

## **CORROSION MONITORING TRIALS TO UNDERSTAND THE EFFECT OF CHANGING WATER SOURCES ON EXISTING WATER TRANSPORT INFRASTRUCTURE**

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### **Abstract**

Internal corrosion will inevitably occur on metallic water transport infrastructure throughout their service life. Development of surface films may limit the progress of corrosion but these films can be disrupted if alternative water sources are introduced to transportation pipeline infrastructure.

To obtain data on the effect of changing the supply water source, a specialist, multi-channel corrosion monitoring test facility has been developed to allow corrosion trials to be undertaken to monitor for changes in corrosivity using methods of Linear Polarisation resistance (LPR) and Electro-Chemical Noise (ECN), in conjunction with measurement of pH, temperature and flow rate.

Corrosion trials have been undertaken with a water industry partner, and this paper will describe the monitoring system and outlines the initial results from the trial.

# 1 Introduction

Intertek P&IA was asked by large water utilities company to develop a method for rapid field evaluation of final water corrosivity. The system was intended to support for the optimisation of pH adjustment and phosphoric acid dosing levels without negatively impacting the service life of the distribution network.

Before the development of the Concerto Water Corrosivity Meter (WCM), the corrosivity of the final supply water was measured using weight loss coupon of the same material as the distribution network, grey flake graphite cast iron. Although this approach established base line corrosion rates from coupons removed at 3 and 12 months, it was recognised that it was not suitable for exploring the effect of short term (daily / weekly) process fluctuations on the factors influencing corrosion. The baseline corrosion rates for the final water across the five sites obtained from the study was around 0.06 mm/yr, with measured rates varying between 0.047 mm/yr and 0.220 mm/yr. The work also identified that the creation of stable protective films was a key driver in the rate of corrosion observed.

The project sort to identify the major factors to which the corrosivity of the final treated water can be attributed for selected materials. The materials of concern to the utility company were:

- Carbon Steel
- Ductile Iron
- Cast Iron
- Copper
- Cement Mortar Lined (CML) Pipework
- Lead

Following the identification of the major factors affecting corrosivity, a summary of the available technologies for monitoring corrosivity was generated and monitoring strategies selected for inclusion into a portable sidestream skid to accurately assess water corrosivity.

## 2 Parameters affecting corrosivity

The utility company was concerned with maintaining the integrity of a large number of different materials located in the distribution infrastructure in addition to the domestic consumer pipework. Differing materials are susceptible to corrosion attack in differing ways, so understanding the parameters which contribute to this attack is key.

Parameters associated with the corrosivity of the water vary dependent on the material under attack and are detailed below:

For carbon steel, cast and ductile iron:

- Oxygen content
- Chlorine concentration
- Temperature
- pH
- Flow rate
- Conductivity

For Cement Mortar Lined (CML) Pipework:

- Concentration of Ca, CO<sub>2</sub>, HCO<sub>3</sub><sup>-</sup> and CO<sub>3</sub><sup>2-</sup>

- pH
- Total Dissolved Solids
- Total Hardness
- Alkalinity
- Temperature

For Copper:

- Sulphate (with Alkalinity)
- Chlorine concentration

For Lead:

- Phosphate concentration
- Dissolved Organic Compounds

Of the parameters listed above, most are currently measured by the Utility company periodically or with online instrumentation connected to their plant SCADA system. While the data is being gathered, not all parameters are monitoring in the same location reducing the usability of the information for undertaking corrosivity measurements.

Based on the range of material which the utility company was most concerned about, carbon steel and iron, the 3 parameters which were believed to be the most beneficial for estimating corrosivity were Dissolved Oxygen content, Temperature and Conductivity.

### 3 Monitoring Technologies

There are many different technologies available to monitor corrosion in process facilities. These range from direct measurement of metal loss of the equipment, to measurement of metal loss of special insert probes (either directly or indirectly) and monitoring of process chemistry and operation conditions (which affect the corrosion threat).

With the different technologies, there are a wide range of measurement sensitivities and response times which means that, depending on the technique used and the expected corrosion rate, corrosion monitoring data could be collected either in real-time (or near real-time), regularly (daily, weekly, monthly) or irregularly (from periods ranging from several months to several years).

In selecting a suitable corrosion monitoring system for a particular process facility / item of equipment, the process conditions (fluid type, flow pattern, etc) and the corrosion threat also have to be taken into account. Corrosion threats include general corrosion, localised (pitting) corrosion, crevice corrosion, environmentally induced cracking, MIC (microbially influenced corrosion), under-deposit, etc.

Most corrosion monitoring systems have been developed for the process industries (oil & gas production, refineries and chemical process industries) and for heating and cooling water systems. Most are aimed at identifying corrosion for carbon / low alloy steels, as well as stainless steels, non-ferrous and corrosion resistant alloys and are used a part of overall integrity management programmes. They can provide on-line monitoring of corrosion control systems, mainly chemical treatment (i.e. use of corrosion inhibitors) and/or process modification (i.e. de-oxygenation, pH control, etc).

