# Predicting End of Life for Single-use Batteries in WA Environmental Conditions

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**Abstract**

*This project intends to estimate actual battery life of single-use batteries used in Water Corporation's water meters across the state. The results will be utilised by the client to inform maintenance strategies, reducing costs of unplanned replacement of meters due to premature failures and reducing instances of gaps in data logged.*

*Field data analysis and accelerated life experiments have been conducted with focus on investigating the impact of elevated temperatures on battery life. An exponential discharge curve over time has been fitted to the data. From this, the reduction in battery life compared to the rated life has been estimated for each region. In experiments thus far, an increased discharge rate has been seen at higher temperatures for loggers operating as normal. However, the opposite tendency has been seen in the accelerated loggers.*

## 1. Introduction

Water Corporation utilises digital meters collecting data on water usage across Western Australia. These meters are powered by single-use Lithium/Thionyl Chloride ($Li/SOCl_2$) batteries, having a predicted 5-year life specified by the supplier. However, they have been found to reach the end of their useful life prematurely in Western Australia. The graph below shows data extracted from the Outpost database on the 10th of August 2023 for a typical meter having reached end of life.

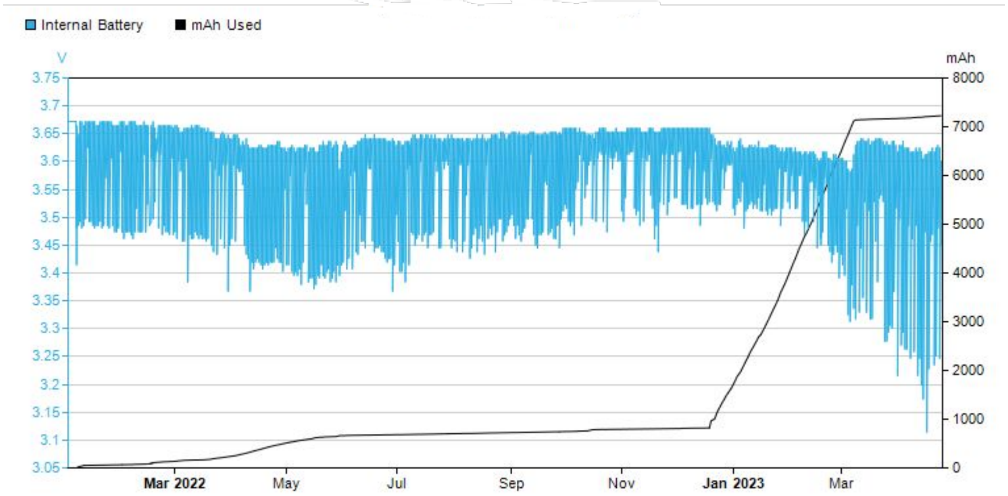



**Figure 1** Battery voltage and current draw over time for meter op59158

A slight variation in voltage is observed throughout its life, and then a reduction in voltage and increased rate of discharge is seen in the months leading up to the logger going offline.
This uncertainty in operating life leads to reactive maintenance and gaps in data due to sudden meter failure prior to the planned replacement date. By predicting end of life of the battery, replacements may be scheduled in a strategic manner, saving on reactive replacement costs.

Reliable operation of these meters allows for effective and continuous monitoring of water leakages. By quickly and consistently detecting excessive water usage, issues may be rectified in a timely manner. Water balance may be improved by reduction of water lost to leaks and not recorded due to meters not working (often referred to as non-revenue water). This in turn improves sustainability of the operations.

## 1.1 Temperature impact on battery life

Single-use $Li/SOCl_2$ batteries are widely used due to their high energy density, high and constant operating voltage, wide range of operating temperatures and long storage life (Ye, Sun, Li, & Zhai, 2021; Băjenescu, 1992; Jain, Nagasubramanian, Jungst, & Weidner, 1999). Battery open circuit voltage is often used as an estimate for battery capacity. However, due to the voltage remaining constant throughout most of the life for these batteries, other measures must be used to accurately estimate remaining life for $Li/SOCl_2$ batteries.

The long shelf life of these batteries is due to a passivation layer forming on the anode, prohibiting reaction and thus limiting self-discharge (Jain, Nagasubramanian, Jungst, & Weidner, 1999). However, this phenomenon also means that upon start-up, a higher voltage is required for the battery reaction to commence and current to flow. This issue is often overcome by the addition of a capacitor to provide this initial voltage level (Sourmey, 2020).

