFRASTRUCTURE TECHNOLOGIES (SWIT)

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Smart Water Infrastructure Technologies (SWIT)

Smart Water Infrastructure Technologies (SWIT) SWIT have the potential to contribute significantly towards improved service delivery and efficiency of water services providers; reducing costs and water losses, streamlining operation and maintenance, and improving data and asset management in Water Utilities, allowing for information based decision making.

SWIT include the following products:

- Smart Metering (AMR/AMI)
- District Metered Areas (DMAs)
- Pressure Management
- Active Leak Detection
- Management Information Systems (MIS)
- Customer Relations Management Systems (CRM)
- Geographical Information Systems (GIS)
- Supervisory Control and Data Acquisition (SCADA)
- Hydraulic Modeling

But are not reduced to those, as information can be complemented by water quality monitoring and hydrological data gathering systems.

SWIT cost is decreasing while their development progresses, it is therefore essential that LAC water operators incorporate SWIT in their operating tools in the most cost effective manner.
To warrant SWIT full benefits are achieved, IDB's Water and Sanitation Division (WSA) is working to:

- Ensure LAC specialists keep abreast with the progress and advances of SWIT
- Facilitate a better understanding by the Utilities of SWIT costs and benefits
- Explore limitations in their implementation and define strategies to address these issues and,
- Present its findings in easily accessible format, maintaining information and discussions current and updated.

EXECUTIVE SUMMARY

The objective of this document is to present an assessment of the current situation in the application of Smart Water Infrastructure Technologies (SWIT) and to provide a summary of potential key recommendations for the integration of such technologies by water service providers in the Latin American and Caribbean region.
Smart Water Infrastructure Technologies (SWIT) have the potential to contribute considerably to improved service delivery and efficiency. Those technologies include:

- Smart Metering (AMR/AMI)
- District Metered Areas (DMAs)
- Pressure Management
- Active Leak Detection
- Management Information Systems (MIS)
- Customer Relations Management Systems (CRM)
- Geographical Information Systems (GIS)
- Supervisory Control and Data Acquisition (SCADA)
- Hydraulic Modeling

And are described in this document, which also presents: a case study of their application by the Barbados Water Authority; a survey of the level of implementation in representative water utilities of the Caribbean region, and recommendations derived from lessons learned.

CONCLUSIONS AND RECOMMENDATIONS

Based on the assessment of SWIT and evaluation of water utilities in the Caribbean, the following conclusions and recommendations can be made.

- In general, professional leadership and commitment for integration of technologies is key to the success of the water system upgrading and modernization program. A "SWIT Integration Team" should be appointed and trained from the beginning of the project.
- It is important for the utility to develop a vision and a long-term action plan for integrating and optimizing SWIT. The planning and vision should be developed with interdepartmental personnel from management, operations, distribution, engineering, commercial, and IT. Also, it is recommended that utilities seek the assistance of professionals with vast experience in the applicable SWIT disciplines.
- SWIT like GIS, Hydraulic Modeling, Asset Management should be developed in an initial preparation phase prior to implementing a capital intensive SWIT like AMR/AMI.
- DMAs and PMAs must be implemented in parallel with an integrated MIS in order to take full advantage of the benefits and optimize the investment.
- Pipe replacement and rehabilitation (R&R) programs should be considered a last resort, only after:
    - Proper condition assessment of the pipes.
    - Criticality analysis of the infrastructure
    - Analysis of cause and effect of pipe bursts
    - Having DMAs and PMAs in the systems and knowing for certain where the non-recoverable water issues occur (by DMA/PMA) so that the pertinent pipe R&R priorities can be established based on a business case.

- Project completion seems to be more successful when a third-party with previous experience in the subject takes over the projects, particularly in turn-key projects.
- Third-party/turn-key project activities also need to be strictly supervised and monitored with regard to budget, timeline, and technical accuracy.
- SWIT projects need a strong component of training and involvement of permanent utility personnel that must be financially and professionally incentivized to carry on the future operations.

Notes:
This publication is an initial review of the SWIT concept that would be complemented by further evaluations, readers' comments and suggestions are therefore welcome, and can be sent to: YVONM@iadb.org
When company or product names are mentioned, this should be considered as illustrative, and not as an endorsement from the IDB of such company or product.

1.0. INTRODUCTION

1.1. ACKNOWLEDGMENT

This Study has been financed by the Inter-American Development Bank (IDB) Knowledge and Learning Department (KNL) through the Cutting Edge Knowledge Fund. It has been managed by the Water and Sanitation Division (WSA) to strengthen the sectorial knowledge on “Smart Water Infrastructure Technologies” or SWIT, through an assessment of the current situation in the application of SWIT in the Caribbean region and the provision of key recommendations for the integration of such technologies by water service providers.

1.2. BACKGROUND

Smart Water Infrastructure Technologies (SWIT) have the potential to contribute considerably to improved service delivery and efficiency of service providers. Such technologies include:

- Smart Metering (AMR/AMI)
- District Metered Areas (DMAs)
- Pressure Management
- Active Leak Detection
- Management Information Systems (MIS)
- Customer Relations Management Systems (CRM)
- Geographical Information Systems (GIS)
- Supervisory Control and Data Acquisition (SCADA)
- Hydraulic Modeling

Recognizing this potential, the IDB's WSA has financed the implementation of such technologies through loans to water utilities across the region. Notably, several Caribbean countries have included a number of smart water technologies within their water and sanitation projects and a specific focus on this region has been adopted.

To warrant the full benefits offered by smart technologies are achieved, it is essential to:

- Ensure Water practitioners keep abreast with the progress and advances of these technologies;
- Facilitate a better understanding of these technologies costs and benefits;
- Explore the barriers and limitations in the implementation all of these technologies such as: cost, institutional resistance to change, inadequate professional capacity, aging existing infrastructure and;
- Define strategies to address these issues.

2.0. OVERVIEW OF SWIT

2.1. SMART METERING (AMR/AMI)

Smart metering is a component of the smart grid that allows a utility to obtain meter readings on demand (daily, hourly or more frequently) without the need of manual meter readers to transmit information. There are two types: (1) automated meter reading (AMR), and (2) automated metering infrastructure (AMI). These two types of technologies are described below.

