THE PERFORMANCE OF 'ICE PIGGING'

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ABSTRACT

In November 2011, Yarra Valley Water (YVW) began trialling an innovative water mains cleaning technology called 'ice pigging'. Due to the success of the initial trial, YVW commenced a full scale program in November 2013 to ice pig approximately 400km of water mains each year for the next five years.

This paper describes the range of cleaning methods being tested to determine which is most cost effective, the scientific approach being applied to assess the long term effectiveness of the program, and the preliminary results from the first year of testing.

INTRODUCTION

Due to the unfiltered nature of the majority of YVW's source water, the supply network carries high levels of natural sediment that accumulates in the pipe network and causes customer complaints following hydraulic disturbances. As a result, YVW experiences a comparatively higher number of water quality complaints than the other Melbourne metropolitan water retailers (who are further away from the source). Additionally, the presence of sediment in the supply network leads to a reduction in the amount of available chlorine.

To mitigate these risks, YVW historically carried out mains cleaning via flushing (80-90%) and air scouring (10-20%) of those supply zones with high numbers of water quality complaints. However, the flushing of mains uses large volumes of water (3 pipe volumes) (D. Ellison et al., 2002) and with the commencement of Stage 3 water restrictions in Melbourne in 2006, the mains cleaning program was suspended.

After a period of research to find a more water efficient cleaning method, YVW began trialling an innovative technology called 'ice pigging' in November 2011.

The ice pigging process works by injecting a saline ice slurry into the water main via a fire hydrant. The slurry is formed into a semi-solid 'pig' within the main, which then uses the upstream pressure of the water to push and carry sediment as it traverses through the pipe. The waste slurry exits out at a downstream hydrant and diverts to a waste tanker which is then taken to a disposal point.

The trial found that ice pigging removed up to 17 times more sediment from the mains compared to flushing, while using half the amount of water.

While it was also found that ice pigging is more expensive on a '$ per metre' basis, when using the indicator '$ per kg of sediment removed', flushing costs approximately $2,655/kg while Ice Pigging is approximately 6 times cheaper, at $470/kg. It is hypothesised that the superior clean achieved by ice pigging will result in less dirty water complaints and therefore lead to cost savings in the reduction of unscheduled flushing jobs and the frequency of mains cleaning of supply zones (P. Dang et al., 2014).

Due to the success of this initial trial, YVW commenced a full scale program in November 2013 to ice pig approximately 400km of water mains each year for the next five years.

The following sections outline the scientific approach being applied to assess the long term effectiveness of the program, as well as the method of supply zone selection, cleaning methodologies and preliminary results for the first year of the program.

YARRA VALLEY WATER ICE PIGGING PROGRAM

YVW began its full scale, five year 'ice pigging' program in November 2013.

Water supply zones were prioritised for ice pigging based on two criteria:

1. Number of water quality complaints in the previous twelve months per 1000 connections and per 1000 meters of water main (equally weighted)
2. Microbiological performance - level of Total Coliforms, *E.coli* and Plate Count

For the 2013/14 program three different cleaning methodologies were trialled:

Method 1 – 100% ice pig
This method involves ice pigging 100% of the mains in the supply zone, unless, due to valve and/or hydrant configuration a main cannot be ice pigged, in which case it would be flushed.

Method 2 – 80% pig, 20% flush
Due to the nature of water supply networks in terms of valve and hydrant locations, in order to ice pig 100% of the mains in a supply zone it is unavoidable that some sections of main will be ice pigged more than once when different operational runs overlap one another.

In an attempt to maximise the efficiency of ice pigging and avoid overlapping of runs *Method 2* was developed. This method involves ice pigging only 80% of the mains in a supply zone and flushing the remaining 20%.

The 80% of mains to be ice pigged are prioritised during the planning stage to be mains with the following characteristics:

- Mains with attributed customer complaints
- Mains with low flow velocity

YVW also specified that cleaning operations be greater than 300m in length for DN 100 mains and that overlapping of runs be minimised.

