PRACTICALITIES WHEN APPLYING AS/NZS4853 FOR AC LOW FREQUENCY INDUCTION RISK ASSESSMENT

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ABSTRACT

AS/NZS 4853 Electrical hazards on metallic pipelines prescribes limits for steady state induced voltages from neighbouring electrical sources. Consequently, low frequency induction (LFI) risk assessments need to be undertaken. These assessments contribute to the overall asset management and life expectancy of the pipeline.

When AC voltages exceed the steady state induced voltage limit, high current densities at small coating defects appear causing AC corrosion. This is the result in part from improved coating quality and increasing interaction between pipeline and power transmission infrastructure. Induced voltage limits are provided for soil electrical resistivity ranges: (a) 4 V AC for soil resistivity ≤25 Ω.m; and (b) 10 V AC for soils whose resistivity is >25 Ω.m. Depending on the risk-based assessment outcome, the requirement for risk treatment of LFI for control of pipeline corrosion may be more severe than the requirement for human safety.

This paper reviews the risk assessment process and the practical limitations for calculating steady state impressed voltages. It also proposes an alternative to calculating these voltages. The paper presents a practical case study along the Watercare (Auckland) Huia No.1 & Niho No.1 replacement watermain. Included in the paper is a discussion regarding the limitations when applying AC measurements as a replacement for calculations.

Practical limitations for calculating steady state impressed voltages are more prevalent to urban type areas when compared to rural based areas. The reason for this is that there are usually multiple urban distribution overhead and underground electrical sources along the pipeline route that influence the pipeline. For computer simulated calculations, it is challenging to obtain accurate operating currents at a specific time/day/season as well as the circuit phasing for all electrical sources. As an alternative, for accurate assessments it is adequate to obtain real-time AC voltage test point recordings.

It can be expected that there are differences between measured & calculated AC steady state impressed voltages. These can be attributed either to a single, or a combination of the factors. These factors and an applied project are discussed in the paper.

KEYWORDS

AC measurements, current density, low frequency induction, steady state, watermain, permissible AC voltage

PRESENTER PROFILE

Tony has more than 40 years of engineering years’ experience and has undertaken numerous risk assessment and control of low frequency induction (LFI) and earth potential rise (EPR) assignments along metal pipelines. Assessment projects include water and gas pipelines from overhead, underground and traction electrical sources in New Zealand and Australia. He is currently the only New Zealand based SES Canada Level 2 Certificated CDEGS software user for specialisation in Advanced Substation Grounding and Electromagnetic Interference (EMI). Tony has a PhD (Electrical Engineering) and a Laureatus in Technology (Doctorate in Technology). He is registered as a Chartered Engineer (CEng) in the United Kingdom and a professional engineer in Australia (PREng) and Queensland (RPEQ).

1 BACKGROUND

1.1 PURPOSE AND SCOPE OF ASSESSMENT

The purpose of the Watercare initiated electrical hazard assessment was to address legal obligations under the Health and Safety in Employment (Pipelines) Regulations 1999. It specifically relates to the identification and risk management of electrical hazards as defined in AS/NZS4853 – in particular, Section 5 Design Process (New Zealand only).

The scope of work was to assess by calculation and measurement the potential electrical hazard along the water pipeline demarcated by WSL – Huia No.1 & Niho No. 1 replacement pipeline and illustrated in Figure 1. Although the initial scope of the project was to assess electrical hazards due to both low frequency induction (LFI) and earth potential rise (EPR), this paper addresses only the LFI generated from the surrounding electrical sources under steady state AC operating conditions.

The water pipeline is installed within an urban area which contains numerous urban distribution overhead lines and underground cables. These distribution power lines consist of both MV & LV multi-circuits and are typically illustrated in Figure 2. In addition to the former multi-circuits, the following five transmission lines are considered in this electrical hazard assessment:

- 110-kV Henderson-Roskill (HEN-ROS)
- 110-kV Hepburn-Roskill (HEP-ROS)
- 110-kV Mangere–Roskill (MNG-ROS)
- 110-kV Penrose–Roskill (PEN-ROS)
- 220-kV Henderson–Otahuhu (HEN-OTA)

