PAPER 15

A PRACTICAL AND PROVEN GUIDE TO MUNICIPAL WATER TELEMETRY-SCADA SYSTEMS

Matthew Hills
Nelson Mandela Bay Municipality (NMBM)

ABSTRACT

The NMBM's drought mitigation plan primarily focussed on supply augmentation and demand management, however, the unsung hero of the drought projects was the development of a Telemetry & Supervisor Control and Data Acquisition (Telemetry-SCADA) system implemented for the water division. Key to avoiding dry taps during the 2015 to 2023 drought was the ability to make instant adjustments to a highly interconnected water network to balance the knife-edge between water demand and severely restricted supply.

A creative engineering solution that improves operation efficiency and response times was needed. A state-of-the-art Telemetry-SCADA system offers the means of overcoming these challenges without the need for more on-the ground personnel. Through experience gained by implementing a Telemetry-SCADA system for the NMBM's water assets, this paper aims to provide a proven and practical guide to successfully commissioning and maintaining a municipal scale water management system. Twelve key themes will be discussed.

1. Recognise that Operational Technology (OT) is a separate system to your institutional Information Technology (IT); 2. Packaging of data starts at the on-site Programmable Logic Controller (PLC) and linked devices; 3. Build a network that allows you to have full control of site connections; 4. Use the cellular network for bi-directional communication and reliability; 5. Build redundancy into hardware infrastructure by including backup power generation; 6. Elect for an open-source protocol, in other words, talk in a language that you understand; 7. Stipulate a tag naming convention so that information is logically stored; 8. Instil a consistent look-and-feel by developing standard icons, graphics, and colours; 9. Develop a security matrix and define access and control permissions for groups of users; 10. Allow for secure remote system access of mobile devices through a web hosted address; 11. Feed data into asset management systems to encourage proactive maintenance; and 12. Integrate into non-revenue water and billing workstreams.

Proactive responses by decision makers to system stressors can only be as good as the information that they are based on. Rolling out a Telemetry-SCADA system enhances the ability of water service authorities to progressively ensure efficient, affordable, economical, and sustainable access to water services to all consumers in its area of jurisdiction, as per the requirements of the Water Services Act.

INTRODUCTION

The Nelson Mandela Bay Municipality (NMBM) is located along Algoa Bay in the Eastern Cape Province and comprises Gqeberha (formerly known as Port Elizabeth), Kariega (formerly known as Uitenhage), Despatch, as well as the Colchester, Blue Horizon Bay, and Seaview areas. The Municipality, covering an area of 1,959km^2, is a Category A municipality, established in 2000 as per the provisions of section 12 of the Local Government: Municipal Structures Act 117 of 1998. It is a major seaport and automotive manufacturing centre and is the economic powerhouse of the Eastern Cape Province. (Nelson Mandela Bay Municipality, 2022)

The NMBM accesses raw water through the Algoa Water Supply System. The main local dams are the Churchill and Impofu Dams on the Kromme River and Kouga/Loerie Dams on the Kouga River, with the latter largely dedicated to the Gamtoos Irrigation Board (now Gamtoos Water User Association). The relatively small Van Stadens Dams, Bulk River Dam, Sand River Dam, and the Uitenhage Springs only supply water to NMBM, whereas the Groendal Dam also serve irrigators. The most significant raw water source, approximately two-thirds of the total volume, is supplied from the Gariep Dam on the Orange River via the Orange/Fish System and Lower Sundays Scheme. Recently, the NMBM commissioned six new groundwater schemes to improve the diversification of supply sources. The Algoa Water Supply System is depicted in the figure below.

FIGURE 1: *Bulk water supply system to the Nelson Mandela Bay Municipality*

The NMBM has only just started to recover from one of its most severe hydrological droughts, which saw some of the lowest rainfall figures in its recorded history, during which the combined remaining storage of its local dams decreased to just 9.98% on 21 July 2021. After accounting for inaccessible dead storage, this figure equated to just 3.43% of combined storage being available.

The Metro has been experiencing extended periods of below-average monthly rainfall since November 2015, resulting in declining dam levels and water storage capacities. In September 2018, specific catchments received favourable rainfall and the average dam levels increased from 17.82% to 54.66% in December 2018. This rainfall created a false sense of security as certain catchment areas did not receive significant rainfall. Since then, the average dam levels continued to drop at a consistent rate

and the storage deteriorated to worse than before. A picture of the largest dam dedicated to the NMBM is shown below.