Method 3 – 80% ice pig, 20% do nothing
Method 3 applies the same approach as Method 2, however instead of being flushed; the remaining 20% of mains are left uncleaned.

It should also be noted that the ice producing equipment can only produce a limited amount of ice per day and therefore, for all three cleaning methods, only mains of size DN 300 or smaller in diameter were ice pigged to maintain efficiency.

2013/14 Program
Following supply zone prioritisation, the following supply zones and respective cleaning methods were selected for the 2013/14 Ice Pigging Program:

Table 1: 2013/14 Ice Pigging Program

Supply Zone	Cleaning Method
Ridge Monbulk	Method 1
Donvale – Area 1*	
Andersons Creek	
Heathmont	Method 2
Donvale – Area 2*	
Croydon	Method 3
Donvale – Area 3*	

* The Donvale supply zone was split into three sub-zones where each cleaning method was trialled

PERFORMANCE ASSESSMENT

For the 2013/14 ice pigging program YVW used four criteria to assess the performance of ice pigging.

Customer complaints
The primary driver of the ice pigging program is the reduction of water quality complaints. The number of complaints per 1,000 connections before and after ice pigging is assessed to determine how successfully ice pigging reduces water quality complaints within each supply network.

Re-suspension Potential Method (RPM)
The Re-suspension Potential Method (RPM) measures the capability of the sediment in a pipe to resuspend as a result of a hydraulic disturbance. The test is conducted by increasing the velocity in the main, by an experimentally derived value that is enough to disturb the sediments in a main without causing customer complaints during the test. A turbidity curve is then established where the area under the curve (AUC) represents how 'dirty' the test main is. *Figure 1* illustrates the test method and the resulting turbidity curve that is produced (J.Q.J.C. Verberk et al., 2004).

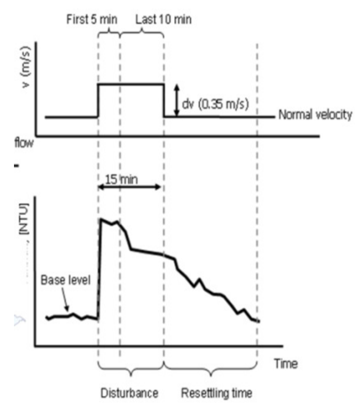

Figure 1: RPM Test Method

YVW's ice pigging performance assessment involves conducting the RPM test at around one site per ten kilometres of main in each supply zone. The test is carried out at each test site before and after ice pigging and then at three, six and twelve month intervals post ice pigging.

While the pre and post ice pigging turbidity curves are used to demonstrate how effectively ice pigging removes sediment, the long term results are used to determine the time it will take for sediments to re-accumulate within the test main and establish the required cleaning frequency for the supply zone.

Figure 2 shows RPM turbidity curves for a test site in Donvale, where it can be seen that over time, the area under the curve is increasing indicating that sediment in the main is starting to accumulate again.

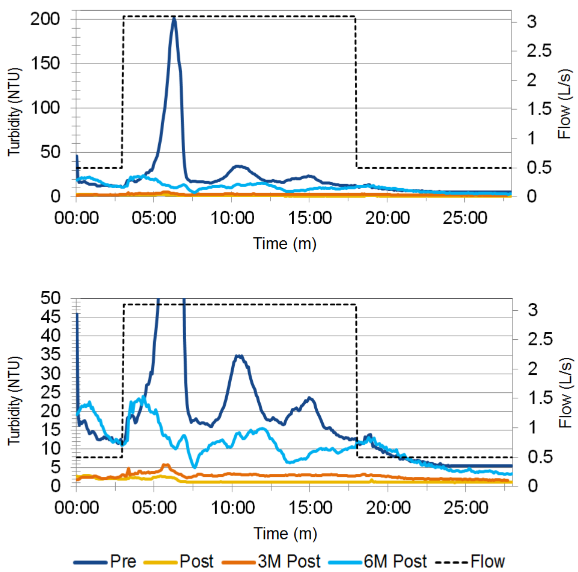

Figure 2: Example RPM Turbidity Curves

Chlorine profiling

Chlorine profiling involves taking water samples at selected hydrants within the supply zone, from the source of the water to the end of the supply zone, and determining the rate at which the chlorine decays.

