Report:

Climate Technology Centre & Network (CTCN): National Water and Sewerage Authority, Grenada (NAWASA) – Improvement of water supply management through a GIS based monitoring and control system for water loss reduction in Grenada

Project Output 4: Presentation of the findings relating to the DMA design process with regards to the quantification and management of Non-Revenue Water.

1. Introduction

The following report issued in May 2020 was developed by the Wood/GISCAD team as a core deliverable of CTCN project entitled "Improvement of water supply management through a GIS based monitoring and control system for water loss reduction in Grenada". This project was delivered in collaboration with technical staff within the National Water and Sewerage Authority of Grenada (NAWASA).

The scope of the technical note relates to the following activities undertaken to achieve the objectives of Output 4 of the project:

- Overview and assessment of current activities and processes:
  - DMA (District Metering Area) design and implementation
  - Data gathering / improvement
  - Water usage and loss assessment
- Implementation of the key steps to achieving effective Non-revenue Water (NRW) management:
  - Step 1: Know your network
  - Step 2: Know your customers
  - Step 3: Know your customers data
  - Step 4: Record leaks and repairs
  - Step 5: Quantification of NRW and the development of the NAWASA Water Audit Tool
  - Step 6: Management of NRW and the development of the Minimum Night Flow (MNF) DMA leakage assessment tool

- Activity 4.1 Deliverables
    - Findings from review of the DMA designs
    - Evaluation of non-revenue water across NAWASA
    - Evaluation of non-revenue water in the two pilot DMAs
    - Support for the development of the NAWASA NRW reduction action plan

2. Overview of activities and processes

Since the beginning of this project in March 2019, the Wood's Water Networks team and GIS teams have worked closely with NAWASA staff. This engagement has contributed to the development of new working process to ensure the outcomes will enhance the ability of NAWASA to quantify, manage and reduce the level of non-revenue water.

Plate 2.1 overleaf provides a summary of the assessments undertaken, technical notes published and technical support provided.

Plate 2.1 Development of the NRW assessment – timeline of activities

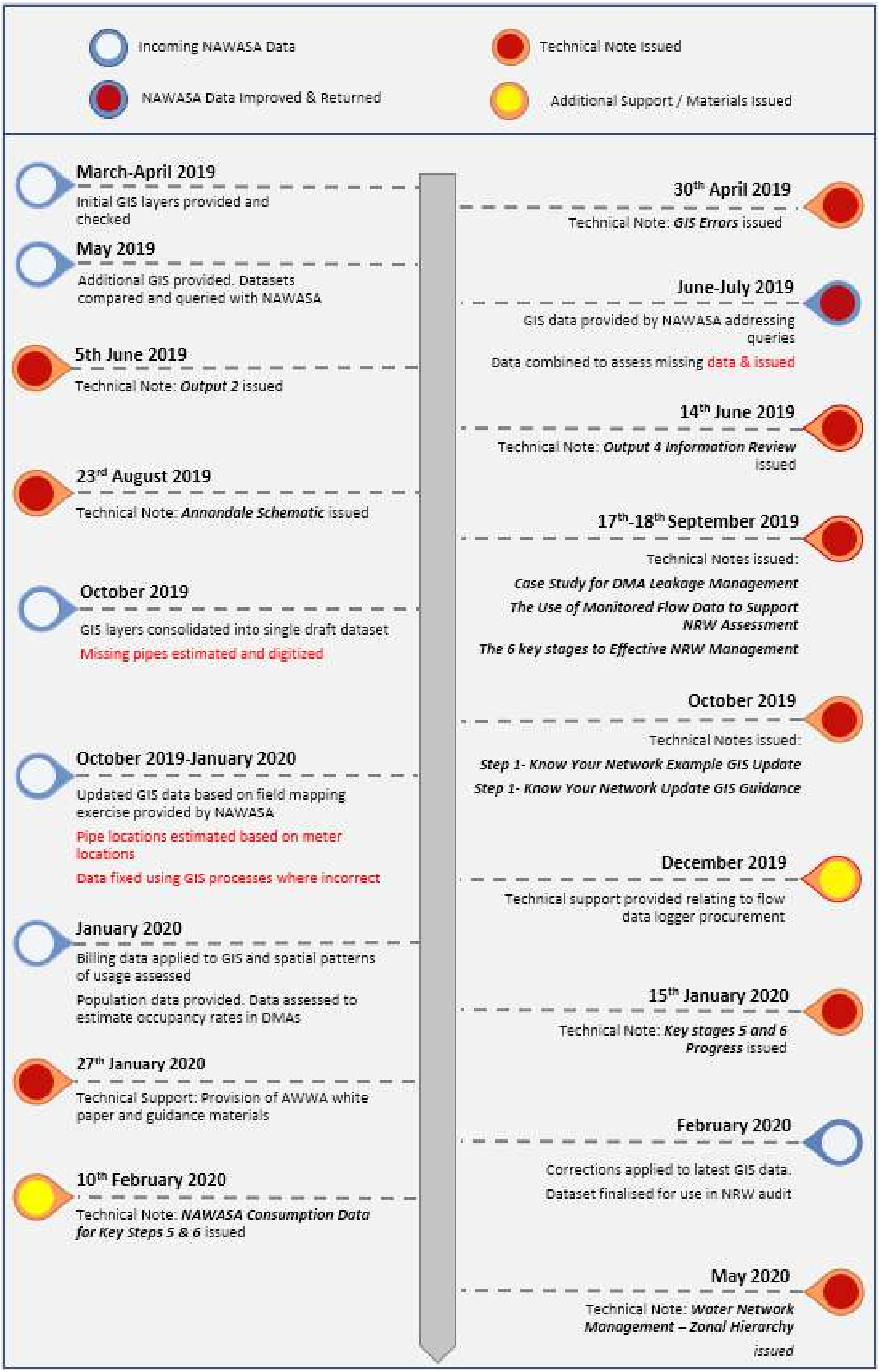


Table 2.1 provides a summary of the progress made during the course of this study and the proposed next steps to further improve the assessment and reduction of NRW.

Table 2.1 Summary of progress and next steps for NRW assessment in NAWASA

Item	Progress	Next Steps
Step 1: Know Your Network	• Operational knowledge from NAWASA engineers captured • Compiled all available GIS layers For the two pilot DMAs (Lance Aux Epines and True Blue): • Digitised additional pipelines from legacy PDF pipeline plots of Grenada from 1988 • Field surveys were undertaken by NAWASA and additional pipework, and logical tee junction locations and service lines were subsequently digitised.	• Collate information for valves, hydrants and other fittings currently not included in GIS • Asset characteristics, such as pipe material and diameter, need to be captured • Develop an asset data capture template and agreed implementation procedure • Commence a long-term programme to remap the primary pipeline distribution network, with an aim to complete a minimum of six DMAs in 2020.
Step 2: Know Your Customers	• Consolidation of 199 individual meter files • Linking of customers to pipes in the two pilot areas • Testing of field equipment for capture of customer meter locations	• Continue currently live testing of digital data collection forms • Use digital data collection to capture the location of new / updated meter location • Build up an enhanced digital record of meter/customer locations. • Promote regular engagement to improve the data capture process. • Develop a NAWASA wide property layer and map customer billing accounts and customer meter assets to the relevant properties.
Step 3: Know Your Customers Data	• Cleansing of billing data to e.g. duplicates, data errors • Mapping of billed accounts to customer meters • Methodology for calculation of customer average consumption • Examination of volumetric and spatial data for the pilot DMAs	• Assign a water usage category to all non-domestic customers e.g. 10hr user, 16hr user, 24hr user. NAWASA accounts do have a 'billcode' field WNON1 to WNON4 but these are based on monthly usage billed rates and not daily usage patterns. • Investigate high consumption customers which are classified as domestic users • Permanent logging of very large users • Validate the accuracy of meter readings • Investigate patterns of variation in customer consumption • Take night time meter readings to establish light usage estimates

Item	Progress	Next Steps
Step 4: Record Leaks and Repairs	• Development of data capture forms based on **QField** app (see Report 2E for details) • Initial testing of the data capture forms during March 2020	• Continue live testing of digital data collection in the work of the metering and T&D maintenance teams. • Implement the asset data recording procedure for leaks and bursts. • Review procedures and amend where potential improvements are identified • Roll out the data capture procedure across the whole network. • Promote regular engagement and feedback from crews using the forms regarding the potential issues and time savings.
Step 5: Quantification of NRW	• Development of a NAWASA-specific version of the American Water Works Association (AWWA) NRW workbook • Collation of data sets required to undertake a system-wide audit • Undertaking of system-wide audit and pilot DMA audit • Assessment of sensitivity to data accuracy • Development of DMA-level Minimum Night Flow (MNF) loss assessment workbook	• Improve the quality of base data through actions for Steps 1-4 • Review DMA design approach and the programme of implementation • Develop 'source to tap' flow monitoring and flow balance arrangements, supported by production of an accurate network schematic. • Establish a set of standard sections of the network for undertaking NRW audits e.g. full system, separate sources, DMA.
Step 6: Management of NRW	• Provision of guidance and examples on the management of NRW using continuously logged flow data. • Provision of DMA-level MNF (BABE) loss assessment workbook	• Continuous improvement in the coverage and accuracy of the data sets used in the NRW calculations, as detailed in Steps 1-4 • Review of the design and implementation of DMAs • Inclusion of additional DMA's within the DMA-level MNF (BABE) loss assessment workbook.

3. The key steps to effective NRW management

The calculation of NRW draws on data from across a number of areas of network operation. The accuracy of the data provided from each area will affect the overall accuracy of the NRW estimate. The approach taken in developing the balance calculation has been to break down the process in to six key steps. Each of these are dealt with separately below.

3.1 Step 1: Know your network

The effective management of a water supply network, including NRW, requires good knowledge of the physical assets it is comprised of, the performance of these assets, and the measurement of related operational parameters.

Asset data storage and maintenance

A key element is maintaining a comprehensive and accurate record of all elements of the infrastructure. The most common way to manage the large data sets required is through the use of a GIS environment. Geospatial presentation allows operators to efficiently identify areas of the network with ongoing or developing issues and to plan interventions and contingency measures.

The information recorded against each asset may vary between utilities, but in general will include:

- Details of physical assets, including pipes, meters, valves, hydrants, tanks and pumps;
- Details of asset characteristics and status e.g. pipe material & diameter, open and closed valves, tank dimensions, regulator settings;
- Details of customers including location, usage type and how they are supplied; and
- Details of network performance, including bursts and repairs, failure of assets (e.g. meters, pumps), and customer contacts (e.g. poor supply, poor quality).

Operational data, such as site production, transmission and DMA flow data, and customer usage data are typically stored in separate non-GIS databases, however it is critical that records have unique references in common allowing the linking of various data sets back to assets.

GIS connectivity and coverage

It is important that the geospatial representation of assets is complete and accurate, including correct connectivity of the elements. This will:

- Allow more accurate assessment of total network length;
- Allow more accurate allocation of customer data and system events;
- Allow quicker and better operational decision-making e.g. pathway tracing from event to customers; and
- Allow more accurate planning e.g. sub-division of the transmission network, design of DMAs

In terms of NRW management, for example, it will allow quicker isolation and repair of bursts and leaks and reduce the impact any outage has on customer supplies.

Network monitoring – establishing network monitoring zones

The active management of network performance, including NRW, will be affected by the level of granularity at which the network is monitored. The smaller the area being monitored, the more accurately events and performance issues can be located. A balance must be struck between the cost of installation and operation of monitoring systems and the operational and financial benefits delivered.

Below is an approach to network monitoring which is commonly adpoted by water utilities. This is based on four levels of network monitoring or 'zonal hierarchy'.

Plate 3.1 Network Monitoring – Water Quality Zones

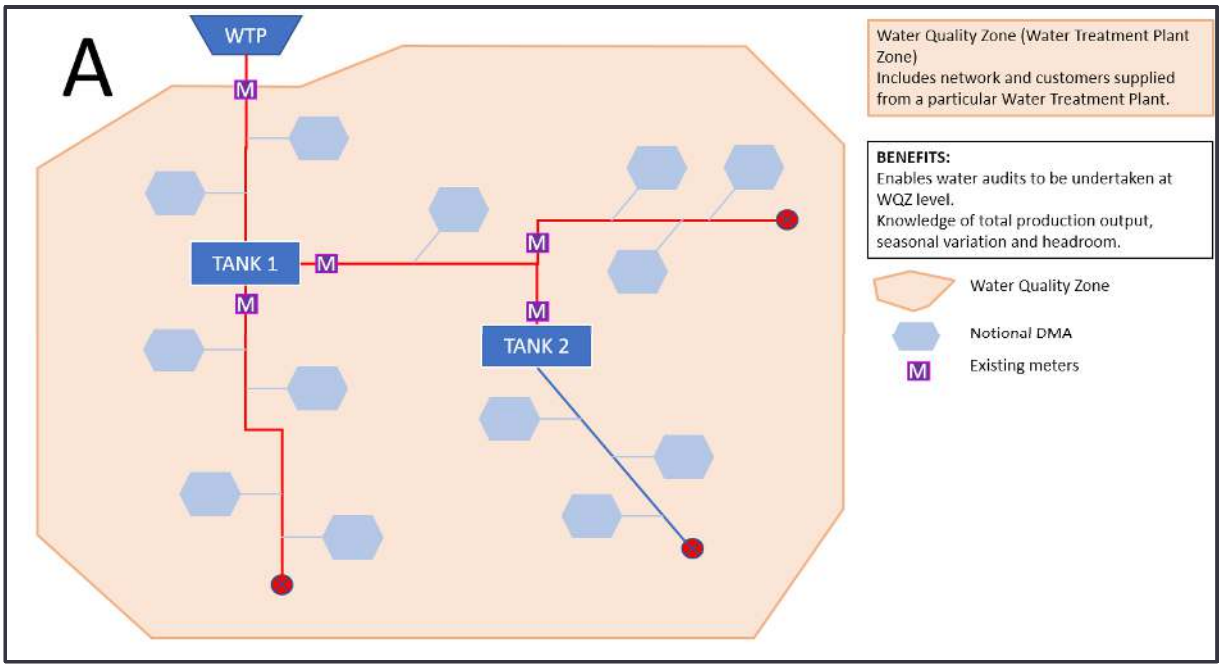


Plate 3.1 shows an example of Level A – Water Quality Zone (Water Treatment Plant Zone).

Most water utilities meter the flows entering the water distribution network from their Water Treatment Plants. Having an understanding of the network and customers supplied (Key stages 1 – 3) enables Water Quality Zones to be established.

Plate 3.2 Network Monitoring – Water Supply Zones

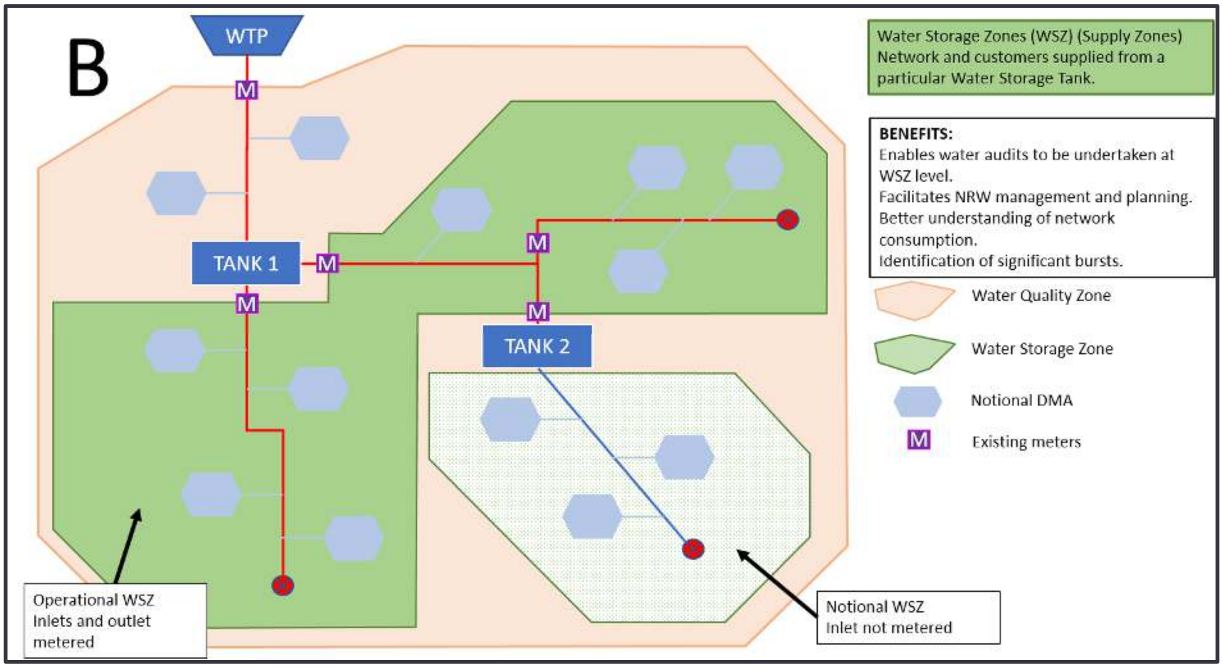


Plate 3.2 shows examples of Level B – Water Supply Zones (Water Storage Zones).

Where metering exists on water tank outlets, the network downstream can be classed as a Water Storage/Supply Zone. Having an understanding of the network and customers supplied (Key stages 1 – 3) enables these monitoring zones to be established.