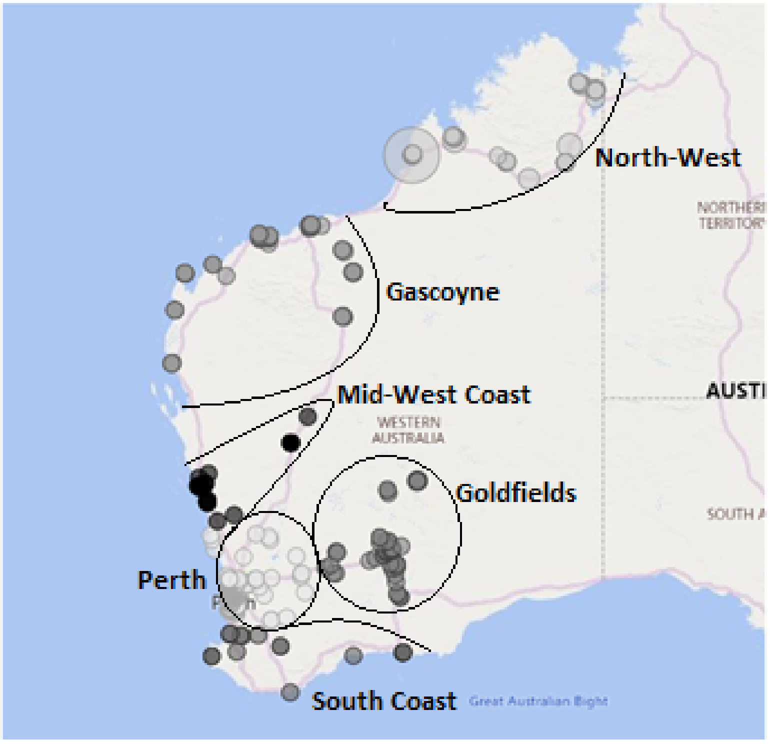
It is suspected that the deviation from the predicted battery life may be due to the environmental conditions in Western Australia. Shorter battery lifespan has been found to be exponentially related to elevated operating temperatures (Duguid, 2016; Fesser, 2018; Kokoh, 2017; Ye, Sun, Li, & Zhai, 2021). Siemens specifies that for their electromagnetic flowmeters a variation in ambient temperature from 15˚C to 50˚C reduces the battery capacity of their D-cell batteries by 17% (SIEMENS, 2014). A trial done on SAFT A-size $Li/SOCl_2$ cells showed a reduction in battery life when operating in the temperature range 16-32˚C compared to 6-21˚C (Kokoh, 2017). However, these trials were based on maximum temperatures much lower and with less variation than arise in Western Australian. Hence, this investigation is to be undertaken to analyse the battery life in Western Australia environmental conditions.

# 2. Methodology

The project consists of two main activities: field data analysis and an accelerated-life experiment at controlled temperatures. Available data and knowledge is reviewed to identify knowledge gaps and potential relationships that may be investigated. From this, an accelerated life experiment is undertaken to investigate suspected data trends and relationships in a controlled environment. Finally, field data and experimental data is analysed to identify trends and visualise the results.

## 2.1 Field Data Analysis

The data loggers record a water reading every 15 minutes and once per day, they record their operating parameters (battery voltage, current drawn, temperature and signal strength). All this data is sent to a database through the mobile 3G or 4G network daily. This data was extracted with help from the supplier to allow for analysis using PoweBI and MATLAB. The data loggers have been grouped by temperature region to analyse the battery characteristics throughout the life for each region as seen in the figure below.




| Average operating temperature (˚C) | Region |
|---|---|
| 28 | North-West |
| 28 | Gascoyne |
| 24 | Mid-West Coast |
| 22 | Perth |
| 21 | Goldfields |
| 20 | South Coast |

**Figure 2** Western Australia Temperature Regions with data logger locations

## 2.2 Accelerated-Life Experiment

The aim of the experiment is to analyse the performance of the meters under controlled operating conditions at specified temperatures. To do this, units are placed in a temperature-controlled incubator. The table below shows the experiments that have been commenced thus far.

| Experiment | Temperature (˚C) | Running time (days) |
|---|---|---|
| 1 | 35 | 22.5 |
| 2 | 45 | 31.5 |
| 3 | 50 | 27.5 |
| 4 | 5 | Current |
| 5 | 25/50 | Current |

**Table 1** Controlled temperature experiments

Two loggers are tested at each temperature, where one operates as normal, collecting data every 15 minutes and sending it to the database once a day. The second logger is collecting and sending data every minute. Each experiment is then run until the accelerated logger has reached end of life. The data is monitored throughout the duration of the experiment and extracted from the online database and analysed upon completion.

# 3. Results and Discussion

## 3.1 Field Data Analysis

From the field data, a consistent discharge is seen throughout most of the life and then accelerated discharge as the voltage decreases towards the end of life. This may be explained by the data loggers requiring constant power, hence the batteries compensate for the lower voltage by increasing the current output. For each region, the average depth of discharge (DOD) has been plotted and an exponential trendline fitted to the data.