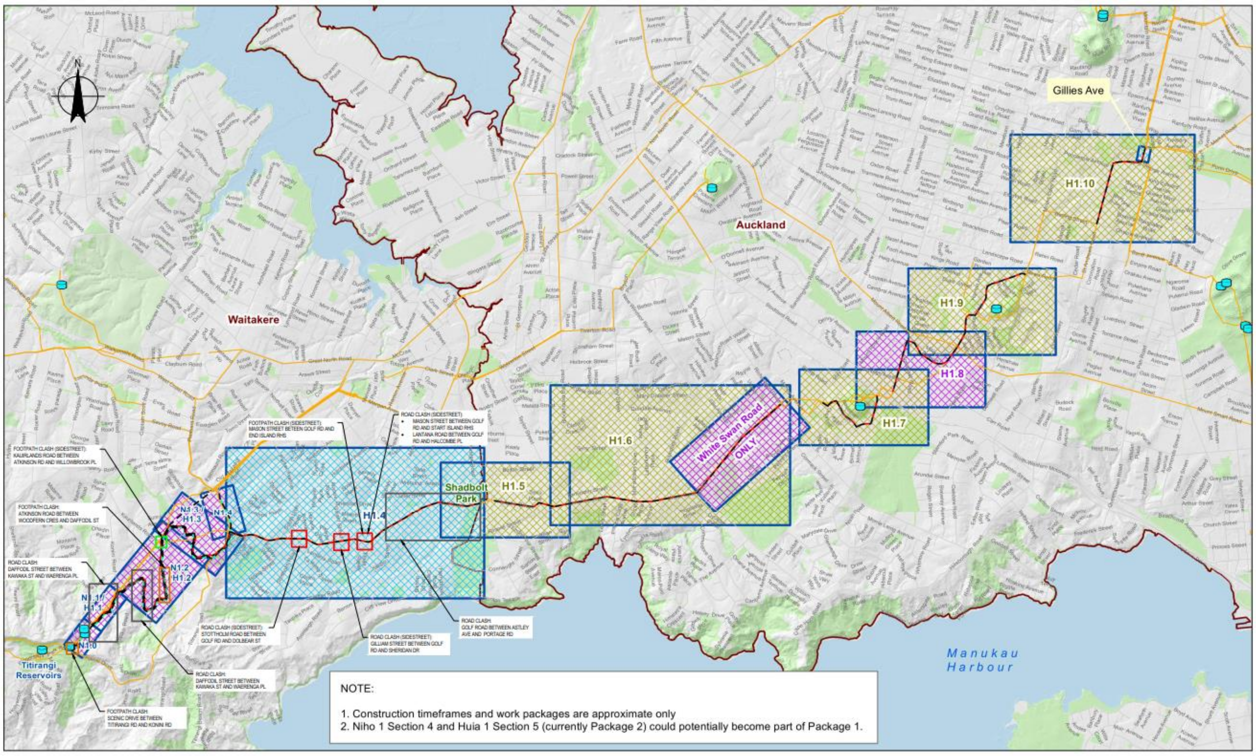

Figure 1: Huia No. 1 Watermain Replacement Cover Sheet & Locality Plan

Figure 2: Distribution low voltage and medium voltage multi-circuit power lines

1.2 MECHANISM OF AC CORROSION

Metal pipelines provided with high resistant coatings are subject to alternating current (AC) induction from parallel overhead and or underground electrical sources. AC corrosion is the metal loss that occurs from an AC current source transferred along a metallic pipeline at a defective point in the protective coating. A defect is commonly named a ‘holiday’. A holiday may include lack of bonding, pinholes, cracks in coating and insufficient or excessive film thickness. Pinholes and holidays are illustrated in Figure 3. These defects expose the unprotected metal surface to either the atmosphere for above ground, or soil for underground installed pipelines.

(a) Pinholes[1] (b) Holiday[2]

Figure 3: Pipeline defects

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[1] Source: https://epr-inc.com/blog/pinholes

[2] Source: https://www.corrosionclinic.com/types_of_corrosion/what-is-AC-corrosion-of-underground-pipelines.htm

The rate of corrosion and severity of metal pipeline corrosion in soil depends on high electrical conductivity, high levels of moisture and high levels of dissolved salts and acidity. The mechanism of AC corrosion includes electrical factors such as the magnitude of the induced voltage, the magnitude of the AC-current through a coating defect (per unit area of the defect), or the level of cathodic protection (CP) supplied to the pipe.

