EARLY WARNING NETWORKS FOR RAINWATER-DEPENDENT COMMUNITIES

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"When the well is dry, we know the worth of water."

— Benjamin Franklin

ABSTRACT

The remote location of many Pacific Island Countries present significant challenges in providing emergency water supplies during rainfall deficits. This paper provides a commentary on the first stage of prototyping and piloting a low-cost water shortage early warning system. As harvested rainwater is a primary water source in remote PICs, the proposed system used a network of low-cost rainwater tank monitors. By analysing tank levels, water consumption and precipitation forecasts, the water availability of a region can be predicted.

Thirty remote monitoring devices were installed on tanks across two Northland communities to evaluate the technical feasibility of the proposed system. Following a six-month trial period, the accuracy of the initial runout date predictions were assessed. A web-based interface delivered predictions and relevant information to tank owners and community water managers. Beyond the re-calibration of five monitors, the network operated with a near-100% uptime without intervention. With the ease of installation and maintainability of the network having shown promising performance, the next phases of the pilot will focus on the integration of this network within the socio-cultural context in the Pacific.

KEYWORDS

Climate Resilience, Pacific, Water Tanks, Remote Monitoring Networks, Sustainability, Rainwater, Drought Response.

PRESENTER PROFILE

Zachary Preston is a 21 year old mechatronics engineering student at the University of Canterbury. As a high school student, Zachary began developing a tool to autonomously manage water tank supplies for rural homes. After gaining international recognition in the Microsoft Imagine Cup, Zachary has worked with Engineers Without Borders New Zealand and MFAT to bring these tools to rainwater-dependent communities in the Pacific.

1. INTRODUCTION

1.1 IMPACTS OF CLIMATE CHANGE FACED BY PACIFIC ISLAND COUNTRIES

The availability and security of clean drinking water within Pacific Island Countries (PICs) has become increasingly under threat over the last few years. Climate cycles, such as the El Niño Southern Oscillation (ENSO), have exposed the vulnerability of rainwater-dependent communities as historical rainfall patterns become less reliable. Over the last two decades, PICs have been experiencing more severe and frequent drought events as a result of rising atmospheric temperatures (McGree, 2016).

The contamination of groundwater resources across many PICs has resulted in an increased dependence on rainwater harvesting for freshwater supplies (Dixon-Jain, 2014). Harvested water is primarily stored in private water tanks and communal cisterns, where drinking water may be accessed in between periods of low rainfall. With such high dependence on limited freshwater stores and increasingly infrequent rainfall events, the ability to effectively monitor these resources is key for the sustainable water management of many PICs.

In response to the increasing challenges faced by the Pacific due to climate change, the New Zealand Ministry of Foreign Affairs and Trade (MFAT) has committed $300 million NZD in funding between 2019-2022 (The Beehive, 2018). Half of this funding is focused on helping countries to adapt to the impacts of climate change, and two-thirds is focused within the Pacific region.

As a part of this funding, MFAT has partnered with Engineers Without Borders New Zealand (EWBNZ) to pilot a network of water tank monitors that may enable communities to recognise emerging shortages before crises occur. If technically viable, the proposed system would provide a cost-effective drought early warning system for PICs. To retain tino rangatiratanga (autonomy), such a system must be installable, configurable, maintainable, and valued by local residents and local governing bodies to ensure that local needs are met.

1.2 STAKEHOLDER COMMUNICATION

A desktop study of water security and management practices in the Pacific was undertaken by researching a representative sample of Pacific countries. The water availability and governance practices across the Cook Islands, Tonga and Vanuatu were evaluated. In a survey study conducted by GHD, it was recognised that whilst water challenges were universal in the Pacific, the specific needs vary widely between communities (Falkland, 2011). This variance included the governance of water supply, physical storage mediums and the social and cultural beliefs that govern the views communities have of water.

To build on this previous study and gain further understanding of Pacific communities' approaches to water management, particularly at the household and community level, interviews were conducted with key stakeholders from non-governmental organisations, regional community service organisations and central government departments. Overall, the response to piloting the proposed system was mostly positive and was met with strong interest from several parties. The need for this system in low-lying atoll countries including Tuvalu, Marshall Islands, Kiribati, Tokelau and the Cook Islands was expressed. Following further research into the water practices of these communities, four common stakeholder groups were identified:

- **Owners:** Owners of residential and/or commercial water tanks. Tools for this user group should focus on proactive alerts to warn owners of anomalies such as potential leaks, water-intake blockage or unsustainable usage.
- **Community Water Managers:** Those responsible/elected for the management of communal water supplies. These roles may be taken on by elected community leaders, water-suppliers or government workers. Tools should focus reporting information to help pre-empt water shortages and disseminate responsive actions.
- **Governing Bodies:** National / regional government. Tools for this user group should focus on the visualisation of large-scale data and the generation of resource security reporting material to alert officials to the symptoms of an impending water-crisis.
- **Supporting Agencies:** Third-parties and international organisations supporting the maintenance of water stores. Similar to Governing Bodies, the large-scale data visualisation of at-risk communities may be used to coordinate relief efforts.

The flow of information for a drought early warning system was illustrated in Figure 1.