The field data for the Goldfields region with a fitted exponential trendline is shown below with 85% DOD highlighted. This is the assumed maximum DOD the units will reach prior to going offline as none of the loggers have been observed to reach a higher DOD than this. Here, an increasing discharge rate is observed throughout the life. There is no data on loggers older than about 3 years (1,100 days).

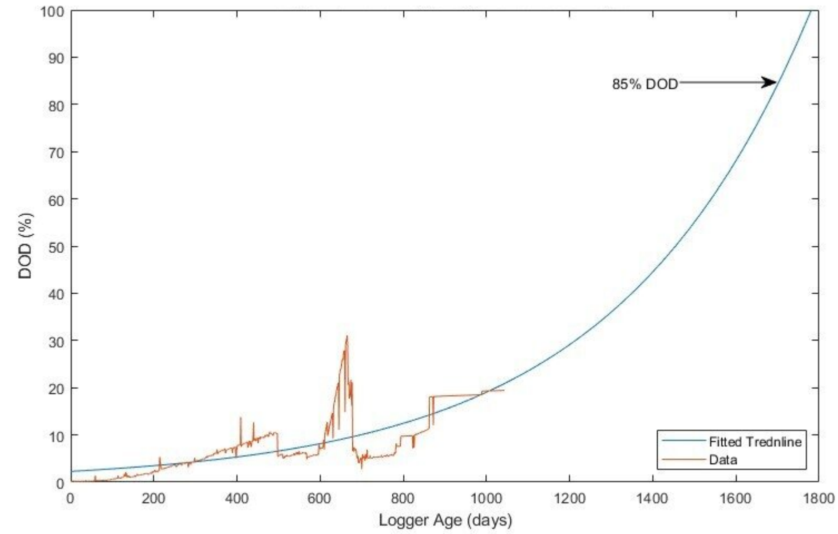



**Figure 3** Average DOD over time with fitted exponential trendline – Goldfields

Based on this, the time to reach 85% DOD was estimated for each region. Figure 4 below shows the average estimated reduction in battery life and average battery temperatures for each region. This shows that the largest reduction in battery life is predicted to be in the regions with highest and lowest average battery temperature, Gascoyne and the South Coast. Reasons for the high discharge rate observed on the South Coast is being investigated. It is important to note that there is only 18 units installed in this region, so the sample size is small. The table below shows the expected battery life and daily discharge for each region.

| Region | Average discharge per day (%) | Average time to reach 85% DOD (years) |
|---|---|---|
| North-West | 0.0690 | 3.38 |
| Gascoyne | 0.0870 | 2.68 |
| Goldfields | 0.0588 | 3.96 |
| Perth | 0.0667 | 3.49 |
| Mid-West Coast | 0.0800 | 2.91 |
| South Coast | 0.0952 | 2.45 |

**Table 2** Estimated average battery life by region

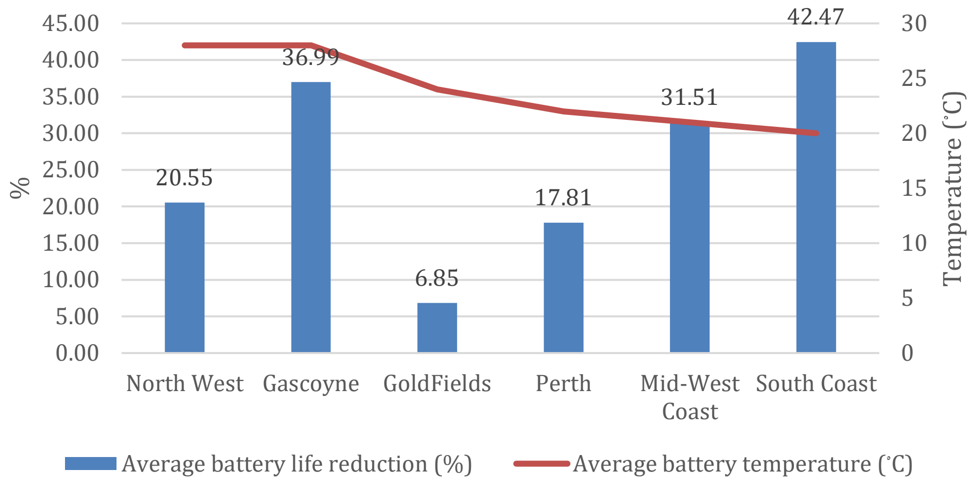



**Figure 4** Estimated battery life reduction and average battery temperature

## 3.2 Accelerated-life Experiment

The figure below shows the experimental results so far. The flat line in the accelerated logger at 45˚C is due to the logger going offline for a few days. This data has been excluded from analysis. Looking at the loggers operating as normal (top), there is an increase in discharge rate with temperature increase as expected. However, the opposite is observed for the accelerated loggers (bottom plot).