Automated Meter Reading (AMR) includes the walk-by and drive-by methods as well as a fixed network, usually with only one-way communication from the meter to the billing system. The AMR technology includes:

> Drive-by metering: This resource-saving metering solution allows water meter data to be collected instantly on-the-go. After installing the reading device and software in a van or work truck, the meter reading crew can quickly obtain accurate meter readings simply by driving through a service area.
>
> Touch-read metering: For areas that are not conducive to vehicles, touch-read metering is an excellent meter reading solution. Touching a hand-held meter reading device directly to the water meter sends a radio signal that automatically transmits meter data and stores it in the hand-held device.

Automated Metering Infrastructure (AMI) refers to a fixed network system, with smart meters providing two-way communications between the water meter and the utility. The use of AMI further improves the efficiency of water utilities and eliminates the costs of routine meter reading. When AMI is combined with geospatial meter data management, it increases the accuracy and precision of the meter read, reducing re-reads. This results in accurate and timely reads that are ready for billing, with an identification of failed and failing meters before actual billing, improving the utility's cash flow.

ADVANTAGES OF SMART METERS

Smart meters can benefit the water utility, the environment, and the utility's customers by:

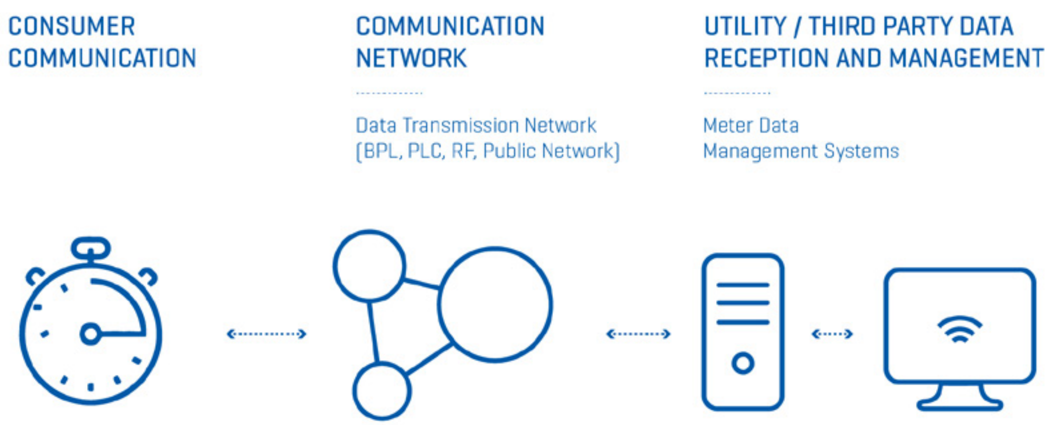
- Lowering the cost of meter reading by eliminating manual meter reading;
- Enhancing employee safety by reducing the number of personnel on the road;
- Reducing billing errors and disputes;
- Monitoring the water system in a timely manner;
- Enabling flexible reading schedules, reducing delays in billing of commercial accounts;
- Providing useful data for balancing customer demand;
- Enabling possible dynamic pricing (raising or lowering the cost of water based on demand, promotions, and customer incentives);
- Benefitting the environment by reducing pollution from vehicles driven by meter readers;
- Assessing Non-Revenue Water in real time or short intervals;
- Facilitating the data to establish the night water consumption patterns, analyzing the minimum night flows (MNF), and offering a more detailed feedback on water use patterns;
- Enabling customers to adjust their habits to lower water bills;
- Providing real-time billing information, reducing estimated readings and re-billing costs;
- Reducing customer complaint calls and increasing customer satisfaction;
- Improving the monitoring of potential meter tampering and water theft; and
- Detecting water line leaks sooner, so they can be repaired faster.

DISADVANTAGES OF SMART METERS

While smart meters have many benefits, they also present challenges to water utilities, customers, and the environment. They require:

- Front-end capital investment;
- Long-term financial commitment to the new metering technology and related software;
- Ensuring the security of metering data and preventing cyber-attacks;
- Transitioning to new technology and processes with proper training;
- Managing public reaction and customer acceptance of the new meters;
- Managing and storing vast quantities of metering data and;
- Disposing of the old meters.

An overview of the smart metering technology is presented below.



> FIGURE 1. Overview of Smart Metering Technology

- Collected data transmitted through:
- Broadband over Power Line (BPL)
- Power Line Communications (PLC)
- Fixed Radio Frequency (RF) networks
- Public networks (e.g., landline, cellular)
- Meter data are received by the AMI host system and sent to the Meter data Mana gement System (MDMS) that manages data storage and analysis to provide the information in useful form to the utility.
- AMI enables two-way communications, so communication from the utility to the meter could also take place.

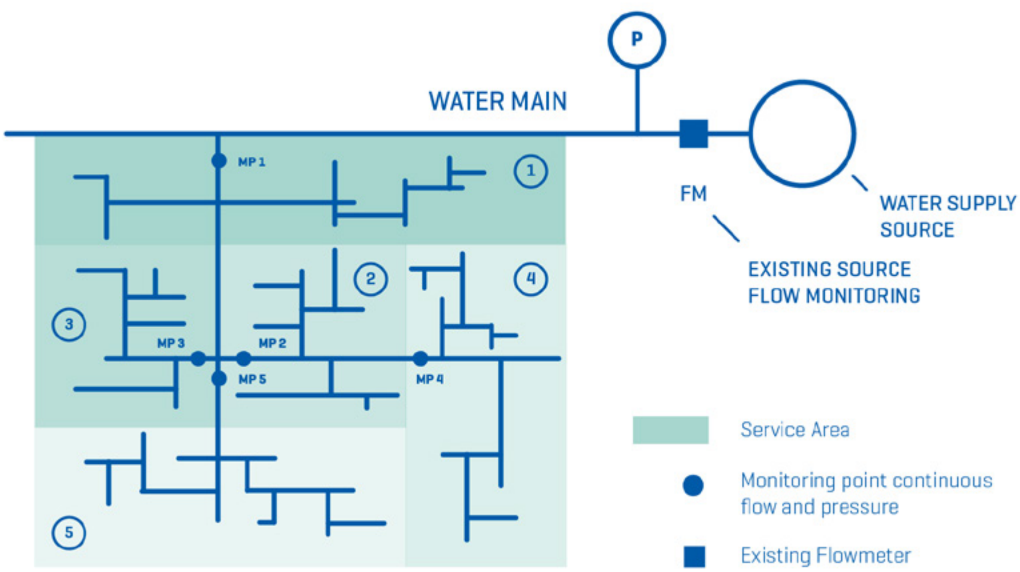
2.2. DISTRICT METERED AREAS (DMAs), PRESSURE MANAGEMENT AREAS (PMAs) AND LEAK DETECTION

All water utilities around the world have water losses due to leakage and commercial inefficiencies, known as non-revenue water (NRW). The most effective and proven methodology for reducing NRW is with the dynamic combination of SWIT that include tools like GIS and hydraulic modeling, the use of DMAs, PMAs, Active Leak Detection, and MIS.