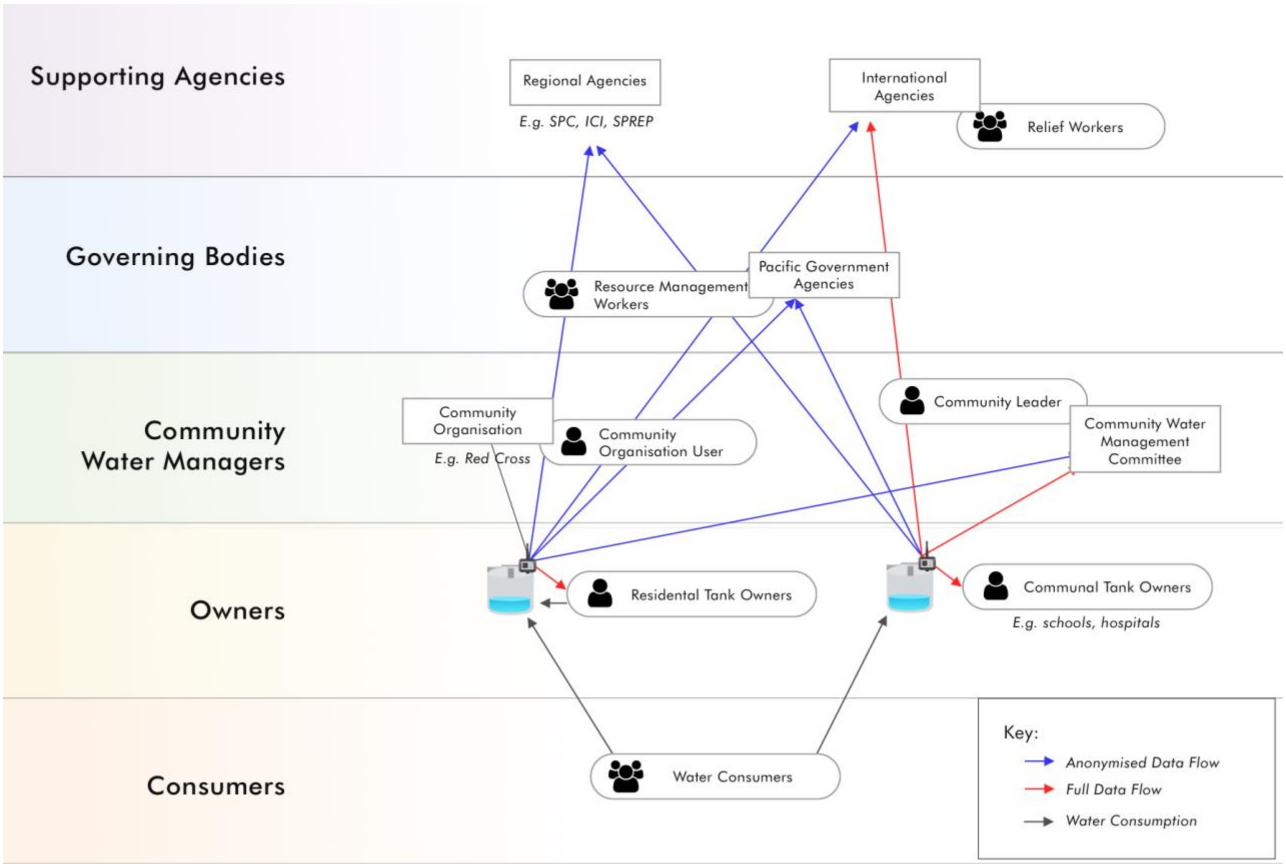

Figure 1: Visualisation of the key stakeholders that would be involved in a Pacific drought early warning system.

1.3 PROPOSED SYSTEM

The primary goal of the proposed system is to infer the current and near future water availability in water tank stores across a geographic region. These regions may vary from townships to entire islands or countries. The effectiveness of such a network is heavily dependent on the accuracy at which a tank's runout date, or zero day, predictions may be made. To achieve this, data must be collected from a set of communal and residential water tanks that represent a geographic region. As illustrated in Figure 2, remote monitors will sample the water levels on these tanks. A historical repository of these raw measurements would then be stored, and used to determine the zero day predictions for each tank. These predictions may be aggregated to infer national and regional water availability, as well as the risk of shortages. Community leaders may then use this information to pre-empt water shortages and coordinate responsive actions.

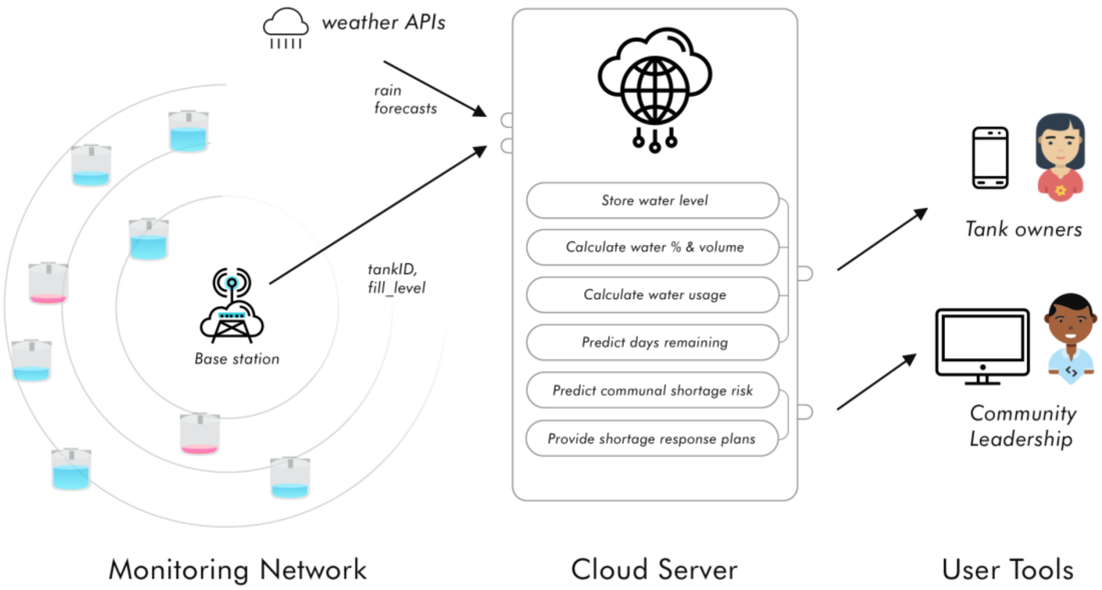

Figure 2: High-level architecture of proposed system.

1.4 PILOT OBJECTIVES AND SCOPE

The first stage of the Drought Early Warning System (DEWS) pilot was centred on assessing the technical feasibility of the proposed system. To achieve this, a pilot network was set up in two communities over a six-month trial period. The performance of the system was evaluated against a success criteria that analysed ease-of-deployment and operational viability. A high-level summary of this criteria was illustrated in Table 1. On the condition that the success criteria was met, a second phase pilot would be undertaken in the Pacific where the socio-economic and geographical contexts are different to that of the initial pilot. As elaborated in Section 5, the long-term goals and subsequent steps of the pilot would prioritise the integration and cultural adoption of the proposed system.

