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Implementing Resuspension Potential Method to Optimise Mains Cleaning Program

Case study: Yarra Valley Water, Melbourne, Australia

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Preface

This is the final report of my MSc study in Environmental Engineering and marks the end of a long but very rewarding academic period in Sweden, the Netherlands and Australia.

After my time as an ERASMUS student in the Netherlands I was given the opportunity to travel to Australia to do my MSc thesis. The thesis is based on the implementation of a Dutch tool to predict the discolouration risk in a distribution network in Melbourne.

This report and its results are mainly based on the analysis performed at Yarra Valley Water, Melbourne, Australia in the period September - December 2006. The work was a co-operation between Delft University of Technology, Kiwa (the water research institute in the Netherlands) and Yarra Valley Water (YVW), Melbourne's largest retail water company.

Acknowledgments

I would especially like to thank my mentors, Jasper Verberk, Jan Vreeburg and Asoka Jayaratne.

Jasper and Jan, you have been my expert panel, sharing your great knowledge within this subject. Thank you for your commitment, feedback and time during these past months. Asoka, you have been helping me at site, guiding me through the work process at Yarra Valley Water.

Thanks also to all the colleagues at YVW who have been involved in this project. Special thanks to Jane Cumming, Bruce Davison, Graham Roddis, Tim Rodman, Daniella Mihu, Chris Saliba, Clea Henderson, Cynthia Wong and Debbie Stephens for all your help, support and time.

I would also like to thank Delft University of Technology, Kiwa and Yarra Valley Water for giving me the opportunity to carry out this project within the framework of your partnership.

"There are no stupid questions but there can be inadequate answers"

Jan Vreeburg, October 2006

Summary

The majority of water quality customer complaints received by water companies in Australia and in many parts of the world are due to discoloured water. In general discoloured water occurs due to the presence of dissolved, colloidal or suspended substances in drinking water.

Discolouration is associated with loose deposits in networks, which can originate from different sources. The processes that determine the water deterioration in distribution systems are known, but complex and relatively poorly understood, in particular in comparison to the water quality processes in the treatment plant.

Both in treatment and in the distribution system there are chemical, physical, biological and hydraulic processes that all influence the generation of discoloured water, but exactly when or where discolouration events occur are not yet possible to determine.

In the Netherlands and in Australia a number of research projects have been undertaken to minimise the generation of discoloured water in the distribution system. In the Netherlands a tool has been developed to evaluate the necessity of mains cleaning. This tool is called the "Resuspension Potential Method "(RPM) and is based on creating an additional velocity in order to resuspend deposited material. An empirically determined velocity of 0.35 m/s is induced on top of normal velocity to create a disturbance, without generating cleaning velocities in the system.

When applying this method, visually noticeable turbidity levels are created and measured. By monitoring the turbidity difference as a result of the velocity increase an indication is obtained whether a certain location needs to be cleaned.

This method is a standard procedure which is both reproducible and repeatable.

Since September 2005, Yarra Valley Water, Melbourne's largest retail water company have applied the Resuspension Potential Method with the goal of optimising their mains cleaning program. This is the first time the method is applied on unfiltered source water.

My work at Yarra Valley Water started in September 2006 with the analysis of RPM data collected since 2005.

My initial evaluation includes 13 water quality zones, but for deeper investigation five zones are analysed. Three of the zones have unfiltered water supply, one zone is supplied with sometimes filtered and sometimes unfiltered water and one zone has a blended water supply.

Evaluation shows that 38 % of the analysed data are completed loosely according to procedure, most of them missing a resettling time. To avoid loosing other important information an additional 23 % can be further analysed. The remaining 39 % have been dismissed due a number of issues such as faults with the data logger and that the procedure has not been followed.

The analysis of RPM data at Yarra Valley Water has three key objectives.

The first one is to evaluate the effectiveness of mains cleaning.

Results show that with only two RPM measurements taken prior to and after mains cleaning it can clearly be seen if the cleaning has been sufficient or not.

The second objective is to evaluate the discolouration risk within a zone and to compare the different zones. To evaluate the "dirtiness" within a zone a ranking table is created based on the measured turbidity levels.