As such many are designed for operation in harsh conditions (high temperature / pressure, high acidity / alkalinity, low conductivity, etc). Hence application in the water treatment works should

not present any significant installation or operational problems. The main issues to be considered are:

- Sensitivity (ability to measure range of corrosion rates / small changes in corrosivity)
- Ability to detect specific corrosion mechanisms

Based on a review of published work, in-house expertise and experience Intertek recommended the following monitoring technologies that should be implemented for the monitoring of water corrosivity:

- Linear Polarisation Resistance (LPR)
- Electrochemical Noise (EN)
- Dissolved Oxygen (DO)

This combination of technologies would allow for the tracking of all relevant corrosion parameters and provide a good basis for a permanent monitoring system should one be required.

LPR was recommended as the component to track the actual instantaneous corrosion rate and EN was recommended as the only online monitoring technology to be able to identify where corrosion is of general or localised nature and provide real time tracking of process upsets. A robust dissolved oxygen meter was recommended to monitor the levels of dissolved oxygen. Intertek also recommended that the sidestream should include the capability to measure temperature, pH and water flowrate.

Although both types of ER monitoring equipment can provide accurate direct values for metal loss, the use of ER was discounted due to the insensitivity of probes designed for long life spans and the use of both new generation ER and standard ER was discounted due to the insensitivity to detecting localised corrosion and the susceptibility to conductive films.