Table 1: High-level Summary of stage one technical success criteria.

Subsystem	**Summarised Objective Criteria**
Monitoring Hardware	30 remote tank monitors were installed across one or many communities. At least 75% of the monitors should transmit water levels within ±10% of the tanks actual volume over a six month trial period at hourly periods without any maintenance following installation.
Ease of installation	Remote monitors could be installed across plastic and concrete water tanks with capacities ranging from 10,000 - 90,000 litres. Installations were carried out by an individual with portable tools with no functional damage made to any tank.
Communication Network	An appropriate communications network was established that linked remote tank monitors to a cloud-based data-acquisition server with an uptime greater than 95% of the pilot duration. The network was run on an open, or publicly-available, wireless spectrum.
Data Ingestion and Storage	Data was stored in a secure but flexible medium that allowed for (simple) data analysis whilst protecting the privacy of tank owners.
Data Processing	Historic usage and fill volumes were calculated using tank dimensions. Both usage data and rainfall forecasts were used to predict the runout date of owner tanks. The status of multiple tanks were used to infer regional water availability. The zero day predictions were accurate to ±14 days across the majority of pilot tanks.
User Interface(s)	A web-based interface was made available to pilot participants that displayed (near) real-time water tank information. The dashboard was capable of hiding and showing data and/or widgets depending on a user's access rights. The dashboard should and have the capacity to send notifications, alerts and warnings to tank owners. This interface should be responsive such that it is accessible across mobile, tablet and web platforms.

A public request for proposals was opened to realise the proposed system. Tenders from over a dozen bids were evaluated based on the ability to meet a set of technical specifications derived from the pilot success criteria. The cost, adaptability and sustainability of bids were further considered in the assessment process. Pre-existing and off-the-shelf technologies were encouraged to lower the development time, cost and complexity of the system. Following this process, EWB partnered with IoT Water to implement a variant of the TankView system (TankView, 2019) for the DEWS pilot.

2. SYSTEM DETAILED DESIGN

2.1 WATER MONITORING HARDWARE

IoT Water's TankView water tank monitors were determined to best meet the specifications outlined for the remote tank monitors. As seen in the device specifications in Table 2, these off-the-shelf units were well suited to long-term remote applications.

Table 2: TankView Remote Monitor Specifications

Life expectancy	10 years (without solar at a 30 minute transmission rate)
Battery	Lithium Ion with solar charging
IP Code	IP67
Level sensor	CS-P400 pressure sensor
Level accuracy	±5 mm
Level sampling rate	30 minutes (configurable)
Transmission Protocol	AS923 LoRaWAN
Transmission rate	24 hours (configurable)
Rainfall detection	Davis 6465M AeroCone

Differential pressure gauges, as seen in Figure 3.1, were selected as a low-maintenance, high-precision method of detecting tank water volume. By submerging the probe at the bottom of the tank, the height of water above the probe could be determined. This level would be compared against the diameter and height of the tank to determine the current water volume. As nearly all tanks possessed an inlet or opening near the tank ceiling, the device would simply be fixed to the tank or an adjacent mast using mounting points seen in Figure 3.2. The pressure probe could then be fed through the opening until it was submerged at the bottom of the tank.

Figure 3.1: TankView remote monitoring device with pressure gauge (source: IoT Water).

Figure 3.2: Mounting holes on TankView monitor used to fix the device to tanks (source: IoT Water).

2.2 COMMUNICATION NETWORK

Data from tank sensors was transmitted using LoRaWAN (Long Range Wide Area Network) on the Asia/Pacific AS923 standard. This radio-based communication protocol is well suited to low-bandwidth, power-efficient data transfer in regions where cellular networks are unreliable and/or costly. LoRaWAN provides long-range connectivity from remote devices to a gateway base station. Depending on line-of-sight characteristics, tank monitors could communicate with base stations at a range of up to 20km. Base stations would receive, decode and then forward LoRAWAN messages to a cloud server through a 4G backhaul.

For this pilot, each base station consisted of a Multitech Conduit LoRa gateway with a 6dBi fiberglass 923 MHz antenna. Each gateway was paired with a 4G LTE modem and associated aerial. Base stations were positioned in water and tamper proof enclosures at high-line-of-sight areas to maximise the range of the LoRaWAN gateway. The base stations operated on The Things Network. This open-source server allowed for the secure and reliable operation of the LoRa network without significant development time.

2.3 SOFTWARE – DATA PROCESSING

The DEWS software platform managed three key data processing procedures. Firstly, data is ingested from the LoRaWAN base stations. This ingested data is then appended to datasets associated with the corresponding devices. Secondly, this data is turned into information about the water tank. This involved interpolating the raw pressure readings against the (measured) dimensions of the water tank to determine fill volume and percentage. Finally, the future water consumption for each tank was forecasted using historic and current rates of change of water level.

As illustrated in Figure 4, historic water usage would be processed with local weather forecasts to determine the likelihood of the tank depleting before sufficient rainfall was forecast. The runout day, or zero day, for a given water tank is the date that its water reserves would be considered depleted. Anonymised clusters of these tank-specific predictions could be aggregated to provide insight into regional water security. This information may be used by community water managers to pre-empt water shortages and educate responsive actions.

