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IMPLEMENTING *RESUSPENSION POTENTIAL METHOD* TO OPTIMISE YARRA VALLEY WATER'S MAINS CLEANING PROGRAM

by SANDRA KJELLBERG[1], ASOKA JAYARATNE[2,3], JAN VREEBURG[4,5], NISHAL SUKUMARAN[2], JASPER VERBERK[5]

1 Snarringe 11, 231 93 Trelleborg
e-mail: sandra.kjellberg@gmail.com
2 Yarra Valley Water, Private Bag 1, Mitcham Vic 3132, Australia
e-mail: ajayarat@yvw.com.au, nishal.sukumaran@gmail.com
3 Cooperative Research Centre for Water Quality and Treatment, Private Mail Bag 3, Salisbury SA 5108, Australia
4 Kiwa Water Research, PO BOX 1072, 3430 BB Nieuwegein, the Netherlands
e-mail: Jan.Vreeburg@kiwa.nl
5 Delft University of Technology, PO BOX 5048, 2600 GA Delft, the Netherlands
e-mail: J.Q.J.C.Verberk@TUdelft.nl





Abstract

Routine cleaning of water mains is commonly employed by water utilities around the world as a proactive means of managing common water quality issues. When employed correctly, mains cleaning can be effective in removing loosely deposited sediments that can cause water discolouration. Despite its long history in the water industry, water supply practitioners continue to use highly subjective methods to identify when, where and how often to clean their distribution network. This paper discusses the application of the *Resuspension Potential Method* in the distribution network of Yarra Valley Water, Melbourne, Australia. The *Resuspension Potential Method* is an objective tool for identifying the need for and the efficacy of mains cleaning. Furthermore, in this article the potential to find an optimum flushing frequency is discussed. The *Resuspension Potential Method* has been applied by Yarra Valley Water since July 2005. Yarra Valley Water is now able to prioritize and target its mains cleaning efforts to achieve optimum outcomes.

Key words – Customer complaints, discolouration, turbidity, Resuspension Potential Method, mains cleaning program, sediment

Introduction

The occurrence of discoloured water in drinking water distribution systems is a major source for customer complaints worldwide (Vreeburg and Boxall, 2007). The number of customer complaints due to discoloured water varies greatly over the world; typically around 4 complaints per 1000 properties in the United Kingdom while in the Netherlands the annual average complaint rate is about 0.5 to 1 complaint per 1000 properties (Vreeburg, 2007). Australia utilities experience an average of 6 complaints per 1000 properties. Within Australia there is a large variation in customer complaints between the different utilities, ranging from 1.1 to 17.9 complaints per 1000 properties (WSAA Facts, 2005).

Figure 1. *Example of heavily discoloured water (Sandra Kjellberg, 2006).*

Discolouration can be caused by numerous water quality processes (Verberk et al, 2007). As a distribution system is a complex interconnected system it is not exactly possible to determine when and where discolouration events will happen. Intuitively, it can be expected that discolouration events are most likely to occur in unlined mains, pipes with low water velocity and with a high particle loading and in mains with dead-ends, acting as sediment reservoirs. Increases in flows and disturbances caused by events such as increased demand from customers, burst water mains, leakage, the use of fire hydrants and construction activities can also resuspend earlier deposited sediments causing dirty water in local areas. Although the discolouration risks can be very different between distribution systems, there is an agreement that all systems, even the ones that are fed by advanced treatment, foul eventually.

Water utilities can take proactive actions to prevent discolouration events. By routine cleaning of water mains the loose deposits that are easily resuspended are removed from the distribution system in a controlled way. Methods for cleaning the distribution pipes are for example flushing, swabbing, pigging and air scouring. As mains cleaning is labour intensive, high operational costs are involved with cleaning of pipe mains. It is therefore important to determine which mains need to be cleaned with which frequency. Furthermore, in times of water restrictions, it is important that the utilities only clean their mains when absolutely necessary, to set an example to the customers. In Australia a computer model (*Particle Sediment Model*, abbreviated to PSM) has been developed by the Cooperative Research Centre for Water Quality and Treatment to predict where sediment will settle in distribution systems (Jayaratne *et al.*, 2004). Yarra Valley Water intends to use the *Particle Sediment Model* to decide "where" to clean once the validation of the new version of the PSM is complete.

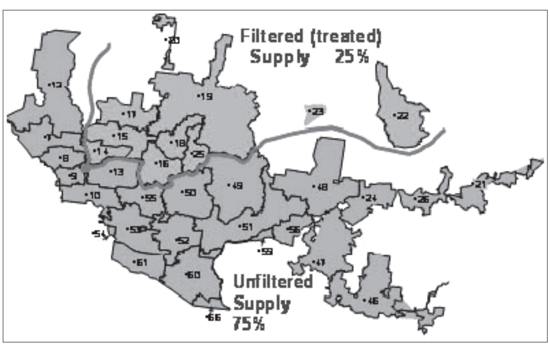

Figure 2. *Treated and untreated zones in Yarra Valley Water's area (Yarra Valley Water 2006a).*

This paper discusses the benefits of using the *Resuspension Potential Method (RPM)*, an objective method of planning and implementing mains cleaning developed by Kiwa Water Research in the Netherlands (Vreeburg *et al.*, 2004; Vreeburg, 2007). The RPM has been applied by Yarra Valley Water since July 2005 in an effort to prioritize and target its mains cleaning programme.

Yarra Valley Water is the largest of Melbourne's three water retail companies and provides water and sewerage services to more than 1.6 million people across Melbourne's eastern and northern suburbs. The company provides water and sewerage services within a defined geographic area of approximately 4000km^2 which is divided into 35 water quality zones (see Figure 2). The water quality zones are created for the purpose of monitoring and controlling the quality of the potable water. A water quality zone is a unique area in which water quality across that entire area is considered to be same. Yarra Valley Water also owns and operates more than 8900 km of water mains, very few of which are unlined (Yarra Valley water 2006b). The water flows with help of gravity to the different zones.