The results show that RPM measurements can be used to assess the discolouration risk within a water quality zone/area. Since measurements have been taken at different times in the five zones it is at this stage not possible to compare the zones with each other using the ranking table. However, other parameters indicate that the unfiltered zones have higher turbidity values than the filtered and blended zone, as expected.

The third objective is to use RPM to determine the zone cleaning frequency.
The RPM results give clear indications, but more and better measurements are required to fully achieve this objective.

INDEX

1. **Introduction**

One of the major sources of customer complaints worldwide is due to discolouration of drinking water supplied to customers.

'Dirty water' may account for 60 to 80% of all water quality related complaints (Polychronopolous et al. 2003). The number of customer complaints due to discoloured water varies greatly over the world; in the Netherlands the annual average figure is 0.5 complaints per 1000 customers, while in Australia the average is 6 complaints per 1000 customers. Within Australia there is also a large variation in customer complaints between the different utilities ranging from 1.1 to 17.9 complaints per 1000 customers.
(WSAA Facts 2005)

In general one can say that discolouration is the result of the presence of dissolved, colloidal or suspended substances in drinking water. However a distribution system is a complex system which makes the understanding of the fundamental process causing discolouration limited. Both in treatment and in distribution there are chemical, physical, biological and hydraulic processes that all influence the generation of discoloured water, but exactly when or where discolouration events occur is not yet possible to determine.

The risk of discolouration events are most likely to occur in unlined mains, pipes with low water velocity with high particle loading and in mains with dead-ends, acting as sediment reservoirs.
In general sediments in the network appear as:

a) Suspended solids in flowing water
b) Attachments to the pipe wall (for instance due to sediments, bio films or corrosion)
c) Loose deposits at the bottom of the pipe

(Slaats et al. 2003)

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 drawing large amounts of water and operational changes can unsettle the sediments causing dirty water in localised areas. (Yarra Valley Water, 2006a)
No matter the variations of discolouration risks in different distribution systems, it can be agreed upon that they will all foul eventually.

The use of customer complaints to identify discolouration risk is important but as a quantification tool it is not suitable. A customer complaint is a very subjective measure which is neither reproducible nor reliable. Customers with bathtubs might have a higher complaint rate than customers with showers since the discolouration of the water will be easier observed. The longer the discolouration lasts, the larger the risk is of a customer complaint. Customers also tend to get used to a certain level of discoloured water and stop reporting to the water utility.

In most countries the number of customer complaints determines the cleaning frequencies for the water company. The water utility chooses to clean when the number of customer complaints increase.

This reactive approach is not the best approach since high costs are involved in a cleaning process. By using routine cleaning of the water mains the water company can take a proactive approach to prevent discolouration risks. It is therefore important to determine which mains need to be cleaned at which frequency.

The discolouration in the tool described in this report relates to the turbidity[1] levels and with a hydraulically induced turbidity the discolouration risk is determined. The method used is called the Resuspension Potential Method (RPM) and is developed by Kiwa Water Research in the Netherlands. This method is both objective and reproducible.

With the Resuspension Potential Method an empirically determined velocity of 0.35 m/s is induced on top of normal velocity[2] to cause a disturbance in the system. (Vreeburg et al. 2004b) This disturbance, measured in turbidity units (NTU) is monitored during a pre set time.

In this report there are mainly three objectives discussed, which the Resuspension Potential Method can be applied for; to determine if mains cleaning has been successful or not, to rank different locations and areas after their "dirtiness" and make prioritization in need for flushing and finally to develop a frequency for mains cleaning; when is cleaning required? As mentioned before this is now often determined based on customer complaint.

In the Netherlands where the RPM is developed, Verberk[3] says that almost all the water utilities use this tool or a similar version of it as basis for their mains cleaning p rogram. In Australia it is the first time the RPM has been trialled for application in the distribution system.

The tool has previously only been used for filtered systems in the Netherlands but is now trialed for unfiltered systems at Yarra Valley Water in Melbourne. In times of water restrictions, especially in Australia, it is very important for water utilities to find efficient methods for cleaning so that it is only done when absolutely necessary, this also to set an example to the customers.

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[1] Turbidity is a measure of the extent a beam of light is scattered by the suspended matter in the water. This scattering is expressed in nephelometric turbidity units (NTU)

[2] Normal velocity is estimated as approximately 0.07 m/s in a 100 mm main between 9am and 4pm. About 55 % of the mains in Yarra Valley Waters supply network are 100 mm mains.