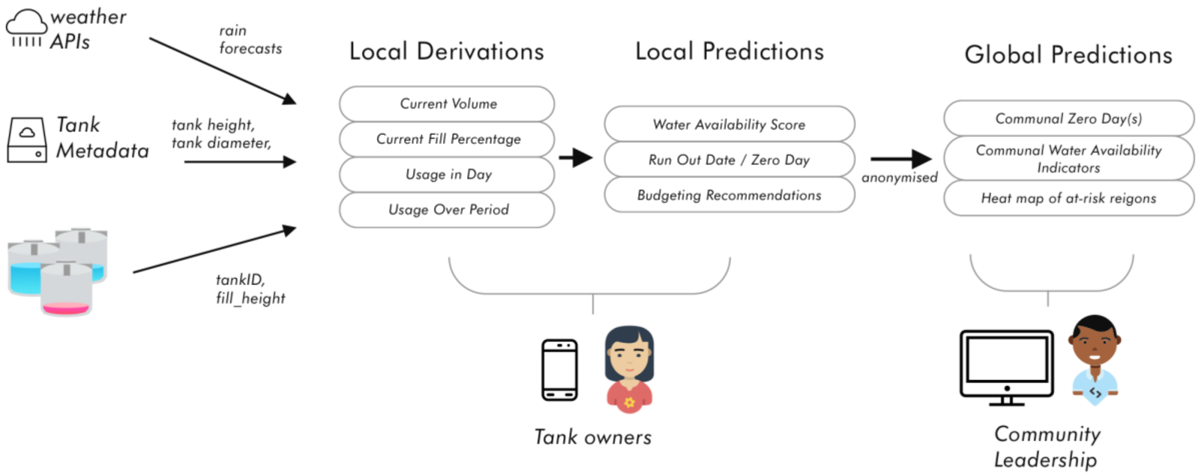

Figure 4: High-level visualisation of the proposed data processing architecture.

The data processing stack was implemented using the AWS serverless architecture. All data transmission and storage frameworks were compliant with the New Zealand Public Sector Cloud Risk criteria and privacy/security obligations. The high-level business logic used to initially identify local derivations and predictions was expressed in Figure 5. It may be seen that the predicted runout date, or zero day, is determined as a weighted sum of precipitation forecasts, current water level, and both recent and periodic water consumption patterns. Periodic consumption includes weekly, monthly and seasonal usage trends as this data becomes available.

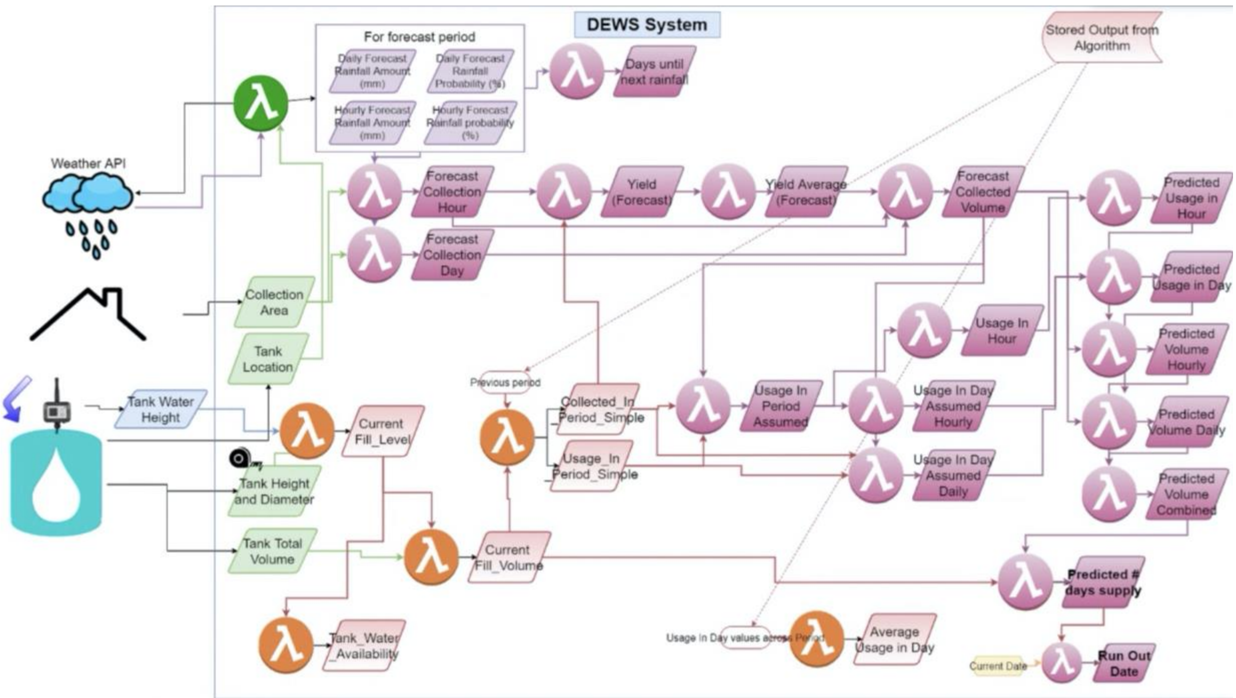

Figure 5: Prototype business rules used to predict individual tank runout dates (source: IoT Water).

2.4 SOFTWARE – USER ENGAGEMENT

The processed information was made available to households through a dashboard-styled interface. To minimise development time, this interface was implemented as a device-independent React.JS application. This allowed the application to scale across mobile, tablet and web browsers. Each interface included several *views* that illustrated the information and predictions made about their tank. An example of an owner's summary view may be seen in Figure 6.1. As indicated by the name, this view summaries the most important high-level information about their tank at a glance. In this view, a water-availability score based on weather forecasts and tank usage is given. Historic information was also accessible in the form of fill graphs and usage graphs, as depicted in Figure 6.2. These visualisations are designed to help owners understand their typical usage patterns. The interface acts as a communication platform during water shortages or in the event of anomalous usage such as leaks. Furthermore, they were key to community buy-in and a sense of inclusion with the pilot.

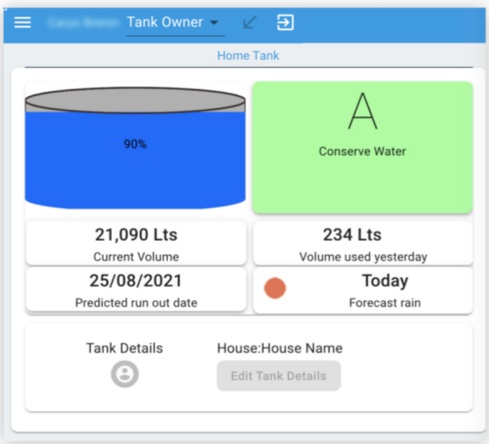

Figure 6.1: Web interface showing owner summary view.

Figure 6.2: Web interface showing owner historic tank level view.