75 percent of YVW's supply is from natural protected forested catchments located to the north and east of Melbourne. These catchment areas of natural eucalypt forest cover more than 150,000 hectares with a large proportion reserved for more than 100 years, solely for the purpose of harvesting water. The water is further stored in reservoirs for up to 4 years allowing it to purify through settling and natural disinfection processing before distributed to customers. The water is also disinfected with chlorination[1], chloramination and UV treatment (Yarra Valley Water 2006c). This unfiltered source water has a turbidity of 0.7–2.3 NTU with predominately material of clay and silt (Prince et al. 2003). The remaining 25% of the supply, which does not come from protected catchments, is fully treated using conventional filtration and micro filtration (in two zones).

Historically Yarra Valley Water has the highest water quality customer complaint results for Melbourne, due to many different factors. All three water companies, (see Figure 3) have supply from unfiltered sources but YVW has a significantly higher level of bursts and leaks. Additionally, the system configurations and characteristics are quite different. YVW also have a very different customer profile and segments (primarily residential) as compared with City West Water (primarily industrial/commercial) and South East Water (mix of residential and commercial/industrial). This could help to explain that Yarra Valley Waters complaint rates are high because they have a demographic that is more predisposed to making complaints (families, elderly pensioners, etc). Yarra Valley Waters complaint rates could also be higher due to impact of drought and works undertaken by their

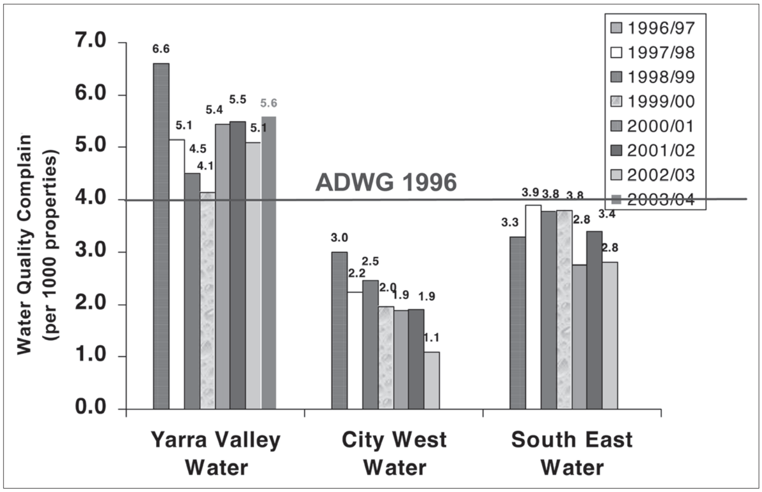

Figure 3. *Water quality complaints compared between the three retail companies in Melbourne.* Australian Drinking Water Guideline (ADWG) recommends a level of 4/1000 customer complaints per year (Yarra Valley Water, 2004).

wholesaler to optimise harvesting and operations – flow reversals, harvesting from tributaries and perhaps their proximity to these sources means that YVW experience complaints earlier than the other two retailers.

The majority of Yarra Valley Waters customer complaints (75%) refer to their experience of discoloured water due to resuspension of naturally occurring sediments from unfiltered source waters. (Sukumaran, 2007[2]) Yarra Valley Waters target is to reduce water quality complaints to 4 complaints per 1000 customers by June 2008 (this equals a reduction of 29% from 03/04). This target is in accordance with the Australian Drinking Water Guidelines which recommend a customer complaint level of 4/1000. By year 2013 the target set by Yarra Valley Water is 3 complaints per 1000 customers. Although the target is set on customer complaints, there is a need for an objective measuring tool to assess the progress made. The need for this tool is univeral and would therefore also be of great interest for the Swedish distribution systems. The RPM opens the possibility to measure discolouration risk before it leads to complaints.

Method (based on Vreeburg (2007))

Resuspension Potential Measurement description

Irrespective of the origin, the presence and mobility of loose deposits determines the discolouration risk. The Resuspension Potential Method (RPM) is based on measuring the capability of the sediment in a network to resuspend as a result of a standard procedure of flushing and measurement. During a controlled, normalised and moderate increase of the velocity in a pipe the turbidity is monitored. The resulting hydraulic shear stress causes sediment to resuspend. Practical restriction to this procedure is that the change in hydraulic regime should only cause a moderate increase in shear stress as only the sediment capability to resuspend is assessed and it is not the intention to clean the main or to cause customer complaints. Figure 4 illustrates the protocol of the method:

- Isolate the pipe for which the discolouration risk is assessed by closing the valves that connect other feeding pipes to the pipe being evaluated, creating unidirectional flow.
- Monitor the turbidity in the main for some time to determine the base level turbidity;
- Induce an acceleration of the flow for 15 minutes by opening a fire hydrant in such a way that the velocity in the pipe is increased by an additional 0,35 m/s on top of the normal velocity and maintain this increased velocity during fifteen minutes. The velocity of 0,35 m/s is empirically determined. For a 100 mm internal diameter pipe this requires only a limited flow volume of 2,5 m^3.
- Monitor the turbidity in the main during the disturbance;
- After fifteen minutes, reduce the velocity to normal and monitor the turbidity until it is back at the starting or initial level or until a predefined turbidity level or resettling time is obtained.

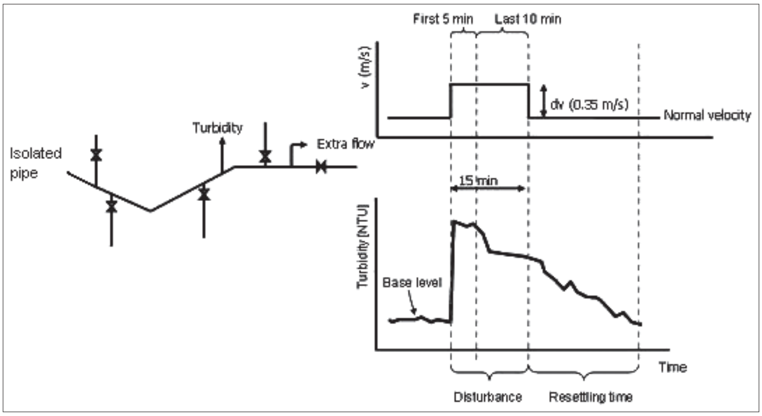

Figure 4. *Concept of RPM procedure (Vreeburg, 2007).*

The RPM-curve

The result of an RPM experiment is the turbidity pattern as observed in the main. A typical theoretical turbidity curve of an RPM experiment is shown in Figure 4, right bottom graph. For rating the discolouration risk four elements of this curve are important. These elements are:

- Base turbidity level
- Initial increase in turbidity at the start of the hydraulic disturbance;
- Development of turbidity during the hydraulic disturbance;
- Resettling time to base (initial) turbidity level, resettling time to predefined turbidity level or turbidity after predefined resettling time.