In the same manner as the RPM testing, chlorine profiling is carried out in each supply zone before and after ice pigging and then at three, six and twelve months post ice pigging. Chlorine tests are conducted on site using hand held equipment and both total chlorine and free chlorine are measured.

Unfortunately, the variability of chlorine levels within the supply zone at different times of day was underestimated and test times were not specified for chlorine tests during the 2013/14 program. As a result of this most of the 2013/14 chlorine profiling results are inconclusive.

During the 2014/15 program YVW started to use the hydraulic model for each supply network to determine the time it takes for a parcel of water to move from the source of the water to each test site. Field staff have been instructed to take the chlorine sample at each test site at the time indicated by the model. This adjustment to the method has successfully produced conclusive results.

Microbiological performance

This performance assessment criteria is only applicable to supply zones with relatively high levels of Total Coliforms and/or *E.coli* and/or Plate Count. For the 2013/14 ice pigging program this criteria did not apply to any supply zones.

In future ice pigging programs for applicable supply zones, levels of the aforementioned parameters before and after ice pigging will be assessed to determine how successfully ice pigging improves the microbiological performance of the supply zone.

<u>RESULTS</u>

Customer complaints

Complaint reduction

Figures 3-9 show the monthly number of water quality complaints per 1,000 connections for each water supply zone from December 2011 until November 2014.

The results illustrate that for every supply zone, once ice pigging has taken place; a significant decrease in the number of water quality complaints in the zone is achieved.

For zones where *Method 1* was used (Figures 3-5), the incidence of water quality complaints was almost eliminated, post-ice pigging, for all three supply zones.

The exceptions do not reflect a lack of ice pigging performance as the one complaint registered in *Ridge Monbulk* was from a customer on a main that was not pigged due to operation issues. Additionally, a RPM site close to the complaining customer in *Donvale – Area 1* showed that at the time of the complaint the RPM AUC value was almost the same as the value immediately post ice pigging, indicating that the incidence of dirty water was most likely caused by internal plumbing or the close proximity of the customer to an un-pigged DN 300 main.

Legend for figures 3-9:

No. complaints/1000 customers (due to ice pigging operations)
No. complaints/1000 customers
No. complaints/1000 customers (12 month rolling average)
No. complaints/1000 customers (adjusted 12 month rolling average)

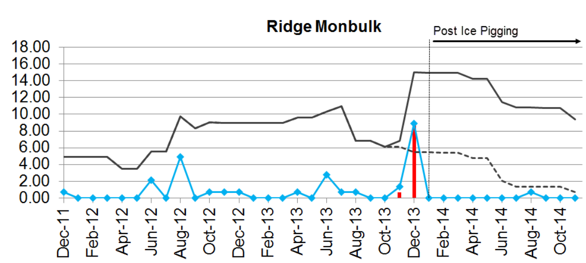

Figure 3: Ridge Monbulk - Complaints per 1000 connections

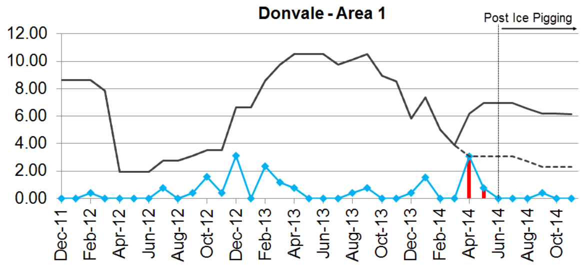

Figure 4: Donvale - Area 1 - Complaints per 1000 connections

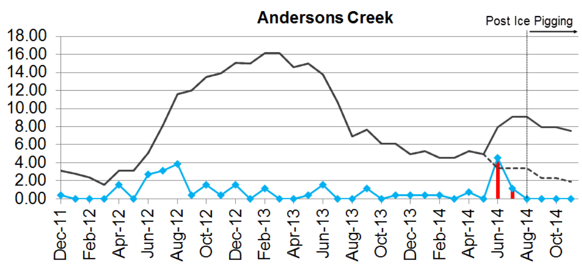

Figure 5: Andersons Creek - Complaints per 1000 connections

For zones where *Method 2* was used (Figures 6-7), in *Donvale – Area 2* both complaints registered post ice pigging were on dead end mains that were flushed.