Plate 3.3 Network Monitoring – Super DMA Zones

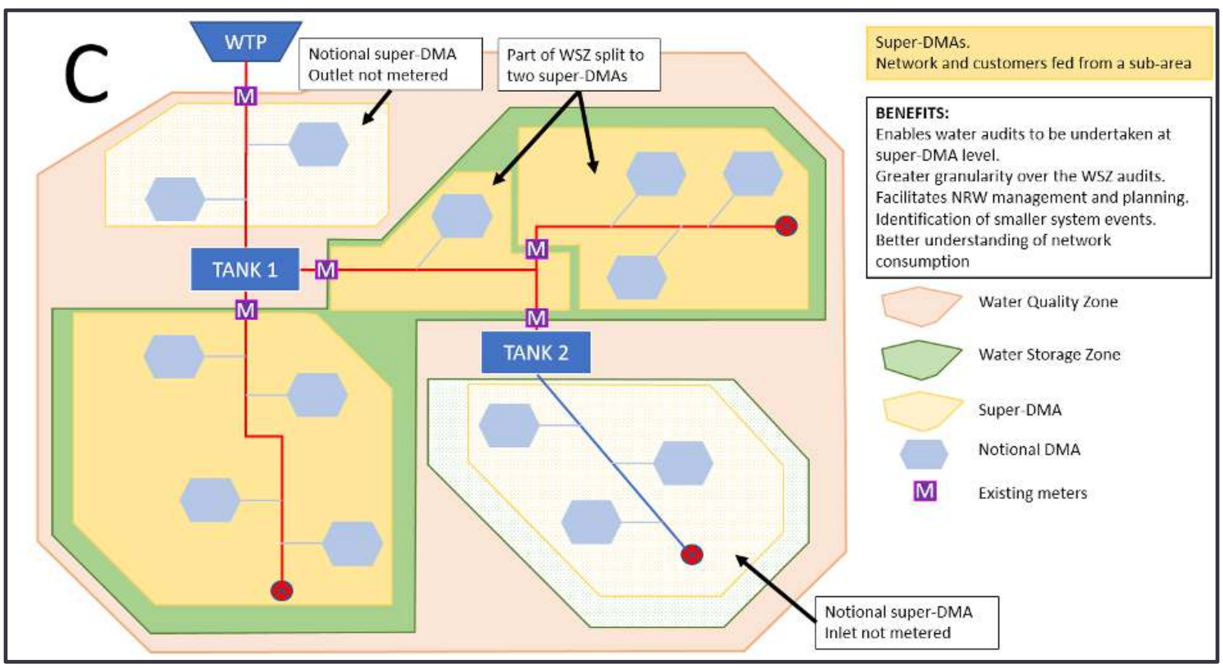


Plate 3.3 shows examples of Level C – Super DMA Zones.

A common approach taken across many water utility companies is the use of a metered 'trunk' main/DMA structure, where the network is divided into sub-sections, with flow meters installed to allow calculation of net flow in each. This sub-division allows for a better understanding of how water is conveyed from source to customers and can facilitate the calculation of water balances across the network.

The 'trunk' (or large diameter distribution) mains would ideally be metered at source outlets, DMA offtakes, and, where required, at additional strategic points along the trunk network. Trunk main leakage can be quantified using a super DMA structure.

Plate 3.4 Network Monitoring – Improving coverage with DMAs

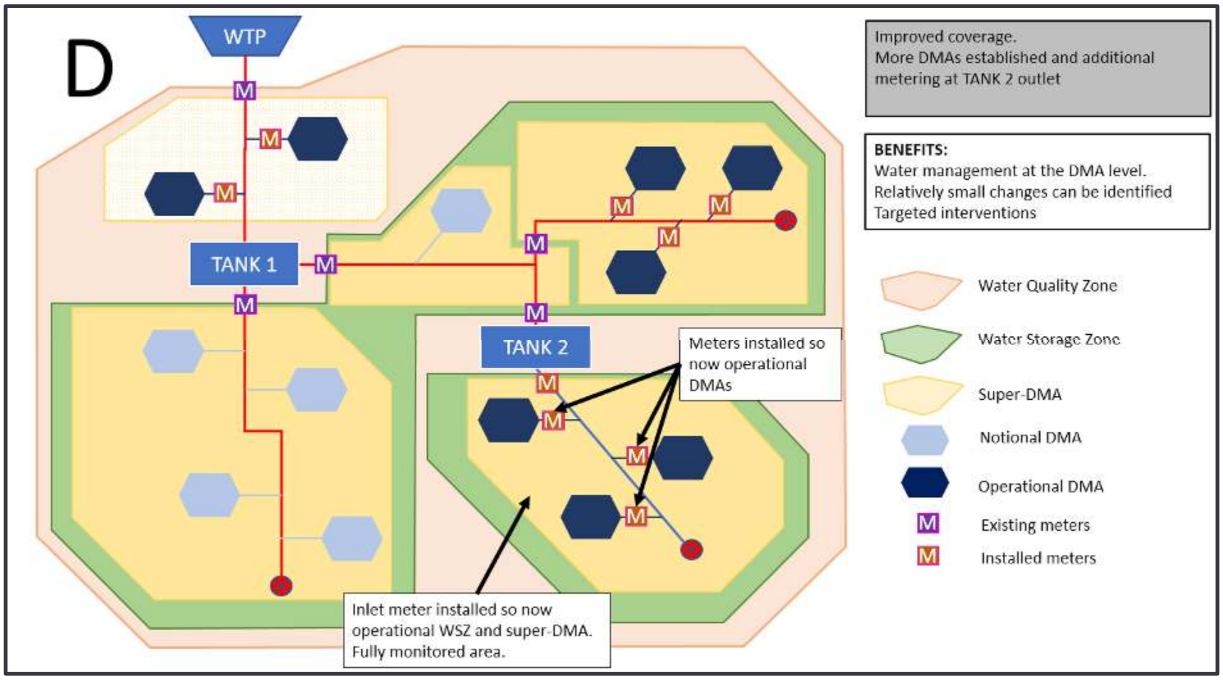


Plate 3.4 shows examples of improving monitoring coverage with DMAs

The number of DMAs required, and the number of customers within each DMA, should be dependent on the network configuration and capacity, though a range of 300 to 3000 customers per DMA is typical.

The management of the network using a DMA structure provides a number of benefits:

- Better estimating of direction of flow and velocity of flow;
- Identification of, assessment of and targeting of required investment e.g. better understanding of capacity requirements;
- Quicker incident response; and
- Better management of NRW

However, DMA establishment may result in the following issues when compared with operating a more 'open system' and these need to be considered and mitigated for as much as possible during the DMA establishment process:

- Restrictions in the full use of network capacity (higher headloss, higher pressure cycling range);
- Additional low flow or no flow 'dead ends' with potential water age and quality issues; and

- Additional CAPEX costs in setting up the network and OPEX costs in managing and maintaining equipment.

Plate 3.5 Network Monitoring – Desired configuration

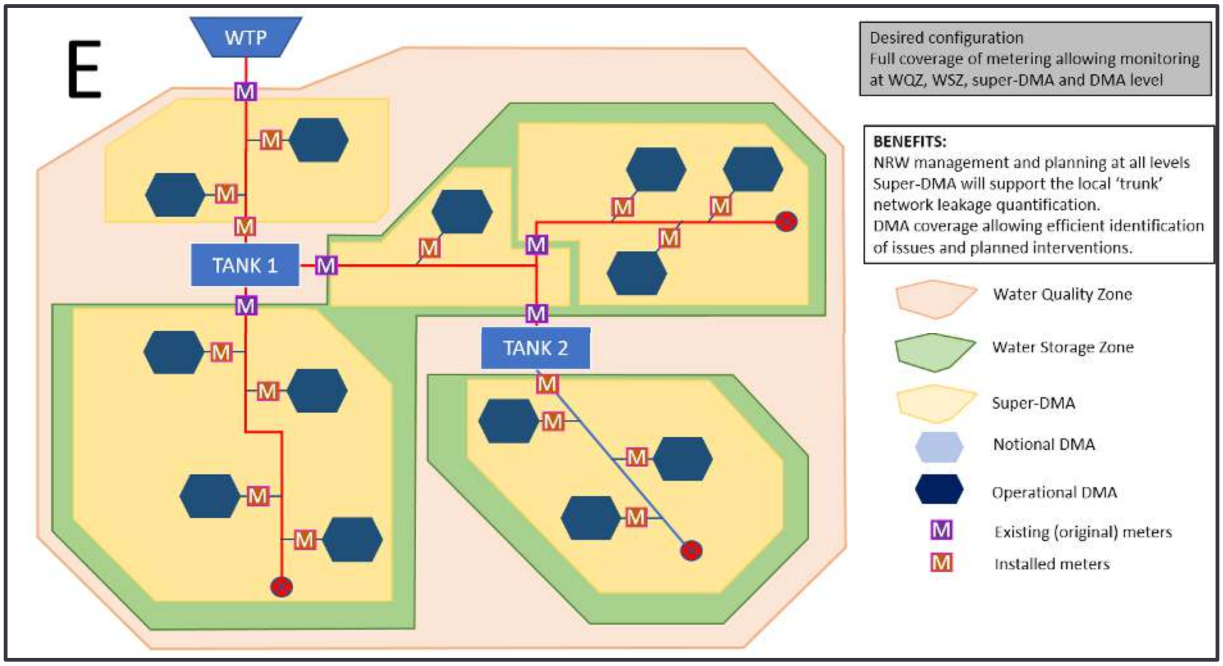


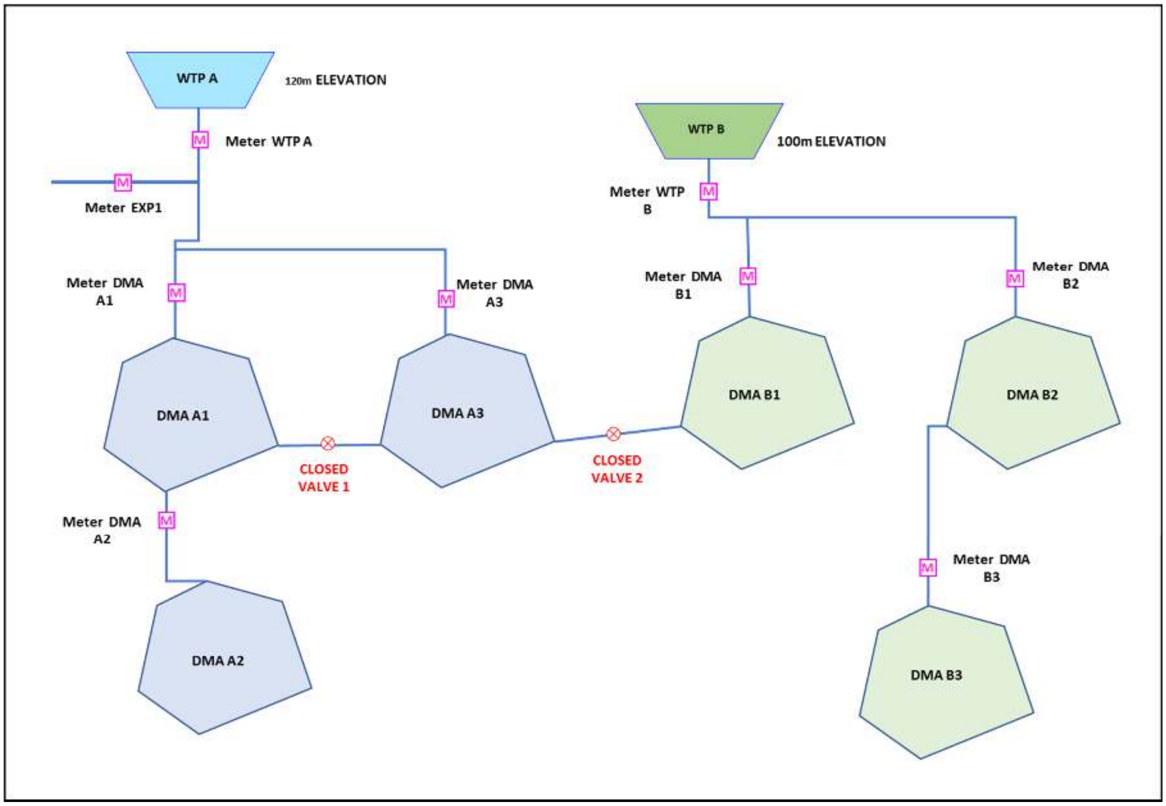
Plate 3.5 shows an example of a desired network monitoring configuration for a Water Quality Zone.

Installing additional metering will allow for total coverage of monitoring for an entire Water Quality Zone. This will facilitate accurate NRW and leakage quantification as well as enabling effective NRW management and planning at all levels.

Network monitoring – system water balances

Plate 3.6 below shows an example of a generic water network.

Plate 3.6 Generic water balance diagram



Using Plate 3.6 as a reference, the following examples illustrate how sub-division of the network and flow monitoring enables water balances to be calculated and performance monitored.

Example A: WTP A outflow balance = WTP A – EXP1 - DMA A1 – DMA A3

- This section would be classed as a 'trunk' mains (or super DMA) balance and there will be no or little demand drawn directly from the mains. The flow pattern will be determined by local demand and will show this daily variation.
- Similar arrangements are seen, for example, between WTPs and storage tanks or pumps to storage tanks, however for these the flow pattern will more likely be determined by pump controls or storage tank inlet controls.
- The balance residual will be comprised of real losses, a relatively small amount of customer usage, and any metering error

Example B: DMA A1 usage = DMA A1 – DMA A2

- In practice, there may be a number of levels in the cascade of DMAs.
- The accuracy of the net flow calculation will be affected by the ratio of consumption to on-flow (on to the cascading DMAs) and by the number and accuracy of the meters forming the balance.

Example C: Opening of CLOSED VALVE 1 between DMAs A1 and A3 would breach the boundary. The combined area could be assessed through calculation of net flow of the combined area. Both DMAs operate on similar head from WTP A. It is likely there will be some change in the flow recorded through each meter with a low risk of reversals. Flow recorded at WTP A would be unlikely to change.

Example D: Due to the higher head at WTP A compared to WTP B, opening CLOSED VALVE 2 between DMAs A3 and B1 would likely result in higher flow through meter DMA A3 and WTP A, and lower flow through WTP B with possible reversal at DMA B1. Operational issues may need to be considered, such as reversal of flow and the additional demand placed on WTP A.

Continuous monitoring of flow data from the meters, with data accessible at a central location, would allow identification of any such breaches through assessment of changes in the recorded flow patterns.

Step 1 - Progress

The assessment of the available GIS data for the pilot DMAs (and wider network) in the summer of 2019 identified a number of areas for improvement. These included:

- Two NAWASA GIS asset records exist with differing data and pipeline pathways;
- Many pipes and fittings within the GIS are 'floating', that is, they are not located on pipelines; and
- The current GIS represents, in the most part, larger diameter mains only

The identification of these issues and further discussion with NAWASA personnel led to the development of a plan through autumn and winter 2019 to improve the coverage and accuracy of the GIS record for the two pilot DMAs, Lance Aux Epines and True Blue, both located in the south of Grenada. This work included:

- Capture of the operational knowledge from NAWASA engineers;
- Digitisation of additional pipelines from legacy PDF pipeline plots of Grenada from 1988; and
- Use of a 'join the dots' approach to add pipes to the GIS record where property meters are shown but pipes are missing

Further improvement to the GIS record was achieved through undertaking site visits and street walks to identify assets which were missing from GIS and the PDF plot.

NAWASA conducted a field survey of the two pilot DMAs to validate the estimated data, identify other missing assets and correct the locations and connectivity of 'floating' assets. The process has resulted in further improvements to the accuracy of coverage, connectivity and complexity e.g. mains running in parallel on some sections on the north-south spine.

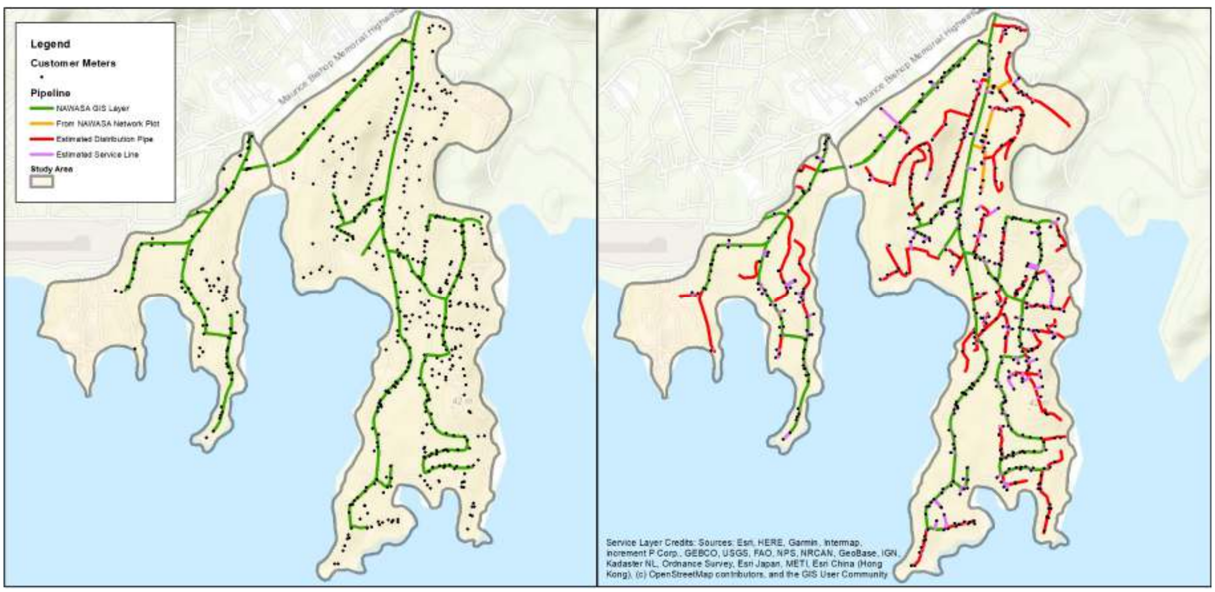
A summary of the improvement in data is provided overleaf in Table 3.1:

Table 3.1 Length of distribution pipelines and service mains in the two pilot areas

DMA	Length of mains in NAWASA GIS (m)	Length of mains following estimates and site inspections (m)	Number of customer meters	Estimated length of service mains (m)
SG-1	19,814	54,965	617	317
SG-2	9,850	12,599	136	3686
Total	**29,664**	**67,564**	**753**	**4003**

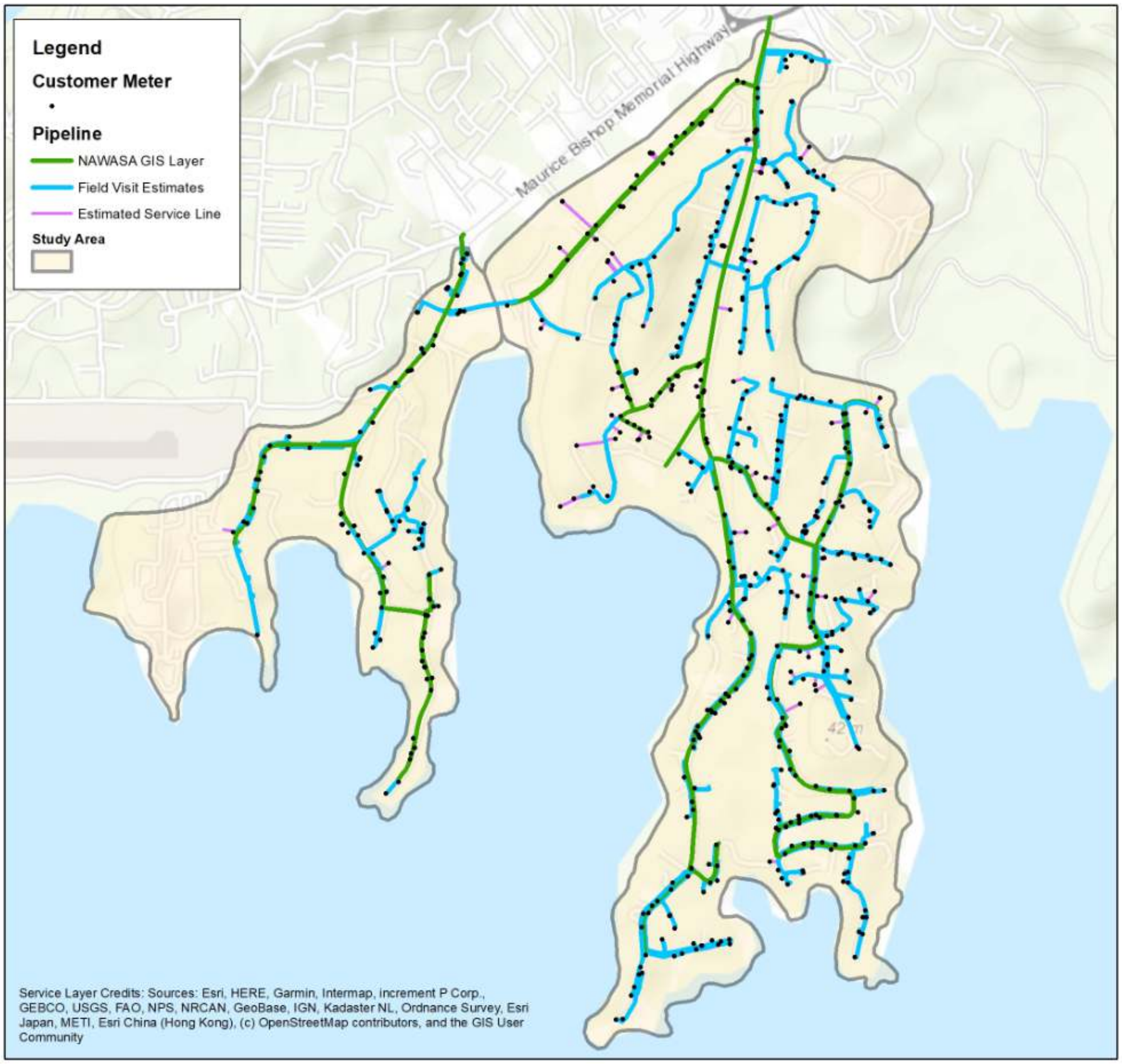
Plate 3.7 shows the impact of this exercise on the representation of the distribution network. The total length of the represented pipework has increased significantly, which has allowed for more accurate estimating of distribution mains length and service pipe lengths, both of which are required in the NRW audit.