Assuming a uniform soil resistivity along a length of metal pipeline, an uncoated pipeline will have a uniformly distributed resistance. For a high resistance coating, the largest portion of voltage drop is in the vicinity of the coating defect.

The induced AC leads to the discharge of AC current at coating defects. This AC current density will be governed by the AC voltage (i.e. the coating stress voltage) and the area resistance which is influenced by the size of the coating defect, the soil resistivity at the coating defect, the structural properties of the soil, and by the cathodic protection current density in the coating defect. The AC current density may lead to direct current (DC) depolarization. This means that a higher DC CP current density is required to maintain a certain cathodic protection potential.

1.3 DIFFERENCE BETWEEN AC CORROSION AND STRAY CURRENT CORROSION

Stray current corrosion is caused by DC current typical from traction supplies and are not affected by the orientation of the pipeline to the DC source – i.e. perpendicular or in parallel. AC corrosion is caused by AC current sources typically from overhead lines and cables laid in parallel with pipelines. The severity of damage by DC stray current corrosion is much greater than that by AC corrosion. AC corrosion can be effectively prevented through the control of:

- AC current density
- AC voltage
- AC to DC current density
- Cathodic Polarization

AC corrosion can be predicted by utilising using software such as CDEGS. Alternatively, AC measurements can be obtained at existing test points along the pipeline.

2 SOURCES OF ELECTRICAL HAZARDS ON PIPELINES

2.1 GENERAL

Electrical hazards on pipelines can be caused by numerous coupling mechanisms which transfer electrical energy onto to the pipeline. These mechanisms include both steady state and intermittent conditions which are discussed below.

2.2 STEADY STATE CONDITIONS

Under steady state conditions there are three main coupling mechanisms. These include low frequency induction, conductive coupling and capacitive coupling.

2.2.1 LOW FREQUECY INDUCTION

Low frequency induction (LFI) is the dominant interference mechanism during steady state transfer conditions in parallel sections. It is also relevant for single phase earth fault conditions. The load current flowing in three phase conductors is relatively low in magnitude when compared to fault conditions. The electromagnetic interference is due to the difference in the relative distance of each phase from the nearby pipeline and any unbalance in the currents the three phases carry as well as currents induced in the shield wires. There are numerous distribution voltage level electrical sources along the existing and Watercare pipeline route. These are in the form of Vector's underground high voltage (HV – 33kV) and medium voltage (MV – 11kV) cables, overhead power lines and pad-mount transformers (11kV/400V).

2.2.2 CAPACITIVE COUPLING

Capacitive coupling is the condition whereby the capacitance between the phase conductors or any metal object which is located above ground. The pipeline voltage is proportional to the voltage of the power line and the capacitances. The electromagnetic interference due to capacitive coupling is a function of the system voltage and the relative distance of each phase from the nearby pipeline. Induced voltages on unmitigated pipelines can be excessive where the water pipe runs 'above ground' and parallel to the power line. Relative to the total length of pipelines, these areas are generally negligible as most pipelines within New Zealand are buried. For purposes of this report assessment the capacitive interference is ignored as the entire pipeline is buried.

2.2.3 CONDUCTIVE COUPLING

During a single phase-to-earth fault anywhere along the electrical sources, a large fault current returns to the source by being distributed via the soil, underground metallic objects (pipeline) and cable screens. The local soil voltage surrounding the faulted asset and the induced voltages in an unprotected water pipeline can reach thousands of volts. This represents a safety hazard at exposed water pipelines appurtenances. In addition, accelerated corrosion in areas of damaged pipeline coating may also be a consequence. The magnitude of this conductive interference is primarily a function of the earth potential rise (EPR) of the overhead line (OHL) structure; the separation distance; and the size of the structure earthing system; soil structure; and the pipeline coating resistance. The induced voltage may exceed the insulation strength of the pipeline coating and equipment, therefore compromising the integrity.

Although conductive coupling is primarily under earth faults, single wire earth return (SWER) networks present conductive coupling under steady state conditions. Also, unbalanced phase conductors may cause a current flow along overhead earth conductors. This current will circulate between affected towers via the soil.

