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 2: Review of GIS systems and recommendations for future development

Deliverable 2B: Report presenting the evaluation of potential GIS software – including assessment of database, mobile and web software options

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1. Introduction

The following report updated and issued on the 26th July 2019 was developed by the Wood/GISCAD team as a core deliverable of UNIDO/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 this report relates to the following objectives of Output 2 of the project:

- Review of the existing GIS and data systems used by NAWASA;
- Review of GIS, database systems and data models used by UK water companies and Caribbean water agencies – with a specific focus on the assessment of non-revenue water (NRW);
- Defining the functional requirements for NAWASA's future GIS system;
- Review of database, desktop GIS, mobile data capture and web mapping software options; and
- Defining the functional specification for a future NAWASA GIS data management system.

2. Review of existing GIS and data systems used by NAWASA

A detailed review of the current GIS systems and datasets used by NAWASA was undertaken at the start of the study. This review was largely informed by the series of face-to-face meetings held at the NAWASA head office in St George's, Grenada in early May 2019.

The remainder of this section covers the outcome of this review and extends to the following topics:

- Current GIS software capabilities; and
- Existing GIS and related data systems

2.1 Current GIS software capabilities

The core GIS software currently used by NAWASA is QGIS 2.18 (2016 version) software. This software is a free open source GIS product and is currently used by three members of NAWASA staff (Damani Bruno, Annel Roberts and Stephen Benjamin) to undertake various data management, analysis and mapping tasks. The skills of this small group of users has been developed largely through self-learning, while using the software for day-to-day project activities.

The initial review meetings also flagged that NAWASA had previously used the older ESRI 9.3 ArcGIS software, but its use was not continued due to cost of the software. The review also highlighted that the department had also previously assessed a trial version of SuperGIS product, but wider use of the software had not progressed due to software costs.

At present, a majority of the GIS processing tasks are undertaken on a single standalone Dell GIS workstation (Windows 7, 16 Mb Ram, Processor i5 2.4GHz), with further tasks undertaken on a small number of standalone laptops. No formal processes currently exist for automated backup of data, with ad-hoc backup of data currently undertaken using flash drives.

Discussions with representatives of Mod 1, NAWASA's IT support provider highlighted ongoing work to develop a solution, which in the future will backup all virtual machines in the NAWASA server cluster, including any new machines added for mission critical purposes. The solution will ensure that backups will take place several times a day and will be stored on a separate appliance on-island but in a different physical location from the primary server cluster. There will also be backups taking place to the cloud for off-site resilience. The creation of this corporate solution which will also covering the new GIS system will be an important step forward in the creation of a resilient GIS system and capability for NAWASA.

2.2 Current NAWASA data systems

The meetings held in early May 2019 also highlighted the following characteristics of the current spatial data systems used by NAWASA.

- Data management - NAWASA's current GIS data is currently managed on individual standalone PCs/laptops as a series of individual ESRI shapefile (vector layers) or grid-based images files (.jpg or .tif). The May meetings also identified that there is no current centralised database used for management for this data.
- Data Register - There is no current data register which records standard metadata details for the core data held by NAWASA. A structure for this register and initial population will also be undertaken under the scope of Output 2;

- NAWASA GIS pipeline data – it is estimated that about 60% of pipeline location are recorded in a digital GIS form, with data recently created for the Greater St George and south west part of the island being the most accurate and up-to-date. Older pipeline data/information was identified during the review but there are no metadata records which define the source, accuracy and quality of the data included.
- NAWASA GIS District Metered Area (DMA) meters – This information is currently held in an ESRI shapefile defining 34 DMA locations across the island. Most of these locations are defined a unique DMA reference ID but several points are currently unassigned and to be aligned with the DMA boundary dataset – see below.
- NAWASA GIS DMA boundaries - This information is currently held in an ESRI shapefile defining 37 DMA boundaries across the island. Most of these locations are defined a unique DMA reference ID but several boundaries are currently unassigned.
- NAWASA GIS Customer meter locations – NAWASA estimate that around 70% of customer meters are mapped in GIS format but more needs to be done to improve quality of the data available. This information is currently held in a series of 199 individual shapefiles, with each file defining a single route area used to undertake manual monthly meter readings.
- NAWASA GIS other data – NAWASA also holds additional GIS data covering area served, meter route areas; sewer system, tanks and boreholes and infrastructure details – including water valves etc. No metadata records exist for these datasets.
- Customer / meter / finance system – NAWASA currently uses a Canadian Software product called Northstar for the management of its customer accounts and meter reading data. This information is stored using a structured SQL Server back-end database. This includes two key SQL tables of interest: "pu_water_meter" (key metering details) and "pu_water_hist" (historical metering values but around 4 million records).
- Other GIS data sources – Meetings held with representatives of the Ministry of Agriculture, Forestry and Fisheries also highlighted the potential access to additional GIS data sources which could be used to support the future operational activities. These datasets included 2018 digital aerial imagery and Lidar (detailed elevation) survey data; and older land use (2009), soils and geology layers.