Plate 3.7 Distribution pipeline data – Developing a more representative network



The revised GIS does provide a more accurate estimate of the extent of the network for use in the NRW audit and as a basis for the reporting on network events. It must be noted that for a proportion of the pipes added to the record following the data gathering activities there is little or no information available on the material or diameter and in most cases there will be a level of uncertainty over the accuracy of the asset location. The current situation is shown in Plate 3.8.

Plate 3.8 Distribution pipeline data for the two pilot areas - March 2020

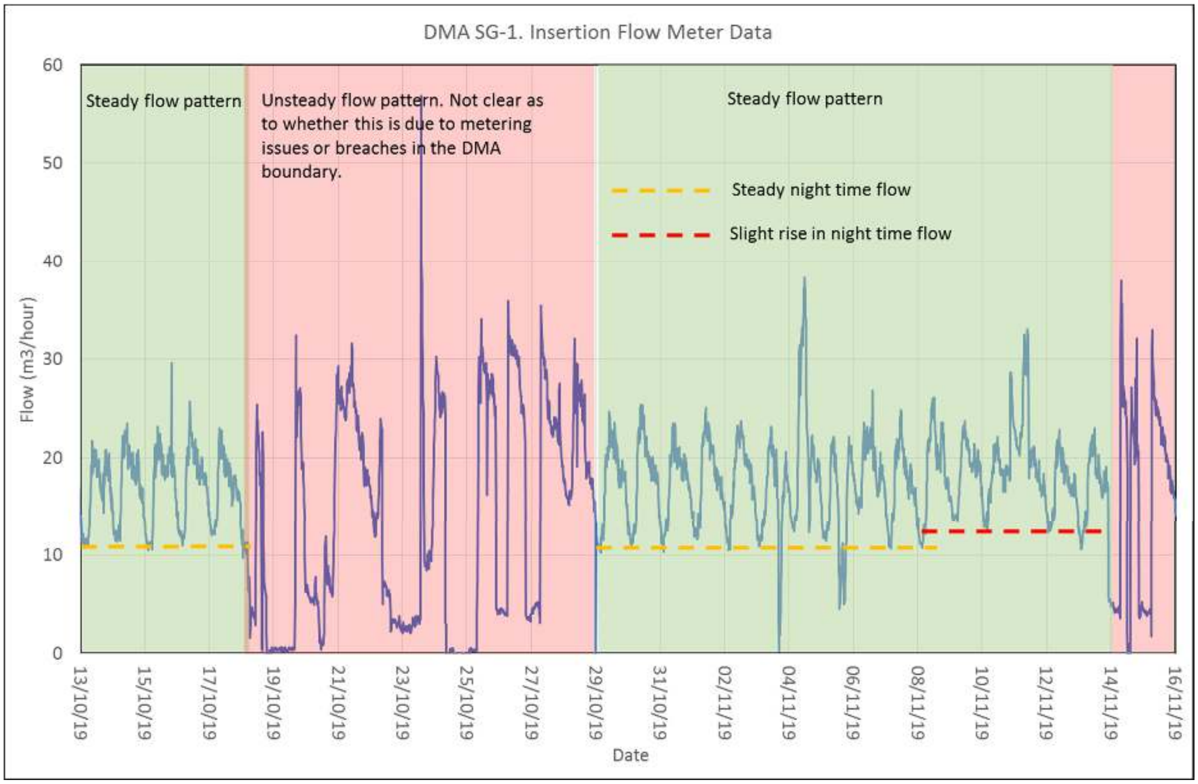


NAWASA have commenced their DMA design and implementation programme, with 36 notional DMAs defined within GIS. These cover approx. 20% of customers (based on meter locations). Most of the DMAs have meters installed, however none so far has a permanent data logger installed on the inlet meter.

For DMA SG-1, an insertion probe meter and data logger were installed downstream of the permanent meter on 12 October 2019. This has been recording flow data at 15 minute intervals. Plate 3.9 shows part of the data set.

For the majority of the time the data is showing a steady pattern with a consistent minimum night flow, peak flow and daily flow pattern. There are periods where the flow pattern is erratic. The reason for this is unclear from examination of the data and could be meter error, network reconfiguration issues or the result of a network incident.

Plate 3.9 DMA SGA 1- Illustrative flow measurement record



Step 1 - Action plan

'Knowing your network' is not limited to having accurate asset records. An understanding of how the water supply network operates in a format readily available to operations personnel is critical to achieving effective day to day operation and the implementation of appropriate network management strategies.

It is best practice to understand which sources (water production) supply which storage tanks, trunk networks, and in turn, distribution areas (DMAs). It is also important to record where connectivity between supply areas exists, and the locations of unmetered (unmonitored) sections of the network.

Traditional methods of obtaining and recording this information include the development of network schematics, a set of 'source to supply' flow balances (aligning with the 4 levels of network monitoring / zonal hierarchy), and written instructions covering configuration, operating constraints, and contingency options. Accurate network schematics (again aligning with the 4 levels of network monitoring / zonal hierarchy) and details of system operation will benefit all aspects of network management including NRW. However to develop these an accurate record of assets is required.

Further work will be required to improve the GIS asset records, both for the pilot DMAs and the wider network. Actions include:

- Collation of information for valves, hydrants and other fittings currently not included in GIS;
- Capture of asset characteristics, such as pipe material and diameter;
- Development of an asset data capture template and agreed implementation procedure. Take advantage of data capture opportunities when pipework is exposed for any reason e.g. to facilitate a pipe repair;

- Commencement of a long term (at least 2-3 years) programme to remap the primary pipeline distribution network, with an aim to complete a minimum of six DMAs in 2020. This programme would require additional resourcing with an additional long term aim to complete remaining DMAs/priority areas by the end of 2022.

Based on assessment of the DMA boundary GIS layer provided by NAWASA and the customer meter GIS data, the customer meter counts within the 36 DMAs vary from 16 to 718, with an average of 214, and with 15 DMAs having 100 customer meters or fewer.

Consideration must be given as to whether it is cost effective to install and maintain meters and data loggers at this density. It is likely the low customer counts will result in high instantaneous variation in flow leading to unsteady readings, and the meters may not be able to record good data across the full flow range leading to 'drop outs' in night flows.

It is recommended that the DMA design strategy be adjusted to identify, where possible, areas containing 300 or more properties for permanent monitoring. This will reduce the overall number of DMAs required to cover the NAWASA supply area and the associated CAPEX and OPEX, and provide DMA coverage at the density typical for this size of distribution network.

3.2 Step 2: Know your customers

Customers are the source of revenue for the utility company so are a very important part of the operation. Accurate recording and estimation of consumption will provide valuable data for various areas of operation, including:

- Water resource management e.g. seasonal variations and the potential requirement for development of new resources and storage;
- Distribution capacity and storage planning; and
- NRW auditing and DMA-based NRW monitoring

Customer location

Ideally, the location of all properties in the supply area should be known and mapped in GIS. The properties with customer accounts should be linked to records of customer characteristics and water usage. The information recorded should include, but not be limited to:

- Details of customer type e.g. domestic, commercial, disconnected and unregistered customer accounts;
- Details of metering and monitoring e.g. meter type, age and size, consumption estimates (if unmetered); and
- Details of how the property is supplied e.g. distribution pipe identifier, DMA, water source

At the start of the project, a review of the available GIS datasets highlighted a series of 199 individual files which included locational details of customer meters across Grenada. Each of these files related to one of the customer metering areas, which are manually walked for meter readings each month. Although these files cover a majority (estimated around 85%) of the accounts which NAWASA bills, the review also identified differences in the quality, age and structure of the individual files. These characteristics will result in:

- Difficulties identifying properties with no water billing account;
- Reduced accuracy in estimating the length of service pipes from the distribution main to the customer meter and from the customer meter to the property; and

- Reduced accuracy in estimating authorised consumption, metered and unmetered, within each DMA or supply area

Over the course of the project, improvements have been made in linking the billing data record to the customer meter data. More detail on this is provided in the project Report 2D and in the following section of this report.

Unauthorized consumption

In most water distribution networks, the proportion of total system inflow taken through unauthorized consumption is likely to be relatively low but difficult to locate. It may include:

- Properties connected to the network but not logged on the customer or meter databases;
    - Inaccurate records of connected properties – unauthorized by omission/oversight
    - New constructions not complying with regulations
    - Deliberate illegal connection to the water network.
- Transient, short-term illegal connections, for example drawing from a hydrant to fill a tanker or other storage point.

Efforts to reduce the number of connected unauthorized consumers would benefit from having access to a fully referenced property address data set for Grenada. This can then be used to investigate properties which have no billing data.

Unauthorized consumption not only affects the water balance and increases the costs to paying customers. It can also pose a risk to the quality of the water, with cross-connections to non-potable water systems and the risk of back-siphoning into the distribution network.

Step 2 - Progress

During 2019, a data consolidation exercise was undertaken to combine all of the 199 individual meter files into one single GIS layer.   This process included creating a consistent data structure and the production of a single GIS layer which is now included in the GIS master database on the central GIS server.

It is important to note that this dataset still has inherent data gaps and quality issues but does provide a basis for future data refinement and update. This has been identified as a priority area of future work to help the continual improvement of NAWASA's GIS system.

As part of the GIS improvement work, a process has been developed to link customer meter locations to the supplying water distribution pipework. A notional supply pipe is created by taking the perpendicular line from the customer meter and the nearest pipe. These can then be used to estimate the total length of services in the DMA.

In addition, the project has also developed and tested different mobile mapping apps connected to GPS to facilitate the future capture of meter locations. This work is fully documented in project report 2E.

Step 2 - Action plan

The ongoing improvement of the customer metering datasets will require the following focused activities:

- Continue current live testing of digital data collection forms created by GISCAD in the work of the metering and T&D teams   This will need to be supported by staged investment in data collection tablets

- Use digital data collection to capture the location of new / updated meter locations and over time build up an enhanced digital record of meter/customer locations.
- Promote regular engagement and feedback from crews using the forms regarding the potential issues and time savings. This will help quantify the benefits of the investment required to update the information.

It is expected that these approaches will, over time, lead to the development of a more robust property layer / spatial record for the whole supply area, which will not only feed into future NRW assessments but also provide additional operational benefits to NAWASA. These benefits may include improved access and response to customer queries and optimised planning of future infrastructure investment requirements.

3.3 Step 3: Know your customers data

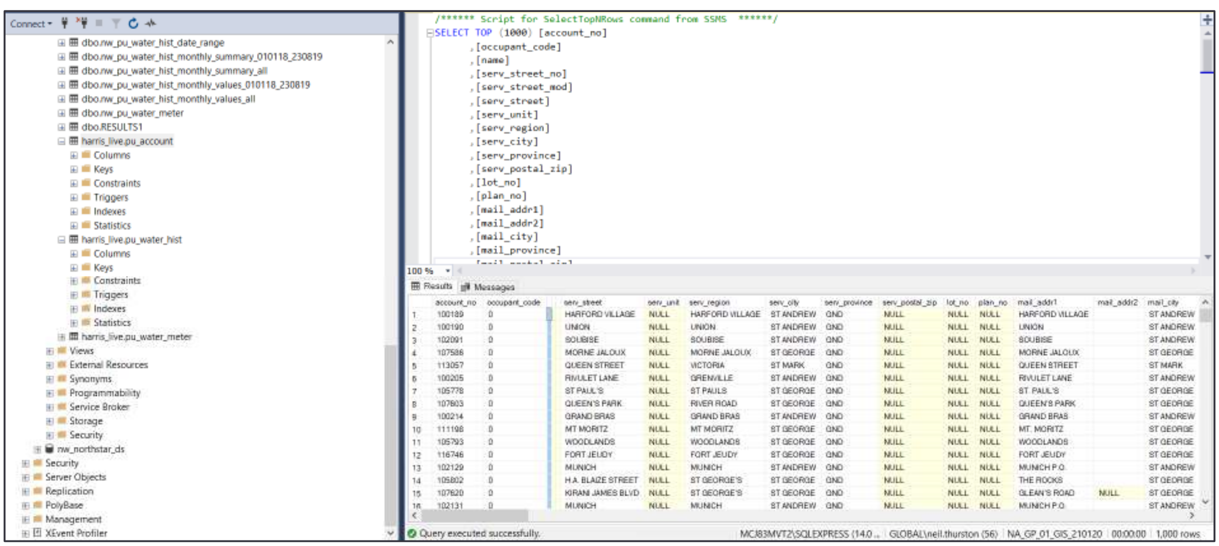
Accurate customer consumption data is required to populate the NAWASA NRW audit and to inform the DMA leakage Minimum Night Flow (MNF) models.

At present, NAWASA's Northstar customer billing database holds information on the property address, meter readings and date of readings, meter size and type. Each customer has also been assigned a usage category e.g. WDOM and WNON1-4. The WNON categorisation is based on monthly billed consumption rates:

less than 2,800 gallons	WNON1
2,801 - 20,000 gallons	WNON2
20,001 to 100,000 gallons	WNON3
Greater than 100,000 gallons	WNON4

An example section of the database is shown below in Plate 3.10.

Plate 3.10 Northstar database – Customer accounts sample records



However, the Northstar database does not contain any spatial referencing information and/or link to the defined DMA areas used by NAWASA. This issue was identified during the start of Output 4 and led to the development of a database workflow to produce effective customer data which could be used in the NRW assessment.

Step 3 - Progress

Prior to use in the NRW assessment, the updated customer billing data was cleansing to remove duplicate accounts, identify potential data errors and apply corrections. For each account, the annual and average daily consumptions were calculated using the following process:

- Identify the earliest reading in the period being assessed e.g. consumption in January 2019;
- Identify the latest reading in the period e.g. consumption in December 2019;
- Calculate the sum of consumption between the dates and the number of days between readings;
- Factor the consumption figure to estimate annual consumption and
- Factor the consumption figure to estimate daily consumption

These calculations were achieved using MS Access which included connections to the PostgreSQL GIS database and duplicated Northstar database created for the project. Plate 3.11 provides an indication of the processes involved and Plate 3.12 an example of the output.