2.3 INTERMITTENT CONDITIONS

Intermittent or abnormal operating conditions occur when an earth fault occurs anywhere along an electrical source. During this occurrence, a conductor phase faults to ground resulting in the fault current returning to its origin as discussed in section 2.2.3. This fault current will flow along the path of least resistance. In such a case, any exposed (non-insulated) conductive object will be deemed an attractive path when compared to the soil resistivity (ρ). For purposes of this paper, only steady state conditions are considered – more specifically only low frequency induction (LFI) under steady state conditions.

3 ASSESSMENT

3.1 APPLIED STANDARDS

Main standards applied in the electrical hazard design process include AS/NZS 4853:2012[1]. AS/NZS 60479.1: 2010 Effects of current on human beings & livestock –

General aspects, and AS/NZS 1768: 2007 Lightning protection. Of particular relevance to assessments performed in New Zealand is Section 5 Design Process (New Zealand Only). This section within AS/NZS 4853 contains the electrical hazard design process.

3.2 AC VOLTAGE PIPELINE CORROSION LIMITS

AS/NZS 4853 addresses corrosion resulting from steady state LFI by stipulating steady state induced AC voltage limits for varying soil resistivity. These voltage limits are from previous research documented in the CIGRE TB 290 guideline[2] and state limits are 4 V AC for soil resistivity $\leq$ 25 Ω·m; and 10 V AC for soils whose resistivity is > 25 Ω·m. The intermittent or abnormal condition voltage limits are for equipment integrity and human safety are higher than the AC corrosion limits. For example, equipment integrity limits are listed in Table 1.

Table 1: Equipment integrity assessment

Equipment Subject to Hazard	Voltage Limit (V)
Electrical equipment (ICCP & telemetry)	1,000
Insulation flange kits (FIKs)	1,000
Monolithic insulation joints	5,000
Pipeline coatings	10,000

3.3 CHALLENGES WHEN ASSESSING THE LFI AC VOLTAGE

As previously noted, the water pipeline is installed within an urban area which contains numerous rural distribution overhead lines and underground cables. For computer simulated calculations, it is challenging to obtain accurate operating currents at a specific time/day/season as well as the circuit phasing for all electrical sources. As an alternative to computer calculations, for accurate assessments it is adequate to obtain real-time AC voltage test point recordings.

There will be expected variations between measured & calculated AC steady state LFI impressed voltage results attributed to the following:

a) Real-time operating current is not the same as modelled. Operating currents provided by electricity utilities are provided as maximum, average and minimum values. These may vary significantly during seasons and time of day.
b) The modeling of overhead line assumes consistency in configurations, phase spacing and average conductor height along the entire length of the pipeline. Actual parameters do vary resulting in variations between calculated voltages and measured voltages.
c) Different phasing of multi-circuit powerlines may reduce or increase the overall assessment results.
d) Spatial distances between the actual and model may differ due to variations in the provided source of GIS data for pipeline and overhead lines.
e) Due to the complexity, the shielding effect of multiple earthing networks (MEN) situated between electrical AC sources and pipelines is omitted from modelling.

3.4 ASSESSMENT METHODOLOGY

EPR and LFI induced voltages under intermittent or abnormal conditions can be simulated with reasonable accuracy. To overcome the modeling challenges for AC steady state LFI mentioned above, the real-time voltages have been obtained via measurement from test points (TP) along the pipeline as illustrated in Figure 4. These measured values are compared against the permissible voltage limits. Ideally, there should be additional TP between TP 1 (168 Konini Rd) and TP 2 (1 Connell St). The absence of these TP and their consequence was considered after the results were compared to the steady state voltage limits.

3.5 MEASURED AC VOLTAGES

Measured AC impressed voltages provided over a 24-hour period for each pipeline TP location were obtained [3]. Datalogging sites are listed in Table 2. All results comply with AS/NZS 4853 for soil resistivities of less than, and greater than 25 Ω·m (maximum voltage of 4 V and 10 V respectively). The highest recorded AC voltage of 2.106 V occurs at Mt Roskill TP1 BSP – respectively representing 53% & 21% of the 4 V & 10 V limit. It can be concluded that the pipeline does not incur any potential AC impressed voltage risk. Therefore, no control measures for mitigation are required.