3. Review of GIS, database systems and data models used by UK water companies and Caribbean water agencies

The following section provides a summary of the process and GIS/database systems used by the UK water industry and neighbouring Caribbean islands (Barbados, St Lucia and Trinidad & Tobago) to help manage and monitor water resources and ultimately contribute to reducing levels of non-revenue water. This review was undertaken to help inform the development of the data model (see project report 2C) and to provide context for the Output 3 mission visit to the Water and Sewerage Authority (WASA) of Trinidad and Tobago.

3.1 UK water industry

Since the 1980's, the UK water industry has been very proactive in the development of global best practice relating to NRW management. Fundamental to effective NRW management is an accurate GIS system as the GIS underpins the entire process through the provision of knowledge of network assets, network operation, network performance and customers.

All best practice for effective NRW management can be broken down into 6 key stages. These are followed by water utilities throughout the world.;

1. Know your network:

Managing NRW effectively is not possible without a good knowledge of the water network. Water utilities need to have a comprehensive record of all water infrastructure elements in a GIS environment (pipes, meters, valves, hydrants, tanks, pumps etc.).

DMA's can then be created and an understanding of how the water is conveyed from water treatment plants to DMA's can be gained which facilitates the production of water balances across key sections of the transmission network.

It is important that connectivity is digitised as accurately as possible as this facilitates more effective NRW reduction activities through the use of GIS analysis - for example, to reduce the loss of supplies to customers while repairing leaks by understanding which valves to operate to repair the leak whilst maintaining supplies to as many customers as possible.

2. Know your customers:

In addition to having customer accounts recorded in a billing database, their locations need to be known. All customers need to be mapped in GIS and linked to the customer register in the billing database. There should be a differentiator between metered, unmetered, disconnected and unregistered customers accounts. Ideally, each customer should have a link to either the supplying customer meter or the supplying distribution main. Service connection lengths and associated leakage estimates can then be calculated.

3. Know your customers data:

This primarily concerns water consumption and willingness to pay for consumed water. Understanding customer consumption will enable consumption patterns to be analysed and any unusual patterns can be acted on.

4. Record leaks

Leaks need to be recorded as a layer on the GIS. These records should have a linkage back to the water utilities works management system. Understanding the historic performance of a network through visual representation of leaks in GIS can greatly assist with water loss reduction initiatives. This information can also form the basis of justification for mains replacement programmes of work.

5. Quantifying NRW

Information in GIS from stages 1-4 is used within the NRW water balance model. This can either be a standalone application or combined with a GIS application. NRW can be quantified at a company level, water treatment plan supply area level and DMA level. Trends can be established to assess the impacts of non-revenue water reduction initiatives.

6. Management of NRW

To target water reduction initiatives, a robust 'bottom up' balance is needed. DMA flows should be continually monitored to enable minimum night flow (MNF) assessments of losses. Pressures should be

monitored throughout the DMA network to assist with pressure dependency leakage assessments and to identify potential for pressure reduction. Active leakage reduction activities should be focussed on DMA's with a high night flow. Transmission main meters should be tested for accuracy and replaced if necessary. Mains renewal should be considered for mains with a high failure history.

Specifically, within the UK, water authorities have, since the late 1980's, developed very accurate GIS records of all water network assets, DMA's and other supply system boundaries, customers, monitoring points and network performance records such as burst pipes, customer contacts and water quality sample data. Most UK water utilities utilise ESRI as their GIS platform

Leakage reduction is a regulatory requirement in the UK with challenging targets year after year. There are significant financial penalties involved with failing these targets so water utilities have invested in specialised water network management I.T. systems to address not only non-revenue water reduction but also to allow them to operate their network more effectively and efficiently

One example of a leading application for NRW management in the UK is the commercial Netbase (Crowder Consulting) software product, which is used by several of the largest water utilities in the UK. These water utilities supply in excess of 20million households in the UK. Netbase is also used around the world in places including the WSC in Bahamas, NWC in Jamaica and water authorities in Brazil, China, Malaysia and Saudi Arabia.

Netbase is based upon an integrated enterprise level (Oracle) database, which helps manage a time series data repository of all flow, pressure and level data, updated from monitoring systems on at least a daily basis. The database also contains relational tables and activities tables of network information loaded and regularly updated from corporate systems including GIS systems. It is a multi-user system and fully supports many users on the local network and through remote access. Netbase also provides a variety of additional reporting and analysis tools relevant to the assessment of NRW.

3.2 Caribbean Water and Sewerage Authorities

Barbados (BWA)

In 2011, the Government of Barbados (GOB) received a loan from the Inter-American Development Bank (IDB) to enable the Barbados Water Authority (BWA) to undertake a 5-year project to upgrade the water and sanitation systems across the island. A key stated aim of this project was to reduce the levels of Non-Revenue Water (NRW) from 44-49% to 39%. The project was delivered in three components, namely the:

- Re-organisation and modernisation of the BWA (US$6.4 million);
- Rehabilitation of potable water supply (US$35.6 million); and
- Wastewater treatment action plan and upgrades (US$3.45 million). This aspect is not relevant to the objectives of this study and is not considered further.