DISTRICT METERED AREAS (DMAs)

Most water utilities perform a system wide water balance, or audit, measuring the water supplied to the customers and subtracting the volume consumed by customers. Such water audits are useful for obtaining the total NRW volumes of the system as a whole but are limited in showing the operators where the losses, or what type of losses, occur. A DMAs is a proven method that uses a combination of SWIT to measure water loss. It can be defined as a discrete sub-system of a water distribution network where the water supply and consumption can be measured individually from the rest of the system. By dividing the system into several sub metered areas or DMAs, the utility management can identify areas where NRW is predominant and develop specific action plans and interventions to reduce the losses. DMAs are usually created by closing boundary valves or by permanently disconnecting pipes between neighboring areas. Water flowing into, and out of, the DMA is metered and flows are periodically analyzed in order to monitor the level of NRW. DMAs can be classified into three different categories:

- single inlet
- multiple inlets
- sleeper -- where boundary valves open or close to meet specific levels of service of a utility



> FIGURE 2. Schematic of a district metered area of a water distribution system

What makes the DMA method a successful SWIT?

A DMA includes a combination of smart tools, instrumentation, and software, managed by knowledgeable people in charge of the system. The effectiveness of the DMA depends on how the utility personnel use these smart tools and technologies to identify anomalies in the sub metered service area in order to make the appropriate intervention in the shortest possible time. Typical SWIT used in setting up and operating DMAs are:

- Digital master meters;
- Customer meters (analog or digital);
- Geographical information systems (GIS);
- Hydraulic and water quality models;
- Supervisory Control and Data Acquisition (SCADA);
- Wireless and cellular remote transmission systems;
- Pressure transducers;
- Servers and/or cloud-based storage systems; and
- Software and hardware for generating reports of key performance indicators (KPIs).

Advantages of DMAs

DMAs can benefit the water utility, the environment, and customers by:

- Identifying deviations from normal flows and pressures;
- Reducing response time for leak repair;
- Helping in prioritizing leak pinpointing efforts;
- Enabling advanced analysis of customer consumption and leakage patterns and their quantities;
- Controlling background leakage when used in conjunction with proactive pressure management;

- Extending life of mains by managing pressure; and
- Supporting water conservation efforts by reducing pressure-dependent demands.

Disadvantages of DMAS

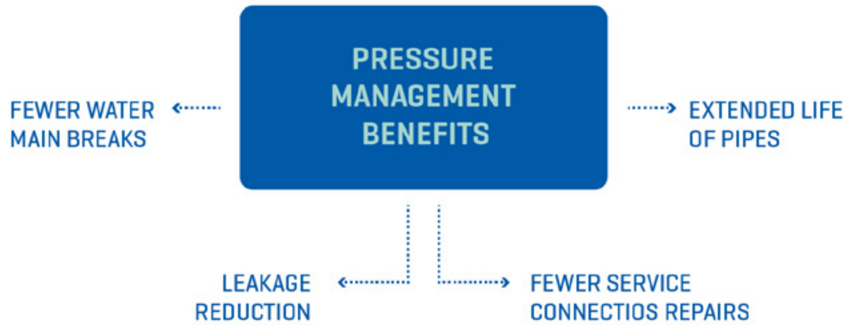
DMAs require:

- Capital investment: varying degree depending on configuration and operational status of valves, appurtenances, and data communication capability;
- Careful planning, design and incremental start-up to maintain adequate hydraulic (domestic and fire flows) and water quality performance;
- Proactive maintenance plans; and
- An increase the frequency of hydrant flushing to maintain water quality.

PRESSURE MANAGEMENT AND PRESSURE MANAGEMENT AREAS (PMAS)

Pressure has a fundamental influence on leakage rates in distribution systems and an ever-increasing number of utilities are now recognizing that good pressure management is the fundamental foundation of good leakage and infrastructure management.

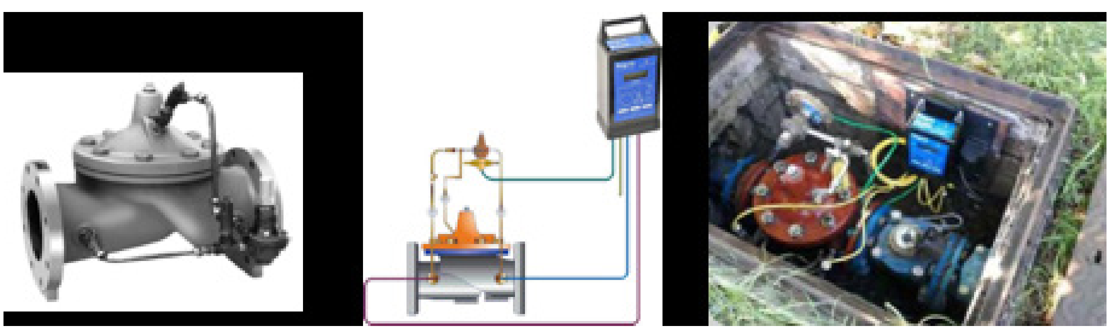
The proven benefits of pressure management in distribution systems include not only the water reducing leakage and some components of consumption, but also water utility and customer benefits arising from reduced numbers pipe failures and leaks. These include reduced repair and reinstatement costs, reduced public liability and adverse publicity, reduced costs of active leakage control, deferred infrastructure renewals and extended asset life of mains and service connections, as well as fewer problems on customer service connections and plumbing systems, all leading to fewer customer complaints. A PMA is a permanently isolated DMA with pressure control and metering used to control background and unreported leakage and to assist in reducing break frequencies.