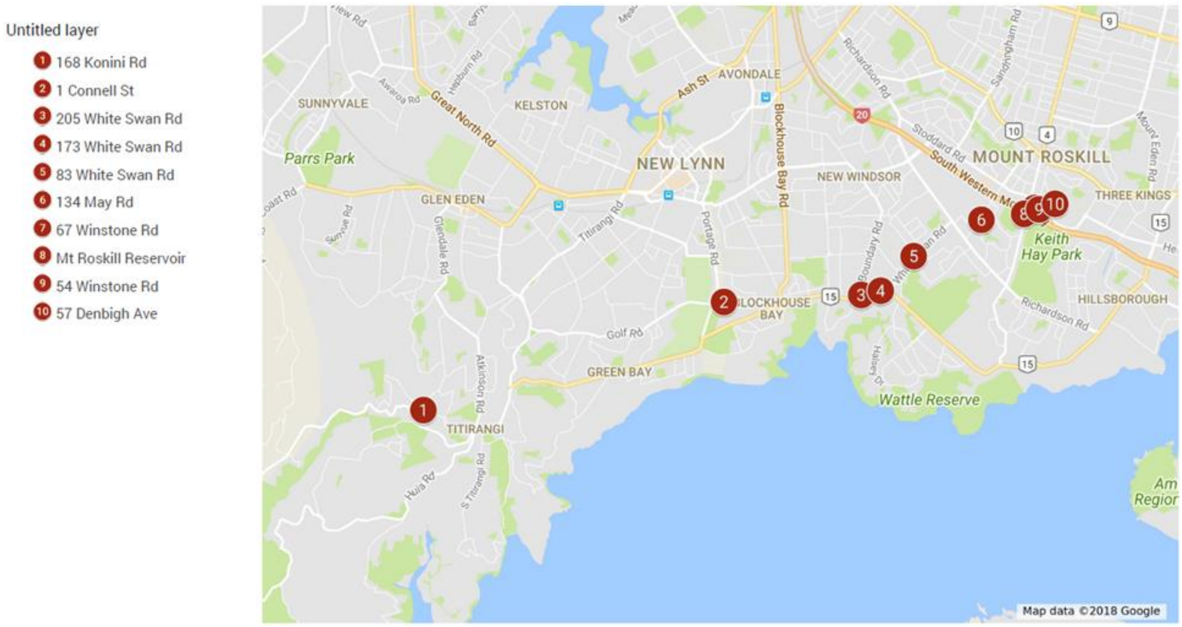

Figure 4: Huia 1 datalog test points

A summary of recorded minimum, maximum and average voltage results are listed in Table 2 below. These represent a summary from graphs for each site illustrating the values of voltage change over a 24-hour period. Figure 5 illustrates the changes in voltage for the recorder installed at Mt Roskil Reservoir TP1 BSP (location demarcated as ‘8’ in Figure 4).

Table 2: Summary of datalogging results

Test Site	Description	Recorded voltage (mV)		
		Minimum	Maximum	Average
1	Titirangi P/S 168 Konini Road	11	504	136
2	1 Connell St	2	743	275
3	205 White Swan Rd BSP	3	262	152
4	173 White Swan Rd	72	902	345
5	83 White Swan Rd	2	450	131
6	134 Mays Rd	2	1,181	402
7	Mt Roskill Reservoir TP1 BSP	281	2,106	906
8	TP4 54 Winstone Rd	2	689	287
9	TP3 67 Winstone Rd	114	1,196	510
10	Pipe Crossing 57 Denbigh Ave	15	292	15