The first component focused on a variety of actions to help modernise the work of the BWA. This included the development of a long-term business plan covering a human resources strategy; implementation of organizational/corporate structure changes; an operational strategy; change management/re-branding; benchmark performance standards; 24-hour service provision of maintenance services; implementation of long-term customer service plan; and a review of the role of the BWA as regulator of water abstraction.

The first component also focused on the integration of various IT systems and installation of the Customer Information System (CIS) and subsequent training. The IT development also led to the development and installation of new Supervisory Control and Data Acquisition (SCADA); Geographical Information Systems (GIS); and a Hydraulic Network Model and training.

These developments were used to help support subsequent phase 2 activities to help rehabilitate potable water supply and contribute to Non-Revenue Water (NRW) reduction. This was achieved through new meter installation and replacement projects; establishment of island-wide Water Management District; mains replacement project; upgrade of potable water facilities and equipment upgrades and energy efficient alternatives, including renewable energy.

Contact with BWA in May 2019 also highlighted that the active use of GIS to support planning and operational activities in recent years has been limited. This has recently been addressed by the recent appointment of a new member of staff who will be dedicated to the management and update of the organisation's GIS system.

BWA have also worked over the past 5 years to implement a program of works to install up-to 98,800 household smart water meters across the island[1]. This project was originally conceived to deliver improvements to overall customer service through more accurate water bills, faster response times, improved client record management, increased fairness among consumers, earlier identification of leaks, replacement of broken water meters, improved transparency, and ultimately increased consumer confidence in the Barbados Water Authority (BWA).

The recent contact with BWA has confirmed that although work on the installation program has largely been completed. However, the benefits of this work have yet to be fulfilled, with BWA continuing to undertake a degree of manual meter data collection and the management of the meter data in a database system which is not linked to the GIS.

St Lucia (WASCO)

Over recent years, St Lucia's Water and Sewerage Company Inc. (WASCO) have developed an integrated GIS and database management system and hardware to help assist in the future management of water resources across the island.

The starting point for the development of this system was a detailed analysis of the water and sewerage network and the monitoring solutions already used by WASCO. This led to the design, development and implementation of an integrated geographical information system and database system based upon SQL server 2012 database technology. The final GIS application was developed around a bespoke geoportal, which includes modules which provided tailored functionality for individual WASCO departments (customer service, technical department, etc.). These modules include:

- A Customer service dashboard which enables users to keep track of different types of events and faults on the water and sewerage networks. The module provides a series of functions, including access to the latest image of the water and sewerage networks and integration of water meter readings exported from the customer service information system;
- An Operations Dashboard which enables WASCO operating departments to have access to various editing and analysis tools and enables integration of data on assets with operating and maintenance information so that assets can be located on the map. The system can also be used to check personnel organisation, work orders and general and maintenance work on the infrastructure;
- An Enterprise Asset Management and Maintenance System (EAMMS): the part of the systems provides more focus data relating to:

[1] http://cowatersogema.com/project/barbados-water-authority-smart-meter-business-transformation-project/

- descriptive data on company assets (water pumps, hydrants, meters, system and control valves);
- descriptive data on operating and maintenance objects (work orders, timetables, projects, inspections, budgets, contract work, etc.);
- supply of reports and charts to improve analysis and consultation of operating and maintenance data (work orders by origin, work orders by status, work order priority).

The development of the system was also aligned with a focused program of capacity-building activities (including on-the-job training) to ensure the use, maintenance and development of the new system. The project also included a year of maintenance and consultancy services from the consultancy responsible for the development of the system.

Trinidad & Tobago (WASA)

The Water and Sewerage Authority (WASA) was established by an Act of Parliament in 1965 to manage the water and sewerage sector of Trinidad and Tobago. WASA's mission is to:

- be a leading provider of water and wastewater services;
- deliver customer service along the highest internationally recognized and accepted standards;
- continuously develop best business practices utilizing advanced technology and a well-developed and motivated workforce;
- leverage on industry expertise to offer global water and wastewater services; and
- sustain a commercialized business while remaining sensitive to the environment

The Water and Resources Agency (WRA) is a division within WASA since 1976 and has a responsibility to manage water resources, using the integrated water resources management (IWRM) approach, and to promote development, conservation and protection of water resources.

WRA also works with a range of other organisations to manage water resources across Trinidad & Tobago. These organisations include the Environmental Management Authority (EMA), The Ministry of the Environment and Water Resources (MEWR), the Ministry of Works and Transport Drainage Division, Ministry of Food Production, Land and Marine Resources, Ministry of Public Utilities, Office of Disaster Preparedness and Management (ODPM), and the Meteorological Services of Trinidad and Tobago (MET).

One of its key responsibilities of WASA/WRA is to maintain a national water resources database and information system. This objective was addressed through a 2012 project to implement a software tool called HydroManager, a bespoke Geographic Information System (GIS) and a web-enabled National Water Resources Information Management System (NWRIMS).