Community (group) views were made accessible to community water committee managers and relevant governing bodies. The *community overview* allowed a community water manager to quickly view the water situation of the community as a whole, and the water availability of tanks within that community. In this view, the distribution of water availability scores across the community may be seen. The current, and predicted, water utilisation in the community was also accessible. The communal trends were visible over time in both litres and relative percentage changes.

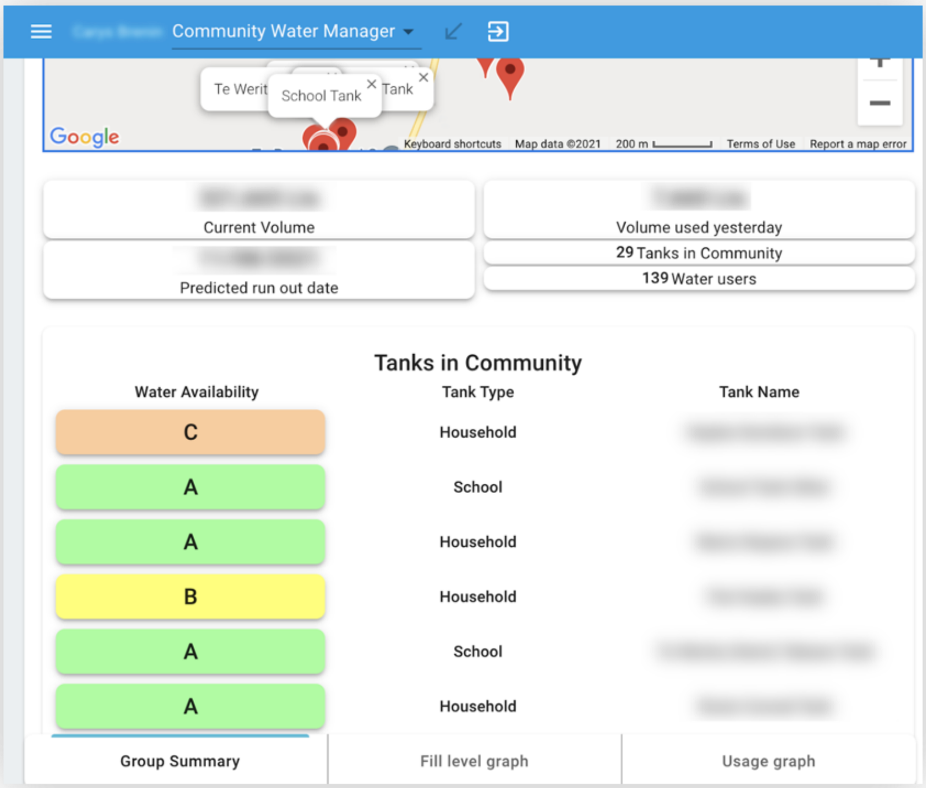

Figure 7: Web interface showing community water manager summary view (identifying information has been blurred to protect the anonymity of participants).

3. PILOT IMPLEMENTATION

3.1 LOCATION

A New Zealand-based pilot community was pursued in favour of a Pacific-based community. Piloting the prototype network within New Zealand boasted several advantages. These included, accessibility of pilot locations, and partnership with a higher distribution of digitally-experienced users. Cultural similarities may aid in a greater willingness to communicate instances of early-stage design faults and bugs. Following communications with townships across Canterbury, Whangārei the Far North District, two pilot communities were selected.

Ngunguru and Te Kao were chosen as they offered a range of residential and communal tank assets across coastal and inland locations. Through an opt-in process, a total of 30 tanks were selected to participate in the pilot. To best simulate the Pacific context, a diverse range of tank materials, sizes and shapes were selected. These featured modern concrete tanks (less than 10 years old), old concrete tanks and plastic tanks. Furthermore, communal tanks on commercial and recreational sites were included in the pilot network.

3.2 HARDWARE INSTALLATION

Tank monitors were installed across Ngunguru and Te Kao with the support of the Northland Regional Council (NRC). The installation process included the setup of base stations, mounting of remote monitors, and pressure sensor. Each monitor was activated paired with the closest LoRa base station. Meta-data about each tank including the tank dimensions, typical usage and owner details were recorded during this process.

As seen in Figure 8, installations took place across a variety of concrete and plastic tanks. It was recognised that caution was required when working with older concrete tanks. This was from both the point of view of the risk of collapse, and contaminants entering the tank. As seen in Figure 8.3, tanks without an easily-accessible lid required a 25mm hole for the pressure sensor entryway.

Figure 8.1: Installation of monitor on an old concrete tank.

Figure 8.2: Installation of monitor on a new concrete tank.

Figure 8.3: Installation of monitor on a plastic tank.

Some modern tanks feature traceable model numbers that may be used to determine the tank volume and production dimensions. However, as these model numbers are not present on concrete tanks or older plastic variants, it was assumed that model numbers may not be relied upon in the Pacific context. To overcome this, the height between the inlet and outlet, as well as the circumference of the tank were measured onsite with a tape measure. By modelling the tank as a perfect cylinder, the volume was approximated by rounding down to the nearest common tank capacity. For example, a measured 34,762 litre volume would be assumed to be a 30,000 litre tank.

Two LoRaWAN base stations were installed, with one servicing the Te Kao network, and the other servicing the Ngunguru network. The Te Kao base station was installed on an outdoor mast near the epicentre of all associated tank monitors. Whilst the Ngunguru base station also possessed 4G backhaul, it was initially connected to a household internet modem. This indoor base station setup was used to assess the viability of using a pre-existing household internet connection.

4. System Evaluation

4.1 HARDWARE INSTALLATION AND PERFORMANCE

Two notable issues were identified during the installation process. Firstly, many tanks had excess cable length, as seen in Figure 9.1. If this cable slipped from its fastening, the accuracy of the water level readings would be compromised. This was overcome by placing a cable tie around the coils in Figure 9.2. Silicon paste was placed around this to secure it in place in the tank grooves. However, this relied on the silicon drying relatively quickly and the cable not slipping within the cable tie.

Figure 9.1: Excess sensor cable on tank.

Figure 9.2: Coiling and tying of excess sensor cable.