> **FIGURA 3. Benefits of pressure management.**

Pressure Management (PM) is achieved by lowering the hydraulic grade line (HGL) of a service area using:

- Variable Frequency Drives (VFD)
- Conventional Pressure Reducing Valves (PRV)
- Smart PRVs
- Storage Tanks



> **FIGURE 4. Pressure control devices**

The previous figure shows a Smart PRV using a pressure regulating device that controls the output of a PRV according to a preset control method. It incorporates Global System for Mobile communication (GSM) technology, which allows remote data transmission and 'over the air' control parameter configuration. The regulating unit modulates the outlet pressure of a PRV in one of four methods:

- Time Control: outlet of PRV adjusted according to a preset daily or weekly time profile;
- Flow Control: outlet pressure modulated according to demand;
- Closed Loop: outlet pressure adjusted according to real time pressure feedback from a critical point; or
- Self-Learning: critical point pressure from a pressure transducer is used to automatically generate a control profile: in the event that the critical pressure falls outside preset limits, alarm messages from the transducer are used to correct the PRV outlet pressure.

ACTIVE LEAK DETECTION AND LEAK DETECTION SURVEYS

Leakage is usually the major cause of water loss in water-distribution systems. To minimize public health risk, economic loss, and to conserve water, utilities should regularly audit their distribution systems and conduct leak-detection surveys. Water audits provide an overall view of water losses and identify areas of the distribution system having excessive leakage. Leak-detection surveys determine the exact location of leaks by using acoustic listening devices and modern leak-noise correlators. Acoustic equipment is effective for metal pipes but not so effective with plastic pipes. However, several vendors of acoustic-based leak detection devices have developed important modifications to improve the effectiveness of leak noise correlators as well as field procedures for plastic pipe. Leaks in both metal and plastic pipes could also be located with non-acoustic techniques such as tracer gas, infrared imaging, and ground penetrating radar. The use of these techniques is still very limited and their effectiveness is not as well established as that of acoustic methods.

Undetected leaks, even small ones, can lead to large quantities of lost water since these leaks might exist for a long time. Active leak detection is crucial in identifying unreported water leakage and losses in the distribution system. Finding and repairing water losses through an active leak detection program will reduce water loss and, in many cases, save substantial money. Without a leak detection program, leaks may only be found when they become visible at the surface, or when major infrastructure collapses. Active leak control will reduce expensive emergency overtime repairs and the associated liability costs. Detecting leaks is only the first step in eliminating leakage. Leak repair is the most expensive step in the process.

In general, leak detection and repair results in an immediate reduction of NRW, whereas replacement will have a longer-lasting impact to the extent that it eliminates the root cause of leaks. The most important factor in a leak detection and repair program is the need for accurate, detailed records that are consistent over time and easy to analyze. Records concerning water production and sales, and leak and break costs and benefits, will become increasingly important as water costs and leak and break damage costs increase and as leak detection and rehabilitation programs become more important. Generally, the water system should keep three sets of records: (1) monthly reports on NRW, (2) leak repair records, and (3) updated GIS of the distribution system showing the location, type, pipe material and history, and class of each leak.

Helium Gas Leak Detection Technology

The helium gas leak detection technology is used for detecting leaks in water distribution systems. This process is described below.

The helium gas is injected into a water line through stainless steel components. The dissolved helium is circulated throughout the water system by means of the normal water system operation. The gas finds its way to the ground surface through leaks in the water system (pipe breaks, connections, service lines, meters, etc.). Since helium is 5x lighter than air, once the helium and water mixture escapes from the water system, the helium gas migrates to the earth's surface. The path of the pipeline is traced above ground with specialized helium detection equipment to measure the concentration of helium in the atmosphere. An abnormally high concentration of helium measured above the surface of the ground is indicative of a leak. Where impervious services are encountered above the pipes, small holes are drilled into the surface to promote a quicker release of helium. Once a leak is detected it is marked for identification purposes.

Satellite Scanning Technology

This technology uses spectral aerial imaging – taken from satellite-mounted sensors – to spot leakage in underground distribution and transmission pipes. The raw imagery is then overlaid on a client's GIS water network and is processed by Utilis' unique algorithms. The algorithm detects drinking water by looking for a particular spectral "signature" typical to drinking water.
The company offering this technology – Hydromax, processes the data to deliver a pinpointed leakage graphic report overlaid onto a map with streets, pipes and size information. The result is that leaks are found without the time and manpower of field based acoustic surveys.

Ground Penetrating Radar (GPR)

The GPR geophysical method is a rapid, high-resolution tool for non-invasive subsurface investigation. GPR produces electromagnetic radiation that propagates through the ground then returns to the surface. The radar waves travel at velocities that are dependent upon the dielectric constant of the subsurface. Reflections are produced by changes in the dielectric constant due to changes in the subsurface material and/or conditions. The travel time of the electromagnetic waves as they leave the transmitting antenna into media and reflect back to the receiving antenna at the surface is a function of the depth of the reflection point and the electric properties of the media. Thus, interpretation of this reflected energy may yield information on subsurface structural variation and condition of the media. As in seismic geophysical techniques, there is a trade-off between frequency and structural resolution. The high-frequency waves produce higher resolution models at shallow depth only, whereas low frequency waves produce lower resolution models that may be located at greater depth. The choice of appropriate antenna is a target dependent on the projects goal. Data are most often collected along a profile, so that plots of the recorded signals with respect to survey position and travel-time can be associated with images of the subsurface structure. GPR signals can be collected fairly rapidly and initial interpretations can be made with minimal data processing, thereby making the use of ground penetrating radar for shallow geophysical investigation cost-effective with the least technical support (Cardimona et al., 1998).

GPR could, in principle, identify leaks in buried water pipes either by detecting underground voids created by the leaking water as it erodes the material around the pipe, or by detecting anomalous change in the properties of the material around pipes due to water saturation. Unlike acoustic methods, application of ground penetrating radar for leak detection is independent of the pipe type (e.g., metal or plastic). Therefore, GPR could have a higher potential of avoiding difficulties encountered with commonly used acoustic leak detection methods as it applies to plastic pipes (Hunaidi and Giamou, 1998). GPR could also be used as a supplement to these methods to increase accuracy in high risk areas such as high traffic streets and large structures.

2.3. MANAGEMENT INFORMATION SYSTEMS (MIS)

Management Information Systems (MIS) are a very important component of the SWIT for any water utility. However, most utilities work in silos and use separate information systems for billing, customer relations management (CRM) systems, work orders, asset management, customer metering data, GIS, and hydraulic models; very few utilities have integrated MIS. as such systems require expertise in hardware and software, and in most cases, specific programming and coding.

MIS have helped water utilities to improve the monitoring of unbilled or under-billed usage, enabling them to find uncollected revenue. They are now able to monitor water usage, NRW and conservation more effectively, while gaining improved regulatory compliance by using consistent reporting on customer service. These systems are providing an increased awareness of customers' inquiries, complaints, behaviors and preferences, helping utilities provide more effective services and create customers incentives to manage water demand.