In *Heathmont* there were seven post ice pigging complaints registered. Six of these were registered by customers connected to mains that had previously been ice pigged. Upon further investigation it appears that two of these complaints are most likely an internal plumbing issue.

As for the other four complaints it is unclear whether the complaints were caused by the proximity of these customers to upstream un-pigged (not flushed) mains or by the natural re-accumulation of sediment in the previously ice pigged mains.

The other complaint in *Heathmont* was registered by a customer on a dead end main that had been flushed.

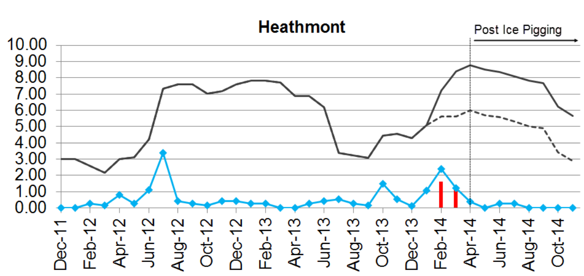

Figure 6: Heathmont - Complaints per 1000 connections

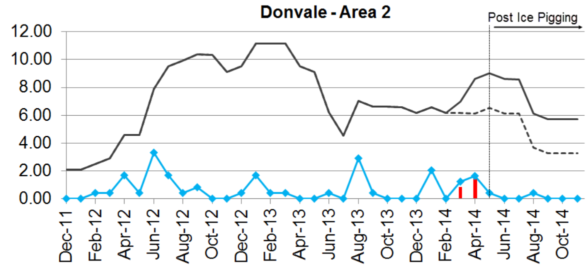

Figure 7: Donvale – Area 2 - Complaints per 1000 connections

For zones where *Method 3* was used (Figures 8-9), in *Croydon* there were nine post ice pigging complaints registered. Four of these complaints were caused by bursts or nearby maintenance activities.

Of the other three located on pigged mains, one of these was a taste complaint and the other two were located on pigged mains in close proximity to an un-pigged main. Two complaints were registered on un-pigged mains, one of which was a dead end.

In *Donvale – Area 3* of the two post ice pigging complaints registered, one was on an un-pigged main and the other was located on a pigged main in close proximity to an un-pigged dead end main.

At this stage it is unclear whether the complaints on pigged mains in close proximity downstream of un-pigged mains are caused by the transport of sediment from these nearby dirty mains or by the natural re-accumulation of sediment in the previously ice pigged mains themselves.

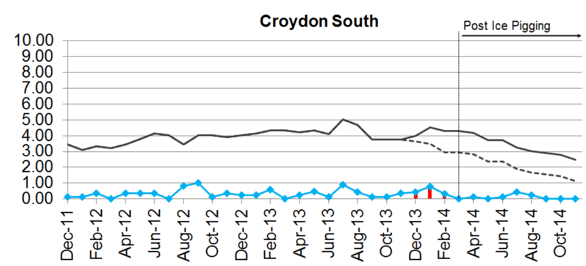

Figure 8: Croydon South – Complaints per 1000 connections

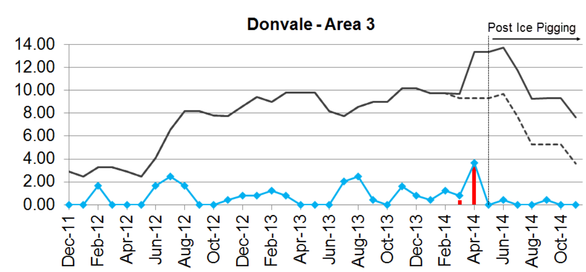

Figure 9: Donvale – Area 3 - Complaints per 1000 connections

Figure 10 shows the average number of complaints per 1000 connections for the 2014 post ice pigging period for each supply zone as compared to this same period in previous years. These results confirm that the reductions seen post ice pigging in Figures 3-9 are not due to variability in complaints from seasonal changes.