Plate 3.11 MS Access workflow for account based consumption calculations

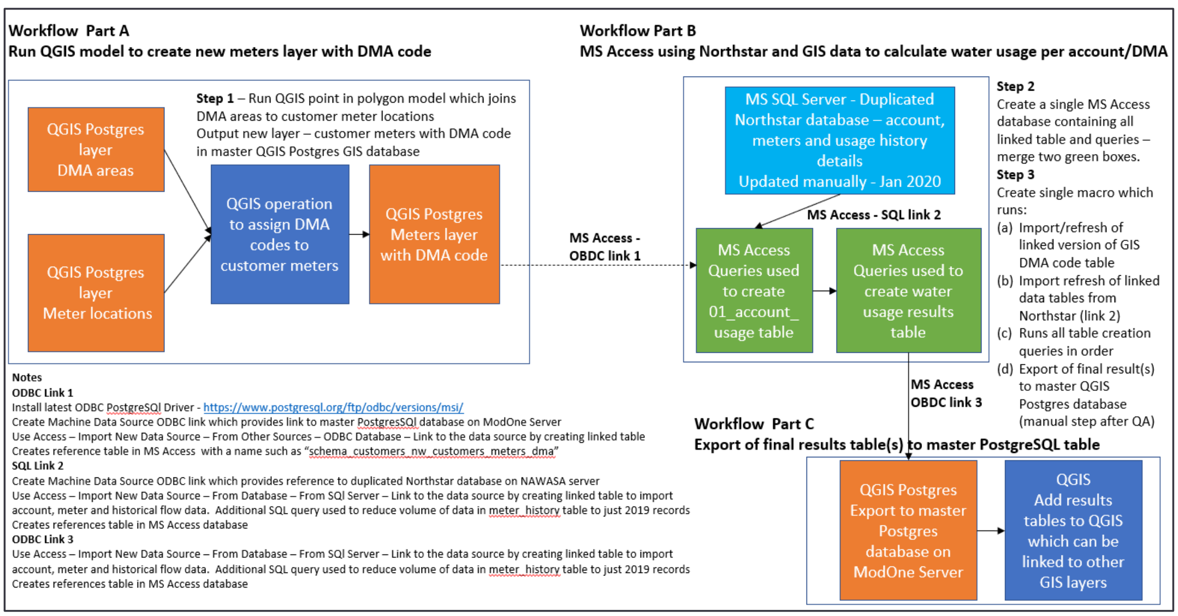
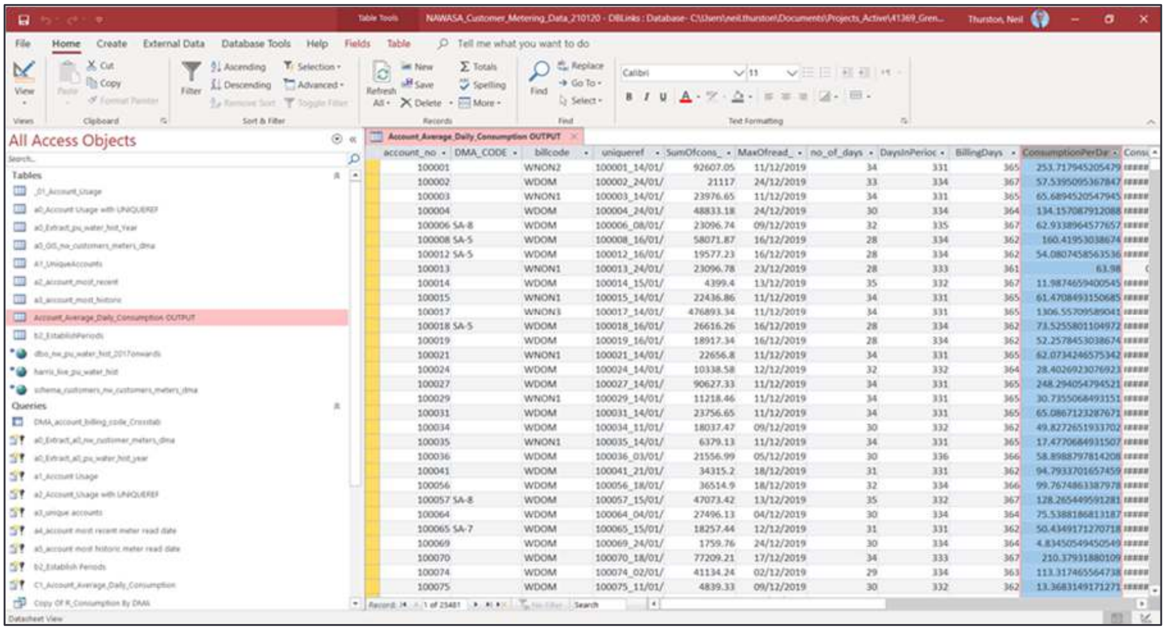


Plate 3.12 MS Access workflow for account based consumption calculations – Sample output



The calculated figures were assessed to identify unusual values e.g. zero values, very low consumption, and very high consumption. Some of these values may be genuine, though others may be due to data errors and will affect the accuracy of consumption estimates. The validated figures will be used in the NRW audit and other water usage assessments.

Usage volume and category assessment

Customers in the test DMAs are a mixture of domestic and non-domestic users. Plate 3.13 shows the spatial arrangement of customers categorised by daily usage. The plot shows a number of the high daily consumers located closer to the coast, which may be hotels or other holiday accommodation sites.

Plate 3.14 shows the number of customers and total usage by range (in m^3/day) for customers categorised as non-domestic.

Plate 3.15 shows similar for those categorised as domestic.

To quantify customer usage for use in the NRW audit and other network performance assessments, it will be necessary to select customers within the study area and interrogate the billing data to determine usage during the assessment period. Much of the progress to date has been in relation to improving the data sets to facilitate this. Activities include:

- Assessment of GIS data to ensure that GIS customer meter features are linked to the correct record in the Northstar billing database via the unique “meter_no” reference. Analysis to-date has highlighted a number of discrepancies.
- Undertaking of mobile mapping activities to capture the location of meters for accounts in Northstar with no GIS record.

Plate 3.13 GIS mapping of billed usage in 2019 within SG1 and SG2

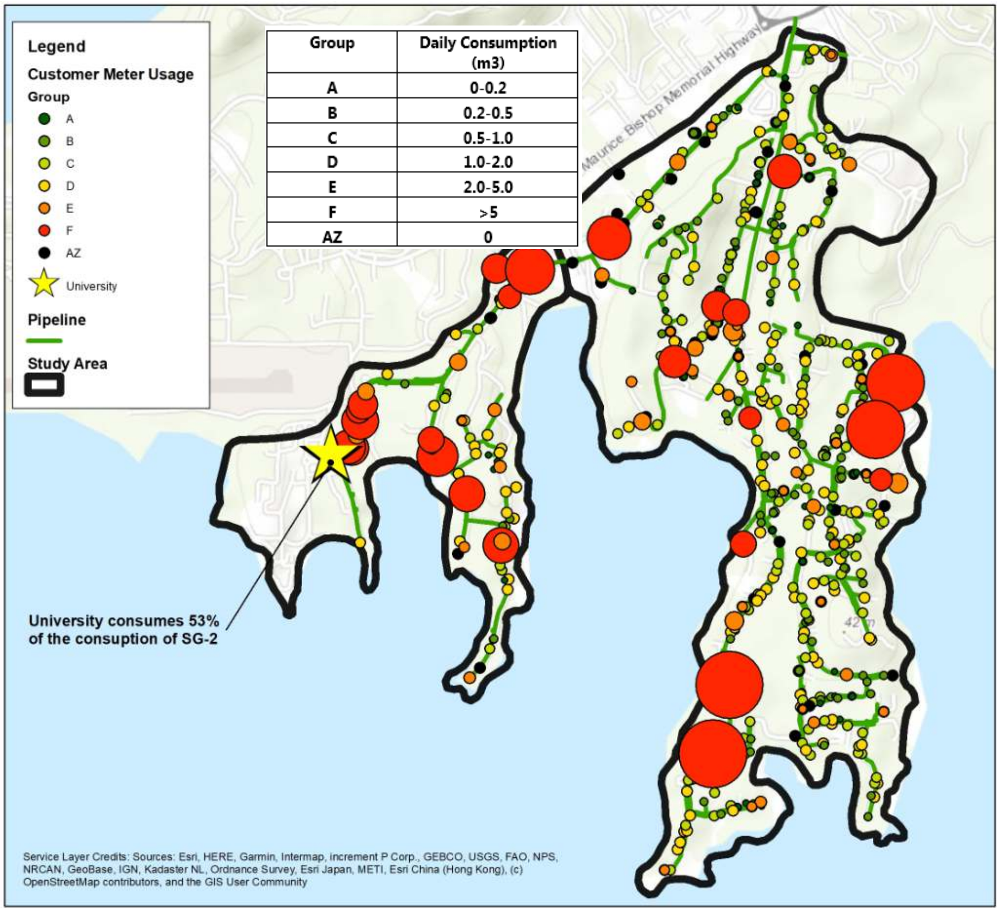
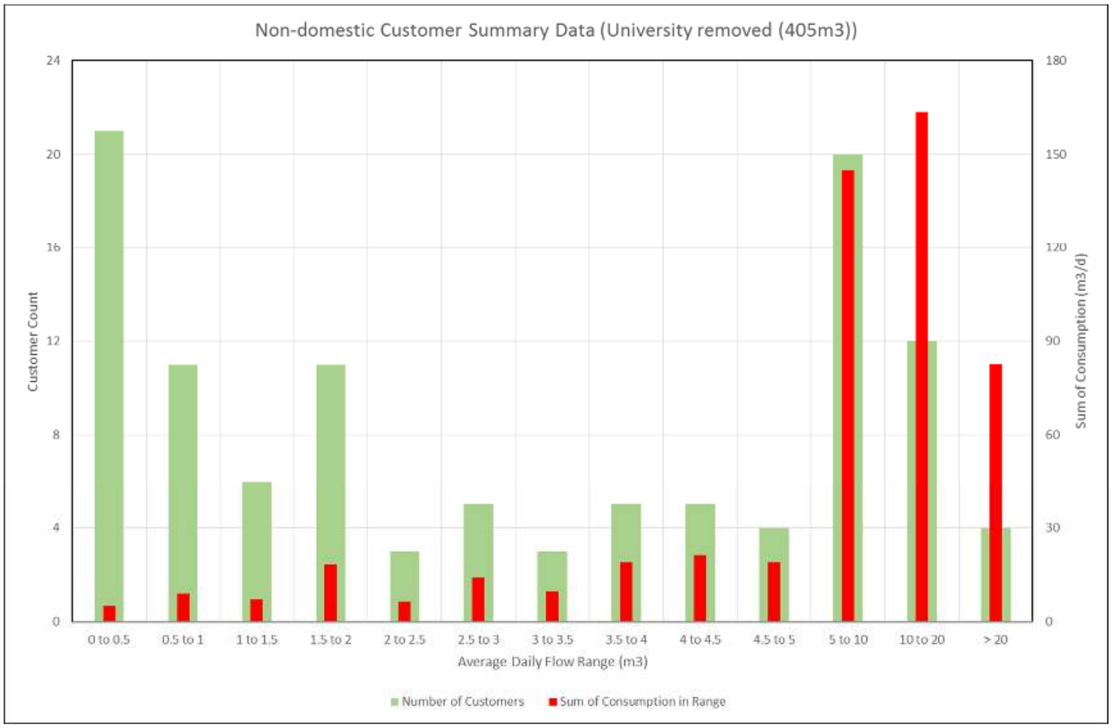
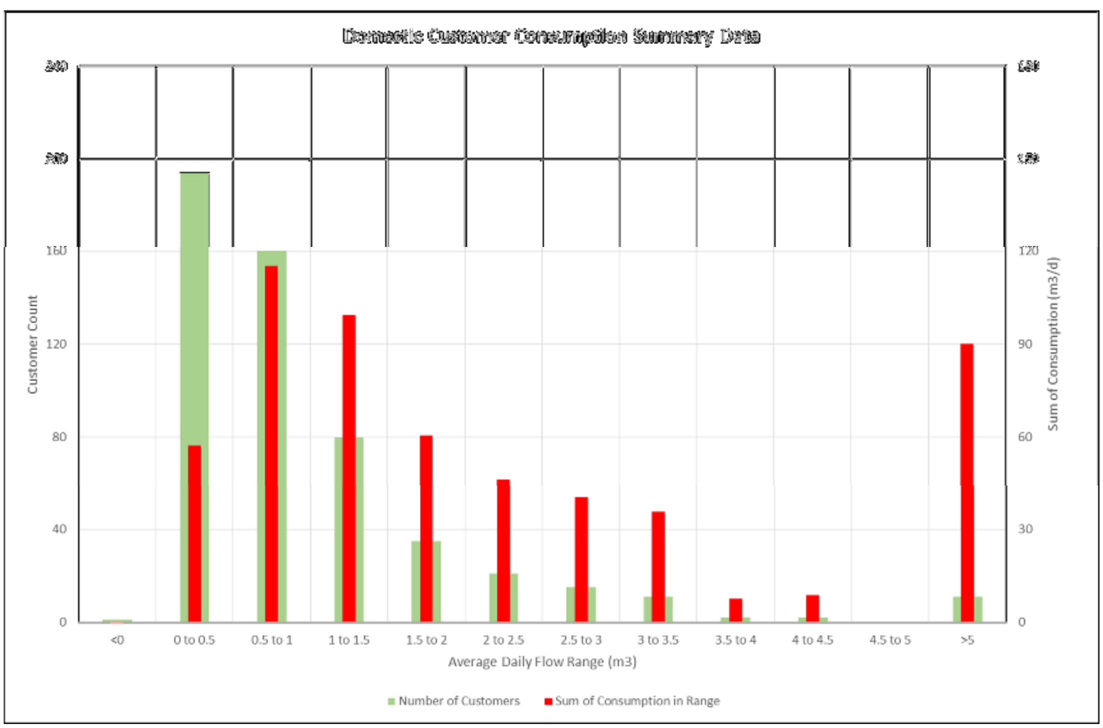


Plate 3.14 SG1 and SG2 – Patterns of non-domestic water use during 2019



The majority of usage is in the higher daily consumption ranges (5m^3 to 10m^3 upwards). There are a significant number of customers with lower daily consumption. It is understood that some of these may actually be smaller retail outlets.

Plate 3.15 SG1 and SG2 – Patterns of domestic water use during 2019



The majority of the customers and usage fall in the range which may be expected for domestic consumers. A significant amount of usage is for domestic customers consuming in excess of 5m^3/day. It is recommended these be investigated with a view to re-categorising them – are they actually domestic customers?

Step 3 - Action plan

The following actions are recommended to improve the quality of the billing data:

- Investigate high consumption customers classified as domestic users and reclassify where required
- Consider installation of permanent flow data loggers for very large users.
- Validate the accuracy of meter reading and processing e.g. meter error, data entry, processing errors
- Investigate variation in customer consumption demand patterns e.g. seasonal, weekday/weekend, and educational term times. Consider the use of customer interviews / questionnaires.

To allow more accurate DMA-level NRW assessment using the MNF method, it would be beneficial to include categorisation based on likely night-time usage. The categories may include, for example, RESIDENTIAL, COMMERCIAL 10HR USER, COMMERCIAL 12HR USER, COMMERCIAL 16HR USER and COMMERCIAL 24HR USER. The profiles and demand patterns to be used will need to be agreed following a more detailed review of typical usage patterns on the island. Night-time usage allowance factors, as a proportion of average daily flow, can then be applied to the MNF usage calculations.

3.4 Step 4: Record leaks and repairs

The accurate recording of leaks and bursts identified on the network, ideally within the GIS environment, will provide a number of benefits:

- Highlighting ‘hotspots’. These may have various causes:
  - Deteriorating assets – old, poor quality, aggressive ground conditions
  - Pressure fluctuations, including transients
  - Quality of construction
- Support targeting of investment such as mains replacement programmes and pressure calming measures.

Currently, for parts of the NAWASA network, the record of asset characteristics is not complete. Recording of general information whilst undertaking repairs will provide valuable information to improve asset records. This should include:

- Details of mains location, material, diameter
- Details of service connection locations, material and diameter
- Details of ground conditions, depth of cover
- Type of failure – lateral, circumferential, point, joint

Step 4 - Progress

During October 2019 and March 2020, a series of forms were developed using an Android app called Qfield to help aid the future capture of digital information relating to leaks on the pipelines. Further details of this work are presented in project **Report 2E**. Based on assessment of the information currently available, the following action plan is suggested.

Step 4 - Action plan

The ongoing improvement of digital information relating to the location and characteristics of distribution pipeline leaks will require the following focused activities:

- Continue currently live testing of digital data collection in the work of the metering and T&D maintenance teams. This will need to be supported by staged investment in data collection tablets.
- Use digital data collection to capture the location of bursts and repairs.
- Implement the asset data recording procedure and transfer all information to GIS.
  - Review procedures and amend where potential improvements are identified
  - Whilst the focus should be on the pilot DMA areas, rolling out the data capture procedure across the network would start the process of gathering valuable asset data for future use.
- Promote regular engagement and feedback from crews using the forms regarding the potential issues and time savings. This will help quantify the benefits of the investment.

It is expected that these approaches will over time lead to the development of a layer of leakage event location and severity, which will not only feed into future NRW assessment but also provide additional operational benefits to NAWASA. These benefits may include improved access and response to customer queries and the optimised planning of future infrastructure investment requirements.

3.5 Step 5: Quantifying NRW

The widely accepted standard for undertaking NRW audits is the methodology developed by AWWA. This breaks down system inflow to Revenue and Non-revenue components with further sub-division of each, as shown in Plate 3.16.

Information on network operation and characteristics, as described in sections 3.1-3.4, is used within the NRW water balance model. It is possible to quantify NRW at a company level, water treatment plant supply area level, water storage supply area level, super DMA area level and at the DMA level.

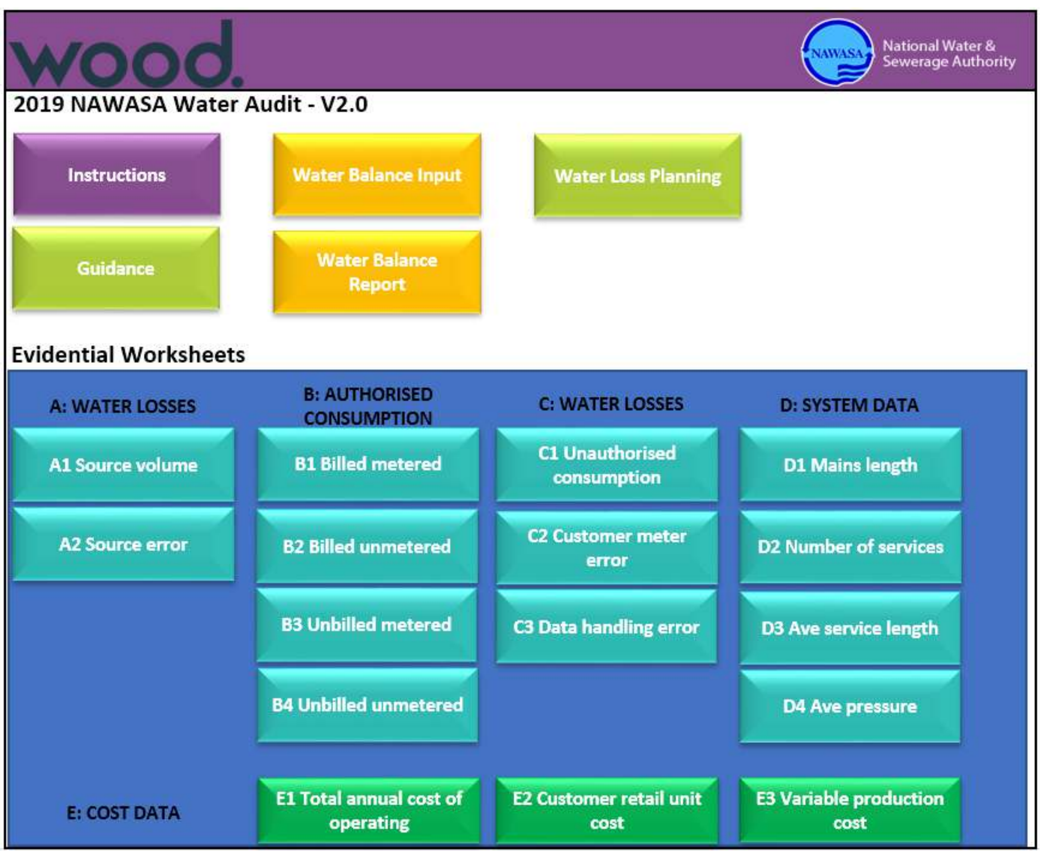
Over time, through regular assessment of NRW performance, trends can be established to assess the impacts of NRW reduction initiatives.