Secondly, accurately measuring the height from the sensor to the outlet was difficult, especially with a dual tank system and the outlet on the other tank. For example, in some systems it is not obvious what areas of roof feed the tank, or what the height of the outlet was. Given the importance of reliable tank measurements, further investigation should be undertaken to simplify and standardise the required tank measurements. These procedures should be detailed in a more simplified and illustrative installation guide. As Pacific-installations would initially be carried out by individuals with little to no prior experience, illustrations and infographics should be more widely used.

Following the initial installation, 25 of the 30 installed monitors performed without any recognised faults or issues. Consistent data packets were received from all devices at the expected hourly intervals. The only identified fault was that five monitors reported fill heights greater than the tank total height several weeks into the pilot. Following inspections from a Northland Regional Council team, the pressure sensors were found to have moved after installation and were resting on the bottom of the tank. Due to this, the fill heights in these tanks were 100-200mm greater than the measured height. Once these sensors were repositioned, no further faults were identified with the monitors. As seen in Figure 10.2, coils were kept within the tank for wind shielding where possible.

Figure 10.1: Loosened sensor cable coils due to weather conditions.

Figure 10.2: Coiling and tying of excess sensor cable inside a concrete tank.

This finding reaffirmed the installation feedback that the monitors were difficult to secure, and an alternative fixture method was required. Whilst the monitor mounting brackets could withstand up to 78 ms^{-1} gusts (greater than that of a Category Five cyclone), the coiled sensor cabling may pose risk of slipping in extreme weather events. To combat this, the ease-of-installation and device security criteria was updated to require a more suitable fixture method.

The measurements of the tank height and diameter were found to be prone to human parallax and zero measure errors. For example, the inlet-to-outlet height measurement was found to typically possess a ±100mm uncertainty. For a 30,000 litre water tank with a height of 3.2m, this alone would account for a ±3.2%, or ±1000 litre, error margin. Furthermore, each tank was modelled as a perfect cylinder with its volume approximated as the nearest whole standardised tank capacity. This tank model failed to account for variable cross-sectional area or wall thickness, and that the bottom 5-15% of many water tanks contain accumulated silt and sludge that is undrinkable. As less than a quarter of the pilot tanks possessed traceable or readable model/serial numbers, on-site measurements were the most reliable modelling method. Further research should be undertaken to assess if these uncertainties compound, or if they are destructive. By identifying a typical error margin on detected water levels and tank volumes, their impact on data processing algorithms may be better understood.

4.2 NETWORK STABILITY

All 30 monitors transmitted at the expected intervals without any recognised downtime or data corruption. The remote Te Kao network performed with a near-100% uptime and did not require any maintenance. However, the household internet-connected Ngunguru base station was observed to go offline overnight. Following communication with the household, the issue was attributed to the router disconnecting overnight. In response, the base station was switched to a 4G backhaul. Based on operating logs, the network did not experience any further connectivity issues and has held a near 100% uptime following the transition.

Whilst connecting to household internet is cheaper than a 4G subscription, there would be associated risk in the dependency on the household. The topology of LoRaWAN inherently faces this problem due to the dependency on LoRaWAN gateways. This reduces hardware costs in high-density environments, but if a base station goes down, the entire network would be crippled. For remote and low-density regions, the emerging field of low-earth-orbit satellite networking may be a well-suited alternative. Satellite platforms like Myriota may be the lowest-cost means of operating an early-warning network in remote regions. This is because the installation and connectivity of remote monitors would no longer be dependent on the installation and operation of nearby LoRa base stations.

4.3 DATA PROCESSING

As the stored datasets grew over the duration of the pilot, the latency in displaying historic information in the user interfaces became noticeable. To combat this, a data lifecycle plan was developed in Figure 11. This process distilled historical data into key values. In doing this, the storage and performance costs of a widespread system rollout would be significantly reduced. As the pilot datasets continue to mature, a cost-benefit analysis should be conducted to better determine which historical data should be stored.

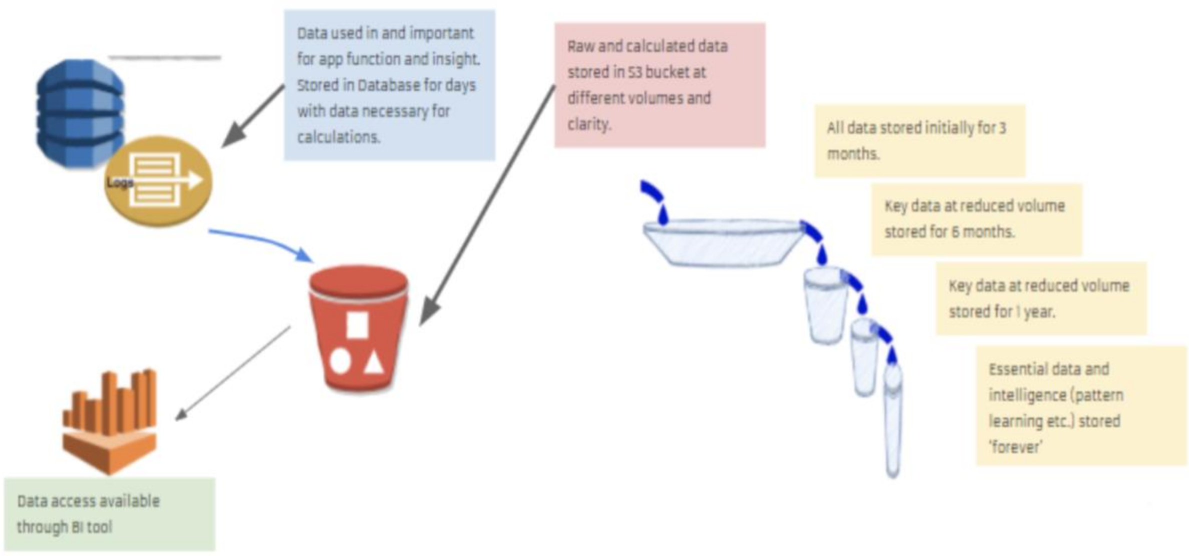

Figure 11: Access and distillation of tank data over time periods (source: IoT Water).