[3] Jasper Verberk, conversation 13 February 2007

2. Background

2.1 Discolouration

Discolouration is the result of a combination of factors, for instance active corrosion in combination with large mains or the presence of sediments combined with hydraulic disturbance (Slaats et al, 2003).

Discolouration is mostly due to corrosion of cast iron pipes, valves and fire hydrants (ferrous material). The presence of manganese and iron colours the water red, brown or black. (Vreeburg et al 2004b)

Other sources causing discolouration is the presence of loose deposits and sediments in pipes and reservoirs.

The sediments in the system can originate from a number of different sources. It can come directly from the treatment plant, especially treatment with sand filtration where sediment can be introduced in the network.

It can also come from corrosion of unlined cast iron mains, which is regarded as a dominant process. During installations and maintenance work, sand, clay and silt easily enter the system. Also the formation in the network by precipitation of dissolved elements (iron, manganese, and calcium) or sediment formation, caused by micro- and macro organisms in the water main are a contribution to the sediments in the system. Depending on flow conditions the suspended particles may be transported or deposited as sedimentary deposits. (Slaats et al. 2003)

The origin of the accumulated sediment is multiple and is often demonstrated as following the mass balance model, see Figure 1.

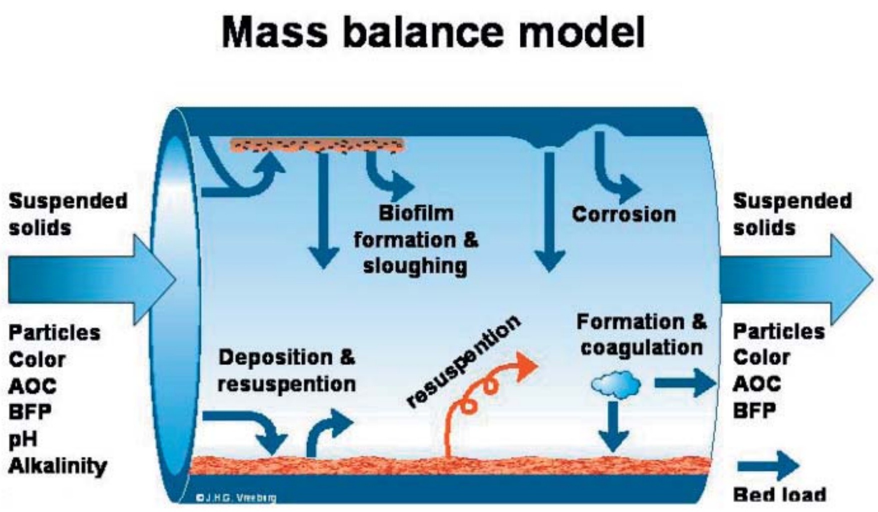

Figure 1 - Schematic mass balance model of sediment going in, retained and out of the system (Technical University of Delft, 2007)

The suspended solid enters the system, either from the treatment plant or from upstream in the network. Corrosion of ferrous material or leaching of cementitious material will form particles that can either settle on the pipe bottom or stay in suspension and directly colour the water. The bio film will materialise in biological activity and the sloughing of bio film will contribute to the formation of mass as well.

Destabilisation of suspended matter can lead to extra particles and smaller parts can also coagulate to larger parts and settle.

The variation of flow over time influences the shear stress in the system leading to the resuspension and settling of particles. The suspended solids leaving the system will either be supplied to the customer or removed by cleaning of the pipes. (Vreeburg et al 2004a)

Apart from the amount of sediment in the pipes the mobility of the sediment is also important when determining the discolouration risk. Relatively heavy particles as sand grains will settle quickly. Lighter particles which are easier resuspendable, mostly of organic origin and iron flocks, will take longer time to deposit.
Gauthier et al. (2001) found that the organic matter represents the most important fraction of suspended solids (from 40% to 76 %) in treated and distributed water.
Another factor that influences the mobility of sediments is the roughness of the pipe wall (Vos, 2005).

Prince et al. (2000) found after evaluating grab samples of finished water that the turbidity evaluated could be quite low, as the grab samples are not measured at the time of the day that the brown water incident occurs. Although the results of a grab sample might be very low, the fouling in the network can be quite considerable.