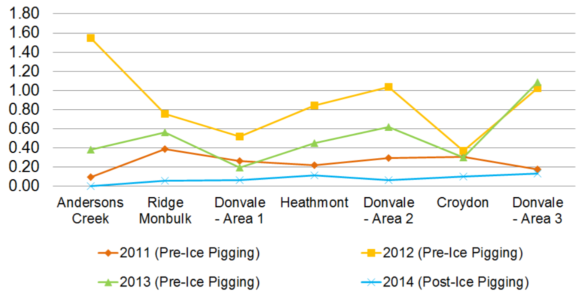

Figure 10: Average number of complaints per 1000 connections in the post ice pigging period compared to same period in previous years

Ice pigging related complaints

Another evident factor when looking at Figures 3-5 is the spike in water quality complaints that occurs in each supply zone during ice pigging. These complaints are caused by the stirring up of sediments in yet to be pigged mains when valves and hydrants are operated during ice pigging operations. Also due to inaccurate customer property information of customers connected to trunk mains in *Ridge Monbulk*, a number of such customers were not notified of ice pigging operations during the first two days of the program.

It is expected that as the ice pigging program progresses, and processes become 'well-rehearsed' there will be less operational issues resulting in customer complaints.

Figures 3-5 show the twelve monthly actual rolling average of water quality complaints as well as an adjusted rolling average where ice pigging operational related water quality complaints have been removed. In all supply zones, with ice pigging related complaints removed, rolling averages post ice-pigging start to decline and we can see in the cases of *Croydon South* and *Ridge Monbulk* (the first two zones ice pigged) that an all-time low for the three year period is reached. In time, the same result would also be expected from the other zones.

However, when looking at the true rolling average, the results are not as positive, especially in the cases of *Ridge Monbulk*, *Heathmont* and *Donvale – Area 3* where rolling averages are at a peak, post-ice pigging, for the three year period.

At this point in time it is unclear as to whether or not the benefits in complaint reduction achieved post ice pigging will be outweighed by the complaints caused by the activity itself. Long term results will be required to draw this conclusion.

Resuspension Potential Method (RPM)

Pre vs Post Ice Pigging

Figure 11 shows the RPM AUC results for all RPM sites across all supply areas. It can be seen that the post-ice pigging value is consistently low at every test site and is not proportional to the pre-ice pigging value. This demonstrates that ice pigging achieves a consistently high level of sediment removal across the supply zone regardless of how 'dirty' a main is.

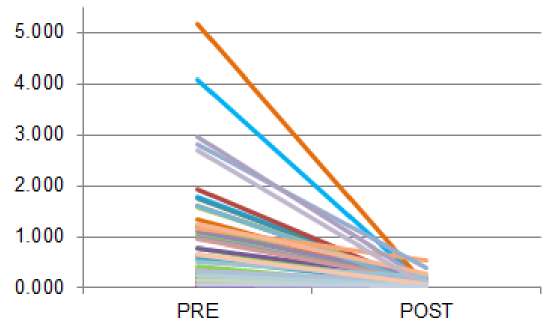

Figure 11: Pre and post ice pigging AUC values

Cleaning frequency

Figures 12-18 show the pre, post and three, six and twelve month post ice pigging RPM AUC results for each RPM test site within each supply zone.

Within each supply zone it can be seen there is a large variability in pre ice pigging AUC values. Sites with an AUC value of 3 or more are considered to be extremely dirty with turbidity readings in excess of 300 NTU during the disturbance period of the RPM test. All sites with these turbidities are dead ends or looped mains with extremely low velocities (less than 0.05m/s).