The system also comprises a number of different commercial software products, including ArcGIS, Oracle/SQL Server database and specialist software products, including HydroManager, AquaChem and Hydro GeoAnalyst[2]. These products in combination provide additional functionality to analyse and view hydrological data, records, publications and GIS information.

The creation of this system has led to creation of a mature GIS department which now has 5 permanent members of staff. This team is responsible for the management and analysis of multiple datasets within the system, including pipeline, as-builts, utility infrastructure, water resource mapping etc.

[2] https://www.waterloohydrogeologic.com/

At the time of writing this report, it was planned that Wood and GISCAD staff will undertake a more detailed two-day mission visit to WASA to discuss the capabilities, benefits and potential limitations of WASA's GIS system. The outcomes of the review mission will be reported fully in the Output 3 report produced in this study.

4. Defining the functional requirements for NAWASA's future GIS system

The review meetings conducted at NAWASA and wider consideration of GIS and database systems used in the UK and neighboring Caribbean islands helped the identification of a series of functional requirements for an enhanced GIS system and capability for NAWASA. These requirements are summarised below in Table 1 and were used to assess different software solutions in the remainder of this report.

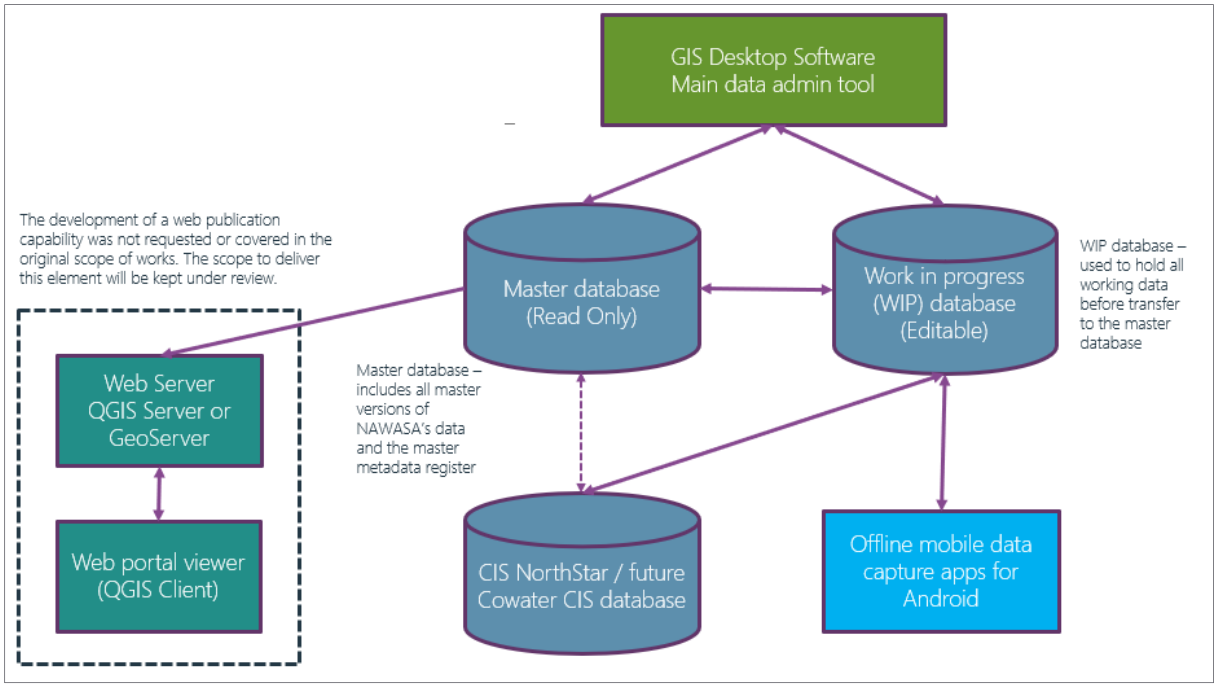
Table 1 High level requirements of a future GIS system for NAWASA

Component	Description	Reason for the future
Core Database	Creation of a centralised master database for management of master versions of spatial data used by NAWASA.	Provide a single master managed data source for NAWASA's infrastructure data. Provide a structured master data source for use by desktop GIS users and/or the future production of web mapping services.
Core Database	Creation of a parallel centralised "work in progress – WIP" database for management of development versions of datasets prior to movement to the master databases.	Provide a single data source for the editing and update of NAWASA's infrastructure datasets prior to movement of the data sources to the master database.
Core Database	Development and population of a centralised GIS data register for the master GIS databases – including detailed metadata information for all core datasets.	Provide a single easy to access list of the master data holdings held in the central database.
Core Database	Automated backup and disaster recovery of the centralised database.	Ensure full resilience of NAWASA's data holdings.
GIS Desktop Software	Future use of a no/low cost GIS software product which will be used to undertake all tasks needed to update data in the WIP or master databases.	Minimise future software costs and thereby increase budget for investment in other GIS related needs.
Mobile	Ability to view, update and/or capture new infrastructure data using mobile devices.	Improve the quality of data held in the system through the removal of manual data capture processes.
Web database, publication and viewing	Basic and secure internet-based viewer to enable review and query of key NAWASA data holdings.	Increase the overall awareness of data held and used in NAWASA. Provide direct access to data for approved users across the authority.
GIS desktop	Development of simple workflows to enable the increased use and analysis of NAWASA's core GIS and CIS data systems.	Improve the efficiency and quality of derived data used across NAWASA.
Training	Detailed training of NAWASA staff in the use of revised GIS system.	Increase the number and level of GIS skills and capability within NAWASA and thereby ensure long-term resilience for this important function.