CUSTOMER RELATIONS MANAGEMENT SYSTEMS (CRM)

Companies are becoming closer to the customer and more collaborative, self-service platforms within customer relationship management (CRM) support this evolution. Cloud computing and big data include social media management or 'social business,' with customers updating in real-time their good (and not so good) experiences. Customers can also use self-service applications to directly turn on and off services — providing 24/7 support by eliminating the need to speak directly to a customer service representative, with the added benefit of reduced costs.

Digital technology brings the capability to provide more accurate billing and payment processing, as well as faster response times for changing addresses and bills, removing and adding services, as well as many other functions. Through technology, water utilities can now gain new insight into customer needs and provide more value to individual households.

2.4. GEOGRAPHICAL INFORMATION SYSTEMS (GIS) INCLUDING ASSET GEO-REFERENCING

Geographic information systems (GIS) are an organized collection of computer hardware, software, and geographic data, supported by trained personnel to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. GIS operates primarily on spatial data but also include events and specific data.

The volume of geospatial data collected by water utilities is growing exponentially. Geographic measurement is being driven by both new technologies — GPS, satellite and airborne digital cameras, Light Detection and Ranging (LIDAR), and other digital surveying devices — as well as more deployment of these technologies. Key GIS applications for water utilities include surveying and recording the following geospatial information:

- Pipe network – pipe ID, diameter, material, date of installation, and line break and repair history;
- Valves: valve ID, location coordinates, elevation, size, material, date of installation, seri-

al number, status (open, closed, or partially open);

- Pumps: pump ID, brand, model, centerline elevation, weight, dates of installation repairs, maintenance records, capacity, motor size, and status;
- Storage tanks: location coordinates, material, base elevation, high water elevation, and dimensions;
- Customer meters: major size, brand, serial number, account number, installation date, register replacement date, calibration dates, and customer consumption records;
- Hydrants: location coordinates, size of pipe, brand, maintenance records, date of installation; and can also include
- Pictures and other digital information.

The proliferation of mobile devices impacts every industry and application, and GIS is no different. Advances in GIS technology and mobile and Cloud computing now enable organizations to take GIS to the field, where workers can interact directly with the information needed to view, capture, update, and synchronize changes between the field and the office.

2.5. SUPERVISORY CONTROL AND DATA ACQUISITION (SCADA)

The Supervisory Control and Data Acquisition (SCADA) system is a software application program supported by electronic real time data gathering, capable of automation from a basic level to a very high level of sophistication. SCADA can be expanded with the addition of sensors that collect data on equipment such as pressure at a pump, tank levels, water temperature, residual chlorine concentration, etc.

Advantages of SCADA

- Water users do not have to manually read and record meter readings at regular intervals because data on water use is collected automatically;
- Data can be downloaded at the user's convenience. Can generate instantly Preprogrammed reports; and
- Can be rigged for telemetry access by radio, satellite, cell phone, or telephone landline

and allow the user to remotely control the system and access data instantly.

Telemetry. Telemetry basically refers to accessing the data and controlling the system by remote means. Basic SCADA telemetry can be done via satellite, radio, cell phone, or telephone landline. With a telemetry setup, users can program the system to run automatically and can access the system remotely to check the status of, and operate the system at any time.

2.6. HYDRAULIC AND WATER QUALITY MODELING

Hydraulic models have become an essential tool for water utilities in the planning, design, operations, and optimization of water distribution networks. Some advanced utilities are currently using hydraulic models in real-time to monitor and troubleshoot their water distribution system. It is becoming an increasingly important part of utility operations. One application of hydraulic modeling is pipe network analysis. Using programmed algorithms to repeatedly solve continuity and energy equations, computer software can greatly reduce the amount of time required to analyze a closed conduit system. Hydraulic models can become a valuable tool and many water utilities have developed models of their water systems and use them for planning future growth and system expansions.

Hydraulic models are often used to validate the design of new or rehabilitated pipelines. They are also used to verify the system capacity or to analyze the effect of modified infrastructure within the context of the entire water distribution system or its sub-system. Most commercially available hydraulic modeling software provide the following features:

- Steady-state analyses;
- Extended period analyses;
- Fire flow analyses;
- Hydraulic transient analyses;
- Water quality analyses;
- Development of scenarios;
- Pressure optimization;

- Existing and future demand scenarios;
- Operational optimization;
- Existing and emergency water supply analyses.

Model calibration and verification based on the observed data is required in order to establish the necessary level of accuracy of a hydraulic model. Adequate staff training is also necessary in order to develop trust in the ability of the model to represent what is currently happening in the system, and what can happen under future scenarios.

WATER QUALITY MODELS

Water quality, though acceptable when it leaves the treatment plant, may deteriorate before it reaches the user. Changes in quality may be caused by chemical or biological transformations, by a loss of system integrity, or by blending of waters from different sources. Until recently, little attention has been paid to the problem of changes in water quality in the distribution system. Field quality data is important in developing, verifying, and understanding predictive models. Such quality data should be collected at time intervals sufficient to reflect changes in system dynamics.
Water quality simulations support the water utility in maintaining the quality of drinking water. The water quality scenarios that are often simulated with water quality models are:

- Blending water from different sources;
- Age of water throughout a system;
- Chlorine residuals levels;
- Growth of disinfection by-products.

2.7. REMOTE WATER QUALITY MONITORING

The most commonly used method for drinking water disinfecting worldwide is chlorine dosing and a residual concentration of chlorine is essential throughout the water distribution network to prevent recontamination. Most water utilities around the world conduct periodical monitoring of residual chlorine and Heterotrophic Plate Count (HPC) at different points of the network. This procedure is tedious and requires the water samples to go to a laboratory for analysis; the data could be recorded and then analyzed to determine if the system is in compliance with the chlorine residual limits. In recent years many utilities have implemented remote water quality monitoring systems which have been mostly driven by security issues. Most common parameters monitored in these remote monitoring systems are:

- Turbidity
- pH
- Conductivity
- Residual chlorine
- Total organic carbon

Installation and operation of continuous monitoring throughout the distribution system or "Smart Grid Systems" provides an understanding of water delivery conditions that may have been previously unknown or incompletely understood. The advantages of using remote monitoring are:

- Enabling correction of problems in a short time span;
- Improving the delivered water quality by having real-time water quality data;
- Providing added protection of public health;
- Providing early warning of system tampering and terrorist attacks;

- Monitoring conventional water quality parameters (e.g., chlorine, pH, and conductivity) has the potential to detect certain high consequence contamination scenarios that would not otherwise be detected in time for exposure-reducing response actions; and.
- Savings in operational and maintenance/replacement costs.