Base turbidity level

The base turbidity level is the level preceding the hydraulic disturbance. Base line turbidity can be linked to the turbidity of the source water and gives some insight in the source of the sediment. Base line turbidity is also needed to determine the time required for the turbidity to resettle after the imposed disturbance stopped.

Initial increase in turbidity

Following the actual disturbance the turbidity will rise immediately to a certain level. This initial velocity increase results in the resuspension of instantaneous mobile sediment. A loose layer of sediment causes the initial turbidity peak. The initial turbidity increase is an indication of the maximum turbidity caused by a hydraulic incident.

Development of turbidity during the hydraulic disturbance

The hydraulic disturbance is kept for a standard period of 15 minutes, allowing the turbidity to develop to an elevated level. If the turbidity level stays at almost the same level, during the entire disturbance period as during the first five minutes, then it can be concluded that there is a considerable amount of sediments in the pipe, meaning a high discolouration risk and that the composition of the sediment layer is homogeneous.

In almost all cases the turbidity drops during the 15 minutes disturbance time. Three phenomena can explain this:

- A relatively small amount of heavy sediment is present in the pipe. The extra forces in accelerating the flow also promote the initial whirling up of this heavy sediment (Blokker *et al.*, 2003). The significance of this sediment layer is limited because it is settling even during the deviating hydraulic circumstances, making the discolouration risk smaller. The chance the initial discoloured water actually reaches a tapping point in which it can be visually identified is small.
- A too short length of isolated pipe can be the second reason for a declining turbidity during the 15 minutes disturbance. If the length is less than 315 meter, water is drawn from pipes upstream the isolated pipe. This water originates from the looped network or from pipes with larger diameters and is less disturbed than the 0,35 m/s.
- A non-homogeneous deposit over the length of the tested pipe, for instance in a hilly area with concentrations of sediment in the depression of a pipe.

In all cases however, the level of turbidity following the first peak determines the continued discolouration risk. This level will be present during a longer time, allowing customers more time to see it.

Resettling to base level, resettling to predefined turbidity or turbidity after predefined time

After 15 minutes of disturbance the hydrant is almost totally closed creating original daily flow conditions and the turbidity is monitored until the base turbidity level is reached. It will take some time before the turbidity resettles to base level. This time is important for the discolouration risk or actually the complaint risk. If the turbidity stays high during a longer period, the risk of noticing the turbidity in an application as filling a white basin (bathtub, washing bin, bathroom sink, etc) is larger.

Evaluating RPM curves

The RPM is interpreted on five aspects items that are all rated equally:

- Absolute maximum value of turbidity during first five minutes of disturbance (20 %)
- Average value of turbidity during first five minutes of disturbance (20 %)
- Absolute maximum value of turbidity during last ten minutes of disturbance (20 %)
- Average value of turbidity during last ten minutes of disturbance (20 %)
- Time needed to resettle again to initial turbidity level (20 %)

For each aspect a validation on a scale of 0 to 3 is made: 0 is the lowest or best rating and 3 the highest or worst rating. The lowest value equivalent with 'no discolouration risk' is 0 (zero) and the highest value or 'maximum discolouration risk' is 15. For the rating per aspect a scale must be made, that is calibrated to the turbidity equipment used. The discolouration risk established in this way is a relative figure that can be company specific or even zone specific, allowing for assessing effects of changed operation of the network. Table 1 gives the values for discolouration risk for a Dr Lange equipment turbidity meter used in a Dutch distribution system.

The ranking table can be tailored to the actual application. Depending on the values that are set for each category different objectives can be met. For example, when lower values are used than the ones displayed in Table 1 the RPM can be used to distinguish subtle differences in resuspension to see what the effects are of different cleaning methods. For that application it is important that the measurement is sensitive. Higher values of turbidity can be used when a priority of the need for cleaning in a whole area, that has a certain level of complaints, is needed. In that case the sensitivity should be in the higher turbidity values to rank the areas that most urgently need cleaning. With the ranking the sensitivity of the measurement can be tuned to the actual needs and equipment. This allows for a change in measuring equipment or measuring locations without older data being lost. The ranking can also be adjusted to for instance changing standards or company policies.

Table 1. *Example of ranking RPM for discolouration risk using Dr Lange turbidity meter in a Dutch system (Vreeburg, 2007).*

Category Points	0	1	2	3
Absolute maximum first 5 minutes	< 3 NTU	3 – 10 NTU	10 – 40 NTU	> 40 NTU
Average first 5 minutes	< 3 NTU	3 – 10 NTU	10 – 40 NTU	> 40 NTU
Absolute max last 10 min	< 3 NTU	3 – 10 NTU	10 – 40 NTU	> 40 NTU
Average max last 10 min	< 3 NTU	3 – 10 NTU	10 – 40 NTU	> 40 NTU
Time to clear	< 5 min	5 – 15 min	15 – 60 min	> 60 min