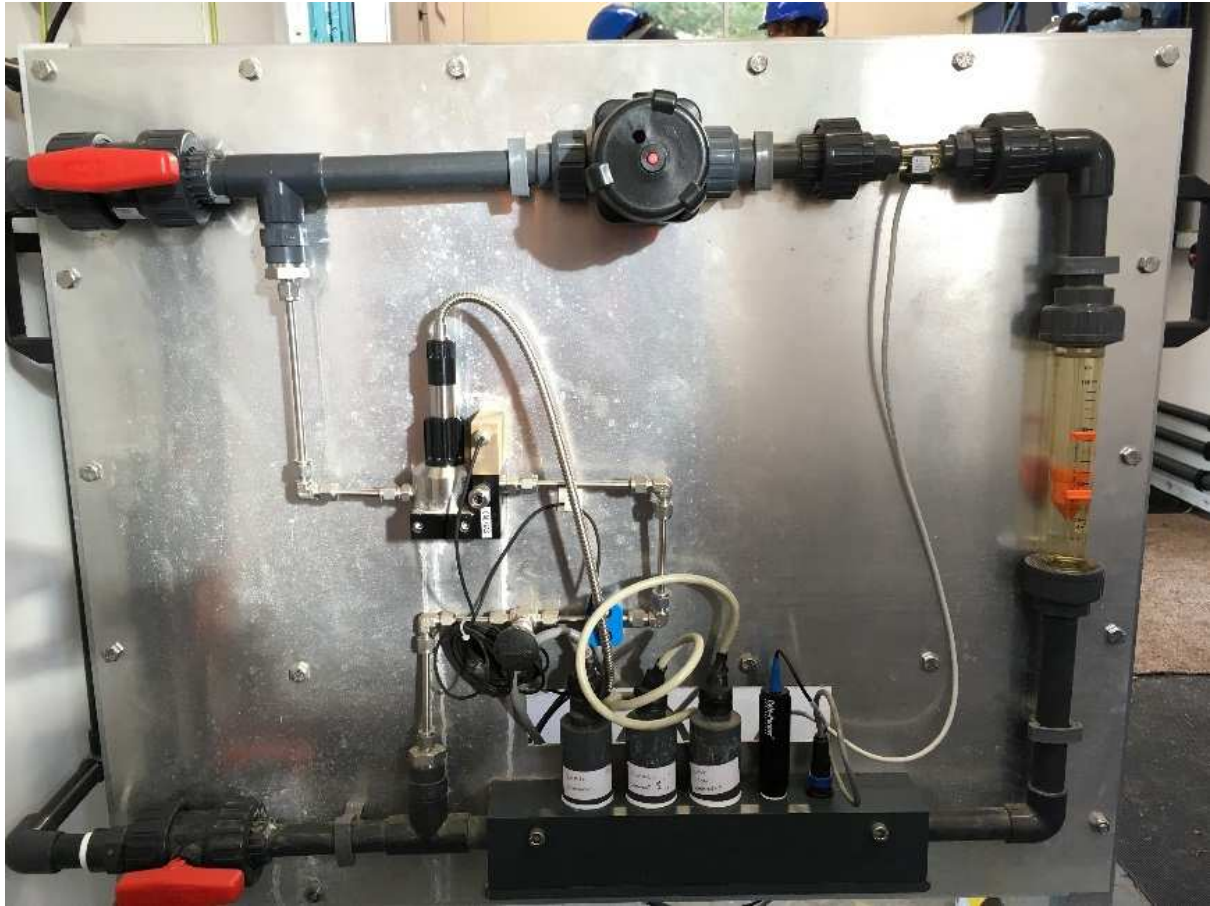
## 4 The WCM Design

With the selection of the required monitoring techniques, 2 designs of system were considered: An inline monitoring system and a sidestream. The advantages of placing the sensors in to a section of treatment plant pipework are measurements are obtained at the actual operating condition of the system. If a sidestream is used, it is likely that the operating pressure of the sidestream is lower than that of the treatment plant requiring the pressure to be throttled potentially changing the conditions monitored. But the sidestream provides increase flexibility with respect to installation location and the ability to relocate the sidestream to an alternative location when the corrosion monitoring trial was complete.

After evaluating the 2 options, the sidestream concept was selected because of the increased flexibility it offered and the design to use the system as a rapid corrosivity evaluation tool on multiple treatment sites. However, the electronics within the system can be paired with suitable insertion probes and used in a permanent monitoring installation.

### 4.1 The Sidestream

The sidestream was designed to be self-contained, requiring only power, water supply and waste water connection to be made following installation. The general layout of the sidestream is shown in Figure 1.



*Figure 1: Sidestream General Layout*

The major components of the sidestream are flow chamber which can accommodate 3 LPR corrosion probes, a 1 pH sensor and a temperature sensor, the Orbisphere LDO O<sub>2</sub> sensor, feed and waste isolation valves, flow control valve and both digital and analog flow meters.

The sidestream is constructed from uPVC tubing with the flow chamber machined from a single block of PVC. The sidestream is mounted to an aluminium skid which weighs 15kg when built (including the instrumentation).

The flow chamber has been designed with a channel of known dimension allowing a throughput of water to be set to mimic that expected to be experienced in the treatment plant or distribution network. The throughput could be set to match the velocity of the water within a pipe, the shear of water against the pipe wall or the mass transfer of oxygen to the pipe wall.

## 4.2 The Instrumentation

The instrumentation of the WCM comprised of the Concerto WCM HMI unit and an Orbisphere LDO O<sub>2</sub> system.

The Concerto HMI is an Intertek designed and manufactured self-contained instrumentation package which is capable of monitoring LPR corrosion probes, a pH sensor, a temperature sensor and the digital flowmeter. Measurement information is displayed on an intuitive 8 inch touch screen display which also allows the user to view present and historic graphical trends, view or edit measurement setting and download gathered measurement data via a USB flash drive. It also gathers dissolved oxygen measurement from the Orbisphere LDO unit removing the required to separately download the O<sub>2</sub> data set.



Figure 2: WCM Instrumentation Panel

## 5 Operational Results

The water utility company has used the WCM over a period of 7 years and undertaken a number of different trials to understand the effect of varying chemical dosing to corrosivity or the introduction of an alternate water source. An example of the different types of trials and the system outputs is described below.

### 5.1 Effect of Changing PO<sub>4</sub> Dosing Levels

A trial adjustment of PO<sub>4</sub> residual levels was undertaken to understand what effects this has on corrosivity of the final water. Dissolved PO<sub>4</sub> is derived from the injection of orthophosphoric acid (75%) and the rate of injection is controlled by the detection of PO<sub>4</sub> residuals in the final water. Under normal operating procedures the levels of PO<sub>4</sub> residuals is maintained at 1 mg/L. For during this trial, the residual level was adjusted by up to 0.2 mg/L above and below the normal level. The water utility company identified 1 occasion where the trail residual level was reset to the normal level by the site operators but this has not affected the results of the trial.

Trail dosing levels are detailed below:

- 09/03/2012 – 0.9 mg/L
- 19/03/2012 – 1.1 mg/L
- 30/03/2012 – 0.8 mg/L
- 10/04/2012 – 1.2 mg/L
- 20/04/2012 – Dosing returned to normal 1.0 mg/L

Prior to the start of each trial, the Channel 1 probe is removed from the WCM to be cleaned ensuring the fresh uncorroded cast iron was exposed for the new PO<sub>4</sub> dosing level. The uncorroded surface is more sensitive to changes in the water chemistry over the corroded surface of the Channel 2 probe. While this sensitivity allows us to have more instantaneous response to changes in corrosivity, the corroded surface corrosion rate measured by the Channel 2 probe is more representative of the effect of changing of PO<sub>4</sub> dosing on the bulk of any existing distribution infrastructure.