Plate 1 provides an overview of the connectivity between these system components and provides the framework for consideration of specific software elements in Section 3.

Please note that the web database, publication and viewer capability for NAWASA was not included in the original proposal scope. We will consider the feasibility of providing this element as the project develops.

Plate 1 NAWASA – initial high-level GIS system design



5. Database, GIS and web mapping software review

A detailed review of database, desktop GIS software, mobile and web mapping options was undertaken during May 2019. The results of the review are presented below and form the basis of the core system design presented in Plate 1.

The core criteria used to inform the review are detailed below and were based upon key requirements identified from the user meetings conducted in Grenada between the 2-9th May 2019.

Core system criteria

- Database – Provide centralised data handling and management for spatial and tabular data
- Functionality - High degree of spatial management and analysis functionality
- Cost – Limit these as far as possible while maintaining key functionality
- Data Rich - Ability to access/read a wide range of database and spatial formats
- Skills – Complement the existing GIS software skills within NAWASA
- CIS connectivity - Ability to read and manipulate data from the current (Northstar) and future CIS systems used by NAWASA

- Mobile - Provide based for mobile data capture forms
- Web – Ability to publish core GIS dataset to secure web mapping services

5.1 Database management software

The key features of four centralised database software reviewed are summarised below in Table 2.

Table 2 Review of database software

Software	Key features	Limitations
Microsoft SQL Server	Microsoft SQL Server is a relational database management system developed by Microsoft. The key advantages of SQL Server are: • The product is well established, fast and stable; • The core engine offers the ability to adjust and track performance levels, which can reduce resource use; • The structure allows data and visualisations to be viewed on mobile devices; and • It forms part of the wider Microsoft product suite and therefore allows close integration with other Microsoft technologies such as Azure, Office 365 etc.	The key limitations of SQL Server include: • Ongoing up-front and long-term maintenance costs typically at least £1000 per annum; • Enterprise pricing may be beyond what many organizations can afford; • Microsoft SQL Server is very resource intensive; and • Many individuals have issues using the SQL Server Integration Services to import files.
Open Source PostgreSQL /PostGIS	PostgreSQL is a powerful, open source object-relational database system with over 30 years of active development. PostgreSQL runs on all major operating systems, wide spread use across many industries and has a range of add-ons to provide additional capability – including the PostGIS geospatial database extension. **SQL compliance**: PostgreSQL is closely aligned to SQL standard and currently supports 160 out of the 179 features required for full core SQL:2011 compliance. This is higher than other open source database software products. **Open-source and community-driven**: As fully open-source project, PostgreSQL's source code is developed by a large and devoted community. Similarly, the Postgres community maintains and contributes to numerous online resources that describe how to work with the DBMS, including the official documentation, the PostgreSQL wiki, and various online forums. **Extensible**: Users can extend PostgreSQL programmatically and on the fly through its catalog-driven operation and its use of dynamic loading.	**Memory performance:** For every new client connection, PostgreSQL forks a new process. Each new process is allocated about 10MB of memory, which can add up quickly for databases with lots of connections. It is expected that the number of connections within NAWASA will be relatively small and therefore this feature is not expected to be a problem. **Popularity:** Although more widely used in recent years, PostgreSQL has lagged behind other open source databases in terms of popularity. This means that there are fewer third-party tools that can be used to manage a PostgreSQL database.
SQLite	**Small footprint:** SQLite library is very lightweight taking up less than 600KiB of space. Additionally, it's fully self-contained, meaning there aren't any external dependencies you have to install on your system for SQLite to work. **User-friendly**: SQLite doesn't run as a server process, which means that it never needs to be stopped, started, or restarted and doesn't come with any configuration files that	**Limited concurrency**: Although multiple processes can access and query an SQLite database at the same time, only one process can make changes to the database at any given time. This means SQLite supports greater concurrency than most other embedded database management systems, but not as much as client/server RDBMSs like MySQL or PostgreSQL.