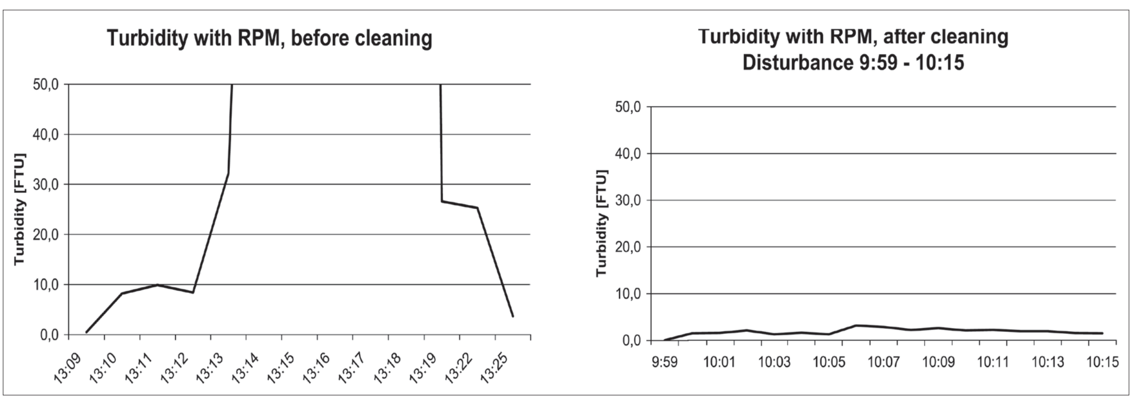

Figure 5. *Results of RPM method applied pre- and post-cleaning to evaluate the effectiveness of the operations.* The pre-cleaning RPM (left) is 11 according to Table 1 and post-cleaning (right) is 1; resettling time is ignored (Vreeburg, 2007).

Ranking the RPM by using Table 1 is a very useful method when the efficacy of mains cleaning is assessed or when the dirtiness of water quality zones are compared with each other. The ranking method can however not be used to quantify the sediment loading of a main. A possible method to quantify the sediment loading can be to calculate the area under the turbidity curve. This evaluation method is still in investigation.

Currently RPM curve is the most appropriate method to rank dirtiness of the mains. However, there are of course variations in RPM implementation and other possible methods of calculations of the ranking. No matter which application of the method the water utility chooses, it is important that only one method is applied and that the RPM's are always performed in the same way.

Yarra Valley Water's RPM program – objectives, equipment and data evaluation

RPM program and objectives

Programmed mains cleaning ceased in November 2002 with the introduction of the Stage 1 water restrictions in Melbourne. Yarra Valley Water recommenced its annual water mains cleaning program in July 2005. Currently the decision to clean each individual water quality zone is purely based on the level of customer complaints. Since September 2005 Yarra Valley Water has incorporated RPM measurements to its mains cleaning program with the objective to develop a proactive indicator to determine "when" to clean. Yarra Valley Water will use the RPM measurements to:

- determine effectiveness of mains cleaning program;
- rank dirtiness of mains and water quality zones/areas to prioritise mains/areas and zone cleaning program;
- predict the cleaning frequency for each water quality zone/area.

To achieve these objectives a research project was initiated with the 2005–06 mains cleaning program. In this project RPM measurements are being collected from thirteen of Yarra Valley Water thirty-five water quality zones at selected sites across each zone at regular intervals. Data collection was undertaken at frequencies of one week prior to cleaning (pre cleaning RPM measurement), one week after cleaning (RPM base rating) and several times in the following months. Different frequencies between successive RPMs are trialled to determine the minimum necessary frequency to perform a flushing action for zones supplied from different source waters (unfiltered, blended and fully filtered). In this study only data form 5 water quality zones are used. Characteristics of the zones are given in Table 2.

The RPM data of five of the above mentioned zones are evaluated: Croydon, Somerton and Lilydale receive unfiltered water; Supply to Bulleen zone is blended with filtered and unfiltered; Epping zone receives either filtered or unfiltered supply. The five zones chosen for the analysis are shown in Figure 6.

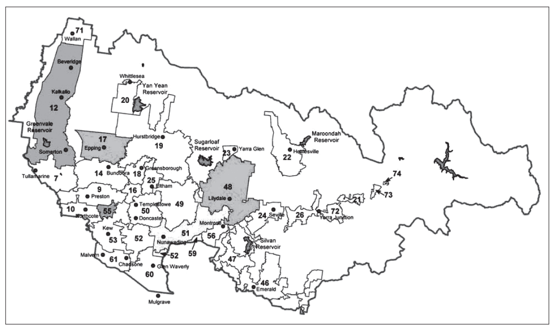

Figure 6. *The five zones, zone 12, 17, 48, 51 and 55 (see Table 2) that are evaluated and their location.*

Table 2. *Characteristics of the targeted supply zones.*

WQZ	WQZ Characteristics	No. of hydrants with valid data[a]	RPM Measuement Intervals[b]
Croydon	Unfiltered (Silvan), close to source, no tanks	8	Pre, p2w, p3m, p4m, p6m, p8m and p11m
Epping	Alternated filtered (Yan Yean) to unfiltered (Silvan), intermediate distance from sources, storage tanks	5	Pre, p1w, p6m, p7m, p8m, p12m
Bulleen	Blended or alternated filtered (Sugarloaf) to unfiltered (Silvan), far from sources, storage tanks	5	Pre, p1m, p2m, p3m, p6m, p9m, p12m
Somerton	Unfiltered, far from source, storage tanks	6	Pre, p2m, p9m, p12m
Lilydale	Unfiltered, close to source, no tanks	6	Pre, p7m,p10m, p12m

[a] Valid data including all measurements between 10–15 minutes disturbance time
[b] Pre = measurement before mains cleaning, p1m = measurement 1 month after mains cleaning etc.

RPM Equipment

A schematic picture of Yarra Valley Water's RPM equipment is shown in Figure 7. The flexible hose (50mm) diameter between the hydrant and the flow meter has a length of 4 meters allowing enough length for the trailer to be placed near the hydrant. After the flow meter (Yeokal 613) a 30 cm transparent hose is used, connected to the turbidity unit with elbow connections. The main reason for the transparent hose is to visually observe the colour of the water. A data logger, a Yeokal 611, connected to the turbidity meter is used to log the turbidity every minute.

From the turbidity unit a 2 meter 50mm diameter hose is connected allowing the water to flow out to drainage. Both the turbidity unit and the flow meter are placed in angle to avoid air bubbles getting trapped and having effect on the measurements.