Figure 3, Figure 4 and Figure 5 show PO<sub>4</sub> residuals level and the effect that changes in these levels has on the corrosivity of uncorroded cast iron (Channel 1), corroded cast iron (Channel 2) and copper (Channel 3) respectively.

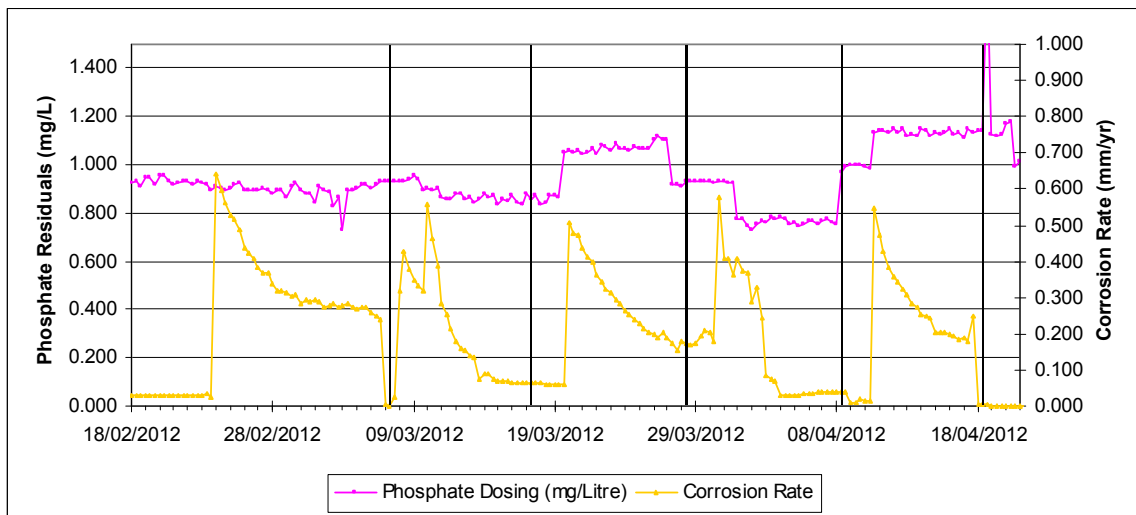


Figure 3: PO<sub>4</sub> Residual Level and Channel 1 Corrosion Rate

The effect of cleaning the probe surface can be clearly seen in the data in Figure 3 with abrupt peaks in corrosion rate.

The data in Figure 3 generally shows that the trial dosing periods with the lower PO<sub>4</sub> residual levels display the lower the measured corrosion rates after stabilisation has occurred. For the 0.9 and 0.8 mg/L PO<sub>4</sub> residual levels the stabilised corrosion rates were 0.06 and 0.04 mm/year respectively. These are significantly lower than the corrosion rates measured for the 1.1 and 1.2 mg/L PO<sub>4</sub> residual levels which were 0.17 and 0.18 mm/year respectively

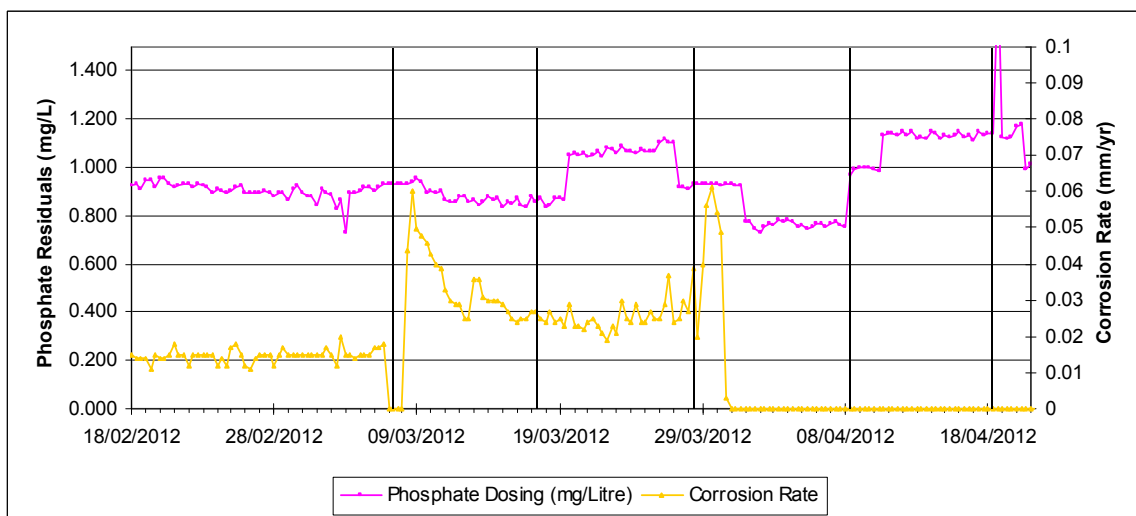


Figure 4: PO<sub>4</sub> Residual Level and Channel 2 Corrosion Rate

The data in Figure 4 show that for a corroded surface, the change in PO<sub>4</sub> residual levels have little or no effect on the corrosion rate. The data does show that after the 29-Mar-2012 a significant drop off in the corrosion. This reduction corrosion rate occurs after the final increase in PO<sub>4</sub> dosing levels and is likely due to build-up of corrosion deposits on the electrodes surfaces which increases the perceived solution resistance thus reducing the corrosion rate.