Plate 3.16 AWWA Non-revenue Water audit components

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption	Revenue Water
			Billed Un-metered Consumption	Non Revenue Water (NRW)
		Unbilled Authorized Consumption	Unbilled Metered Consumption	
			Unbilled Un-metered Consumption	
	Water Losses	Apparent Losses (Commercial Losses)	Unauthorized Consumption	
			Customer Meter Inaccuracies and Data Handling Errors	
		Real Losses (Physical Losses)	Leakage in Transmission and Distribution Mains	
			Storage Leaks and Overflows from Water Storage Tanks	
			Service Connections Leaks up to the Meter	

The AWWA audit workbook (WAS v5.0) has been used as the basis for development of the NAWASA NRW audit workbook. It has been adapted to meet the particular needs of NAWASA and structured to hold all the base data required and provide locations for the recording of estimates and assumptions. The audit workbook contains help and guidance on all elements of the audit process.

Plate 3.17 NAWASA Non Revenue Water (NRW) audit workbook - front sheet



Step 5 - Progress and action plan

The work undertaken to date to improve the quality of network data, as detailed in sections 3.1 to 3.4, will result in more accurate NRW audits and MNF calculations. However, there is scope for further improvements, as detailed in each section under **Action Plan**.

Table 3.2 provides a summary of the items of data used in the calculations with comments on the current level of confidence and scope for improvement:

Table 3.2 Assessment of data accuracy and reliability NRW audit components

Component	Observations	Scope for Improvement
A1: Volume from own sources	Gaps in monthly totals for a number of sites. Unclear whether this is genuine no flow, meter outage or missed readings.	Install permanent data loggers at all source meters. Install permanent data loggers at all fully established DMAs
A2: Source meter error adjustment	Accuracy of source meters not quantified.	Undertake accuracy checks on all source meters. Consider replacing older meter units. Develop system balances (with schematics), possibly install additional sub-meters on the trunk network to provide a check of source meter accuracy.
B1: Billed metered:	Customer billing records available and the majority have a GIS record.	Roll out the pilot DMA billing data improvement programme across the operating area.
B2: Billed unmetered:	Thought to be a low proportion but not quantified.	
B3: Unbilled metered:	Thought to be a low proportion but not quantified.	Review improved customer billing data.
B4: Unbilled unmetered:	Thought to be a low proportion but not quantified.	Review which customers may fall in this category e.g. water company ops, civic offices, and try and quantify consumption
C1: Unauthorised consumption:	Thought to be a low proportion but not quantified.	Use improved customer meter and property location data to identify potential users not recorded in GIS or the billing database. Possibility of illegal connections given the fact that there are thousands of accounts recording zero or very low consumptions
C2: Customer metering inaccuracies:	No current programme for meter accuracy checks. Smart meter trials planned.	Implement a customer meter accuracy testing programme. Use the smart meter trials to gain data on meter accuracy across the metering assets, not just older meters or ones considered to be inaccurate.
C3: Systematic data handling errors:	No current programme to assess this. A number of customers have consumption corrections applied to their accounts	Corrections to consumption data at the beginning of the year can result in an overall negative consumption total for that account over the year. This needs to be considered and addressed when undertaking the annual water audit calculation.

Component	Observations	Scope for Improvement
D1: Length of distribution mains:	Very limited pipework data in GIS Paper/PDF data available for NAWASA area. Improvements made for pilot DMAs	Roll out the improvements across the entire network. Recommend start with digitising all mains on PDF plans first – this will provide the greatest and quickest benefit when it comes to obtaining a better understanding of mains length and this will help with notional DMA design activities.
D2: Number of service connections	Based on current customer billing record for whole system assessment. Based on GIS customer meter record for DMA-level assessments.	This should include all service connections including those without customer meters. Having a customer property layer would be of benefit. Improvements in customer billing and GIS data will improve the accuracy of this number at system and DMA levels.
D3: Average length of customer service line:	For pilot DMAs this is based on distance from estimated pipe lines to customer meters. Average length used in calculations.	Revise estimate following improvement in GIS pipe records for the wider network. Calculate at the system and DMA level.
D4: Average operating pressure:	No data currently available. Pressure values are estimated in the audit.	Develop a programme of pressure monitoring, either a rolling temporary deployment or permanent locations, to allow better estimating of operating pressure across the network.
E1: Total annual cost of operating water system:	Information available within NAWASA	
E2: Customer retail unit cost (applied to Apparent Losses):	Information available within NAWASA	
E3: Variable production cost (applied to Real Losses):	Information available within NAWASA	

3.6 Step 6: Managing NRW

The undertaking of NRW audits, at system (zonal) and DMA level provide a measure of the current position and the potential 'headroom' for improvement. The management and reduction of NRW requires other operational interventions with activities focussed on those trunk sections and DMAs which have consistently high, but unexplained, night flow, and on sections where increases in night flow outside of seasonal and operational trends are observed. Both conditions are indicative of a water loss or otherwise unaccounted for usage.

To maximise benefits from undertaking flow balances, system input flow data and DMA flow data will need to be continuously logged and, ideally, transmitted automatically to a central location for data processing. This will enable assessment of losses based on the minimum night flow (MNF) method and the targeting of NRW reduction activities in the right parts of the network.

Details of how data collected from permanently monitored system input, trunk main and DMA meters can be used to more accurately quantify NRW to allow targeted and timely intervention are outlined below.

Flow balances

Provided below are some examples of how assessment of continuously logged flow data can be used to improve the management of NRW. These are based on the generic example network shown in Plate 3.18.

Plate 3.18 Example trunk/DMA network

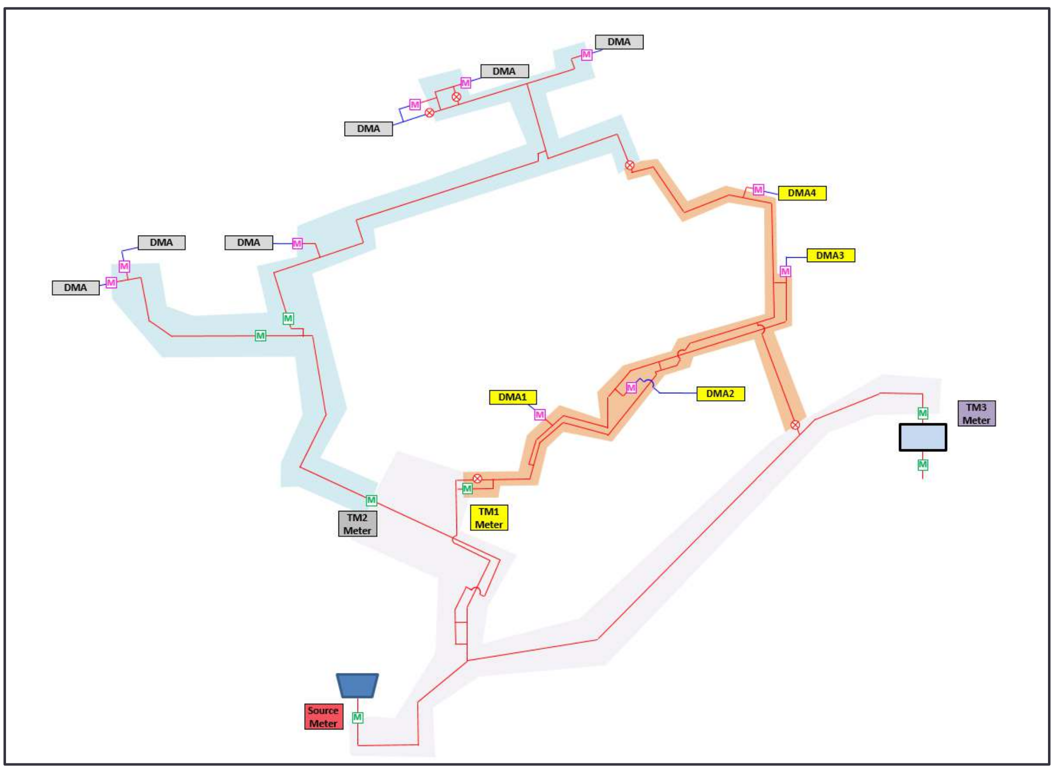


Plate 3.19 shows the summary flow data for a trunk main meter which monitors flow to a part of the network which has a fairly typical domestic usage pattern and a component of seasonal usage with coastal holiday accommodation and associated commerce:

For the trunk main meter:

- The MINIMUM DAILY FLOW stays steady, however there is a slight increase in February 2018
- The AVERAGE DAILY FLOW shows an increase through the summer months
- The PEAK DAILY FLOW shows an increase through the summer and increases on the weekends

Overall, the data is showing the section of the network downstream of the meter is performing in a stable manner. The data shows no unexplained sharp changes in the magnitude or pattern, which may be indicative of changes in operation or performance.

Plate 3.19 Summary daily flow data for meter TM1

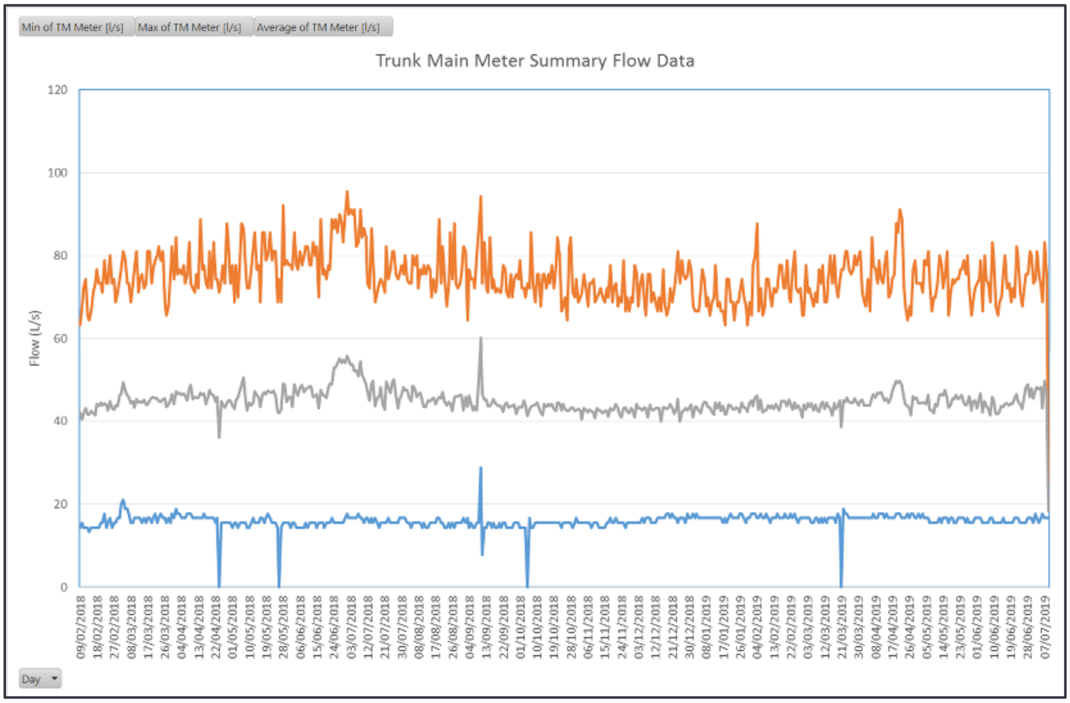
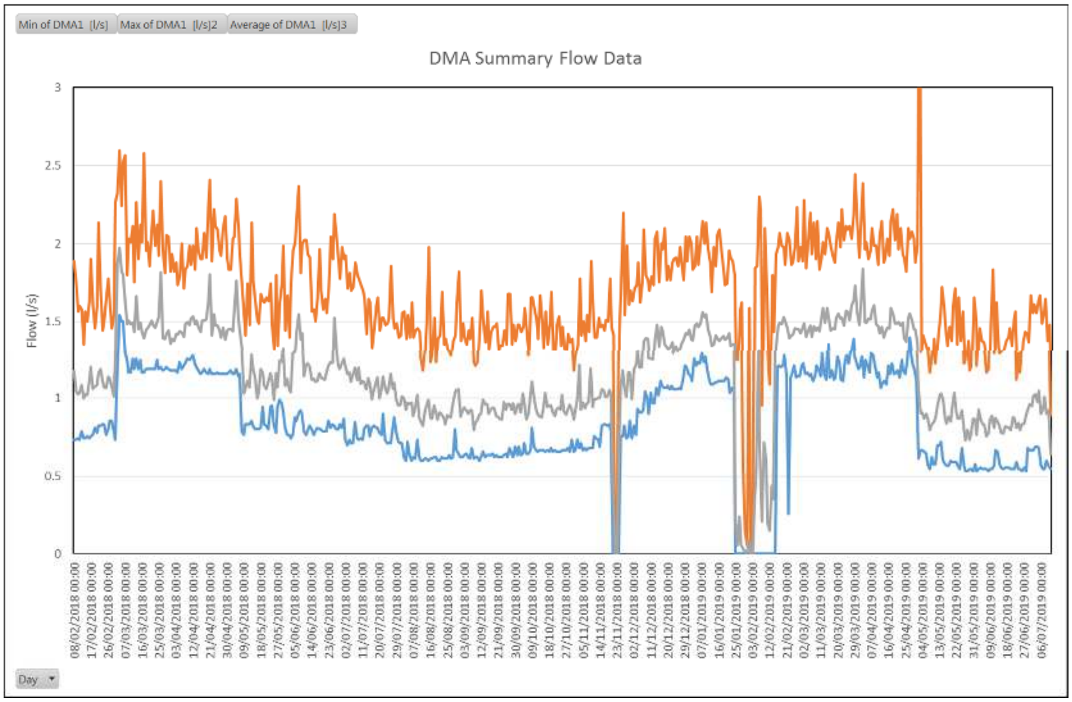


Plate 3.20 shows the summary data for one of the DMAs supplied off the trunk main.

Plate 3.20 Summary daily flow data for DMA meter



The minimum daily flow shows a lot of variation over the period assessed:

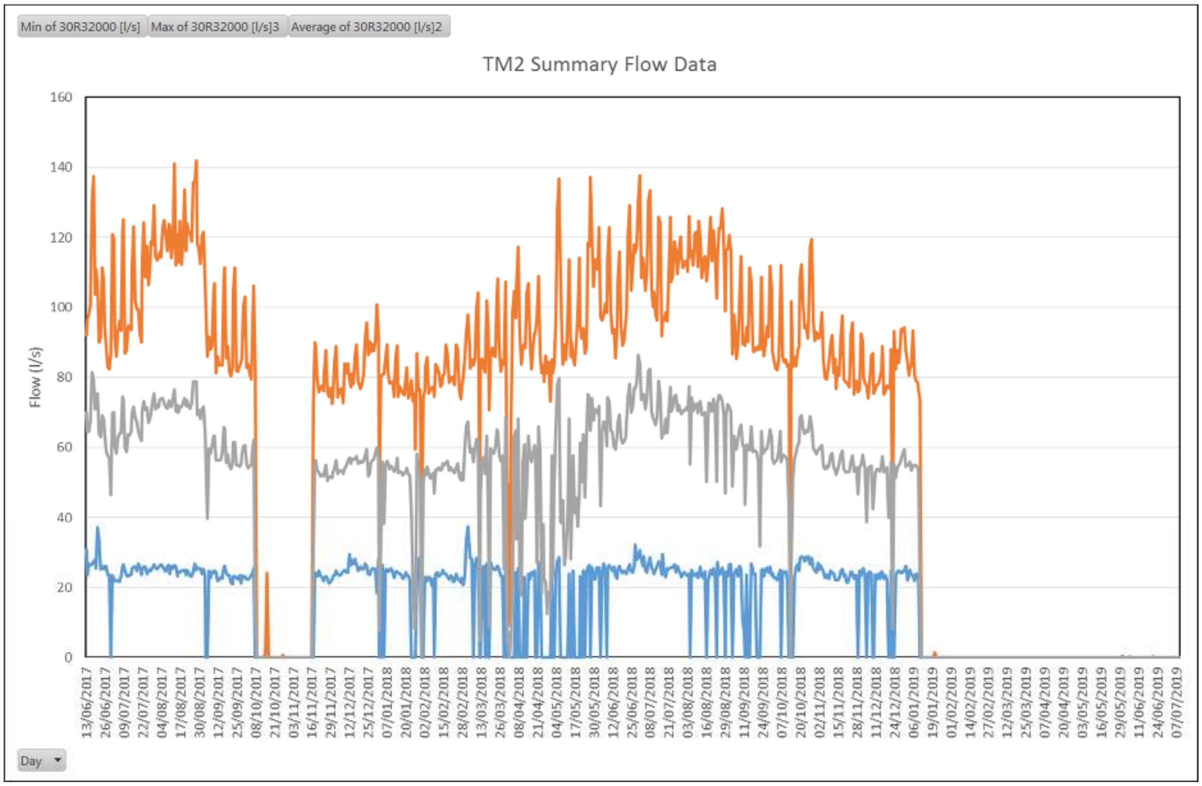
- The increase in February 2018 aligns with a very slight increase in the trunk meter recorded flow (from Plate 3.14). The sharp rise and sharp drop indicate a rapidly developing burst followed by repair;
- The increase in November 2018 does not have an obvious corresponding increase at the trunk meter. The gradual increase and sharp drop indicate a slowly developing burst followed by repair; and
- The DMA **average** and **peak** daily flows are both affected by the burst events with both increasing above the seasonal trend.

Review of flow data from the trunk meter (from Plate 3.19) may have identified the February burst, though the increase is small relative to total flow and may be overlooked. The DMA flow data clearly shows the development of the bursts and increase in water loss. The events can be pinpointed to a smaller area of the network thereby allowing more focussed leak detection and reduction activities.

The optimum arrangement for a network would be to divide it into monitored sections of the trunk network with flow in to any significant sections of distribution network monitored at sub-meters (DMAs). This would allow rapid response to events developing in distribution and, through trunk main balance calculations, losses on the trunk network can be monitored. Depending on the level of sophistication of the data management software, alarm levels can be set for the night flow to prompt investigation.

Plate 3.21 shows flow data for part of the network that supplies an area with a high proportion of tourism-related industry. The variation in average daily flow is much greater than in the previous example. Estimation of losses using average flow rates would be very difficult and, in lieu of accurate daily customer consumption data, would rely on reference to seasonal trends, weekday/weekend trends and variation in the weather. The minimum flow rate shows very little variation, other than where the rate drops to zero, which may be due to meter error or data transmission error.

Plate 3.21 Summary daily flow data for TM2 meter showing seasonal variation



The **average** daily flow and **peak** daily flow values both provide very useful operational information:

- Average flow trends can be used to manage water production and water storage
- Peak flow rates can be used when designing water distribution networks to ensure provision of sufficient carrying capacity.