The contractor performing the measurement uses a timer to ensure the generation of the disturbance for 15 minute period to collect consistent results at all sites.

Data evaluation

The particle loading of distribution systems in various countries will be quite different as a result of different treatment philosophies. In the Netherlands a multiple barrier treatment without chemical disinfection is used, resulting in many treatment steps in series for surface water and thus a very low particle loading expressed in turbidity, normally in the range of 0.02 to 0.2 NTU. In Australia, specifically in Melbourne, water from protected catchments is only treated with chlorine/ chloramine or UV. Turbidity in this unfiltered supply can reach values up to 4 NTU under normal operating conditions. The ranking table used by Kiwa for Dutch water utilities (Table 1) will result in a higher ranking score if used for unfiltered supplies in Australia. In Yarra Valley Waters case the RPM-curves are evaluated based on different turbidity values (see Table 3). Furthermore, the category of time to clear was not considered due to lack of complete (Table 1) data on the resettling/time to clear period to make a comparison between locations feasible.

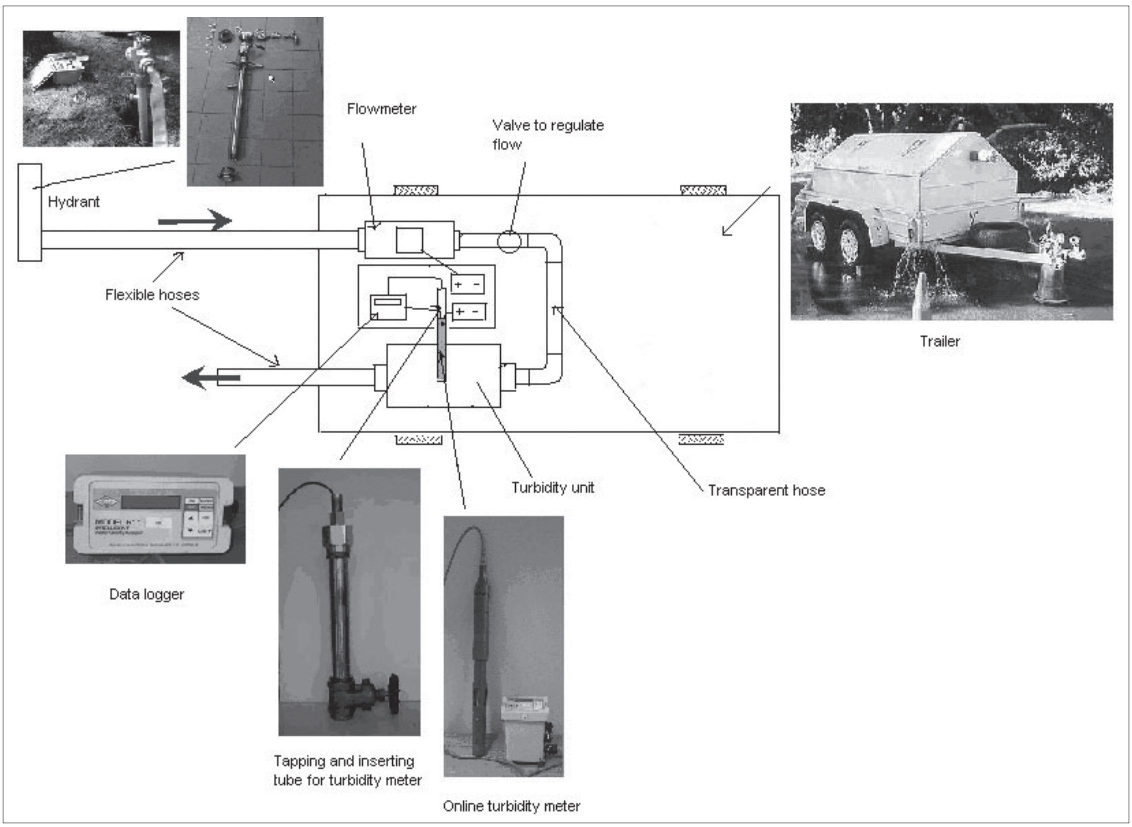

Figure 7. *Schematic of Yarra Valley Water's RPM Equipment.*

Table 3. *Yarra Valley Water RPM ranking table to calculate discolouration risk using a Yeokal 611 turbidity meter.*

Category	Points 0	1	2	3
Absolute maximum first 5 minutes	< 10 NTU	10 – 50 NTU	50 – 100 NTU	> 100 NTU
Average first 5 minutes	< 10 NTU	10 – 50 NTU	50 – 100 NTU	> 100 NTU
Absolute max last 10 min	< 10 NTU	10 – 50 NTU	50 – 100 NTU	> 100 NTU
Average max last 10 min	< 10 NTU	10 – 50 NTU	50 – 100 NTU	> 100 NTU

The first four categories of the RPM data still provide sufficient information to rate the dirtiness of the mains. Yarra Valley Water decided to have a rating score of 10 points as the threshold to clean the main/area.

Results

In 2006–07 approximately 500 RPM measurements were undertaken. As the equipment and the procedure had to be refined during the measuring period to improve the RPM procedure not all curves can be used to determine the most effective cleaning frequency.

Effectiveness of mains cleaning program

By performing an RPM before and after cleaning of a main the efficacy of the cleaning action can be evaluated. In Figure 8 the turbidity curves before and after cleaning in Illawarra Crescent in the Croydon zone are given. Before mains cleaning the RPM-curve has high turbidity readings and an RPM score of 8 points (out of the maximum of 12). This main is rated as quite dirty. After the RPM measurement the main was cleaned by water and air scouring. A week after the mains cleaning, the RPM measurement was repeated and the RPM score reduced to 4. The difference between pre and post RPM scores indicate the effectiveness of the mains cleaning. From this example it can be concluded that the mains cleaning has not been sufficient or more particles have been accumulated due to other operational activities within a very short time since the RPM score after cleaning is still 4 and the desired target should be 0 (zero) or possibly 1.