FIGURE 2: *Impofu Dam at just 7.27% capacity on 06 January 2023.*

The drought was not localised as it affected many water supply schemes across South Africa. The Eastern Cape province was declared a provincial state of drought disaster on 04 December 2017 and again on 24 October 2019. The Head of the National Disaster Management Centre then declared a national state of drought disaster on 08 February 2018 and on 26 February 2020 in response to worsening conditions. Persistent and continuous negotiations ensured that the NMBM was classified as a national drought disaster area on 20 July 2021, which it yet to be rescinded.

Since then, good rains experienced during the winter and autumn months of 2023 brought some much-needed relief. The Algoa Water Supply System has largely recovered with the NMBM's local dams sitting at a combined storage capacity of 78.42% on 30 June 2024. With the Impofu Dam still relatively low at 42.82%, the NMBM has been cautious about lifting restrictions abruptly and continues to implement the projects identified within its Drought Mitigation Plan.

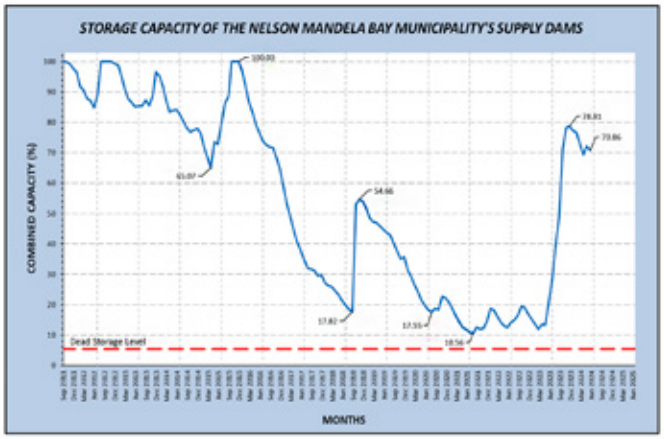

FIGURE 3: *Combined dam level trend for the NMBM's local dams from September 2011 to May 2024.*

With the aim of preventing the supply dams from running dry and ensuring water security for its consumers, the NMBM implemented numerous water augmentation and water conservation measures and strategies. These are well documented in the NMBM's Drought Mitigation Plan with detail on each workstream and project. The strategy employed was focused on two main objectives, namely measures taken to augment the NMBM's water supply and measures taken to reduce the NMBM's water demand.

An unsung hero of the drought projects was the development of a Telemetry-SCADA system implemented for the water division. Of all the workstreams that either added more water to the system or conserved what little was left, it was this system that proved absolutely key to avoiding dry taps during the recent drought. It gave the NMBM the ability to make instant adjustments to a highly interconnected water network to balance the knife-edge between the consumers water demand and a severely restricted supply.

TELEMETRY & SCADA

Towards the end of 2019, the NMBM embarked on a major overhaul of their Telemetry & Supervisor Control and Data Acquisition (SCADA) system for its water network infrastructure. The existing system was severely limited in terms of functionality, covered only a minor portion of the network, had communication that was notoriously unreliable, gave no confidence in the data it displayed, and was ultimately not very useful. A screenshot of the NMBM's water network overview on the legacy SCADA system.

FIGURE 4: *Legacy NMBM water network SCADA system.*

In the context of a municipal water supply system, the telemetry includes the communication from equipment to the on-site computer and the network that links this to a central server. In simpler terms, it includes all the electronic data available on site and the sending of that data from each site to head office. A site could be a dam, borehole, water treatment works, pump station, reservoir, or even a chamber containing a flow meter, in this instance.

Make no mistake, these are complex systems requiring specialised skills to develop, implement, maintain, and operate. Many local municipalities and water boards have incorporated some form of telemetry and SCADA system, however, very few have become invaluable to the day-to-day operation and management of water systems valued at billions of rand.

Water Service Authorities and Water Service Providers alike struggle with insufficient human resources, lack of tools of the trade, rampant infrastructure vandalism and theft, excessively high non-revenue water, and an aging skilled work force, making it hard for them to fulfil their "duty to all consumers or potential consumers in its area of jurisdiction to progressively ensure efficient, affordable, economical, and sustainable access to water services" (Water Services Act 108 of 1997, 1997). A state-of-the-art Telemetry-SCADA system is a creative engineering solution to overcome these challenges as it improves operation efficiencies and response times, without the need for more on-the ground personnel.