Challenges with remote water quality systems can include:

- Achieving an acceptable invalid alert rate and developing an alert investigation process that effectively manages invalid alerts, minimizing operational impact and maintaining staff attentiveness;
- Managing the variability in distribution system water quality among other conditions, as it can complicate invalid alert rate management;
- Financing initial capital costs and on-going O&M costs which could be high (actual costs will depend on the number and type of sensors installed) and providing the adequate training of the utility personnel;
- Maintaining and calibrating the sensors, through ongoing, consistent utility efforts; and
- Currently, the available remote monitoring technology is not capable of measuring certain parameters of interest on the spot (e.g., radionuclides and direct detection of pathogens). Developers of continuous monitoring devices are being challenged to fill in this important gap.

Effectiveness of remote water quality monitoring depends on the:

- Type, number, and placement of sensors (tools do exist to support sensor placement optimization);
- Data collection frequency and analysis procedures;

- Effective maintenance and calibration of the equipment;
- Degree to which monitors are integrated into an overall comprehensive program including first responder partnerships; and
- Utility culture of support (e.g., staff following established procedures)

In this chapter, an extensive but not exhaustive review of SWIT options has been presented, together with their main advantages and constraints. It appears that the implementation of those technologies should be embedded in the utility long term strategy, and that there should be a progressive and constant effort to scale-up the use of those technologies with the objective of improving the quality of the service, reducing its costs, and optimizing the use of the human financial and environmental resources.

3.0. CASE STUDY: The Barbados Water Authority(BWA)

The Barbados Water Authority (BWA) case study is presented because BWA has implemented several SWIT, including Hydraulic Modeling, Management Information Systems (MIS), Customer Relations Management Systems (CRM), Geographical Information Systems (GIS), Supervisory Control and Data Acquisition (SCADA), and Smart Metering. It is based on:

- Interviews with several BWA personnel to obtain a briefing on the "lessons learned" in the implementation of SWIT and the level of proficiency reached by the utility in taking full advantage of such tools and SWIT;
- Review of relevant records that could provide information of the effectiveness of SWIT implemented by the utility;
- Review of the general integration strategy and timeline for implementation of SWIT by the utility;
- Observation of relevant installations of SWIT tools used by BWA.

BWA is the entity in Barbados charged with supplying the island with potable water as well as the provision of wastewater treatment and disposal services to the sewered areas of Bridgetown and the South Coast. The Authority is also responsible for the monitoring, assessment, control and protection of the water resources on behalf of the public's interest.

BWA provides near complete coverage in water supply although some individuals have historic pumping rights to exploit groundwater from their own wells and boreholes. Its resource is mainly good quality ground water from unconfined aquifers which it disinfects and pumps into the distribution system. The BWA has been able to supply water to the customers on a 24/7 at a relatively good pressure. Conversely, the system is not strongly integrated, is fairly inflexible, and poorly monitored. In 2011, the IDB provided funding to BWA for a technical cooperation (TC)(BA- T1010) to help BWA develop a long-term strategic planning and detailed action plan to improve its economic efficiency, quality of service and long term financial sustainability. Specifically, the TC was designed to develop the institutional framework, to assess the adequacy of human resources, Management Information Systems (MIS), water supply and wastewater networks and water resources management. The project included a preparation of an Action Plan for institutional strengthening and improvements of the water infrastructure. The findings of the TC supported the definition of the scope of IDB Loan BA-L1015.

3.1. ASSESSMENT OF SWIT BASED ON INTERVIEWS DURING SITE VISIT

BWA has made significant improvements to the water supply and distribution system in the past five years, however, some of the efforts for improving the utility's efficiency are still ongoing and in some cases the planned activities have felt short of reaching goals, or have not met expectations. Specifics related to SWIT are presented below.

1. GIS — the implementation of a GIS system was initiated as part of the consultancy that developed the action plan for improving the efficiency of BWA. Further work was done, supported by an external consultant. However, the field validation of several attributes of the GIS is still pending and quite a lot of efforts are still needed towards the development of a full GIS System.

2. Geo-Referencing of Customer Meters — This task was procured, contracted and completed. Validation and review of the accuracy of the information and of the actual level of completion still needs to be done.

3. Hydraulic Model — A hydraulic model was initiated as part of the initial consultancy that developed the action plan for improving the efficiency of BWA. During the past year, this effort was further advanced. The files of the hydraulic model where evaluated. , however the model is still not fully functional as several errors were detected, such as: negative pressures, nodes with zero elevation, etc. In addition, BWA does not have the appropriate software to use the full model; the version of the software owned by BWA is restricted by the number of pipes and the updated model exceeds the number of pipes authorized. This being a crucial tool for BWA in order to do the proper planning of DMA's and integration of AMR and management information systems. BWA should:

    - Require the Consultant developing the model to deliver a fully functional model as soon as possible; and

- Acquire the needed software to fully utilize the model.

4. Master Meters — BWA purchased part of the master meters needed for the planned DMA project, those meters had not yet been installed At the time of the evaluation.

5. Pipe Replacement — BWA replaced 48.5 km of pipe at a cost of $19.0 Million USD or about $392 per meter. This was done using conventional methods as well as trenchless techniques such as pipe bursting and directional drilling. Additional pipe replacement activities are being planned by BWA which should be based on:

    - a revised condition assessment of the pipes;
    - the information to be collected from future DMAs; and
    - a revised analysis of pipe failure data to determine the cause and location where pipe deterioration is more predominant.

6. SCADA — BWA procured the services and hired an external consultant to set up a SCADA system that included tank levels and pump status. The system is operating but the BWA staff is apparently not using it as part of the day-to-day operations. Therefore, BWA should:

    - Provide SCADA training to operations personnel;
    - Revise its Standard Operating Procedures; and
    - Include SCADA as an operational tool to manage wells, pumps and tanks and DMAs when installed.

7. Management Information Systems — BWA is currently implementing a Business Transformation Project through a grant from the Canadian government. According to the contractor executing this activity – CoWater, this project will accomplish the integration of the management information system for the utility. It will include improved customer information systems (CIS), work order management, and commercial – billing systems. The MIS is expected to handle data from 50,000 customer meters. It will

also include 200 commercial customers on AMR drive-by network. BWA should ensure that those activities, which would be completed in 2017, are integrated with the other utility initiatives such as future DMA's and the NRW reporting.