Rating of mains and water quality zones/areas

In total 194 RPM measurements (as of November 2006) were performed in Croydon, Epping, Bulleen, Somerton and Lilydale. Only 119 of these RPM measurements are used in the evaluation of the data. Data for the remaining locations were excluded as the measurement protocol was not always strictly followed by the field staff. The data inaccuracies were due to incorrect test flows and inadequate post cleaning data.

As typical examples of turbidity curves during an RPM measurement the curves of Taronga Court in the Croydon zone and Redesdale Road in Bulleen are given in Figure 9 and 10, respectively. At both locations prior to mains cleaning an RPM measurement is performed. High pre cleaning turbidity values are observed at Taronga Road, up to 450 NTU, while in Redesdale road the maximum turbidity did not exceed 100 NTU. The RPM-rating of Taronga Road prior to cleaning is 12 points (on a rating from 0 to 12). Three months after cleaning the RPM is repeated at the same location. All turbidities are lower, the maximum turbidity is 60 NTU and the RPM score is 7 points. After 6, 8 and 11 months another RPM measurement is done. A clear increase in the turbidity, compared with the previous RPM curve, is observed. The RPM scores are 2, 11 and 12 points, respectively. This means that a large amount of sediment has been deposited in the mains in the period between first and last measurements and this mains needs to be cleaned within one year. Also mains in the direct neighbourhood having a similar pipe geometry have to be cleaned or at least an RPM has to be made to see if they need to be cleaned. The Redesdale road had an RPM score of 7 prior to cleaning. RPM measurements are done after 1, 2, 3 and 6 months with rating scores of 5,

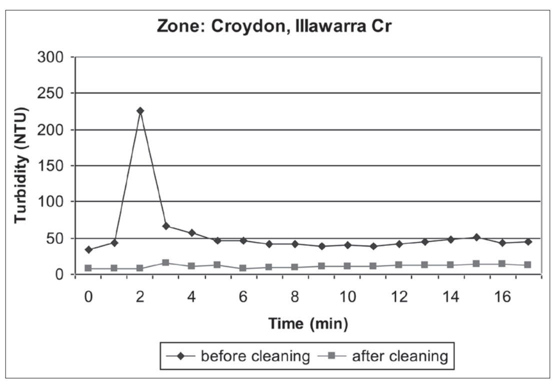

Figure 8. *Pre and post RPM-measurement to determine effectiveness of mains cleaning.*

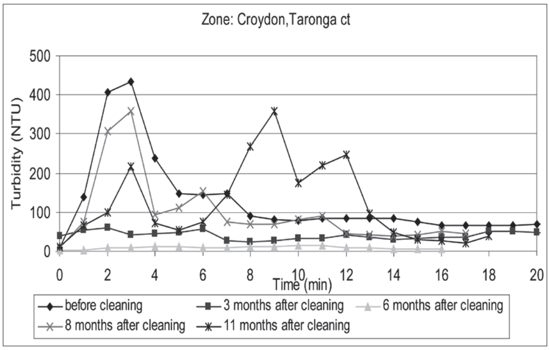

Figure 9. *Turbidity curve for Taronga Court in Croydon supply zone.*

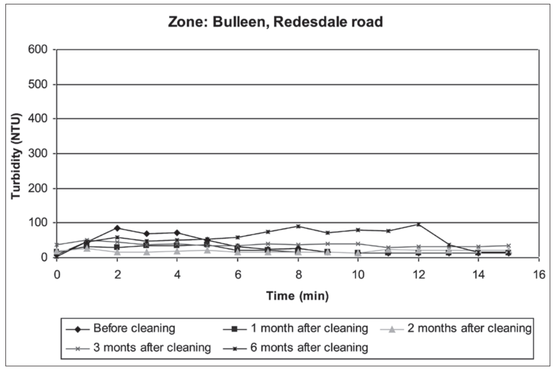

Figure 10. *Turbidity curve for Redesdale Road in the Bulleen supply zone.*

4, 5 and 7, respectively. A lower increase in RPM score is observed at this location and it is not necessary to clean this location after 6 months.

A key objective of the research is to compare the performance of different water quality zones. This is not totally possible since the RPMs are done at different time intervals.

In Tables 4 and 5 the peak values of turbidity and total average turbidity in the five zones are evaluated.

From Table 4 it can be concluded that Epping has in general lower turbidity levels than the other zones. This would also be expected since this zone is at times supplied with filtered water. Bulleen, with blended water also has a total average value, as expected, that is relatively low average compared to Croydon, Lilydale and Somerton.

The highest average value of turbidity in Somerton is 109.4 NTU. The results from Somerton indicated less variation in high and low turbidity levels than for instance in Croydon.

In Table 5 it can once again be found that the lowest maximum turbidity is measured in Epping. Bulleen has the second lowest maximum level and Croydon the highest. It should be noted that the zones have been cleaned at different times which might affect the maximum values obtained in each zone. Croydon has been

Table 4. *Total average of turbidity (NTU) in each zone.*

Category	Croydon n = 36	Epping n = 24	Bulleen n = 21	Somerton n = 17	Lilydale n = 21
max 5 min	122	49	71.6	154	103.2
Average 5 min	63.1	30.3	39	94.5	59.4
max 10 min	84.9	56.6	63.8	125.4	92.5
Average 10 min	60.3	29.3	35.5	63.7	49.2
Average	82.6	41.3	52.4	109.4	76.1

n = number of locations

Table 5. *Maximum turbidity (NTU) during RPM measurement.*

Category	Croydon	Epping	Bulleen	Somerton	Lilydale
max 5 min	434.6	118.7	359.4	359.4	534.9
Average 5 min	314.1	68.8	158.4	210.2	360.5
max 10 min	534.9	149	353.1	286.3	379.6
Average 10 min	498	64.2	72.1	137.6	156
Average	445.4	100.2	235.7	248.4	357.8