Software	Key features	Limitations
	need to be managed. These features help to streamline the path from installing SQLite to integrating it with an application. **Portable:** Unlike other database management systems, which typically store data as a large batch of separate files, an entire SQLite database is stored in a single file. Means that the file can be shared via removable media or file transfer protocol.	**No user management:** SQLite reads and writes directly to an ordinary disk file. This makes SQLite a poor choice for applications that require multiple users with special access permissions. **Security:** A database engine that uses a server can, in some instances, provide better protection from bugs in the client application than a serverless database like SQLite.
MySQL	**Popularity and ease of use:** Its popularity means that there is a large amount of documentation on how to setup and administer MySQL databases. There are also many third-party tools — such as phpMyAdmin which can be used to simplify the process of getting started. **Security:** MySQL comes installed with a script that helps you to improve the security of your database by setting the installation's password security, defining a password for the root user, removing anonymous accounts, and removing test databases that are, by default, accessible to all users. Also, unlike SQLite, MySQL does support user management and allows you to grant access privileges on a user-by-user basis. **Speed:** MySQL does implement certain features of SQL which enables to achieve high processing speeds. **Replication:** MySQL supports different forms of replication, which is the practice of sharing information across two or more hosts to help improve reliability, availability, and fault-tolerance. This is helpful for setting up a database backup solution or horizontally scaling a database.	**Known limitations:** Because MySQL was designed for speed and ease of use rather than full SQL compliance, it comes with certain functional limitations. For example, it lacks support for FULL JOIN clauses. **Licensing and proprietary features**: MySQL is dual-licensed software, with a free and open-source community edition licensed under GPLv2 and several paid commercial editions released under proprietary licenses. Because of this, some features and plugins are only available for the propriety editions. **Slowed development:** Since the MySQL project was acquired by Sun Microsystems in 2008, and later by Oracle Corporation in 2009, there have been complaints from users that the development process for the DBMS has slowed down significantly, as the community no longer has the agency to quickly react to problems and implement changes.
Netbase	**Functionality:** This commercial database and analytical product has been specifically designed for water utility operations and provides a variety of functionality relevant to the assessment of NRW. The full use and benefits of the functionality is dependent on access to structured GIS and data flows.	**Software cost:** Implementations of Netbase can start from $15-20k / annum but can be a considerably higher depending on the nature of the build / functionality required. This includes reliance on Oracle as the underlying database technology. **Access to structured data:** the full analytical functionality of Netbase requires access to fully structured GIS datasets and telemetry type data flows. NAWASA are just starting the development of these capabilities through this initial project.

Based upon this review, **PostgreSQL/PostGIS was selected for use as the central database technology for future storage of GIS spatial and tabular data within NAWASA**. Its selection reflected its proven track record of use; free cost and ability to directly link to expected desktop GIS, mobile and web mapping technology that will be used by NAWASA in the future.

5.2 Desktop GIS Software

The key features of four desktop GIS software reviewed are summarised below in Table 3.

Table 3 Review of GIS software

Software	Key features	Limitations
ESRI ArcGIS Desktop	Esri's ArcGIS Desktop is a suite of integrated applications (including ArcMap, ArcCatalog, and ArcToolbox) which enable users to perform a wide range of GIS tasks, including mapping, geographic analysis, data editing and compilation, data management, visualization, and geoprocessing. Development of user-based tools and workflows can be produced using the in-built geoprocessing framework and/or python (ArcPy) development language. The desktop product also provides the mechanism for publishing data to ESRI ArcGIS Online and Enterprise Level server products (ESRI Portal).	The key limitation of the ESRI software range is the initial software purchase costs and maintenance costs. For information, initial purchase of a single desktop version (including spatial analyst extensions would be over $5000 with a centralised server web mapping capability starting at $20,000 plus. Annual maintenance costs are typically around 20% of the initial purchase price.
QGIS Desktop	Over the past decade, QGIS has developed into one of World's leading GIS software products, driven by its free availability and increasingly its strong functionality and inter-operability with other data packages and formats. This supports extends to shapefiles, coverages, personal geodatabases, dxf, MapInfo, PostGIS, and other formats. Web services, including Web Map Service and Web Feature Service sources. QGIS also integrates with other open-source GIS packages, including PostGIS, GRASS GIS, and MapServer; and PostgreSQL/PostGIS, SpatiaLite and MySQL databases. QGIS also supports a wide range of plugins written in Python or C++ and extend QGIS's capabilities. QGIS is also one of the key structured resources provided by the Open Source Geospatial Foundation (https://www.osgeo.org/). This "not-for-profit" organisation was founded in 2006 and exists to support and promote the collaborative development of open geospatial technologies and data. The OSGeo community currently comprises more than 30000 subscribers and contributors.	New versions of QGIS are released on a 4-month cycle. The rapid release can present challenges for organisations who deploy many QGIS licences and ultimately need to ensure aligned compatibility across an organisation. Additional functionality is provided by user plugins, which can rely on the installation of additional python modules on individual machines.
Strumap	The GIS software is produced by NorthGate Solutions and is focused on water resource management. It includes a desktop version (cost around £5000 plus $1000 maintenance cost) plus number of additional modules (including network modelling, Web GIS and flushing designer) which can be purchased at additional cost.	Strumap has more limited GIS functionality than QGIS and ArcGIS but with some tools more aligned to the management of water network information. Strumap can import/export several standard GIS formats but does not have a direct ability to use data heled in enterprise level databases such as PostgreSQL or SQL server. Strumap is a commercial software product, so would involve initial purchase and long-term maintenance costs. No current information available for Strumap available on the web and possibly uncertainty