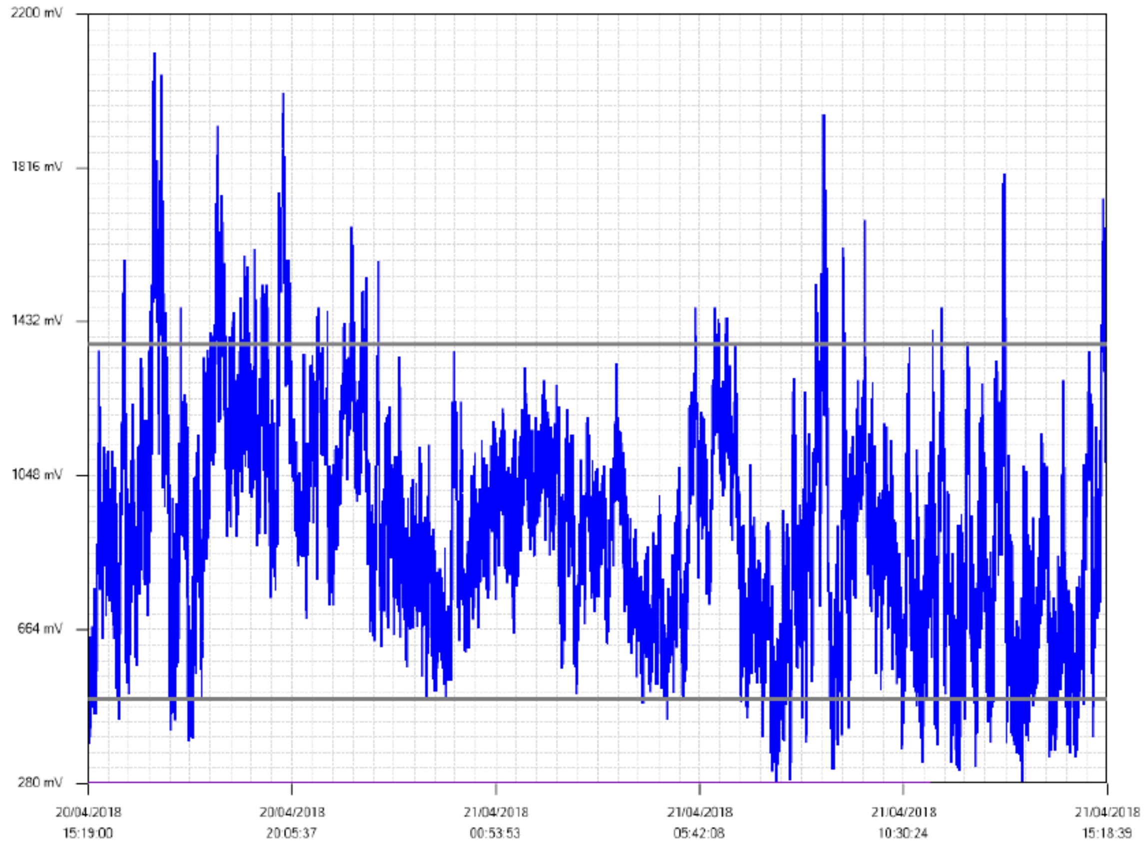

Figure 5: Strayrecorder ID S13071364 results – located at Mt Roskil Reservoir

4 CONCLUSIONS

The practical limitations for calculating steady state impressed AC voltages were considered, and an alternative and accurate method is provided. A practical case study along the Watercare (Auckland) Huia No.1 & Niho No.1 replacement watermain is provided.

Practical limitations for calculating steady state impressed voltages are more prevalent to urban type areas when compared to rural based areas. The reason for this is that there are usually multiple urban distribution overhead and underground electrical sources along the pipeline route that influence the pipeline. For computer simulated calculations, it is challenging to obtain accurate operating currents at a specific time/day/season as well as the circuit phasing for all electrical sources. As an alternative, for accurate assessments it is deemed adequate to obtain real-time AC voltage test point recordings.

The measurement of AC steady state voltages by means of datalogging over a 24-hour period is a preferred option when compared to single point measurements taken at a specific time. The reason for this is that datalogging measurements provide a realistic spread of values. From these recordings, the minimum, maximum, mean, average, median and outliers can be obtained.

When reviewing the measured results, the absence test points between TP 1 (168 Konini Rd) and TP 2 (1 Connell St) did not compromise the credibility of the decision for compliance. The former is based on the fact that the highest average voltage measurement is less than 25% of the minimum voltage limit of 4V.

ACKNOWLEDGEMENTS

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REFERENCES

[1] AS/NZS 4853:2012 Electrical hazards on metallic pipelines

[2] Cigré 95; Guide on the Influence of High Voltage Ac Power Systems on Metallic Pipelines; Working Group 36.02; "Electromagnetic Compatibility with telecommunication circuits, low voltage networks and metallic structures" 1995

[3] Phoenix Solutions; Results for Watercare Services Limited on Huia No.1 Base Load data logging; April 2018