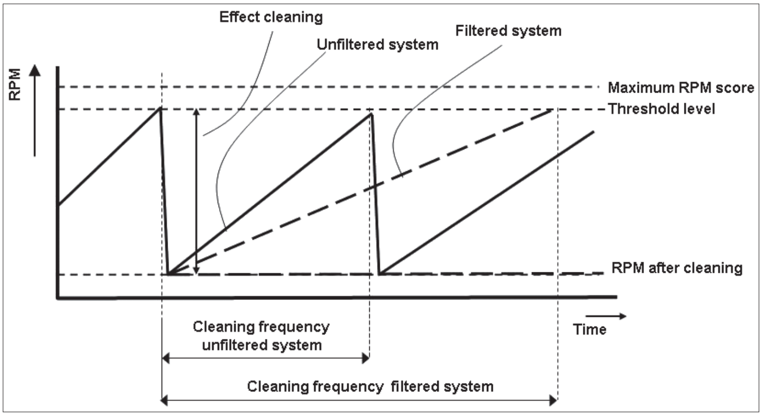

Figure 11. *Principle of making use of RPM measurement to determine cleaning frequency (Vreeburg, 2007).*

cleaned in October 2005, Epping and Lilydale have been cleaned in November 2005, Somerton in March 2006 and Bulleen in May 2006.

A preliminary conclusion from the available data is that the filtered systems have lower turbidities and thus RPM scores than the unfiltered systems.

Cleaning frequency

By performing several RPMs in time and after plotting the RPM score as function of time the period between successive mains cleaning can be determined objectively and pro-active cleaning actions can be taken. In Figure 11 the theoretical principle to determine this time period is given. In time several RPMs are made assuming a more or less constant water quality fed to a distribution system and from the RPM turbidity curves the RPM score can be calculated. This score is plotted in time and when a main fouls an increase in the RPM score in time is observed. When the RPM score is exceeding the threshold level for cleaning the mains are cleaned. Already from a few RPM scores the time period between cleaning actions can be extrapolated when the supply zone is fed with a constant particle loading.

In the analysis of the sediment build-up by using the RPM on a very frequent basis (for example monthly) it should be realised that with every RPM measurement the sediment layer on the measuring location is partly removed. Performing an RPM too often is therefore not useful. If between two consecutive RPMs there is a constant RPM score it means that in the time period between the RPMs the sediment layer is regenerated to the same level again or that only a small amount of sediment has been settled.

In Figure 12 and 13, RPM curves are given for the Croydon and Epping supply zone, respectively. Although not every location is reacting in the same way it is possible to observe a trend in both zones. At most locations in the Croydon zone a sharp increase in RPM score can be observed 6 months after mains cleaning. RPM scores suggest that water mains in Taronga Court, Baker Road and Orion Street need to be cleaned as they

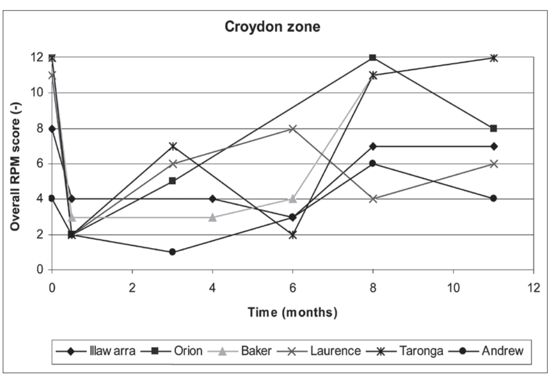

Figure 12. *RPM-scores as function of time for zone Croydon.*

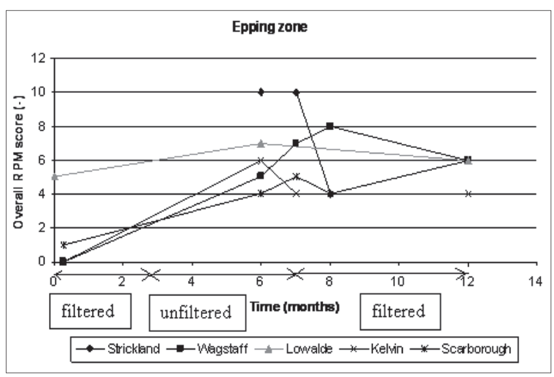

Figure 13. *RPM-scores as function of time for zone Epping.*

pass the threshold level for cleaning (RPM-score of 10).

For the Epping system only limited RPM data is available. This data show that this system is fouling at a lower rate than the Croydon. This is expected as the Epping system sometimes is supplied from a filtered source. Unfortunately no RPM measurements were performed within first 6 months. In this period the water that is fed to the system changed from filtered (first 3 months) to unfiltered (next 4 months).

By careful selection of different RPM locations in a supply zone a geographical trend in fouling of the system can be observed. These trends can be used to determine cleaning areas within a zone.

In the example shown in Figure 14 and 15 it can clearly be distinguished that there is a fouling of certain locations between 6 and 8 months in the Croydon zone.

Six months after mains cleaning (Figure 14) all the locations still have a score of less than 8 points. No measurements were taken at Orion Street after 6 months.

Three locations, Taronga Court, Baker Road and Orion Street, reached the critical score of 11–12 points suggesting that these mains need to be cleaned again 8 months after mains cleaning, (Figure 15).

It can also be seen from Figure 14 and Figure 15 the increase in the number of customer complaints 6 months

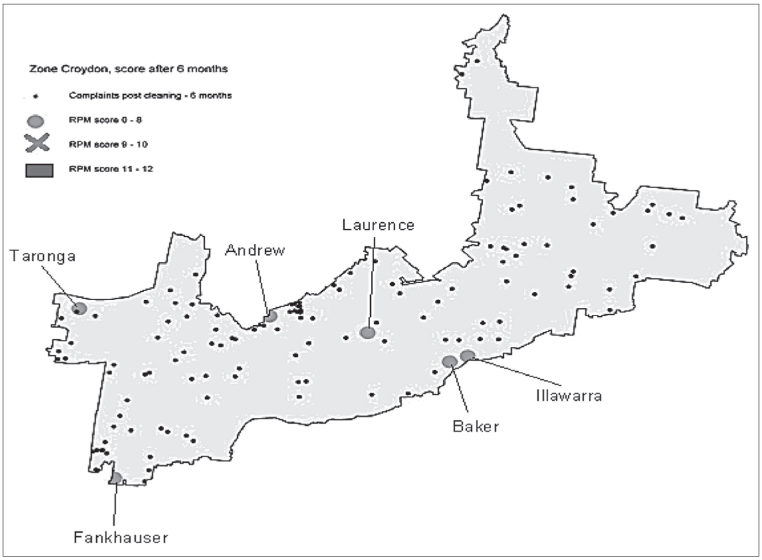

Figure 14. *Ranking of different locations in the Croydon zone, 6 months after mains cleaning. All locations are still with a score that would not require cleaning.*