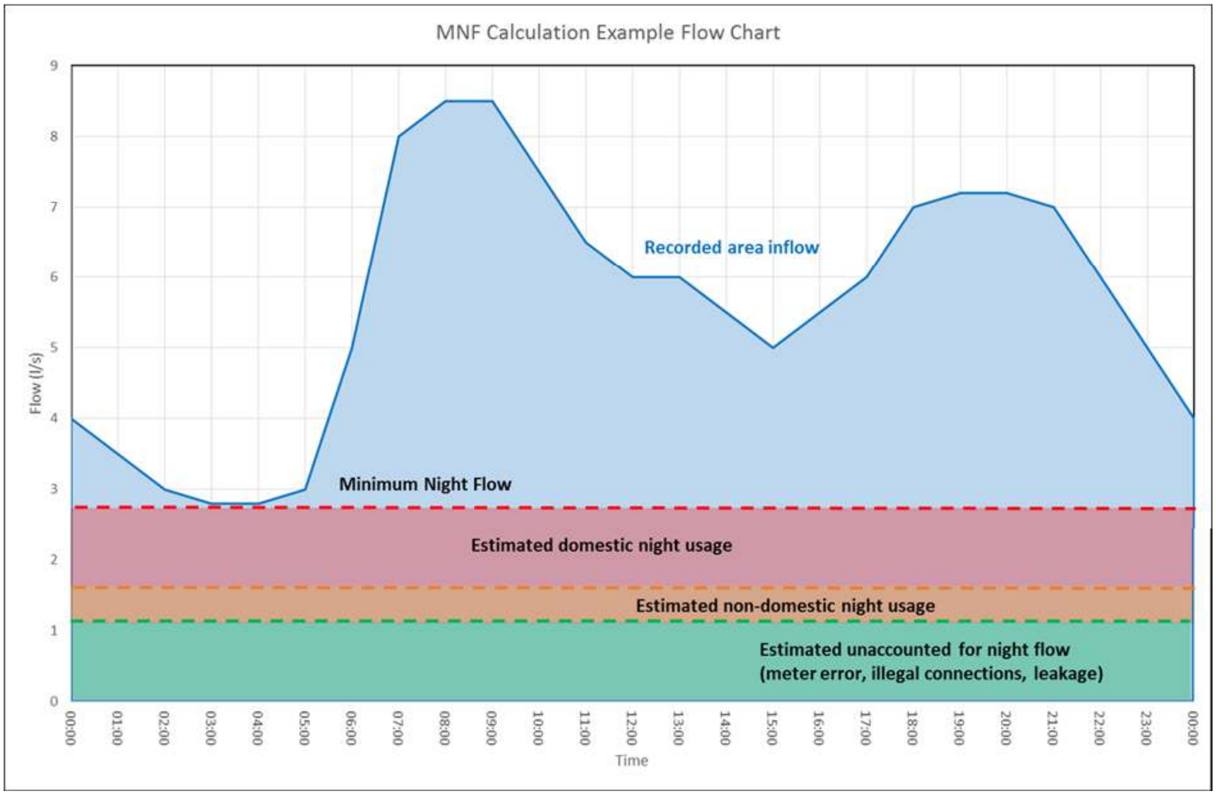
Minimum night flow (MNF) method

For the vast majority of DMAs, most customers will be using very little or no water at night. The flow recorded at this time will be comprised of real losses (leakage) and customer night usage. The usage component can be estimated based on the average daily metered consumption in the area by applying a night use factor, say, 10% of average usage. However, this is not applicable to all DMAs.

Where customers are known to have significant night usage, permanent monitoring using data loggers or taking manual readings at hourly intervals through the night should be considered.

Plate 3.22 shows a typical daily flow pattern recorded at a DMA input meter flow with night flow components detailed.

Plate 3.22 Typical Daily DMA input meter flows with night flow components.



In the simplest of terms, subtracting the estimated legitimate night usage from the recorded minimum night flow will provide an estimate of losses. This can be monitored over time to identify trends which may indicate increases in losses or issues with network operation.

Improvement in the accuracy of the night use allowances can be achieved through, for example, the setting up of 'demand monitor DMA' areas. These will be a set of smaller, permanently monitored areas containing groups of metered properties of known characteristics, such as occupancy rate, customer age, and property size. The daily and seasonal trends can be applied to each balance area to improve the estimate of the night allowance component. Care must be taken however, to ensure that a suitable meter is installed on the inlet to the DMA – a meter capable of accurately monitoring low night time flow rates.

Once all aspects and components of a DMA are better understood, a more comprehensive MNF real losses assessment can be undertaken for the DMA through application of the 'Bursts and Background Estimates' (BABE) method. In addition to the flow data, this approach considers system pressure and infrastructure condition in the assessment of system losses. The BABE methodology can also be extended to include financial and economic analysis of leakage reduction measures and pressure management.

Although some of the required data components of the BABE MNF assessment are not available for the pilot DMAs, a BABE leakage model template workbook was developed for NAWASA as part of this project and trialled for the SG1 - L'Anse Aux Epines DMA. Values for components which are currently not known, such as system night pressure, commercial night use and population, have been estimated.

For the DMA population value, an attempt was made to derive the population for all DMAs represented in GIS by using the available population GIS information. This is comprised of different 'district' polygons which hold the population data, however, these polygons do not align with the DMA polygons. This, coupled with the fact that property data is not available (only customer meter data is available and doesn't cover all properties in Grenada), meant that only an average population for the pilot DMAs could be derived based on a Grenada wide average occupancy rate. The occupancy rate has been calculated as the total population divided by the number of domestic properties (from billing data) and gives a value of 2.5 persons per residential property.

The ***"NAWASA MNF Leakage Model Workbook Version 1.1.xls"*** workbook is included with the issue of this document.

A screenshot of the BABE leakage model workbook for SG1 - L'Anse Aux Epines DMA can be found on Plate 4.9 (NAWASA Water Audit Results – MNF Calculations Summary Data) within section 4.5 of this document.

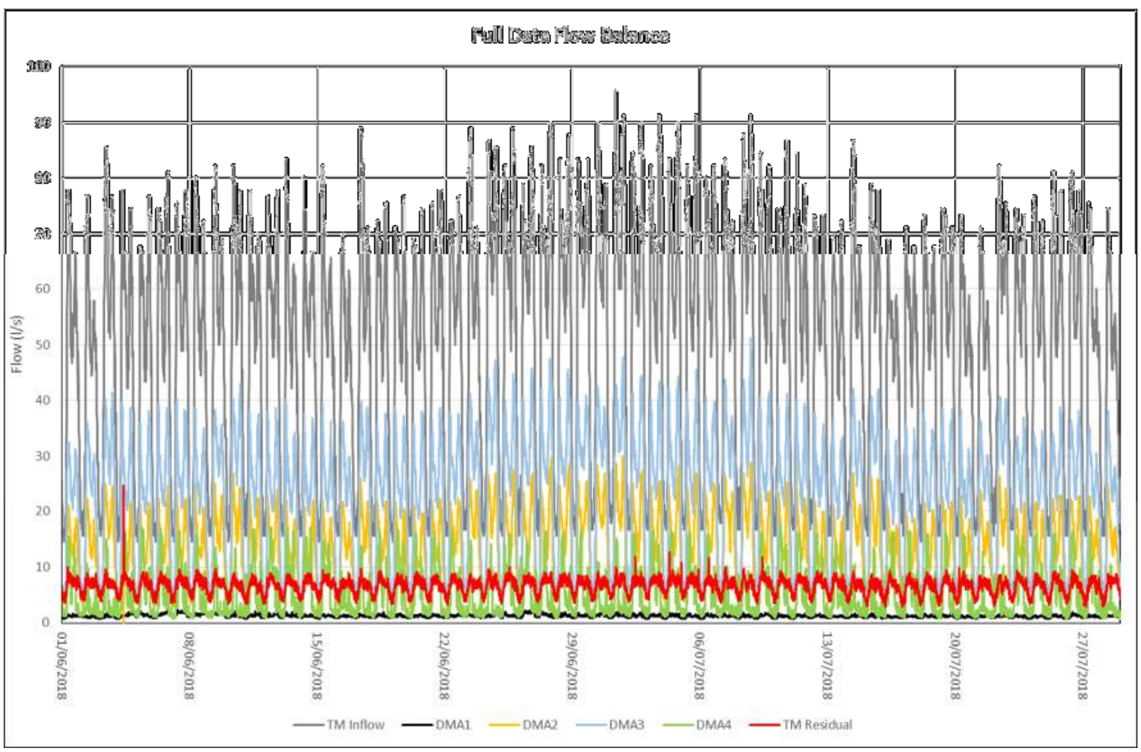
Full system - data flow balance

The ***Flow Balance*** calculations described earlier in this section make use of daily summary data to estimate consumption and losses. An alternative approach is to make use of the full data set, which will typically have flow data at 15 minute intervals. Performing a balance using the full data set will allow examination of patterns at smaller time intervals across the network with the potential to identify recording errors, under/over recording meters, breaches in boundaries and changes to the residual trunk main flow.

Plate 3.23 shows the flow data sets from TM1 and all downstream DMA meters in the example network along with the calculated residual. It can be seen there is daily variation in each of the recorded flows, particularly in the peak flow, however the balance **residual**, shown in red, (which represents the residual demand and losses on the trunk main network plus the impact of any metering errors), remains consistent.

Monitoring of changes in the residual can help identify changes in the trunk main such as increases in losses, errors in the metering, breaches in the area boundary and other operational changes. In this case the **residual pattern** shows a typical domestic demand pattern. This may be legitimate demand supplied directly off the trunk main but may also have a component of unrecorded or illegal consumption. Quantifying the authorised demand and its allocation to the trunk main balance would be recommended.

Plate 3.23 Example of full system balance with residual balance flow



Combined Analysis

All three approaches described above can provide insight in to water usage patterns and the location and magnitude of water loss in the network. The ultimate goal would be to develop an integrated suite of network management tools, most likely based on the GIS as the primary data source, which will allow assessment of flow data, asset performance data (bursts, repairs, customer contacts) and other available asset records. The outputs will inform the network operators and allow quick and accurate diagnosis and response to active incidents and targeting of strategic investments and network improvement activities to deliver longer-term customer benefits through reduced operating costs and greater reliability of supply.

Step 6 - Progress

Assessment of the current coverage of metering and data logging has shown it to be insufficient to allow the assessments detailed above to be carried out. Additionally, operational schematics showing the supply arrangements, points of system separation, and meter locations, are not available. It is our understanding that continuous logging of flow data is only in place at the insertion probe meter at the inlet to DMA SG-1.

Step 6 - Action plan

The management of NRW to achieve reductions and improvement in performance will require an approach comprised of:

- Continuous improvement in data quality (Key steps 1-5);
- Establish the 4 levels of network monitoring / zonal hierarchy
- Increase in DMA coverage with meter and data logger installation;
- Development of 'trunk main' and DMA flow balance data;
- Optimisation of network configuration and operation e.g. pressure reduction and calming; and
- Targeted capital investment to replace failing assets

In addition to the use of flow balances to monitor performance and target activities to reduce NRW, the following operational activities should be considered:

- Monitor pressure at points throughout the network, with some permanent installations. This will;
  - Improve estimates of UARL
  - Identify potential areas for pressure management; and
  - Identify areas with under-capacity assets
- Test the accuracy of transmission and DMA meters and replacement where necessary. This will;
  - Improve accuracy of data in NRW and MNF calculations
- Undertake a rolling programme of customer meter testing/replacement to ensure correct registering of consumption. This will;
  - Improve accuracy of data in NRW and MNF calculations; and
  - Optimise revenue
- Survey storage assets to identify losses from leaks and overflows. This will;
  - Reduce the storage tank leaks and overflows component on NRW

- Undertake mains renewal where there is a history of asset failure. This will;
  - Reduce the transmission and distribution losses component of NRW; and
  - Improve reliability of supply

Table 3.3 provides a matrix of monitoring and intervention options and how they may benefit NRW reduction and wider network management.

Table 3.3 Example leakage reduction measures

Example Leakage Reduction Measures

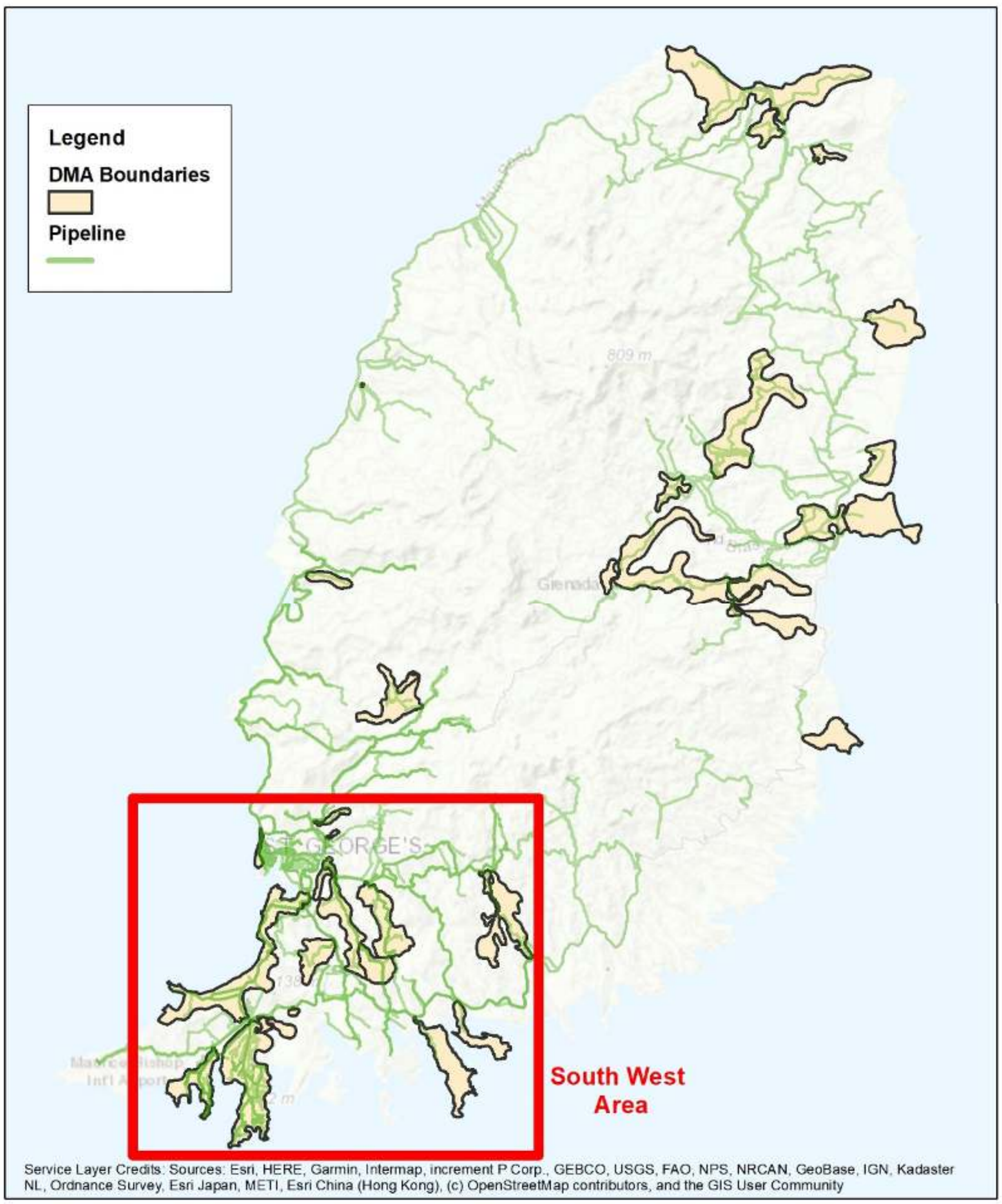
	Reduced Awareness Time	Location	Repair	Reduced Burst Frequency	Reduced Burst Flow Rate	Reduced Background Losses
Pressure Reduction				✓	✓	✓
District Metering	✓	✓				
Active Leakage Control	✓	✓		✓		
Selective Mains Replacement				✓		✓
Free Supply Pipe Repairs			✓			✓
Telemetry	✓					

4. Activity 4.1 deliverables

4.1 Findings from the review of the DMA designs

NAWASA have commenced their DMA design and implementation programme, with 36 notional DMAs defined within GIS, as shown in Plate 4.1. These cover approx. 21% of customers (based on meter locations). Most of the DMAs have permanent meters installed, however none so far has a permanent data logger installed on the inlet meter. Discussions with equipment suppliers are under way with a view to installing equipment for the two pilot DMAs.

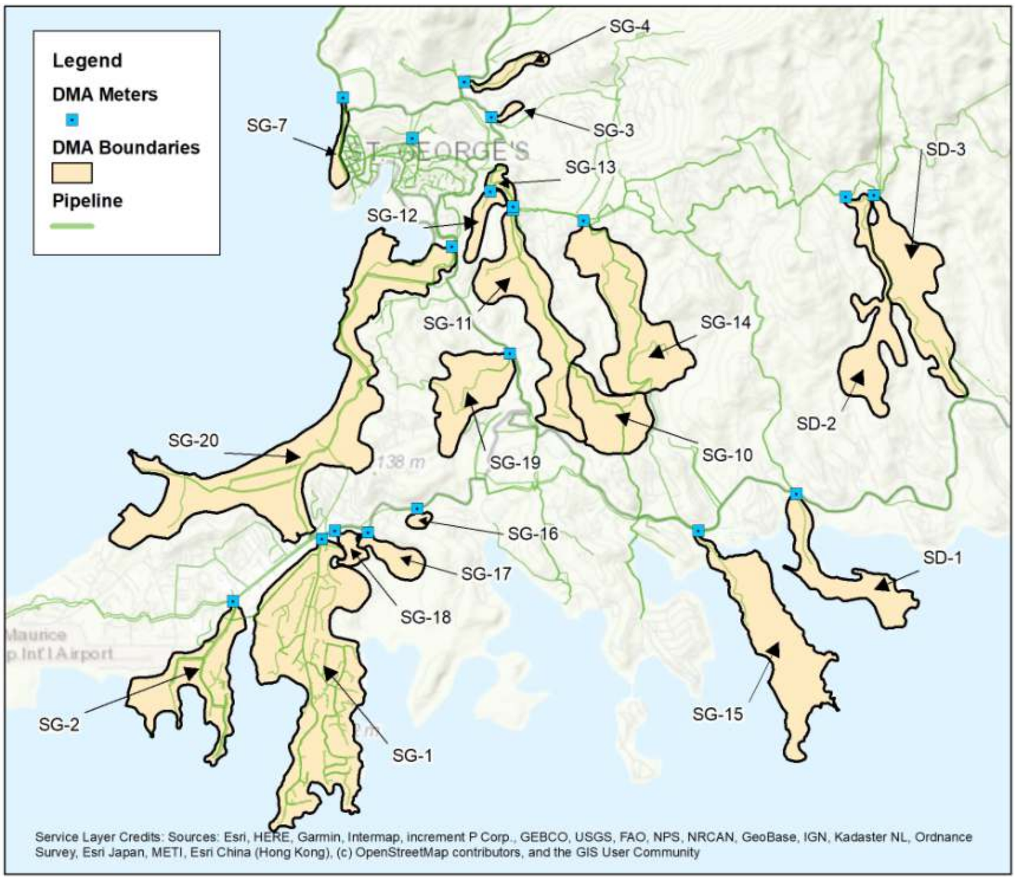
Plate 4.1 NAWASA DMA coverage



Based on assessment of the DMA boundary GIS layer provided by NAWASA and the customer meter GIS data, the customer meter counts within the 36 DMAs vary from 16 to 718 with an average of 214, and with 15 having 100 or fewer. Consideration must be given as to whether it is cost effective to install and maintain meters and data loggers at this density. It is likely the low property counts will result in high instantaneous variation in flow leading to unsteady readings, and the meters may not be able to record good data across the full flow range leading to 'drop outs' in night flows.