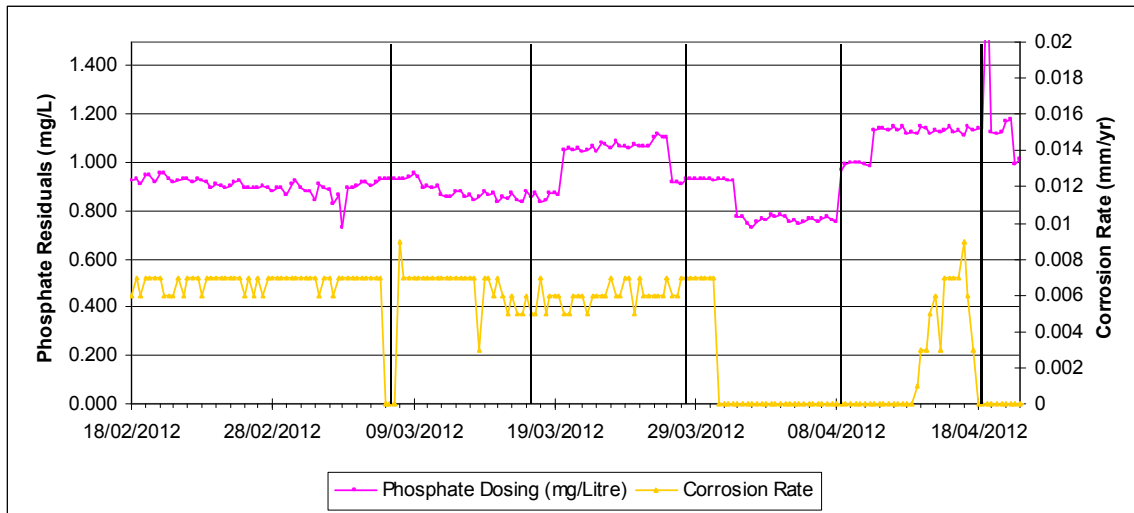


Figure 5: PO<sub>4</sub> Residual Level and Channel 3 Corrosion Rate

Similarly, Channel 3 copper electrodes in Figure 5 shows that changes in PO<sub>4</sub> residual levels have little or no effect on the corrosion rate. The data also show the significant drop off in the corrosion on the 29-Mar-2012 although there is a rise in the recorded corrosion rate in the data between 13-Apr-2012 to the 18-Apr-2012. This will most likely be the due to the same issue as highlighted for Channel 2.

In general, the corrosion rate data shows that, for corroded surfaces, adjusting the PO<sub>4</sub> residuals level does not affect the corrosion rates of cast iron or copper in the timeframes used in this trial. For clean uncorroded surfaces, as in the data in Figure 3, shows that for adjustments in the PO<sub>4</sub> residuals level does have an effect on the settled corrosion rate. It is observed that for lower levels of PO<sub>4</sub> residuals, the lower the settled corrosion rate.

It was noted in the data supplied by the water utility company that the PO<sub>4</sub> dosing trial from the 30-Mar-2012 at a level of was ended 2 days early by the site operators and returned to the standard level of 1.0 mg/L. The upward adjustment of the dosing level had an affected the corrosion rate which can be seen in the data as a reduction on the corrosion rate. To understand this effect more clearly, it was suggested that the water utility company undertaken a further long-term trial of PO<sub>4</sub> dosing lasting for 30 days rather than the 10 days used in the above trial.

## 5.2 Effect of Using an Alternate Water Source

The trial was conducted to understand the effects of undertaking maintenance on an aqueduct which requires the introduction of an alternative water source which is known to have different chemistry to that which normally supplies the aqueduct. The maintenance is scheduled to last for 50 days and will need to be repeated every 5 years. Water Source A (the original source water) was introduced to the WCM between 16 January and 8 March during which measurements were settled and stable.

Following the introduction of the Water Source B on 8 March, a step change in the measurement response was observed from all measurement channels (with the exception of flowrate).