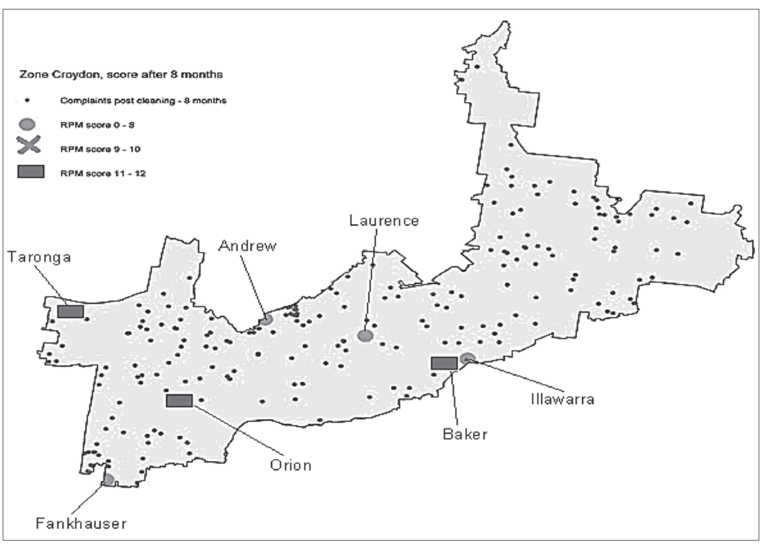

Figure 15. *Ranking of different locations in the Croydon zone, 8 months after mains cleaning. Some locations have a high RPM score so these mains have to be cleaned.*

after cleaning and 8 months after cleaning, 155 customer complaints respectively 223.

Operational experience with RPM at Yarra Valley Water

During an RPM measurement, as with any other experiment, there are always factors that play essential roles in determining the reliability and trustworthiness of the results. Problems experienced during RPM measurements include data logger failure, battery breakdown and inadequately secured fittings such as hoses and inadequate communication between planning and field staff. As a result not all initial experiments were done according to protocol, resulting in experiments that can not be used in this evaluation but they however provided valuable information for understanding the deposition and resuspension process in the distribution network. If a strict protocol is not followed the measurements will not be comparable on all levels to achieve the objectives. In this explorative phase it is always better to concentrate on few zones with a large number of RPM measurement locations to get experience and knowledge on the behaviour of the system. This knowledge can be transferred to other zones which can then most likely be analysed with less measurements. All these issues have been addressed by Yarra Valley Water to improve the quality of the subsequent field data, and should be taken into account when implementing this type of measurements. Though the method in itself is relatively simple, it takes skill and knowledge that usually goes beyond that of contractors, to perform an RPM correctly.

Discussion

The RPM is a very valuable tool for Yarra Valley Water to determine the cleaning frequency of their supply zones. Based on the analysis RPM data differences in required frequency for cleaning between filtered and unfiltered supply zones and within supply zones are evident.

The RPM monitoring program will be continued when the mains cleaning program is resumed after lifting of the water restrictions.

Conclusion

The RPM measurements are used by Yarra Valley Water to achieve a triple objective. From the RPM turbidity graphs before and after a cleaning action it becomes clear that the RPM can be used to evaluate the efficacy of the mains cleaning program. Furthermore, the RPM can be used to rank the discolouration risk of individual mains. By performing several RPM measurements in time it can be observed if in a main an easily resuspendable sediment layer is present. Based on the ranking method it can be concluded if a main needs to be cleaned. If not, no cleaning is yet required and within several months a new RPM measurement needs to be done. By careful selection of different RPM locations in a supply zone a geographical trend in fouling of the system is observed. From this trend it can be decided to clean certain areas of the supply zone. Also a clear trend between different supply zones is observed. The unfiltered zones of YVW deteriorate faster than the filtered zones, indicating that particle load in the water is an important factor in the initiation of discolouration problems (Vreeburg (2007)).

By following the RPM score in time and by comparing yearly RPM graphs it is expected that an extrapolation of the cleaning frequency can be made. However, at the moment not sufficient data is available and analysed to achieve this objective for Yarra Valley Water.

The RPM can also be used by other water utilities. The values for the different categories in the ranking table are adjustable to every utilities policy. It can be used to rank the dirtiness of supply zones, to determine the efficacy of mains cleaning methods and also a frequency between consecutive main cleaning can be estimated. The RPM is in use by all Dutch water supply companies. In Australia several water utilities have shown interest to use this objective ranking method. Hopefully there will also be an interest for Swedish water utilities to explore the possibilities of the Resuspension Potential Method to improve their performance on discolouration problems in the future.

Acknowledgement

This paper is a summary of the thesis work of Sandra Kjellberg. As part of an international collaboration of Delft University of Technology, Kiwa and Yarra Valley Water, Sandra Kjellberg, student at Lund University, completed her final MSc thesis project in Melbourne. Sandra spent 3 months in Melbourne at Yarra Valley Water evaluating already performed RPM data and provided valuable advise to YVW to improve and to successfully implement the Resuspension Potential Method. Interested people can contact Sandra by email (sandra.kjellberg@gmail.com) to receive a copy of the thesis report.

Notes

[1] The average chlorine concentration at customer taps is 0.1mg/L, maximum concentration, set by the National Health and Medical Research Council's Australian Drinking Water Guidelines 2004, is 5mg/L. (Yarra Valley Water, 2006a).

[2] Sukumaran, Nishal, Yarra Valley Water, 2007-01-15.

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