Challenges were faced in the integration of data from various sources and interfaces. Whilst monitoring devices transmitted updates hourly, it was unfeasible to have these transmissions occurring on-the-hour synchronisation. Data interpretation was required to align data periods between weather and monitoring sources in order to perform analytics. This identified the need to make predictions resilient against missing water level readings due to device malfunctions or network downtime.

Using the initial six months of collected data, the accuracy of the zero day predictions were evaluated. As no tanks ran dry during the pilot, linear usage trends were instead estimated from the zero day predictions and were compared against the actual usages. This was achieved by splitting the historic fill data of each tank into 5 months of training data and one month of test data. For a two-week prediction, the fill level of 43.3% of tanks were approximated within ±20% of the actual fill. For a ±30% tolerance, the fill level of 63.3% of tanks were correctly found. Whilst the accuracy of the zero day predictions did not meet initial expectations, they held reasonable performance for initial prototype algorithms. The low-accuracy of the predictions were attributed to several key factors:

- User behaviour is inherently non-uniform. Water usage varies heavily both seasonally and weekly. For example, if a household had another family staying, their water consumption would radically increase. If a family went on holiday, or a drought warning was put in place, the water consumption would plateau.
- Five months is insufficient time to reliably predict the usage patterns of a household or communal cistern. As the datasets mature over time, usage predictions may become more resilient to seasonal and short-term usage variations.
- The contexts of some tanks, especially communal and commercial tanks, may need to be accounted for. For example, school tanks may see significantly less usage during holiday periods.
- Some households had routine water tank refills that were irrespective of the fill level.
- As the total rooftop area, or harvesting efficiency of rainwater tanks could not easily be determined, the increase in tank volume from a rain event had to be estimated empirically during rain events over the pilot.
- Comparing actual fill levels to a linear line between the end of the test dataset and the predicted runout date assumes linear water consumption over the test period, which isn't the case. The next evaluation should compare the actual and predicted dates when the water level would dip below certain levels, such as 50%.
- The accuracy of communal, and regional, predictions will be heavily dependent on the density of connected tanks within the respective region, as well as the distribution of communal and residential tanks. If the selected set of tanks are not analogous to the trends of the wider community, regional predictions may be unreliable.

Due to this, the resolution at which zero day predictions are made should be more thoroughly considered. This is true for both the accuracy in which the runout date may feasibly be made, and the level of detail that stakeholders will find valuable. Predicting water availability is as much of a human behavioural challenge as it is a technical challenge. Greater data availability and the adoption of sophisticated deep learning models are almost certain to improve the current early-stage predictions. But it must be recognised that the aim of this system is to be a *water shortage* detection system, not a high-resolution *water level* detection system.

If more robust, albeit lower resolution, predictions are sufficient for community water managers and governing agencies, these should be developed in favour of more complex algorithms. By gaining a deeper understanding of the value of information to each stakeholder, the cost of developing high-fidelity predictions may be expended only where necessary. Once 12 months of usage data across the Northland pilots have been recorded, a more comprehensive analysis should be conducted on the current methods.

4.4 User Engagement

During the last six weeks of the trial, only 38% of registered trial users accessed the owner application. Out of the users logged onto the system over this period, 70% accessed it more than once. From a total of 55 logins during this period, 28 of these were from a single household. Having a minority of tank owners log in to use the system could be due to several factors:

- The time of year. As this is not a period of traditional drought, many users may not see the need to regularly view their tank levels.
- In Te Kao, it was apparent that the piloting of the DEWS system was largely driven by community leaders. This may contribute to a feeling from individual households that they do not need to engage personally, or that they already have the means of determining their water level.
- There was a delay between the device installation and being able to access the application. This latency may have dampened the novelty of using the application.
- Login behaviour was not logged during the first months of the pilot. Users may have initially logged in during this period and have not had the need to use the application since.

As an early warning system, the fundamental purpose of the owner application is to *alert* owners. The application may then inform owners of any required rationing, and provide feedback on the sustainability of their usage. However, without the stimulus of a water shortage, the motivation to use the owner application was found to be driven by curiosity or the ease of occasionally checking water availability. In future installations of the DEWS system, users will be logged in and shown the application during the device installation. This will both enable the installation team to confirm that owners can access it, and demonstrate the value and usage of the interface.

However, follow up interviews with partnering organisations revealed that the owner interface is unlikely to port well within the Pacific context. This is because many households in rural atolls lack internet or smartphones capable of running sophisticated web apps. In light of this, the use of a SMS-based text interface was considered. Updates and alerts could be intermittently sent to users through a text-based interface. This would not only reduce the development and maintenance costs of the system, but also enable translated and personalised alerts easier to deliver. This would greatly improve the accessibility of the pilot as users would not require smartphones, or cellular/internet credit to use the service.

The digital interfaces instead deliver the most value to community water managers and governing bodies. As this tool is the only means for these stakeholders to gain transparency of the water availability across a region, the existing procedures and responses of these stakeholders should be better understood. Instead of developing the current prototype interfaces into production applications, the use of existing ecosystems should be prioritised. For example, by developing the DEWS interface within the NIWA CliDEsc platform, the technology may be integrated within the existing tech ecosystems within the Pacific. As may be seen from Figure 12.1 and Figure 12.2, CliDEsc already possesses topographical and graphical widgets that would meet the requirements for a regional water management interface.

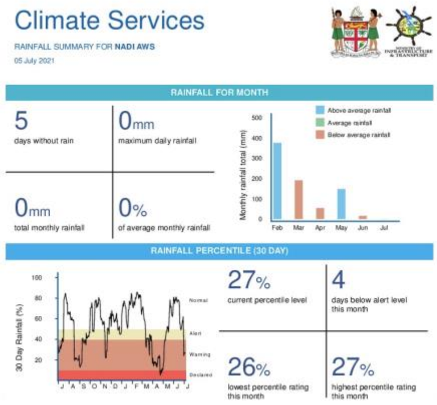

Figure 12.1: CLEWS Fiji - Rainfall Report (Fiji Meteorological Service, 2021).