Software	Key features	Limitations
		regarding the long-term future of the software product.
SuperGIS	SuperGIS Desktop is a Windows based geographic information system (GIS) platform developed by SuperGeoTek. The application is intended for Windows users from the field of transportation, urban planning, real estate, public health, geology, ecology, hydrology, and other similar industries. SuperGIS Desktop has tools to manage assets, distribute resources, analyse spatial patterns, and create data. It also includes spatial analysis software also helps with proximity analysis, overlay analysis, extract analysis, projections transformation, table processing, georeferencing, database management and more.	The standard SuperGIS product has less functionality than QGIS and ArcGIS. SuperGIS is a commercial software product so would involve initial purchase and long-term maintenance costs.

Based upon the review, **QGIS 3.6 desktop was selected as the primary desktop GIS software which will be used by NAWASA GIS staff for the future analysis and visualisation of spatial and tabular dataset**. Its selection reflected its proven track record of use; functionality capabilities, free cost and ability to directly link to PostgreSQL/PostGIS database, which will be used to centralise the management of GIS datasets by NAWASA.

5.3 Mobile data capture

The review of mobile capture apps has focused on three possible options, namely ESRI ArcPad, ESRI ArcCollector, SW Maps and Qfield. The relative features and limitations of these four options are outlined below in Table 4.

Table 4 Mobile data capture options

Product	Key features	Limitations
ESRI ArcPad	Windows mobile data capture app developed by ESRI over the past 20 years. ArcPad is the current data capture used on the older Trimble device used by NAWASA staff.	ESRI's support for the ArcPad product is ending on the 31 Dec 2020. This decision reflects the fact that it relies on MS Mobile Windows – a platform which has not been updated since 2011. The product therefore has a short life-span compared to other available apps. A replacement is therefore required.
ESRI ArcCollector / Survey123	ESRI's modern data capture technology aligned closely to its ArcGIS Online product range. The app works on Apple iOS, Android and Windows devices; and enables the dynamic and synchronisation of data collected in the field.	Although the apps are free to download, they can only be used if users have access to an organisational level ArcGIS Online account. This typically costs around $8000 per annum but costs may be higher dependent on the number of users and functionality required. The future use of ESRI Collector /Survey 123 would require long term investment by NAWASA in appropriate Android or Apple iOS tablet and/or smartphone technology to enable their use for future field data capture.

SW Maps	SW Maps is a free open source data capture app and provides a facility for simple form-based entry of data for pre-defined data layers.	All data synchronisation must currently be done manually with data transferred on/off the device back in the office rather than via mobile connection. The app can only load and edit shapefile, KML or GeoJSON formats only. This is more limited than only mobile data capture apps reviewed. The future use of the SW Maps app would require long term investment by NAWASA in appropriate Android based tablet and/or smartphone technology to enable their use for future field data capture.
Qfield	This Android based app is closely aligned with QGIS and includes a specific QGIS desktop plugin to enable the setup and deployment of projects for field capture. The app can use and sync data to a PostgreSQL/PostGIS database	All data synchronisation must currently be done manually with data transferred on/off the device back in the office rather than via mobile connection. The future use of the Qfield app would require long term investment by NAWASA in appropriate Android based tablet and/or smartphone technology to enable their use for future field data capture.

Based upon this review, **Qfield was selected as the primary mobile data capture app which will be tested by NAWASA staff for the future capture of infrastructure condition surveys and/or the capture of future meter readings**. Its selection reflected its close alignment with QGIS desktop software and ability to use at no cost.

5.4 Web mapping publication software

The review of software options was also extended to the consideration of suitable software products which could provide the basis for the future publication of secure web mapping services, based upon the centralised database described in Section 4.1. It is important to note that the development of a web publication capability was not requested or covered in the original scope of works and therefore remains outside of the current project scope at this stage.

The key options considered are presented below in Table 5.

Table 5 Web mapping publication software options

Product	Key features	Limitations
ESRI ArcGIS Server	ArcGIS Server is ESRI's primary web publication tool and is closely aligned with its desktop product (ArcGIS desktop) and Enterprise product (Portal)	The key limitation of ESRI ArcGIS Server publication software is the cost of licence and additional extensions. An initial basic setup cost can be over £20,000.
GeoServer	GeoServer is an open-source server written in Java that allows users to share, process and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards. These formats include: PostGIS, Oracle Spatial,	Although Geoserver provides a relatively friendly user interface, its overall