When looking at pre RPM values as compared to longer term three, six and twelve monthly levels, it is promising to see that sediment at these extremely dirty sites has not yet re-accumulated to the pre ice pigging value. In most cases it is calculated it will take around three years for these extremely dirty sites to reach pre ice pigging values. It can also be seen that cleaner mains with AUC values of less than 0.5 will return to pre values relatively quickly, within around 12-18 months, however this is most likely not of concern as the levels of sediment and corresponding turbidity response in these mains would most likely not cause a customer complaint.

Legend for figures 12-18:

Blue line - dead end main (DE)
Orange line - through main (TM)

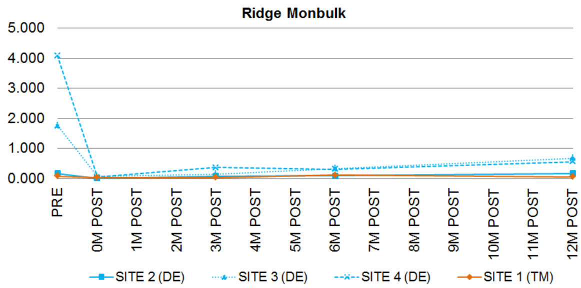

*Figure 12: Ridge Monbulk – RPM AUC**

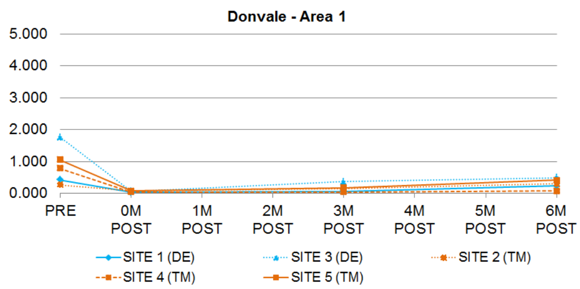

Figure 13: Donvale – Area 1 – RPM AUC

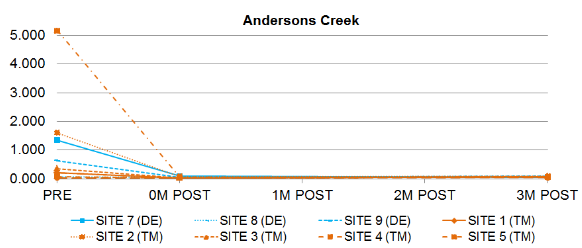

Figure 14: Andersons Creek – RPM AUC

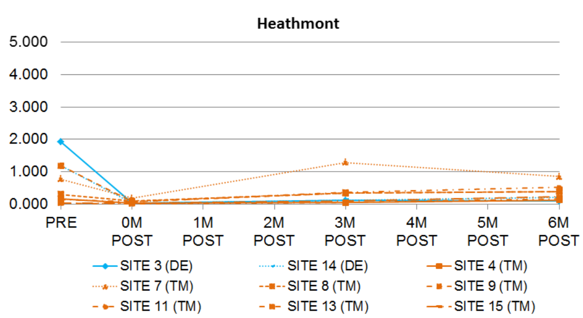

Figure 15: Heathmont – RPM AUC

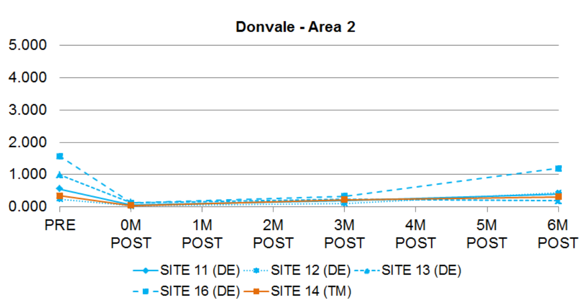

Figure 16: Donvale – Area 2 – RPM AUC

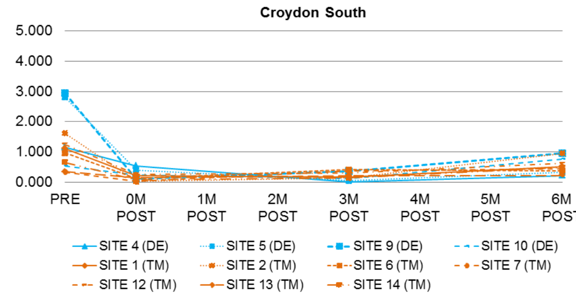

*Figure 17: Croydon South – RPM AUC**

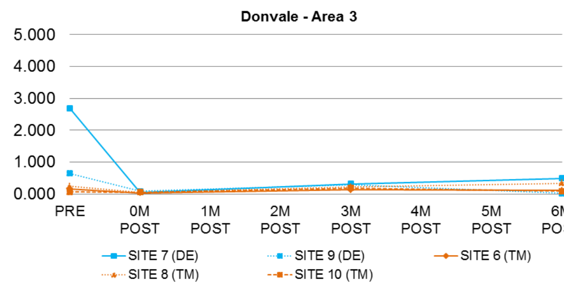

Figure 18: Donvale – Area 3 – RPM AUC

*Due to the presence of air bubbles caused by operational issues during the early phase of pre and post RPM testing, some RPM tests in Ridge Monbulk and Croydon South returned erroneous readings. Sites with evidently erroneous readings were deleted from this analysis. In Croydon South it is possible that results other than those deleted were affected by air bubbles which could be the reason why a number of test sites in this zone exhibit three monthly post AUC results that are less than the immediately post RPM result which would not usually be the case.