8. DMAs and NRW — The BWA is planning on implementing its DMA project with financial resources from a Caribbean Development Bank (CDB) Loan. This project is dependent on the calibration and functionality of the hydraulic model and is crucial for the implementation of the AMR meter replacement. The BWA recently established a new NRW Department that would coordinate those activities. Two NRW reduction pilot studies were conducted by the BWA staff with interesting results (ex. illegal usage from the hydrants for irrigation).

3.2. LESSONS LEARNED AND CONCLUSIONS OF THE CASE STUDY

1. During the last five years, the BWA utility has gained some capacity and some of its personnel have increased their skills in procuring and implementing SWIT. Overall, it appears that the utility staff still lacks the necessary skills, training, and motivation to take full advantage of the benefits of SWIT.

2. It is apparent that procurement and execution of projects have been done without the necessary beneficial integration and proper sequencing.

3. Several SWIT components have been started but few have been completed or validated.

4. It is a common occurrence that once the projects are executed there is no follow-up or supervision to ensure that the work is done according to specifications or plans. In general, there is a lack of technical leadership and professional capacity to execute the projects and take advantage of the benefits of the new technology.
Those observations relating to this case study are actually reflecting common issues encountered in most Utilities around the globe in the implementation of SWIT.

4.0. SURVEY OF UTILITIES

A utilities' survey regarding the use of SWIT was conducted with water utilities in the Caribbean, including: Bahamas Water and Sewerage Corporation, Barbados Water Authority, Grand Bahamas Utility Company, Jamaica's National Water Commission and the Water and Sewerage Authority of Trinidad and Tobago. The survey form and the summary of results is included in Figure 5.

x–Bahamas WSC | **T–**WASA T&T | **G–**Grand Bahamas Utilities Company | **B–**Barbados Water Authority

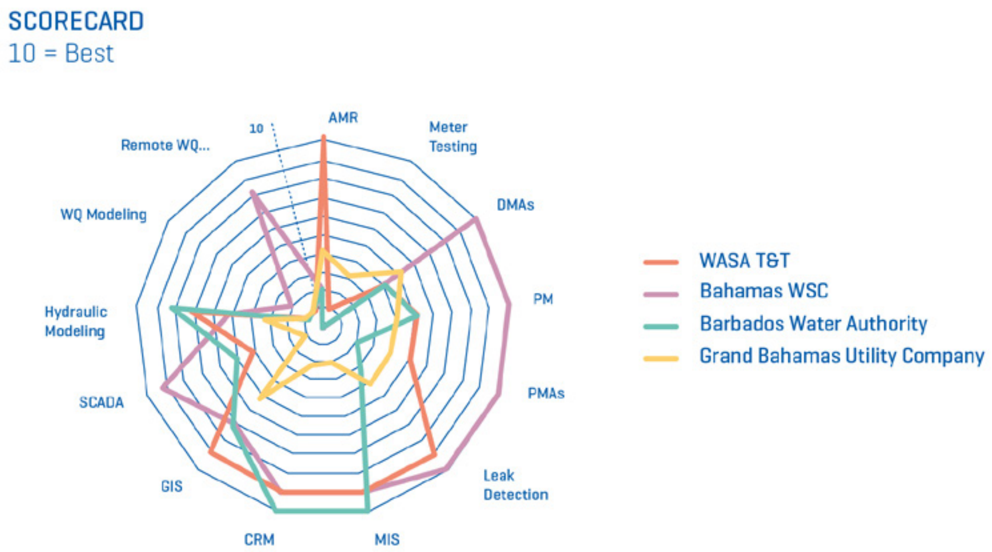
Status of SWIT	Smart Metering [AMR/AMI]	Meter Testing	District Metered Areas [DMAs]	Pressure Management	Pressure Metered Areas [PMAs]	Active Leak Detection and Leak Detection Surveys	Management Information Systems [MIS]	Customer Relations Management Systems [CRM]	Geographical Information Systems [GIS] including asset georeferencing	Supervisory Control and Data Acquisition [SCADA]	Hydraulic Modeling	Water Quality Modeling	Remote Water Quality Monitoring
The Utility has implemented this SWIT	xT		xT	xT	xT	xTB	xTB	xTB	xTB	xTB	xTB		xT
The Utility is planning to implement it	xGB	B	GB	GB	GB							xTGB	GB
Level of development													
Complete			x	x	x	x	x	x	x	x			
Less than 20%	TGB	TGB	B	TB	TB	G	G		G	GB	G	TGB	xTGB
Between 20% and 50%						B							
Between 50% and 80%								G	B		T	x	
About 90%						T	TB	TB	T		xB		
100 %													
Level of Actual Use?													
Less than 20%	TGB	TGB	GB	TGB	TGB	GB	G		G	GB	GB	TGB	TGB
Between 20% and 50%			T			T				T	x		
Between 50% and 80%								T	B		T		
About 90%							B	GB					
100 %	x		x	x	x	x	x			x			x

continues on the next page

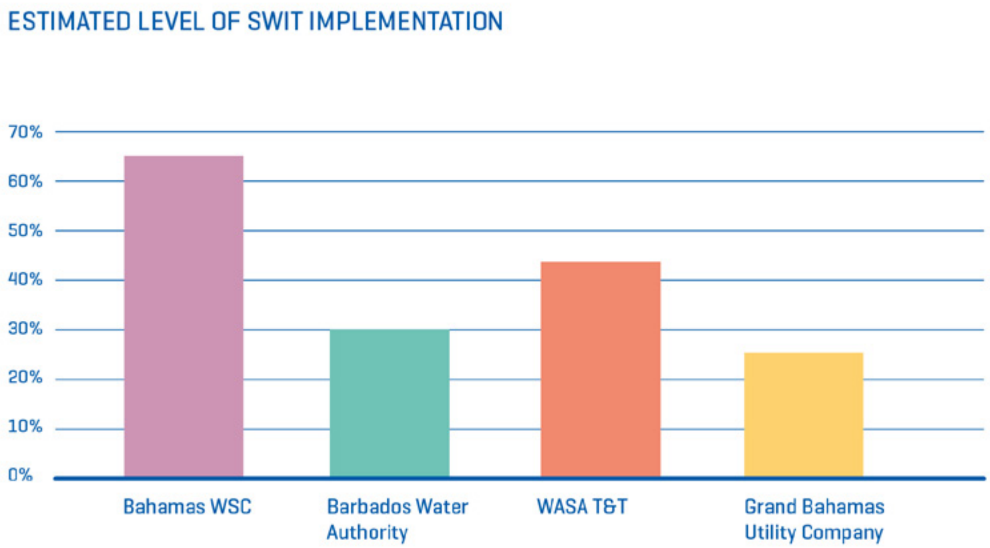
How has this SWIT impacted the Utility?													
Not at all	x		x	x	x	x	x			x			x
Minor impact	x		x	x	x	x	x			x			x
Significat impact	x		x	x	x	x	x			x			x
Level of personnel training													
None	GB	TGB	G	GB	GB	GB	F		G		G	TGB	GB
Less than desirable			B	T				G	B	xGB	xB		
Average	xT		T	x	xT	T	xTB	xT	T	T	T		T
Very well trained			x			x		B	x				
Has this SWIT help the Utility to become more efficient?													
Yes	xT		xT	xT	xT	xT	xTB	xTB	xTB	xT	xTB		TG
No													
Too early to tell	GB	TGB	GB	GB	GB	GB	G	G	G	GB	xG	xTGB	B