Apart from the aesthetic aspect of particles in the drinking water system, also public health could be compromised, as particles can be related to other water quality aspects, such as the biological regrowth problems in the network.
(Technical University of Delft, 2007)

2.2 Yarra Valley Water

Yarra Valley Water is the largest of Melbourne's three retail water companies and is owned by the Victorian Government. The company operates commercially under a Board of Directors appointed by the shareholder, the State Government.

Yarra Valley Water was established on 1 January 1995 and provides water and sewerage services to more than 1.5 million people across Melbourne's eastern and northern suburbs. (Yarra Valley Water 2006b) Each year YVW purchases an average of 170 gigalitres of water from Melbourne Water, its bulk water wholesaler (Yarra Valley Water 2006a). The company provides water and sewerage services within a defined geographic area of approximately 4000km^2 (Yarra Valley Water 2006b).

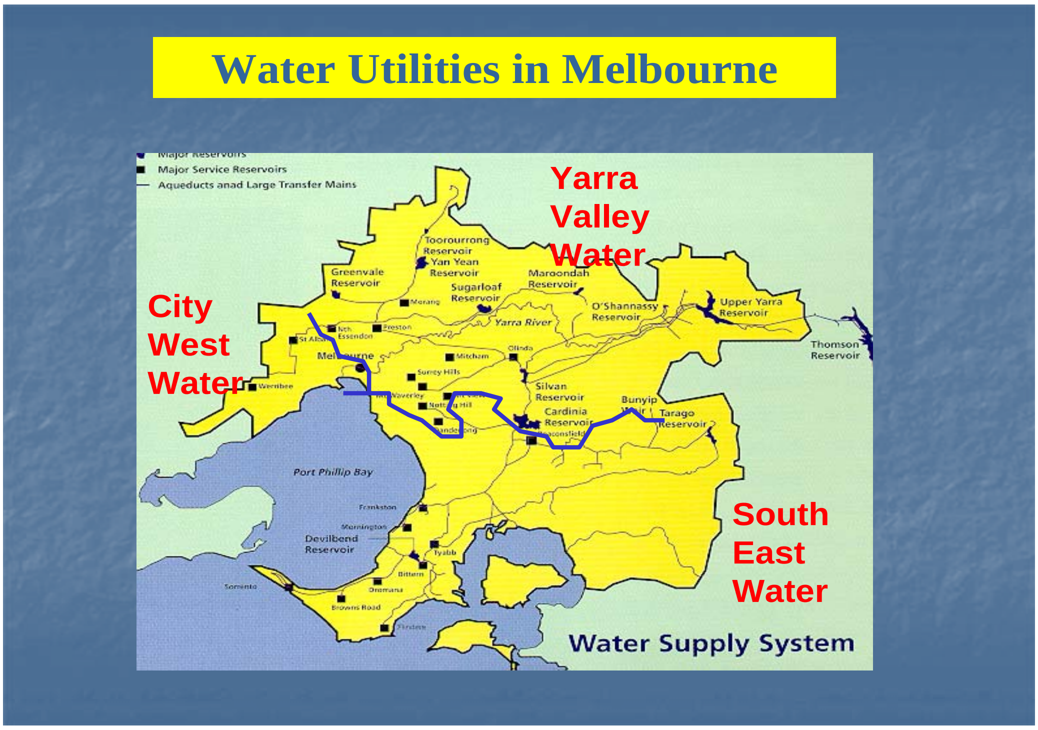

Figure 2 - The cover area of Yarra Valley Water's Supply Area (Jayaratne A, 2006b)

The majority of Yarra Valley Waters customer complaints (75%) refer to their experience of discoloured water due to resuspension of naturally occurring sediments due to unfiltered source waters.

In November 2002 Stage 1 water restrictions were introduced which made the company cease its mains cleaning program. The mains cleaning program was recommenced again in July 2005 when the water restrictions were lifted and by that time the company faced record high customer complaints of 6.22 complaints per 1000 customers. (Sukumaran, 2007[4])

Since September 2005 Yarra Valley Water has been implementing the Resuspension Potential Method to optimise the mains cleaning program with the objective to develop a proactive indicator to determine 'when' cleaning is required. Yarra Valley Water also intends to use the Particle Sediment Model (PSM) (Jayaratne et al, 2004) to determine 'where' to clean once the validation of the new version of the PSM is complete (see also Chapter 4.2.4).