What is of foremost interest is at what level of AUC of the dirtier mains a customer starts to complain at, as these values will dictate the cleaning frequency of each zone. As the project was only recently incepted, this value is still unknown, however YVW plans to use the RPM curves to establish this value in the following way.

Cleaning frequencies will depend on two factors:

1. AUC threshold value
2. Rate of change (ROC)

The *AUC threshold value* is the AUC value for each supply zone, whereby once AUC levels start to rise above such level it would be expected that customer complaints would start to increase significantly.

This value cannot yet be established as customer complaints in all supply zones continue to be at a low level post ice pigging. However, YVW plans to closely monitor customer complaint levels in relation to RPM AUC levels for each supply zone over time in order to eventually establish *AUC threshold values*.

It is expected that the *AUC threshold value* will differ from zone to zone as, from customer research previously conducted by YVW, it was found that customers' tolerance to dirty water and likeliness to complain varies across the YVW service area.

The *ROC* refers to the change in RPM AUC value over time for each RPM site, or in other terms, the rate at which sediment within the RPM test main, and thus the supply zone, is re-accumulating after ice pigging.

Figure 19 shows an example of a cleaning frequency establishment curve.

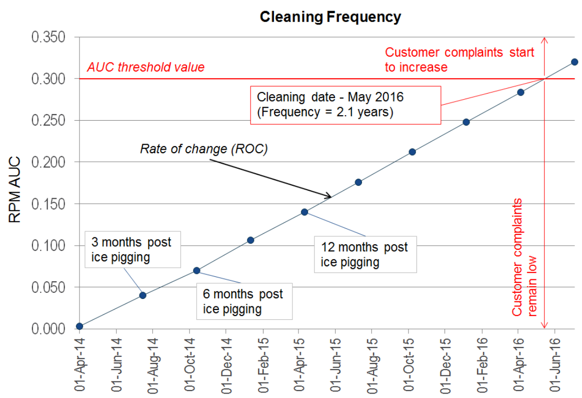

Figure 19: Example of a cleaning frequency establishment curve

Sediment accumulation

Figure 20 shows the average RPM AUC ROC for each supply zone. It can be seen that in most cases, as expected, sediment in dead end mains accumulates at a faster rate than through mains. It can also be seen that sediments in the *Croydon South* zone accumulate significantly faster than the other zones. This is most likely because unlike the other supply zones, water does not undergo any detention in tanks before entering the *Croydon South* zone.