A PRACTICAL GUIDE

Through experience gained by implementing a Telemetry-SCADA system

for the NMBM's water assets, this paper aims to provide a proven and practical guide to successfully commissioning and maintaining a municipal scale water management system. Twelve key themes will be discussed.

1. Recognise that OT is a separate system to your institutional IT

A barrier to entry for many has been an organisational misunderstanding that a Telemetry-SCADA system is required to adhere to the institution's Information Technology (IT) policies. These policies are designed to protect an institution's network, including critical accounting and email systems, and therefore employ strong firewalls and an accompanying administrative process that is cumbersome to say the least. IT Departments within governmental institutions are often short staffed and struggle to procure the most basic hardware and software.

The solution for the NMBM has been to classify its Telemetry-SCADA system as Operational Technology (OT), thereby exempting it from its IT Policy on the condition that the networks remain completely separated. OT includes the hardware and software used to detect or cause a change through the monitoring and/or control of equipment, devices, processes, and events (National Institute of Standards and Technology, 2024). A Telemetry-SCADA system meets that definition.

2. Packaging of data starts at the on-site PLC and linked devices

A Programmable Logic Controller (PLC) is a rugged and industrial form of computer that acts as the brains of the electronics. It's the piece of equipment that reads information from sensors and devices, and then issues instructions and/or commands in return based on a set of programmed rules. By way of example, it's the intelligent box that tells a motor to turn off once the reading from the temperature sensor exceeds the maximum heat limit.

What information is stored within the memory of the PLC is the first building block of a Telemetry-SCADA system. Ideally an institution will issue a set of PLC function blocks, a technical name for lines of computer code, for each type of equipment used within its water infrastructure. This will ensure that the quantity and quality of data available will be easily integrated into upstream systems. It is here that information begins.

3. Build a network that allows you to have full control of site connections

You will need a way to link all your sites and head office onto a network so that they can communicate with one another. In technical terms, this is done by adding all your sites to a Virtual Local Area Network (VLAN). Institutions are familiar with VLANs, especially after the COVID-19 pandemic, as they often use a Virtual Private Network (VPN) to connect to their institutional Local Area Network (LAN) for access to systems and network drives.

Instead of using a VPN service provider, which can prove complicated when it comes to sole-provider procurement, the NMBM has taken control of its OT network by purchasing a perpetual license for a gate manager. A gate manager is a device that enables the connection of and communication with multiple devices on a network. The Secomea GateManager was selected as its locally stocked SiteManager devices automatically take care of network addresses changing and their user-friendly access portal for adding devices to the network. For sites that do not have access to power, the Cloudworks Server package was selected as it was provided free of charge when purchasing their battery powered devices.

4. Use the cellular network for bi-directional communication and reliability

The NMBM's legacy telemetry system made use of an institutionally owned and operated radio and microwave communication system, outlined in the figure below. Although the coverage was great, frequent vandalism and theft of tower equipment (and once even the whole tower structure itself) often led to extended network blackouts. Another major limitation was the limited bandwidth available, severely restricting the volume of communication traffic.

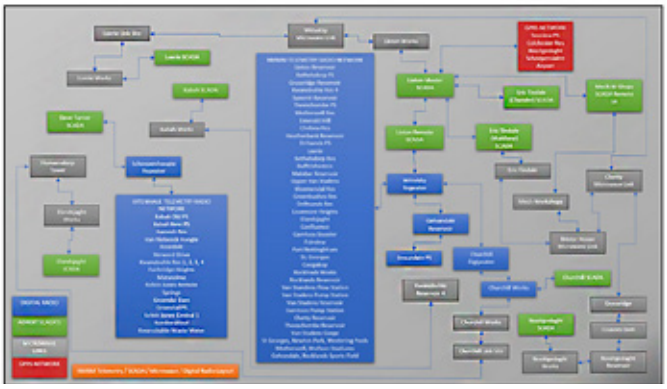

FIGURE 5: *Diagram of the NMBM's telemetry radio and microwave network.*

The chosen way forward was to migrate to the cellular network. Cellular network operators are highly motivated to keep their networks online as they earn revenue for the traffic hosted by their networks. They cannot charge you for a call or for data if you are disconnected from their cell tower. Many cell towers now have backup power solutions installed as a means of mitigating the effects of loadshedding on their business. The reliability and coverage of the cellular network was the primary motivator behind the migration. The secondary being that the high-speed bandwidth would allow the NMBM to work on PLCs remotely.