> FIGURE 5. Summary of survey results for water utilities

The information provided by the Caribbean Water Utilities is interpreted and summarized on Figure 6. This shows the comparable level of implementation and used of SWIT. Likewise, Figure 7 presents a relative comparison of the level to which the utilities have implemented SWIT.



> FIGURE 6. Scorecard diagram comparing the relative level of SWIT.



> FIGURE 7. General ranking of utilities with regard to SWIT.

5.0. CONCLUSIONS AND RECOMMENDATIONS

Based on the assessment of SWIT and evaluation of water utilities in the Caribbean, the following conclusions and recommendations can be made.

- In general, professional leadership and commitment for integration of technologies is key to the success of the water system upgrading and modernization program. A "SWIT Integration Team" should be appointed and trained from the beginning of the project.

- It is important for the utility to develop a vision and a long-term action plan for integrating and optimizing SWIT. The planning and vision should be developed with interdepartmental personnel and with the assistance of professionals with vast experience in the applicable disciplines.

- There needs to be a progression in the implementation of SWIT (ex. AMR/AMI should not be initiated before DMAs and PMAs. In addition, DMAs and PMAs must be implemented in parallel with an integrated MIS in order to take full advantage of the benefits and investment).

- Pipe replacement and rehabilitation (R&R) programs should be considered a last resort, only after:
  - Proper condition assessment of the pipes
  - Criticality analysis of the infrastructure
  - Analysis of cause and effect of pipe bursts
  - Having DMAs and PMAs in the systems and knowing for certain where the non-recoverable water issues occur (by DMA/PMA) so that the pertinent pipe R&R priorities can be established based on a business case.

- Project implementation seems to be more successful when a third-party with previous experience in the subject takes over the projects, particularly in turn-key projects. However, these third-party/turn-key project activities also need to be strictly supervised and monitored with regard to budget, timeline, and technical accuracy. Payment to contractors should be strictly tied to performance and proper execution.

These projects need a strong component of training and involvement of permanent utility personnel that must be financially and professionally incentivized to carry on the future operations.

- SWIT like GIS, Hydraulic Modeling, Asset Management should be developed in an initial preparation phase prior to implementing a capital intensive SWIT. Figure 8 shows a flow diagram of suggested preparation and implementation sequence of SWIT.

- As shown on Figure 8, the planning and implementation of SWIT is an interactive process and takes a significant learning curve for integrating and taking full benefits of the technology and tools. Overall, the human factor in management, operations, engineering, commercial and customer services, information management, training, an outside expertise are key to a successful planning, budgeting, scheduling, and implementing the SWIT.

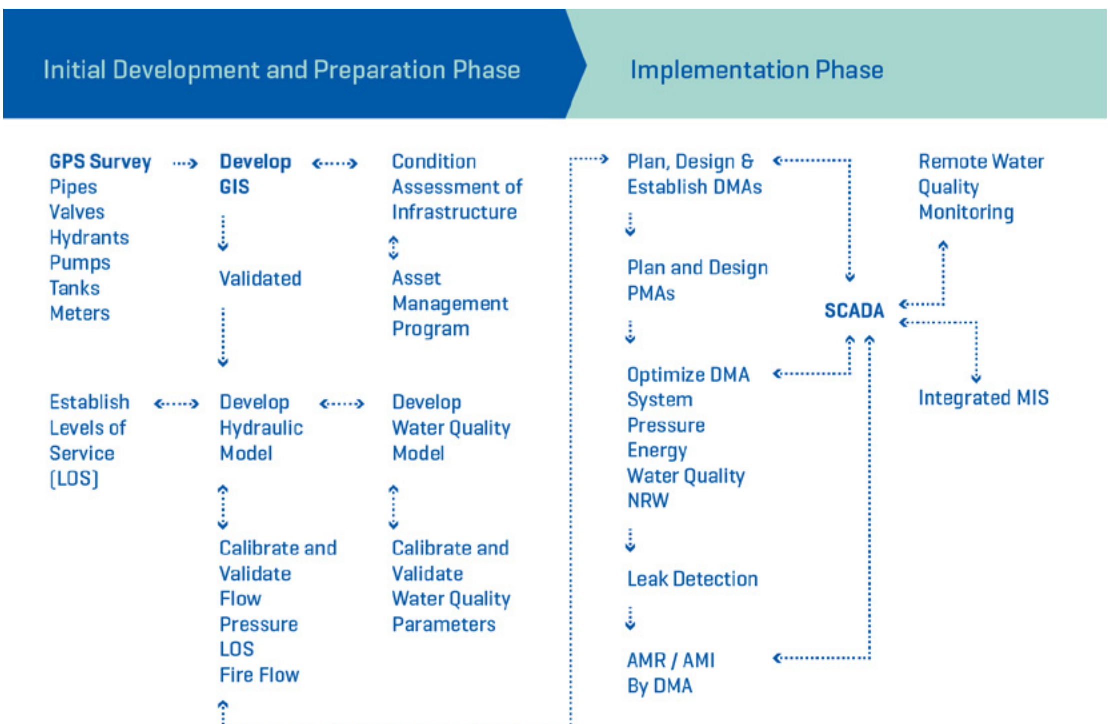


FIGURA 8: Suggested development and implementation of SWIT

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