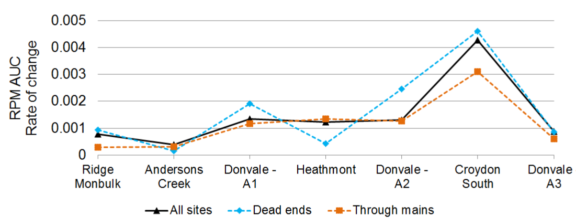

Figure 20: RPM AUC rate of change per supply zone (zone average)

Chlorine profiling

As stated previously, as the variability of chlorine levels within the supply zone at different times of day was not accounted for in the 2013/14 program, most of the 2013/14 chlorine profiling results are inconclusive.

Figures 21-22 show the pre and post chlorine profiling results for two profiles in Croydon North from the 2014/15 program (long term data is not yet available). In both profiles it can be seen that for most test sites there is a decrease in the difference between Total Chlorine and Free Chlorine post ice pigging. These results indicate that the sediment removal achieved by ice pigging causes a decrease in chlorine decay compared to pre ice pigging decay rates and hence improves penetration of chlorine residuals within the supply network.

Long term data at three, six and twelve monthly intervals post ice pigging will be collected to show how long this is maintained.

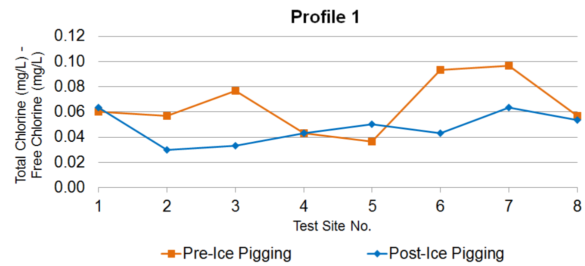

Figure 21: Difference between Total Chlorine and Free Chlorine at Profile 1 test sites

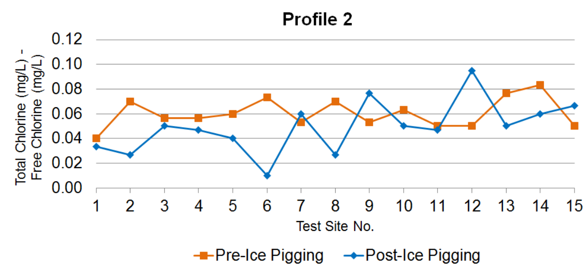

Figure 22: Difference between Total Chlorine and Free Chlorine at Profile 2 test sites

CONCLUSION

The YVW 2013/14 ice pigging program proved to be successful and further validated the conclusions from the 2011 ice pigging trial.

The results to date of the 2013/14 program prove that once ice pigging has taken place; a significant decrease in the number of water quality complaints in the supply zone is achieved. It was also found that ice pigging achieves a consistently high level of sediment removal across the supply zone regardless of how 'dirty' a main is, with post ice pigging turbidities being of the same value for previously 'dirty' mains as for comparatively 'cleaner' mains.

In monitoring customer complaint levels over time in conjunction with RPM AUC results, YVW will be able to establish a cleaning frequency for each supply zone. In doing this, a proactive approach to water quality complaints management can be achieved. The frequency at which each zone is cleaned will depend upon the rate at which sediments accumulate within the zone and the tolerance to dirty water of customers within the zone.

Initial chlorine profiling results from the 2014/15 program also indicate that ice pigging a supply zone improves penetration of chlorine residuals.

At this stage it is unclear whether flushing 20% of mains and/or leaving 20% of mains uncleaned in a supply zone will affect the achievable reduction in complaints. However, preliminary results indicate that not ice pigging these mains will limit the reduction in complaints.

Long term results will be required to see how long sediments take to re-accumulate and hence how long complaint reductions last and also to determine the most efficient cleaning method.

ACKNOWLEDGMENT

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