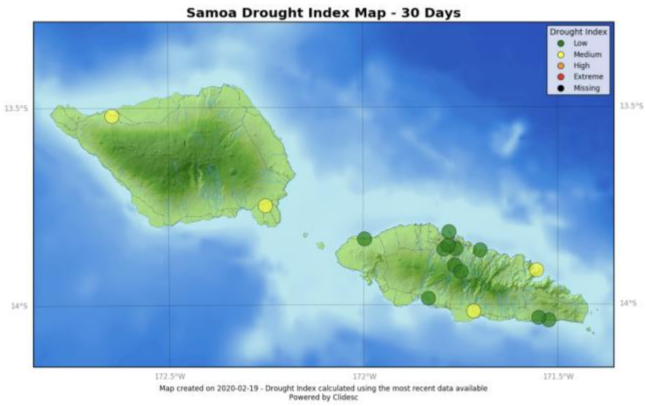

Figure 12.2: CLEWS Samoa Drought Index Map (NIWA, 2020).

5. NEXT STEPS

Having identified the capabilities, shortcomings, and required developments of the Northland pilot, the technical stability of the system was considered to meet the first-stage success. In addition to rectifying the identified areas of development, the second phase of the pilot will focus on the adoption of such a network by key stakeholders in the Pacific. The key objectives of phase two are to:

- Engage the Pacific Community (SPC) and Infrastructure Cook Islands (ICI) to identify the best means of integrating this system within currently used methods and practices for monitoring and managing water resources.
- Undertake an evaluation programme that assesses user perceptions of the pilot and tests whether access to the system changes water management behaviours.
- Detail a Sustainability Road Map that outlines DEWS sustainability as a tool in future rollouts that may be requested by PIC Governments. This may include software and hardware capex considerations, as well as opex considerations.
- Compose a deployment manual that includes engagement protocols, user agreement templates, privacy statements, an installation guide, and train-the-trainer material.
- Develop a communications system that is able to be readily customisable and used by local governments to provide water management messaging specific to each island context.
- Develop remote monitors with satellite-based communication capabilities (and testing these on the atoll of Tongareva.
- Explore radar-based alternatives to differential pressure gauges, and trialling these on

plastic tanks in Aitutaki.

Ensuring that these systems are easily adoptable and valuable within the socio-cultural context of the Pacific will be key to the success of this system in supporting Pacific communities to proactively monitor their water resources. If successfully adopted, this technology may provide the necessary insight and foresight to mobilise relief efforts before emerging water *shortages* become water *crises*.

6. CONCLUSION

The first stage of the DEWS pilot assessed the technical feasibility of using a remote tank-monitoring network as a low-cost drought early warning system. This was accomplished through a trial network of 30 remote tank monitors installed in the Northland region. Overall, the proposed system showed strong performance with all tank monitors transmitting hourly updates through LoRaWAN networks with a near-100% uptime. However, several key shortcomings of the current system were identified. These included the need for a robust method of securing excess coils of the pressure gauge cable, and ensuring that user accounts may be set up during installation. The slippage of five tank pressure sensors identified the need for improved installation standards that are suitable across a wider range of plastic and concrete tanks.

With water usage predictions being a key output of the proposed system, careful considerations need to be made in the storage and processing of tank data. Matured, or older, datasets help to improve predicted usage by smoothing anomalous short-term behaviour. However, with hourly updates from each tank, the distillation of this information over time was key to ensuring that this system may scale to larger networks. The resolution at which predictions could be reliably made, both at residential and regional levels, also requires further investigation. Several factors were recognised to produce low-resolution predictions, with the incorrect measurement of tank dimensions being the most significant. The initial accuracy of zero day predictions were lower than anticipated, but within the range of acceptable performance. This was due to the complexity of modelling non-linear user behaviour, the immaturity of the available data and the early-stage of data processing development.

Having validated the technical feasibility of the system in New Zealand, the second phase of the pilot will focus on adapting the network to ensure it meets the needs of stakeholders in the Pacific. This will involve the continued exploration of a number of alternative technologies including satellite-connectivity, radar-based water level detection, and the integration with NIWA’s CliDEsc platform. If successful, this technology may hold a vital role in ensuring the diagnosis and informed response to drought-affected communities.

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REFERENCES

McGree, S., Schreider, S. and Kuleshov, Y. (2016). *Trends and Variability in Droughts in the Pacific Islands and Northeast Australia*. Journal of Climate, 29(23), pp.8377–8397.

Iese, V., Kiem, A.S., Mariner, A., Malsale, P., Tofaeono, T., Kirono, D.G.C., Round, V., Heady, C., Tigona, R., Veisa, F., Posanau, K., Aiono, F., Haruhiru, A., Daphne, A., Vainikolo, V. and Iona, N. (2021). *Historical and future drought impacts in the Pacific islands and atolls.* Climatic Change, 166(1-2).

Dixon-Jain, P., Norman, R., Stewart, G., Fontaine, K., Walker, K., Sundaram, B., Flannery, E., Riddell, A., Wallace, L. 2014. *Pacific Island Groundwater and Future Climates: First-Pass Regional Vulnerability Assessment.* Record 2014/043. Geoscience Australia, Canberra. http://dx.doi.org/10.11636/Record.2014.043

The Beehive. (2018). *New Zealand increases climate finance commitment to Pacific.* [online] Available at: https://www.beehive.govt.nz/release/new-zealand-increases-climate-finance-commitment- pacific [Accessed 8 Jun. 2021].

Falkland, T. GHD Pty Ltd, (2011). *Pacific Adaptation Strategy Assistance Program Report on Water Security & Vulnerability to Climate Change and Other Impacts in Pacific Island Countries and East Timor* [online] . Available at: https://www.theprif.org/sites/default/files/documents/water_security_in_pics_east_timor_for_dccee_by_tony_falkland_final.pdf [Accessed 6 Jun. 2021].

IoT Water. (2019). *Tank View*. [online] Available at: www.tankview.org/ [Accessed 6 Jul. 2021].

NIWA. (2020). *CLEWS Samoa - Drought Risk.* [online] Available at: http://www.samet.gov.ws/climate/drought_30.php [Accessed 3 Jun. 2021].

Fiji Meteorological Service, NIWA. (2021). *CLEWS Fiji - Rainfall Report* . [online] Available at: https://www.met.gov.fj/climate/m/rainreport.php [Accessed 3 Jun. 2021].