	ArcSDE, DB2, MySQL, Shapefiles, GeoTIFF, GTOPO30, ECW, MrSID and JPEG2000 Using these data sources, GeoServer can publish compliant Web Feature Service (WFS), Web Map Service (WMS), and Web Coverage Service (WCS). Additional formats and publication options are available including Web Map Tile Service (WMTS) and extensions for Catalogue Service (CSW) and Web Processing Service (WPS). These capabilities are reflected in its extensive use as a platform for web applications across the globe.	administration is more complicated than ArcServer. The styling of individual web mapping is more difficult than publication using ArcServer and requires the saving, importing and assignment of style (.SLD) files created using QGIS.
MapServer	MapServer is an open-source development environment for building spatially enabled internet applications. It can run as a CGI program or via MapScript which supports several programming languages (using SWIG). It offers many of the same capabilities as Geoserver	Although MapServer provides a relatively friendly user interface, its overall administration is also more complicated than ArcServer.
QGIS Server	QGIS Server provides a web map service (WMS) using the same libraries as the Quantum GIS (QGIS) desktop application. A key advantage of the QGIS Server approach is that maps and print templates created in QGIS desktop can be published as web maps by copying the QGIS project file into the server directory. The resulting web maps should therefore look the same as in desktop QGIS.	QGIS server capabilities have improved in recent years but still lack behind GeoServer in terms of configuration and performance speed. These limitations are offset by its close alignment with QGIS desktop.

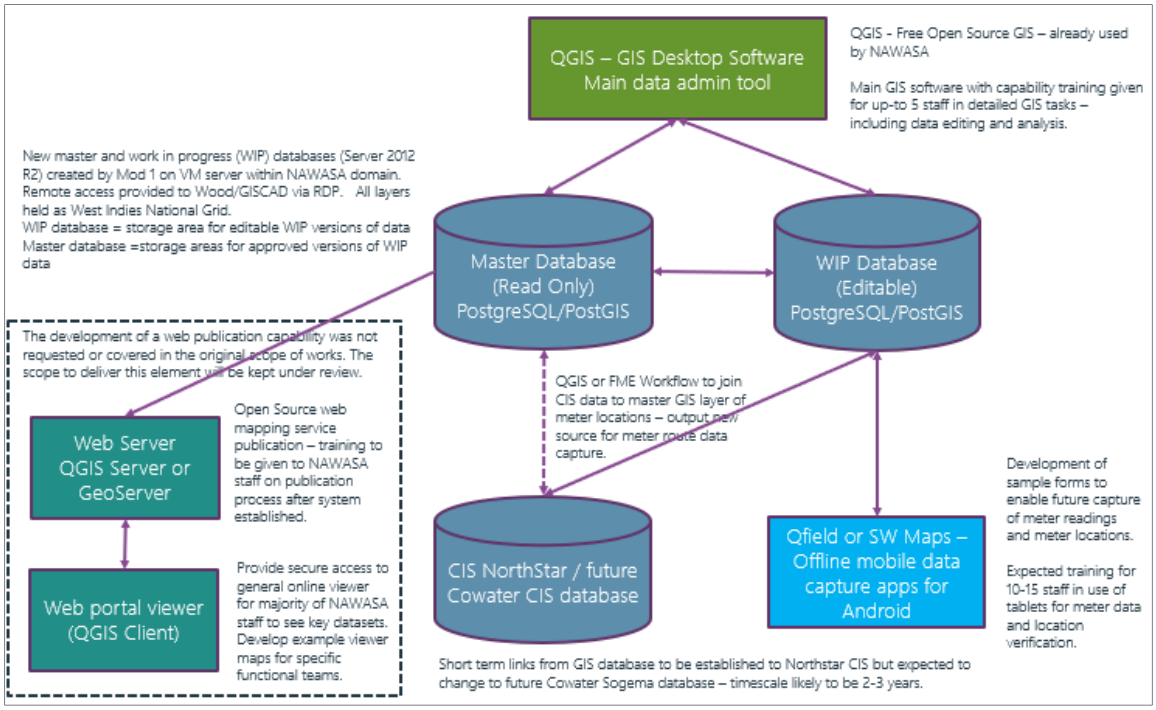
Based upon this review, **QGIS Server and/or Geoserver were identified as the preferred software solutions for any future publication of web mapping services from the centralised database.** The selection of these products reflected their close relationship with the proposed QGIS desktop and PostgreSQL/PostGIS software solutions, which will used to manage future datasets used by NAWASA. It should also be noted that any possible future web mapping developments would be undertaken behind NAWASA's existing firewall and would not lead to the creation of any web services/information which could be viewed by third parties.

6. GIS functional specification

The proposed functional specification for future NAWASA GIS data management system is shown in Plate 2. This design reflects the requirements identified in the face-to-face meetings conducted in early May 2019 and the subsequent review presented in this report.

This specification will provide the basis for more detailed planning and implementation work to be conducted during the remainder of the project. This includes development of a more detailed database design structure for the master and WIP databases; user workflows for management of data within the two databases and workflows for transfer / synchronisation of data from future mobile applications to the GIS databases. These topics are discussed in more detail in the project deliverable reports 2C and 2D produced for the study.

Plate 2 Functional Specification for the future NAWASA GIS system – June 2019



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