Given that the GIS pipeline layer needs to be remapped for most of the network, it is not possible to undertake a detailed review of the DMA configuration. As an example, for the south west area shown in Plate 4.2, the following has been observed:

Plate 4.2 NAWASA DMA coverage (south west area)



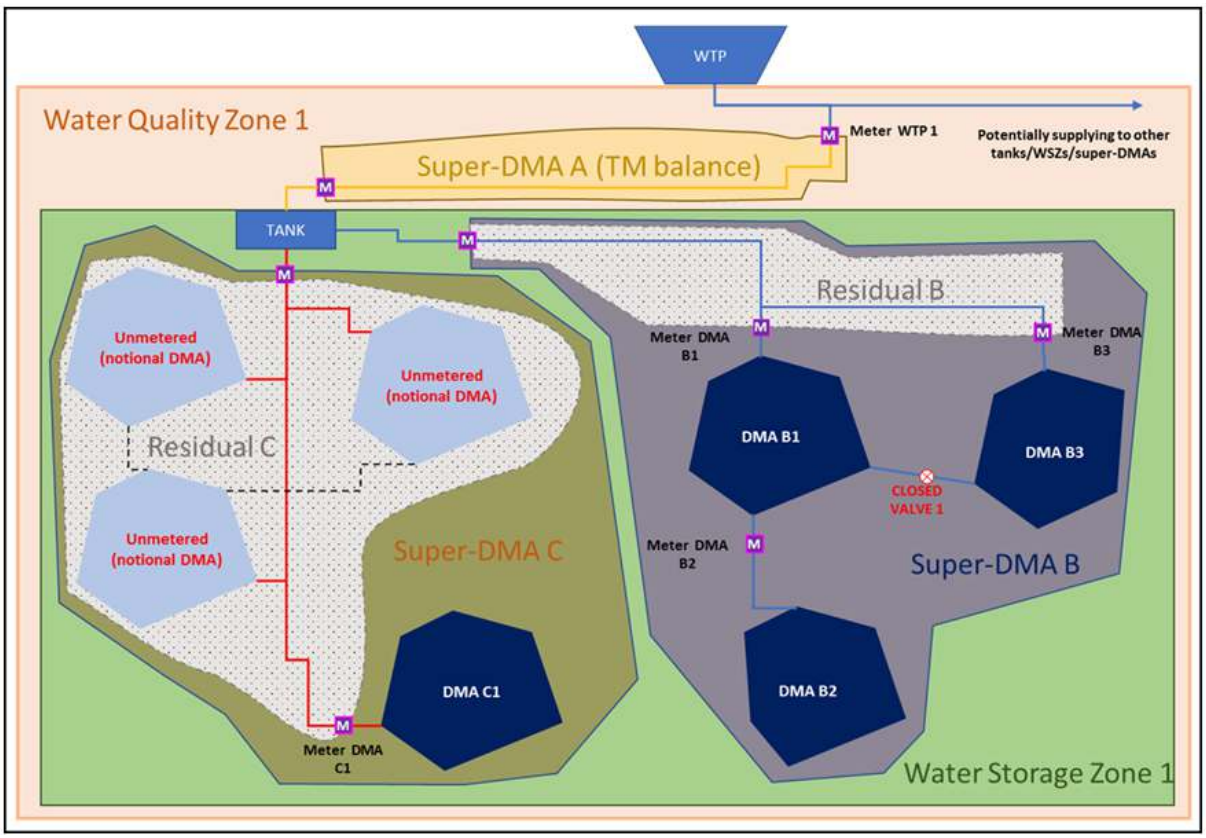
- A number of DMAs cover very small areas and have low property counts e.g. SG-16, 17 and 18. These are likely to have been established as DMAs due to the pipework having no or few connections to the rest of the network and there being an existing meter installation. DMAs of this size do not typically allow cost-effective and reliable NRW and operations management.
- Large sections of the network, in particular the 'trunk' spines and the St George's area, have little coverage.

It is recommended the DMA design strategy for the whole island be adjusted to identify, where possible, areas containing 300 or more properties for permanent monitoring. This will reduce the overall number of DMAs required to cover the NAWASA supply area and the associated CAPEX and OPEX, and provide DMA coverage at the density typical for this size of distribution network. However, it must be noted that DMAs containing lower numbers of customers may be suitable. An example of this is SG2 – True Blue which contains approx. 120 properties. Within SG2 there is a considerable amount of non-domestic properties (approx. a third of all properties) including the University. The combined consumption of the non-domestic properties amounts to approx. 87% of the entire DMA consumption and the flows through the DMA meter are sufficient enough to ensure good data across the full flow range. Other considerations include location and connectivity. For example, a small populated area at the extents of the network without pipework connectivity to other populated areas may be suitable on condition that the metering is appropriate for its size to ensure good data across the full flow range.

4.2 Suggested approach to structured network monitoring

Full DMA coverage is likely to take some time to implement. To allow some level of system monitoring, and to provide data to support the DMA programme, it is recommended a programme be put in place to provide high-level system monitoring to run concurrently with the DMA programme. This would be based on the networks hierarchy detailed in Section 3.1 of this report. Plate 4.3 shows a section of a network with a typical monitoring hierarchy.

Plate 4.3 Example of network monitoring structure



- The areas supplied from a water treatment plant, or Water Quality Zone (WQZ)
- The area supplied from a point of storage (tank), or Water Storage/Supply Zone (WSZ)
- Relatively large areas supplied from distinct sections of the network, or super-DMAs
- Established DMAs within supply zones or super-DMAs

From the example network configuration in plate 4.3, Super-DMA A has no direct demand, though could account for a substantial section of the trunk main network. Monitoring flow at the imports and exports will allow analysis of performance of the pipe assets. This can be extended to a mass balance across the storage tank to identify possible leaks or overflows

Super-DMAs B and C are both supplied from the same WSZ, though each is at a different stage of DMA implementation.

Super-DMA B has established DMAs covering all or the vast majority of the distribution network. Effective leakage management at the DMA level will allow early identification of rising levels of loss and targeting of intervention, such as leak detection sweeps of the affected DMAs. The residual area is likely to have low direct demand. Carrying out a flow balance based on the super-DMA inflow and DMA meters will enable a similar assessment to that outlined for super-DMA A to be undertaken.

Progress towards establishing DMAs in super-DMA C is not as advanced, with much of the distribution network in a single, open, unmetered area. With installation of a meter at the storage tank outlet monitoring can be carried out at the super-DMA level to identify changes, however, due to the larger size of the monitored network, the data will be less sensitive to change and so identifying smaller variations and pinpointing the cause will be more difficult. As the DMA programme progresses the residual area will reduce and the sensitivity of data analysis will improve.

The application of this type of network management hierarchy can allow development of a phased and targeted programme for improvement of flow monitoring, leak detection and NRW reduction. Data gathered through monitoring at the WQZ, WSZ and Super-DMA levels can inform decisions on which areas would benefit most from implementation of a full DMA structure.

4.3 DMA design recommendations

The following approach should be considered:

- Review flow monitoring at the WQZ and WSZ levels and develop a programme of meter installation and flow monitoring to address any gaps.
- Design a set of ‘super-DMAs’ based on areas supplied by water sources to provide high-level system monitoring e.g. the Woburn tank supply system.
  - Establish the boundary conditions, either with closed valves or metered transfers;
  - Test the boundary;
    - The most common approach for DMAs is through pressure zero testing and boundary valve sounding;
    - For super-DMAs this may not be practical. Pressure differential testing across boundaries may be a viable alternative.
  - Make improvements to asset records. This will be required to determine the super-DMA boundary points;
  - Set up balance calculations; These will likely require data from two or more meters; and
  - Set up of NRW audits, the results from which will support the programming of the DMA programme and the re-mapping of the primary pipeline distribution network to provide the level of coverage required to estimate length of distribution and service pipes
- Install additional DMA meters to monitor sections of the network which can be easily established

- Install only where the number of properties supplied will allow cost-effective and reliable NRW and operations management. A property count of around 300+ is recommended, though a smaller count can be considered under the right conditions.

- Based on results from the above activities, commence a targeted programme to complete the set-up of a minimum of six DMAs in 2020, ideally with full coverage for at least one 'super-DMA' or Water Supply Zone.

4.4 Evaluation of Non-Revenue Water across NAWASA

A NRW audit has been undertaken based on data currently available from across the full NAWASA network. System inflow data has been taken from information supplied by the NAWASA metering department in file "**Production Values_ NAWASA_12022020.xls**".

Customer consumption has been determined using customer billing data.

NAWASA Water Audit Results

Water Balance Component Results from the first iteration of the NRW audit, based on the data available at this point, are provided in Plate 4.4.

Plate 4.4 NAWASA Water Audit Results - Water balance components

wood. Water Balance — NAWASA National Water & Sewerage Authority — Home

Reporting Area	NAWASA
Reporting Year	2019

Own Sources (Adjusted for known errors) **2,640.807**	Water Exported **0.000**	Billed Water Exported			
	Water Supplied **2,640.807**	Authorised Consumption **1,953.018**	Billed Authorised Consumption **1,920.008**	Billed Metered Consumption (inc. water exported) **1,828.579**	Revenue Water **1,920.008**
				Billed Unmetered Consumption **91.429**	
			Unbilled Authorised Consumption **33.010**	Unbilled Metered Consumption **0.000**	Non-Revenue Water (NRW) **720.799**
				Unbilled Unmetered Consumption **33.010**	
		Water Losses **687.789**	Apparent Losses **43.920**	Unauthorised Consumption **6.602**	
				Customer Metering Inaccuracies **37.318**	
				Systematic Data Handling Errors **0.000**	
Water Imported **0.000**			Real Losses **643.869**	Leakage on Transmission and/or Distribution Mains **Not broken down**	
				Leakage and Overflows at Utility's Storage Tanks **Not broken down**	
				Leakage on Service Connections **Not broken down**	

Plate 4.5 shows the calculated key performance indicators.

Plate 4.5 NAWASA Water Audit Results – Performance indicators

PERFORMANCE INDICATORS

Financial Indicators

Non-revenue water as percent by volume:	27.3%	
Non-revenue water as percent by cost:	3.1%	
Annual cost of Apparent Losses:	$153,720	
Annual cost of Real Losses:	$64,387	Valued at Variable Production Cost

Operational Efficiency Indicators

Apparent Losses per service connection per day:	2.64	gallons/connection/day
Real Losses per service connection per day*:	38.77	gallons/connection/day
Real Losses per length of main per day*:	N/A	
Real Losses per service connection per day per psi pressure:	0.70	gallons/connection/day/psi
? Unavoidable Annual Real Losses (UARL):	313.35	million gallons/year
? Infrastructure Leakage Index (ILI) [Real Losses/UARL]:	2.05	

* only the most applicable of these two indicators will be calculated

Based on current information available, including approximation of mains length, number of services and operating pressure, the UARL is 313.35 MG/year. Based on the current estimate of NRW performance the ILI is 2.05. Improvements can be made, some significant, in the accuracy of the parameters used in the audit assessment.

NAWASA Water Audit Sensitivity Analysis

Information has been provided below to give some indication of the sensitivity of UARL to changes in the component values:

Water Supplied: The data currently available for water production is based on manual reading of the production site meters. For some meters there are no values or zero values for some months. The proportion of NRW will be greatly influenced by the accuracy of the Water Supplied estimate. The recording of accurate production data will also allow more accurate estimates of total and unit production costs. The accuracy of the meters should be tested on a regular basis and system balances defined where possible to compare system input against recorded flow through sub-meters and recorded demand at DMA meters and directly supplied customers.

Service Connections: The number of service connections is based on the number of customer billing accounts. The accounts database does capture dormant accounts, though there may be a small percentage of connections which are not recorded.

Mains Length: The length of mains in the current audit has been based on the total length in the current GIS and the percentage improvement achieved in mains coverage in the test DMAs. This gives a mains length of 888 miles. The true value may be much higher or much lower which would significantly affect the UARL and ILI values

Service Pipe Length: The length of service pipes to customer meters has been based on an estimated value of 15 feet. The length of service will vary with property type and network arrangements. A doubling of the average service length would increase UARL to 337MG/year with an ILI of 1.91.

System Pressure: The UARL is directly proportional to the pressure, so doubling pressure will double UARL. The value of 55psi is a reasonable assumption within the range of operating pressure in most distribution networks.

Improvement in the accuracy of recording of network flow data and customer usage will greatly benefit the accuracy of calculations and the wider management of the network.

4.5 Evaluation of Non-Revenue Water in the 2 pilot DMAs

Over the course of the project, there has been significant improvement in the quality of asset and customer data for both pilot DMAs. This data, combined with available flow data, has been applied in the NRW evaluation for the 2 DMAs. The results for each DMA are presented below.

SG1 - L'Anse Aux Epines Water Audit Results

DMA inflow data has been taken from information supplied by the NAWASA metering department in file "**DMA Monthly Readings NAWASA_Meter Dept.xls**". Assessment of the meter reading data indicated an error of some form is present from June 2020 onwards. As a result of this, data from 2018 has been substituted in to the balance for June to December. The monthly total consumption figures, along with the average monthly consumption (based on annual metered totals), is shown in Plate 4.6.

Plate 4.6 SG1 - L'Anse Aux Epines DMA Inflow Data

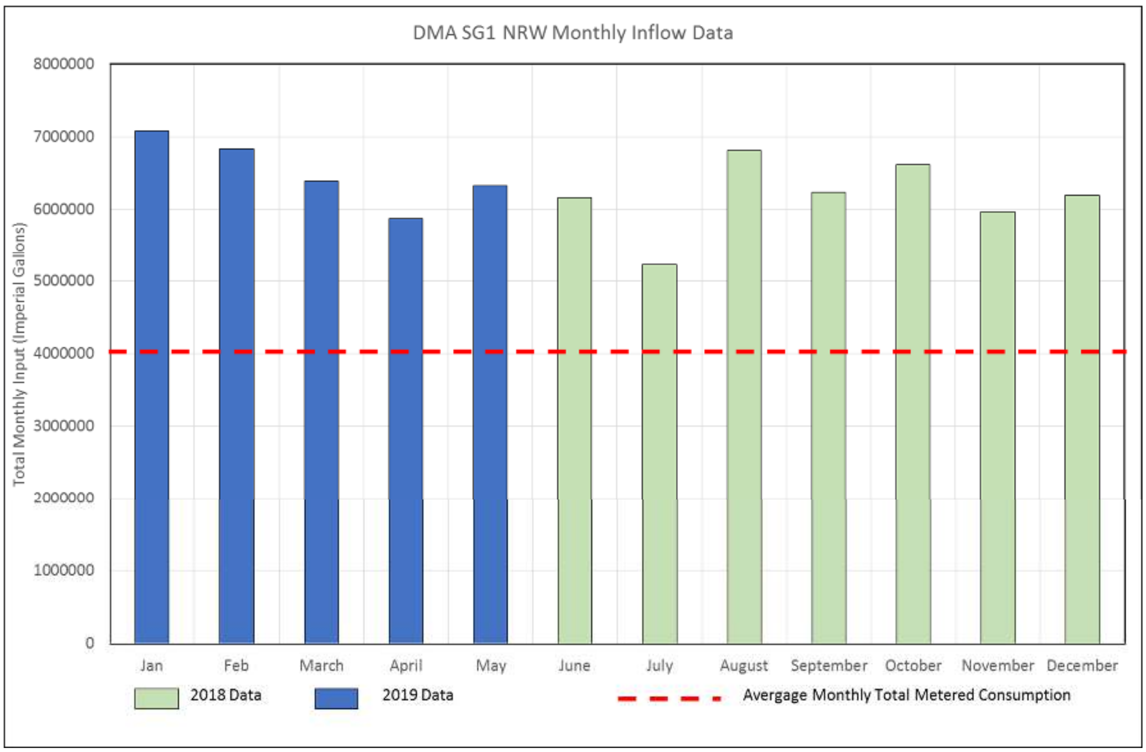


Plate 4.7 shows the audit component table.

Plate 4.7 SG1 - L'Anse Aux Epines NRW Component Table

wood.	Water Balance	National Water & Sewerage Authority	Home	Reporting Area	NAWASA - SG1
				Reporting Year	2019
Own Sources (Adjusted for known errors) 75.727	Water Exported 0.000	Billed Water Exported			
	Water Supplied 75.727	Authorised Consumption 48.644	Billed Authorised Consumption 47.698	Billed Metered Consumption (inc. water exported) 47.698	Revenue Water 47.698
				Billed Unmetered Consumption 0.000	
			Unbilled Authorised Consumption 0.947	Unbilled Metered Consumption 0.000	Non-Revenue Water (NRW) 28.029
				Unbilled Unmetered Consumption 0.947	
		Water Losses 27.082	Apparent Losses 1.163	Unauthorised Consumption 0.189	
				Customer Metering Inaccuracies 0.973	
				Systematic Data Handling Errors 0.000	
Water Imported 0.000			Real Losses 25.920	Leakage on Transmission and/or Distribution Mains Not broken down	
				Leakage and Overflows at Utility's Storage Tanks Not broken down	
				Leakage on Service Connections Not broken down	

Plate 4.8 shows the key performance indicators.