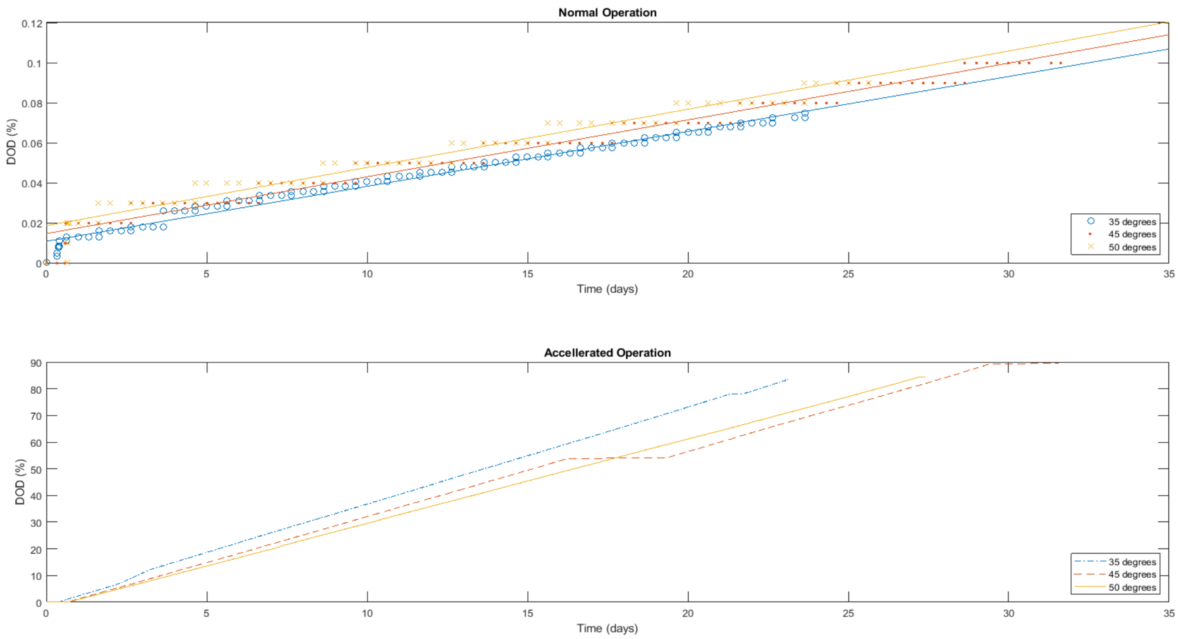



**Figure 5** Controlled temperature experiment depth of discharge (DOD) over time

As seen in Table 3, a larger change in discharge rate per degree is observed between 45˚C and 50˚ C compared to 35˚ C and 45˚ C. This is expected as the relation between capacity reduction and temperature is often described as exponential. However, it is evident that the discharge rate remains approximately constant through the entire experiment. The field data's observed exponential increase near end of life is not observed in the accelerated loggers and the daily discharge under normal operation is much less than observed in the field data (see Table 2).

| Temperature (°C) | % Discharge per day | |
|---|---|---|
| | Normal Operation | Accelerated Operation |
| 35 | 0.0027 | 3.65 |
| 45 | 0.0028 | 3.45 |
| 50 | 0.0029 | 3.17 |

**Table 3** Controlled temperature experiment discharge rates

# 4. Conclusions and Future Work

Discharge rate and remaining life estimations are found to be more accurate when measured by mAh usage rather than operating voltage. It is recommended that mAh usage is focused on in monitoring of the devices. A reduction in battery life has been estimated based on this measure, further testing at lower temperatures may confirm the findings. The discharge curves are linear for most of the life and then exponential as the voltage lowers towards the end of life. The accelerated discharge is not reflected in the experiment. Reasons for this may be the passivation layer not forming between operating cycles in the accelerated units. Due to this, less power is required upon start-up, and so the batteries can supply the required power at the lower voltage.

Further investigations into the reasons for the differences in observations between the experiment and the field data and between the accelerated and non-accelerated units will be conducted through experiments at colder and varying temperatures. Investigations into different hardware versions are being conducted to examine the impact of the passivation with and without a capacitor to mitigate this. Testing of other suppliers' devices will be commenced if time allows.

# 5. Acknowledgements

I would like to extend my gratitude to Andrew for being a great mentor and discussion partner through the project and to Tyrone and Herbert for their advice. Thank you to the team at Outpost for supporting me with knowledge, data, and loggers to test. Finally, thank you to Ratish and Peter at the innovation centre for lending me their equipment and time for my experiments and to the Research and Development team at Water Corporation for funding my project.

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