One of the disadvantages of the cellular network is that SIM cards normally have a dynamic Internet Protocol (IP) address. Every time it switches connection to a different cell tower, and sporadically even if it stays connected to just one cell tower, the IP address of the device changes. This makes it extremely difficult to "find" a PLC on the internet, as if its "location keeps moving". The alternative is to pay an exorbitant amount to a cellular provider to issue you with static IP SIM cards, thereby fixing their address on the internet. Both the Secomea GateManager and Cloudworks Server were also chosen as they handle dynamic IPs automatically. In fact, they work independently of whichever SIM cards are in the device. This means that if the institution changes cellular service providers, switching device SIM cards will not require any additional setup.

5. Build redundancy into hardware infrastructure by including backup power generation

It goes without saying that you need an Uninterrupted Power Supply (UPS) and backup power generation, usually in the form of solar or a generator, for your servers at head office. It is expected that a Telemetry-SCADA system is operational 24/7 with an uptime exceeding 99%. What was overlooked at the time was the need for backup power for our PLCs at each site. When a site experienced a loss of power supply, all too frequently during loadshedding, we would lose communication instantly and have no means of diagnosing the fault or issuing commands to equipment. Installing a backup battery system for PLCs is essential for

understanding what is happening on site and has been specified on all future electronic upgrades.

6. Elect for an open-source protocol, in other words, talk in a language that you understand

A major gripe with the NMBM's legacy telemetry system was that the transmission of data in 1's and 0's from site to head office was in a language that we couldn't understand, known as a closed protocol. This meant that we were "locked in" to a specific service provider and their proprietary equipment. Procurement in local government is complicated enough without having a sole service provider.

Stipulating the use of an open protocol was a non-negotiable for the NMBM as the institution wanted to take back ownership of its communication network and pay zero royalties. For the pull open protocol, whereby head office asks each site PLC for data at set intervals, MODBUS was selected and for the push open protocol, whereby the site PLC sends data when it deems it necessary for head office to know about, DNP3 was selected. Although DNP3 can significantly reduce the amount of unnecessary data on the network (think a borehole level probe telling you that reading 10.78m every ten seconds for a whole month), it has proven complicated to implement at SCADA communication driver level and thus mainly MODBUS has been used to date with the aim of moving to DNP3 in the future.

7. Stipulate a tag naming convention so that information is logically stored

All this information being retrieved from site PLCs needs to be stored in a logical order. The NMBM has developed a standard tag naming convention that designates a unique reference title to each piece of data. A maximum of twenty-nine characters in the following format was specified:

UUUU_VVVV_WWW_XXX##_YYY##_ZZZ

where:
UUUU=Department
VVVV=Site
WWW=Process
XXX##=Work Unit
YYY##=Equipment
ZZZ=Signal

This has made it simple to search through a large database when requesting some data, but also permitted the organised sorting and post processing of all information being retrieved. An example of how this works in practice is shown in the figure below.

WTWK_COEG_FNW_PST02_TT#01_TMP

DEPT		SITE		PROC	WORK			EQUIP			SIGNAL
UUUU	_	VVVV	_	WWW	_ XXX	##	_	YYY	##	_	ZZZ
WTWK	_	COEG	_	FNW	_ PST	02	_	TT#	01	_	TMP

Coegakop WTW Final Water Pumpset No. 2 Motor Drive-End Bearing Temperature

FIGURE 6: *Example of a tag name for a temperature reading from a motor bearing.*

8. Instil a consistent look-and-feel by developing standard icons, graphics, and colours

The NMBM has put a lot of time and effort into a from-the-ground-up redesign of the Graphical User Interface (GUI). Complaints from users of the previous SCADA system often included that it was not "visually appealing" and that it "lacked a consistent look and feel" in terms of navigation and icons. Standardisation of the icons, graphics, and colours to follow a clear "situational awareness" display philosophy was thus developed. Situational awareness aims to only attract operator attention to sites requiring user action, a reservoir overflowing for example.