Plate 4.8 SG1 - L'Anse Aux Epines Water Audit Results - Performance indicators

PERFORMANCE INDICATORS

Financial Indicators			
	Non-revenue water as percent by volume:	37.0%	
	Non-revenue water as percent by cost:		
	Annual cost of Apparent Losses:	$0	
	Annual cost of Real Losses:	$0	Valued at Variable Production Cost
Operational Efficiency Indicators			
	Apparent Losses per service connection per day:	6.04	gallons/connection/day
	Real Losses per service connection per day*:	N/A	gallons/connection/day
	Real Losses per length of main per day*:	2,079.22	gallons/mile/day

Continuous flow data from the insertion probe meter has been used to perform a MNF assessment for this DMA. Data from 29 October 2019 has been used. The recorded flow around this date had a typical usage pattern and stable night flow. Plate 4.9 shows the results from the MNF calculation.

Plate 4.9 NAWASA Water Audit Results – MNF Calculations Summary Data

Colour Coding:
Data Entry in Red
Calculated values in Blue
Default Values in Green

Home

NAWASA	wood.	NETWORK AND CUSTOMERS						FLOW AND PRESSURE DATA					DAILY TOTALS					
		Mains length	No. of domestic and empty properties	Number of unmeasured non-households	Number of measured non-households	Population	No. of supply pipes	Average inflows 3.00am to 4.00am	Average Zonal Night Pressure (AZNP)	Total daily inflow	Total measured non-household demand	Sum of measured night users 3.00am to 4.00am	Inflow	Losses	Unmeasured Use	Measured Use	% Losses when system operational	Per Capita Household Use
DMA NAME:	DATE OF TEST	km	No.	No.	No.	No.	No.	m3/hr	m	m3/day	m3/day	m3/hr	m3/day	m3/day	m3/day	m3/day	%	l/head/d
SG1 - L'Anse Aux Epines	29/10/2019	54.96	511	92	14	1226	617	10.5	30.0	416.3	61.5	1.37	416	176.19	179	62	42.3	95

The NRW of 37% (from the water audit) falls in the expected range for a network with assets in reasonably good condition where there is no active leakage management. The network is too small to allow calculation of UARL and ILI.

The MNF assessment for 29 October estimates losses at 42.3%, which is in line (+/- 20%) with the annual NRW estimate.

Background information relevant to the MNF calculation can be found in section 3.6 under the heading "Minimum night flow (MNF) method".

SG2 – True Blue Water Audit Results

DMA inflow data has been taken from information supplied by the NAWASA metering department in file "**DMA Monthly Readings NAWASA_Meter Dept.xls**". The monthly total consumption figures, along with the average monthly consumption (based on annual metered totals), is shown in Plate 4.10.

The University is supplied from within this DMA and this customer alone had a consumption of 32.6 IMP MG in 2019. Based on the estimated property count and total metered consumption, the average per property daily consumption is broadly in line with what may be expected.

Plate 4.10 SG2 True Blue DMA Inflow Data

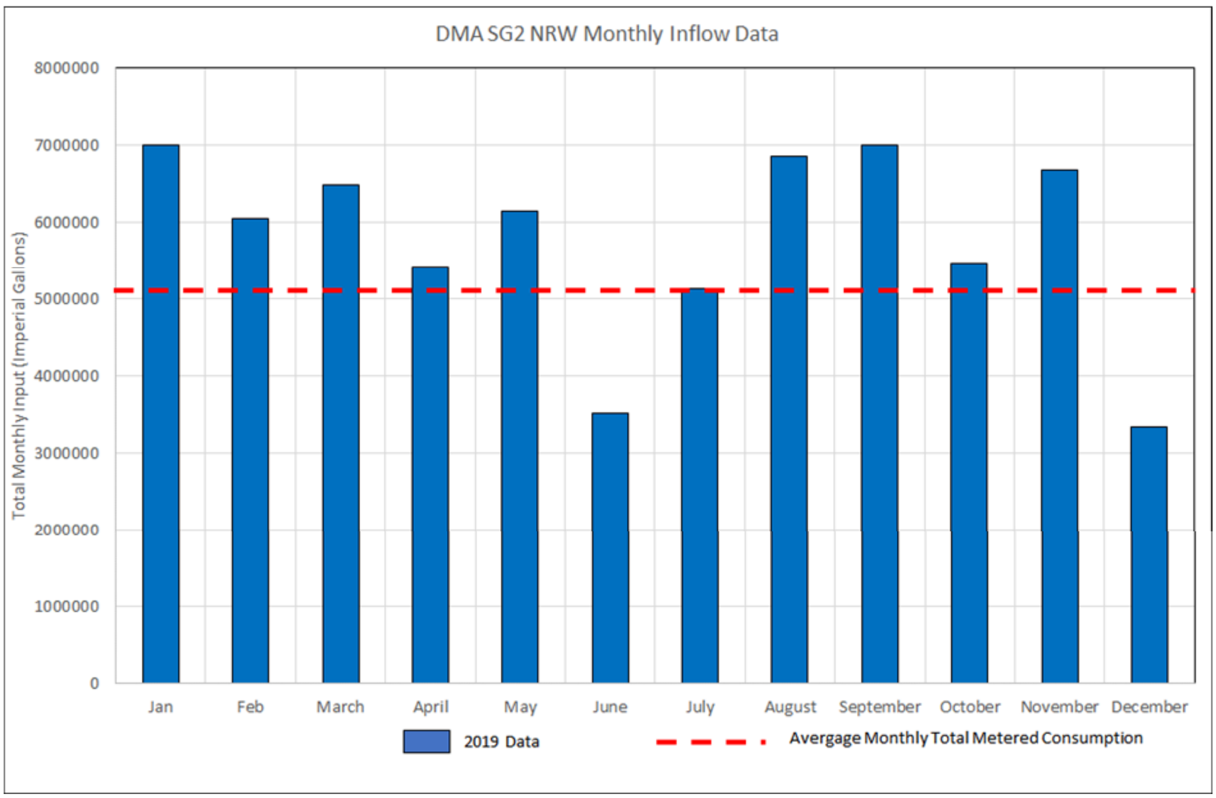


Plate 4.11 shows the audit component table.

Plate 4.11 SG2 – True Blue NRW Component Table

Water Balance			
National Water & Sewerage Authority	Home	Reporting Area	NAWASA - SG2
		Reporting Year	2019

<table>
<tr><td rowspan="8">Own Sources (Adjusted for known errors)
69.097</td><td>Water Exported
0.000</td><td colspan="4">Billed Water Exported</td></tr>
<tr><td rowspan="10">Water Supplied
69.097</td><td rowspan="4">Authorised Consumption
62.480</td><td rowspan="2">Billed Authorised Consumption
61.617</td><td>Billed Metered Consumption (inc. water exported)
61.617</td><td rowspan="2">Revenue Water
61.617</td></tr>
<tr><td>Billed Unmetered Consumption
0.000</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption
0.864</td><td>Unbilled Metered Consumption
0.000</td><td rowspan="8">Non-Revenue Water (NRW)
7.480</td></tr>
<tr><td>Unbilled Unmetered Consumption
0.864</td></tr>
<tr><td rowspan="6">Water Losses
6.617</td><td rowspan="3">Apparent Losses
1.430</td><td>Unauthorised Consumption
0.173</td></tr>
<tr><td>Customer Metering Inaccuracies
1.257</td></tr>
<tr><td>Systematic Data Handling Errors
0.000</td></tr>
<tr><td rowspan="3">Water Imported
0.000</td><td rowspan="3">Real Losses
5.186</td><td>Leakage on Transmission and/or Distribution Mains
Not broken down</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks
Not broken down</td></tr>
<tr><td>Leakage on Service Connections
Not broken down</td></tr>
</table>

Plate 4.12 shows the key performance indicators.

Plate 4.12 SG2 – True Blue Water Audit Results - Performance indicators

PERFORMANCE INDICATORS

Financial Indicators		
Non-revenue water as percent by volume:	10.8%	
Non-revenue water as percent by cost:		
Annual cost of Apparent Losses:	$0	
Annual cost of Real Losses:	$0	Valued at Variable Production Cost
Operational Efficiency Indicators		
Apparent Losses per service connection per day:	32.65	gallons/connection/day
Real Losses per service connection per day*:	N/A	gallons/connection/day
Real Losses per length of main per day*:	1,813.72	gallons/mile/day

The NRW of 10.8% (from the water audit) falls in the expected range for a small network where the majority of demand is non-domestic and the network assets are in reasonably good condition. The network is too small to allow calculation of UARL and ILI.

4.6 Support for the development of the NAWASA NRW reduction action plan

A significant amount of progress has been made over the course of this project and NAWASA now have the foundation and building blocks required to enable the company to improve the future management of water resources across the island.

GIS systems and data capture workflows have been developed and NAWASA staff have been provided GIS training.

For managing the water network, processes have been established around data capture to facilitate an annual NAWASA water audit and a bespoke NAWASA water audit workbook based on the AWWA standard has been designed to enable future water audits to be undertaken.

In addition, a bespoke NAWASA Busts and Background Estimate (BABE) Minimum Night Flow model workbook has been developed. This can be used as and when data becomes available during the roll out of NAWASAs DMA establishment programme. This will enable NAWASA to track and trend NRW/leakage at a DMA level and feed into any subsequent leakage reduction initiatives.

During the course of the project, numerous technical notes have been provided to NAWASA which contain best practice and guidance for a wide range of water network management practices. Much of the graphical input in this document has been abstracted from the technical notes and the technical notes will prove to be a good source of best practice reference going forward for the NAWASA staff.

Within this report, progress against each key step and deliverable has been documented with observations and guidance provided which is focussed on improving data and systems moving forward.

Table 4.1 contains a breakdown of the specific recommendations of this report, tabulated against the associated key step.

There are 3 higher level recommendations proposed by this study. These are;

A: Adjust the **DMA design strategy** to create DMA coverage at a density where CAPEX costs in setting up the network and OPEX costs in managing and maintaining equipment are affordable whilst ensuring that there is sufficient DMA consumption to ensure that the flows through the DMA meter are accurate across the full flow range.

Enablers: Step 1 Know Your Network & Step 2 Know Your Customers & Step 3 Know Your Customers Data

B: Select a water storage asset which supplies a large number of customers and establish a full hierarchy of monitoring to include super-DMA(s) and / or a Water Supply Zone with metered DMAs.

Enablers: Step 1 Know Your Network, Step 2 Know Your Customers & Step 3 Know Your Customers Data

C: Roll out monitoring across all 4 levels of network monitoring / zonal hierarchy and implement water management processes across the entire NAWASA region

Enablers: Successful completion of primary recommendations A and B. Lessons learned during recommendation B can be applied to the full system roll out.

Please note that **A** is a strategic recommendation, while recommendations **B** and **C** require direct intervention through specific action . To provide an indication of the priority to undertake the key stage specific recommendations in relation to achieving the higher level recommendations (**B** and **C**), the last 2 columns in table 4.1 contain references to the specific actions required.

Tables 4.2 and 4.3 tabulate specific recommendations to better quantify and manage NRW over the short to long term.

Table 4.1 Specific recommendations of this report, tabulated against the associated key step.

Key Steps	Recommended Actions	For 'B'	For 'C'
Step 1: Know Your Network	1.1 Develop an asset data capture template and agreed implementation procedure* 1.2 Collate information for valves, hydrants and other fittings currently not included in GIS* 1.3 Capture asset characteristics, such as pipe material and diameter* 1.4a Commence a programme to re-map the primary pipeline distribution network. Short-term aim of covering one water storage tank supply area** 1.4b Commence a programme to re-map the primary pipeline distribution network to obtain total NAWASA coverage** 1.5 Roll out installation of flow logging equipment on district meters to facilitate NRW assessments and support day to day operations 1.6 Develop a set of 'Source to Supply' network schematics across the 4 levels of network monitoring / zonal hierarchy 1.7 Undertake accuracy checks on all source meters. Consider replacing older meter units 1.8 Develop flow balances across the 4 levels of network monitoring / zonal hierarchy 1.9 Consider installing additional sub-meters on the trunk network to check source meter accuracy and to facilitate trunk main balances 1.10 Monitor pressure throughout the network 1.11 Survey storage assets to identify losses from leaks and overflows 1.12 Produce written instructions covering configuration, operating constraints, and contingency options for the networks	1.2 1.4a 1.6 1.8 1.10	ALL
Step 2: Know Your Customers	2.1 Identify and map in GIS property locations. Link the properties with customer accounts to records of customer characteristics and water usage. 2.2 Continue the current live testing of digital data collection forms created by GISCAD in the work of the metering and T&D teams.*** 2.3 Use digital data collection to capture the location of new / updated meter location and over time build up an enhanced digital record of meter/customer locations 2.4 Promote regular engagement and feedback from crews using the forms regarding potential issues and time saving improvements. This will help quantify the benefits of the investment required to update the information. 2.5 Implement a customer meter testing programme 2.6 Use the smart meter trials to gain data on meter accuracy across the metering assets, not just older meters or ones considered to be inaccurate.	2.1 2.2 2.3 2.4	ALL
Step 3: Know Your Customers Data	3.1 Investigate high consumption customers classified as domestic users and reclassify where required 3.2 Consider installation of permanent flow data loggers for very large users 3.3 Validate the accuracy of meter reading and processing e.g. meter error, data entry, processing errors 3.4 Investigate variation in customer consumption demand patterns e.g. seasonal, weekday/weekend, and educational term times*** 3.5 For customers, it would be beneficial to include a categorisation based on likely night-time usage	3.1 3.2	ALL
Step 4: Record Leaks and Repairs	4.1 Continue currently live testing of digital data collection in the work of the metering and T&D maintenance teams*** 4.2 Use digital data collection to capture the location of bursts and repairs 4.3 Implement the asset data recording procedure and transfer all information to GIS 4.4 Promote regular engagement and feedback from crews using the forms regarding the potential issues and time savings		ALL

* Take advantage of data capture opportunities when pipework is exposed for any reason e.g. to facilitate a pipe repair.

** For 1.4 there are existing PDF plots from 1988 showing the pipeline distribution network. Updating existing GIS layers with this would be a good starting point and provide a better understanding of network connectivity and mains length.

*** This will need to be supported by staged investment in data collection tablets.

Step 5: Quantify NRW

NRW Calculation Element	Notes (From Pilot Study)	Actions from Key Steps 1-4
A1: Volume from own sources	Gaps in monthly totals for a number of sites. Unclear whether this is genuine no flow, meter outage or missed readings.	1.5, 1.6, 1.7 & 1.9
A2: Source meter error adjustment	Accuracy of source meters not quantified.	1.7, 1.8 & 1.9
B1: Billed metered:	Customer billing records available and the majority have a GIS record.	2.1 - 2.6
B2: Billed unmetered:	Thought to be a low proportion but not quantified.	2.1 - 2.6
B3: Unbilled metered:	Thought to be a low proportion but not quantified.	2.1 - 2.6
B4: Unbilled unmetered:	Thought to be a low proportion but not quantified.	2.1 - 2.6
C1: Unauthorised consumption:	Thought to be a low proportion but not quantified.	2.1 - 2.6
C2: Customer metering inaccuracies:	No current programme for meter accuracy checks. Smart meter trials planned.	2.1 - 2.6
C3: Systematic data handling errors:	No current programme to assess this. A number of customers have consumption corrections applied to their accounts	2.1 - 2.6
D1: Length of distribution mains:	Very limited pipework data in GIS; Paper/PDF data available for NAWASA area; Improvements made for pilot DMAs	1.4
D3: Average length of customer service line:	For pilot DMAs this is based on distance from estimated pipe lines to customer meters. Average length used in calculations.	1.4 & 2.1
D4: Average operating pressure:	No data currently available. Pressure values are estimated in the audit.	1.10

Table 4.2 A summary of how the recommended actions apply to NRW quantification

Notes:

- The company wide water audit should be reviewed and repeated annually.
- Water audits / balances should be undertaken periodically on a network monitoring zone basis as and when the zones are established.

Step 6: Management of NRW

NRW Management Element	Actions from Key Steps 1-4
Continuous improvement in data quality (Steps 1-5);	All Key Steps 1 - 5
Increase in DMA coverage with meter and data logger installation; Consider using a live telemetry system reporting to a central location	Key Step 1
Develop flow balances across the 4 levels of network monitoring / zonal hierarchy	1.1 - 1.10
Fully populate and maintain a MNF (BABE-type) model to help target active leakage control activities and pressure management requirements	Key Steps 1 - 4
Monitor pressure at points throughout the network, with some permanent installations. This will; Improve estimates of UARL; Identify potential areas for pressure management; and Identify areas with under-capacity assets	1.10
Optimisation of network configuration and operation e.g. pressure reduction and calming	Key Step 1
Test the accuracy of transmission and DMA meters and replacement where necessary.	1.7
Improve accuracy of data in NRW and MNF calculations	Key Steps 1 - 4
Undertake a rolling programme of customer meter testing/replacement to ensure correct registering of consumption. To improve accuracy of data in NRW and MNF calculations; and Optimise revenue	3.3
Reduce the storage tank leaks and overflows component on NRW	1.11
Undertake mains renewal where there is a history of asset failure. This will; Reduce the transmission and distribution losses component of NRW; and Improve reliability of supply	Key Step 4
Undertake Active Leakage Control (Find and Fix)	Enabled by above activities

Table 4.2 A summary of how the recommended actions apply to future NRW management

Note:

- As network monitoring zones are established, NRW can be better quantified across specific sections of the network. This will help form a prioritised programme of required NRW management activities.

4.7 Associated materials issued with this document

Previous technical notes – compiled for final issue

Technical Notes Issued	Originally Issued
Technical Note: GIS errors April 2019	30/04/2019
Technical Note: Output 4 Information Review June 2019	14/06/2019
Technical Note: Annandale Schematic August 2019	23/08/2019
Technical Note: Case Study for DMA Leakage Management September 2019	17/09/2019
Technical Note: The Use of Monitored Flow Data to support NRW Assessment September 2019	17/09/2019
Technical Note: The 6 key stages to Effective NRW Management Wood September 2019	18/09/2019
Technical Note: Step 1 Know Your Network Example GIS Update October 2019	21/10/2019
Technical Note: Step 1 Know Your Network – Update GIS Guidance October 2019	21/10/2019
Technical Note: Key stages 5 and 6 Progress January 2020	15/01/2020
Technical Support: AWWA White Papers Issued	27/01/2020
Technical Note: NAWASA Consumption Data for Key Steps 5&6	10/02/2020
Technical Note: Water Network Monitoring – Zonal Hierarchy	15/05/2020

Water Audit & BABE MNF Leakage Assessments

Description	Type
NAWASA Water Audit Version 1.04 20 March 2020	Water Audit
NAWASA Water Audit Version SG1 Version 1.01	Water Audit
NAWASA Water Audit Version SG2 Version 1.01	Water Audit
NAWASA MNF Leakage Model Workbook Version 1.1	BABE MNF Model

wood.

Issued by

David Price

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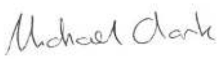

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