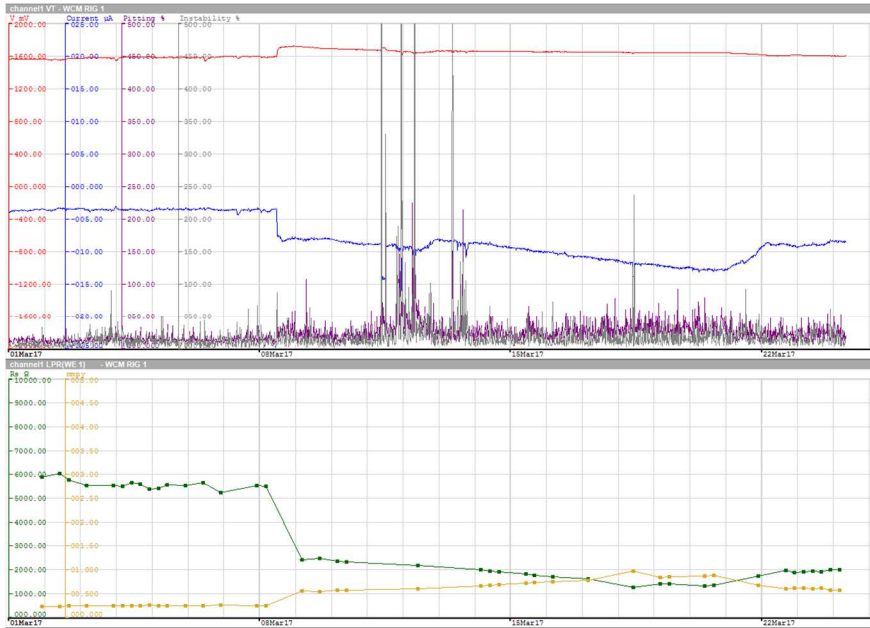


Figure 6: Channel 1 (Lead) responses to Water Source B

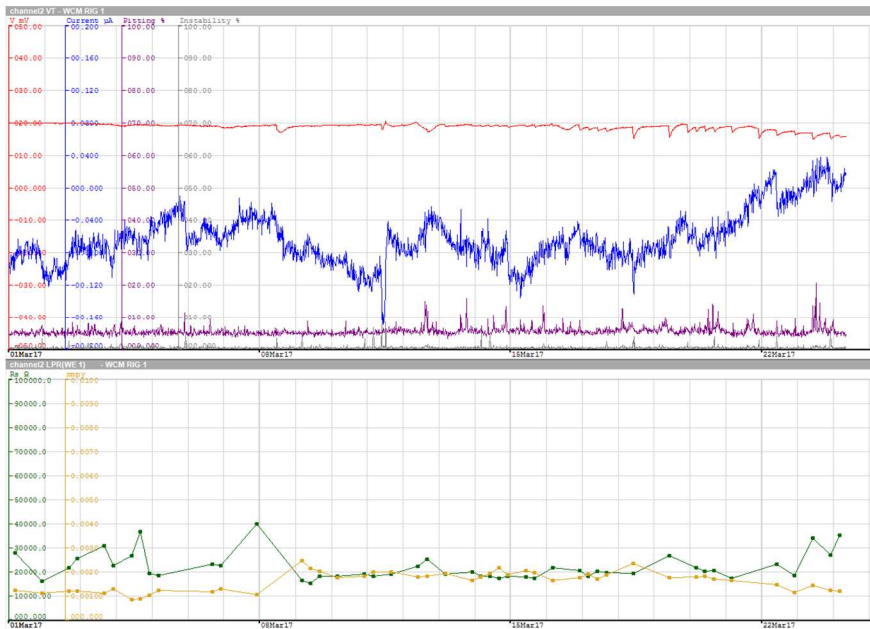


Figure 7: Channel 2 (Copper) responses to Water Source B

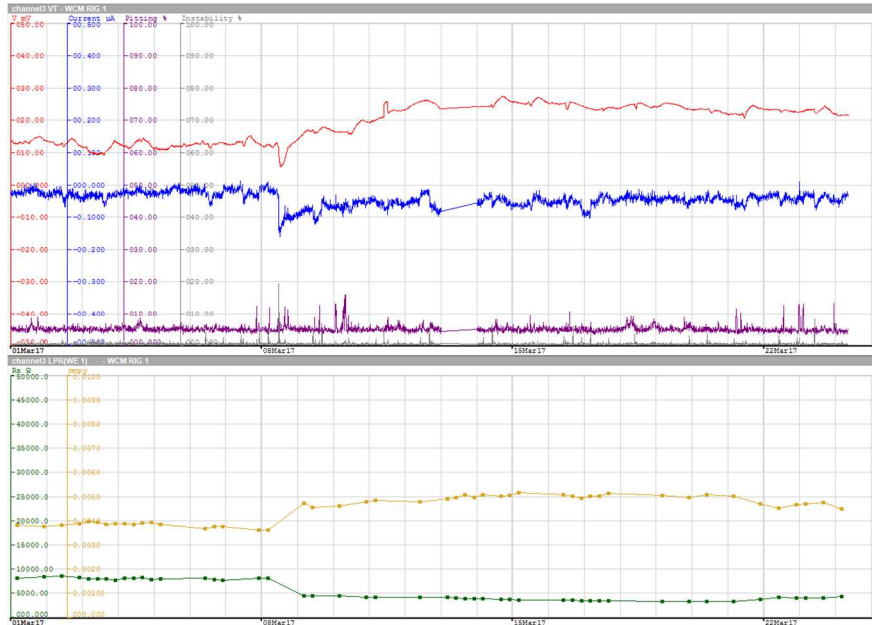


Figure 8: Channel 3 (Cast Iron) response to Water Source B

The response seen in Figure 6 for the Lead probe (Channel 1) and Figure 8 for the Cast-Iron probe (Channel 3) was immediate with significant shifts in the current response for both channels. The data shows that the corrosion rate increased almost immediately by a factor of ca 2x on the lead (ca 0.25 to ca 0.5 mm/y) and 1.25x on the cast iron (ca 0.004 to 0.005 mm/y).

The Copper probe (channel 2) displays a smaller reaction to the introduction of the Water Source B (Figure 7) then the other corrosion probes with little changes in the current and potential responses but also shows a near instant increase in corrosion rate of ca 2x, albeit from a lower value (ca 0.001 mm/y to 0.002 mm/y), an upward shift in the corrosion rate.

Similar but inverse responses can be seen in the data following the switch back from Water Source B to Water Source A with significant step change visible in the data sets.