A template graphic form that separated the screen into four distinct areas created a consistent look and feel when navigating between different sites. Custom icons, in a vector file format, were created to represent each type of equipment within the water network. Even the colours used were standardised, with particular effort into choosing the graphic form background colour to be an off-white so as to minimise eye fatigue of the operators staring at it for extended periods of time, particularly at night. By implementing consistent design standards, the system as a whole is easier to work on and the owner benefits by way of reduced maintenance costs. An illustration of the icon and colours options available for the states and alarms of a pump motor is shown in the figure below.

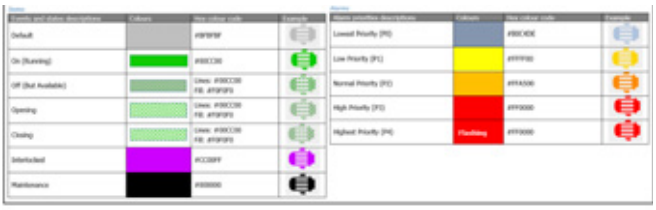

FIGURE 7: *Dynamic colours specified by the NMBM for equipment states and alarms.*

9. Develop a security matrix and define access and control permissions for groups of users

In hindsight, a security matrix that clearly defines the functionality and available control for specified user groups should have been the first step taken in this redevelopment of the SCADA system. One does not want a junior employee to be able to turn pumps on (plant control) or lower the free chlorine targets of a water treatment works (change setpoints). A need to align the level of access and an employee's responsibilities as defined in their job description was identified, with the outcome shown in the figure below.

Functions/Actions	Software Administrator	Maintenance	Supervisor	Process Controllers	Management	Viewers
Alarm Acknowledge	X	X	√	√	X	X
Set Maintenance	X	√	X	X	X	X
Comment	X	√	√	√	√	X
Designer	√	X	X	X	X	X
Documentation	√	√	√	√	√	X
Navigation M 1 (Network Overview)	√	√	√	√	√	√
Navigation M 2 (Site Graphic Forms)	√	√	√	√	√	X
Navigation M 3 (Faceplates)	√	√	√	√	√	X
Change Setpoints	X	X	√	X	X	X
Plant Control	X	√	√	√	X	X

Change Setpoints: This refers to all values that can be changed on the "Setpoints" tab of an objects faceplate.

Plant Control: This refers to all actions that can be performed on the "Control" tab of an objects fac

FIGURE 8: *Security matrix specified by the NMBM for graphic form navigation and control.*

Essentially, three levels of graphic forms and two levels of control were specified as either clickable or non-clickable for each user group.

10. Allow for secure remote system access of mobile devices through a web hosted address

The NMBM has a Water and Sanitation Operation Centre staffed 24/7 that takes responsibility for executing system alterations based on a set of Standard Operating Procedures (SOPs). The management of this fall within each division head, mainly the Water Distribution and Plant Maintenance divisions. A need arose for these division heads, senior management, key stakeholders, and support staff to be able to securely access the SCADA system remotely from their mobile devices and laptops.

A Secure Mobile Gateway (SMG) server hosted on-premise with an open-source certificate manager to ensure a protected connection. Through this, one could make any web browser like Google Chrome (Windows/Android) or Safari (iPhone) to access the SCADA system by navigating to a website through a URL. The figure below shows the login screen, in which a user clicks on their username and then enters a unique password. This has the added benefit of logging all actions taken under a user's profile for future audit queries and investigations.

FIGURE 9: *Screenshot of login screen for securing access to the NMBM's SCADA SMG.*

11. Feed data into asset management systems to encourage proactive maintenance

As mentioned earlier, the NMBM's IT Department supported the development of the water OT system on condition that it remain isolated from the IT system. There has since been only one exception made to this rule; a single, highly secure point of access between the vast amount of information stored by the SCADA system on a Microsoft SQL database and the NMBM's Water and Sanitation asset management system.

Operators of the asset management system are able to send queries to the SQL database at predefined times for selected data. This has tremendously improved the departments' ability to timeously submit International Water Association (IWA) reports to the Department of Water & Sanitation (DWS), the standard water balance to evaluate the performance of water distribution systems. It has also improved on the planning of proactive maintenance based on quantifiable equipment health metrics.

12. Integrate into non-revenue water and billing workstreams

A recent investment into water conservation and water demand management by the NMBM has let to the establishment of numerous Greater Metered Areas (GMAs), District Metered Areas (DMAs), and Pressure Managed Areas (PMAs). The zones of supply connected to these meters can be measured and then compared to the total billed volumes within that same zone. This allows the NMBM to focus its efforts to reduce Non-Revenue Water (NRW) by targeting zones with the highest disparity between the two figures. The SCADA system has automated these investigations, providing real-time and continuous data for analysis and actioning. Two secondary benefits have been the ability to collect data on nighttime flows and data on maximum pressures supplying each zone. With the limited human resources available, this system has allowed the NMBM to improve its operational efficiency and effectiveness.

THE END PRODUCT

All of the twelve key themes and more are documented in a Functional Design Specification (FDS) which includes a full implementation specification to be utilized on all elements of the NMBM's Telemetry-SCADA system in order to ensure a level of standardization. This deviates from the industry norm whereby multiple independent systems are developed by each system integrator appointed for Telemetry-SCADA infrastructure upgrades by ensuring a wholistic, enterprise-level approach is taken. The client now specifies and issues associated standards for the Telemetry-SCADA system, not the other way around.

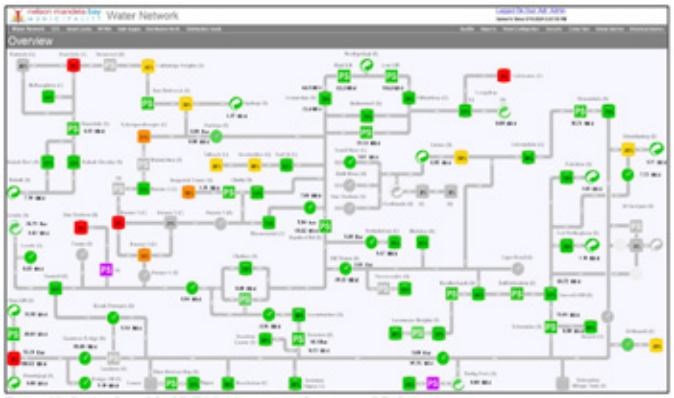

FIGURE 10: *Screenshot of the NMBM's water network overview SCADA system.*

The screenshot in the figure above was taken during a water supply crisis experienced due to a dry-period on the canal system supplying the Nooitgedagt Water Treatment Works. The Telemetry-SCADA system proved itself invaluable to managing a tightly constrained system by facilitating real-time decision making and providing immediate data for measuring of the results.

FIGURE 11: *Screenshot of the NMBM's Glendinning Wellfield technical overview SCADA system.*

Two more screenshots in figures 11 and 12 show the technical overview of a groundwater supply system and a remotely located pump station. Full control is now permissible without the need to send a warm body late at night to an often unsafe location.

FIGURE 12: *Screenshot of the NMBM's Bushy Park pump station SCADA system with pumpset number 2's faceplate shown.*

The NMBM's water network SCADA system was built on the Adroit 10 SCADA Software, which is a real-time data acquisition and reporting package developed in South Africa.

CONCLUSION

The Algoa Water Supply System experienced one of its worst droughts on record from 2015 to 2023. The NMBM's response was to implement numerous water augmentation and water conservation projects. It is evident the project to upgrade the Telemetry-SCADA system was a success, with future development and improvements planned.

Proactive responses by decision makers to system stressors can only be as good as the information that they are based on. Rolling out a Telemetry-SCADA system thus enhances the ability of water service authorities to progressively ensure efficient, affordable, economical, and sustainable access to water services to all consumers in its area of jurisdiction, as per the requirements of the Water Services Act.

By sharing this practical and proven guide to municipal water Telemetry-SCADA systems as outlined in the twelve themes, the NMBM hopes to encourage other municipal engineers to successfully implement similar systems for their infrastructure and thus improve service delivery to all South Africans.

RECOMMENDATIONS

The following recommendations are made to any entity looking to implement a state-of-the-art Telemetry-SCADA system, based on the Nelson Mandela Bay Municipality's own experiences:

- Select a "champion" to lead this project.
- Start small with pilot projects.
- Accept that it will be an iterative development process.
- Standardise and document everything!
- It is only as good as the time and effort that YOU put into it.

The NMBM is willing to share documentation and standards with other government entities provided that collaboration continues into the future, thereby ensuring that the partnership is mutually beneficial.

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