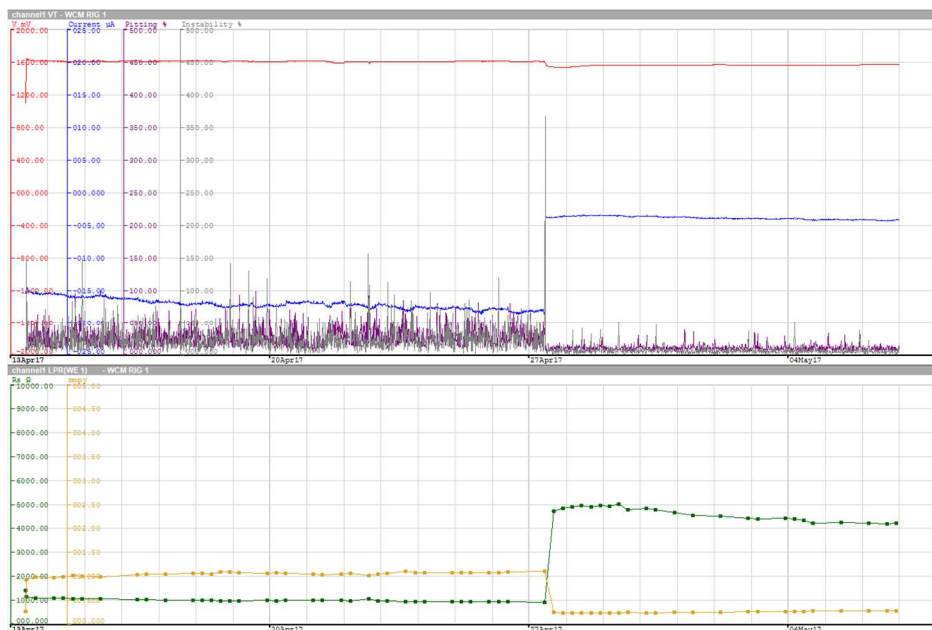


Figure 9: Channel 1 (Lead) responses to Water Source A

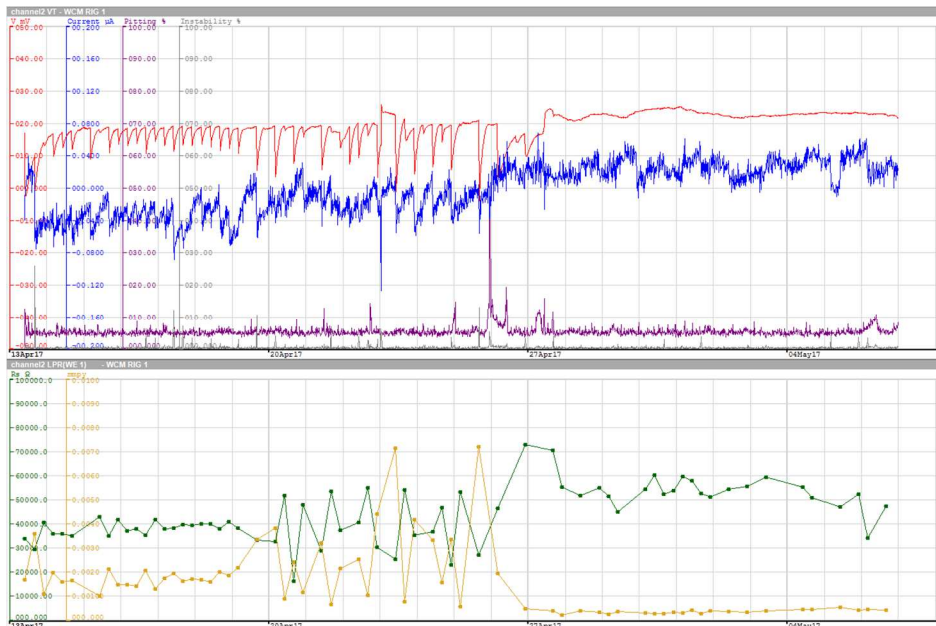


Figure 10: Channel 2 (Copper) response to Water Source A

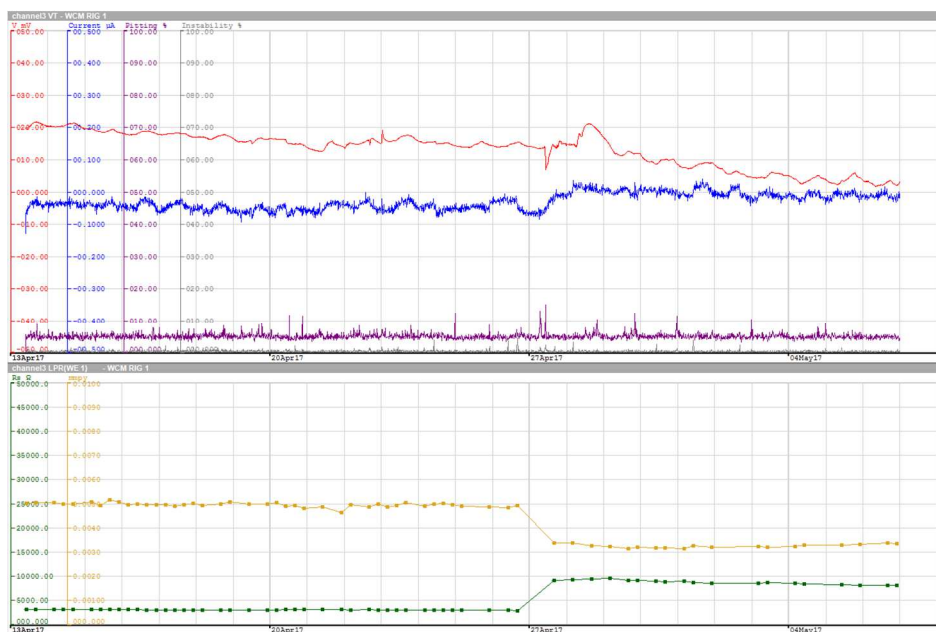


Figure 11: Channel 3 (Cast Iron) responses to Water Source A

Both Lead (Channel 1, Figure 9) and Cast Iron (Channel 3, Figure 11) probes display a decrease in the measured corrosion rates (from 1 to 0.25 mm/y lead, and 0.005 to 0.0035 mm/y cast iron). In addition, a significant quietening can be observed in the EN traces from the Lead probe.

A larger reduction in rate of some 10x is seen in the Copper probe (Channel 2, Figure 10), i.e. from a mean of ca 0.003 mm/y to ca 0.0003 mm/y. Although the data from 19-Apr to 26-Apr was very noisy (oscillating from 0.0007 to 0.007 mm/y). There is also a quietening in the EN response especially with respect to the potential trace. There is also a significant reduction in the variability of the corrosion rate measurement following the switch back to Water Source A.

It is clear to see from the results of the corrosion trial at Water Source B has the potential to be more corrosive than Water Source A presently flowing within the network. The effect of introducing

Water Source B into the network may not correspond directly to an increase in corrosion rate but the analysis showed a disruption to the stable surface films which existed on the 3 corrosion probe material types.

On reintroduction of Water Source A, there is a marked decrease in the corrosion measurements indicated that the system is returning to the stable condition experienced before the introduction of Water Source B.

It can be seen on the Copper probe that prior to the reintroduction of Water Source A, the corrosion rate measurements show significant variation. This variation potential stems the disruption of a surface film which has formed on the copper electrodes due to the polarising effect of the LPR measurement in Water Source B but this variation disappears immediately in the presents of the Water Source A.

## 6 Summary

Monitoring the corrosivity of final treated water provides an invaluable insight into the potential for corrosion of distribution infrastructure. Short term trials offer the opportunity to optimise chemical additive dosing to lower the potential for corrosion, test the effect of changes to plant process or understand the effect of using alternative water sources on existing infrastructure. Permanently installed systems could offer the potential to identify gradual changes in process operating conditions which may adversely affect corrosivity before degradation or failures occur in the distribution system.

## 7 References

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