[4] Sukumaran, Nishal, Yarra Valley Water, abstract 2007-01-15

2.3 System layout

Yarra Valley Water covers an area divided into 35 water quality zones, with a total of 62 pumping stations, 62 pressure reducing stations and 50 reservoirs. Of the 50 reservoirs, 41 are ground level water supply tanks and 9 are elevated water supply tanks.

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.

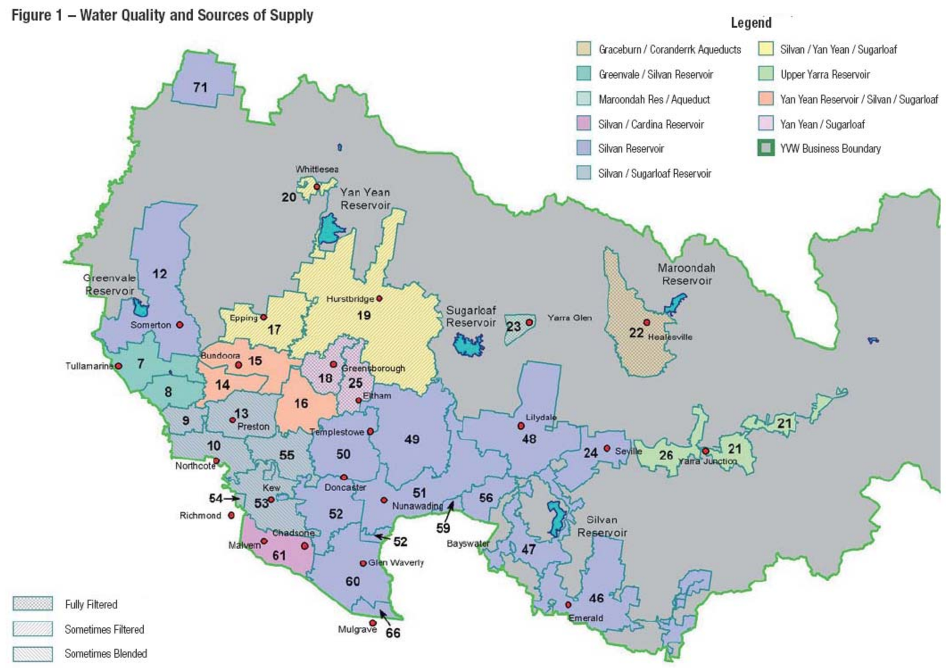

Figure 3 - Yarra Valley Water divided into water quality zones (Yarra Valley Water, 2006a).

Table 1 - Yarra Valley Waters 35 water quality zones and number of customers. Totally 1 522 346 inhabitants (Yarra Valley Water 2006a).

Locality Number	Water Sampling Locality	Population Serviced	Locality Number	Water Sampling Locality	Population Serviced
07	Tullamarine	50,057	25	Eltham	35,006
08	Broadmeadows	46,336	26	Woori Yallock	5,113
09	Coburg	35,312	46	Emerald	13,143
10	Northcote	96,882	47	Ridge/Monbulk	12,632
12	Somerton	61,574	48	Lilydale	41,260
13	Preston	80,137	49	Warranwood	49,091
14	Keon Park	32,577	50	Doncaster	78,115
15	Thomastown	68,921	51	Croydon	126,286
16	Watsonia	51,458	52	Mitcham	109,123
17	Epping	50,929	53	Surrey Hills	109,225
18	Plenty	35,444	54	Richmond	6,209
19	Mernda/Hurstbridge	14,123	55	Bulleen	59,230
20	Whittlesea	2,750	56	Montrose	15,011
21	Upper Yarra	6,756	59	Wantirna	5,813
22	Healesville	8,335	60	Glen Waverley	109,284
23	Yarra Glen	1,628	61	Malvern	79,651
24	Seville	5,113	66	Mulgrave	14,220
			71[1]	Wallan[1]	5,602

Note 1: The new Wallan locality was created in January 2006.

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 supplied by water that can be considered to be of same water quality across that entire area.

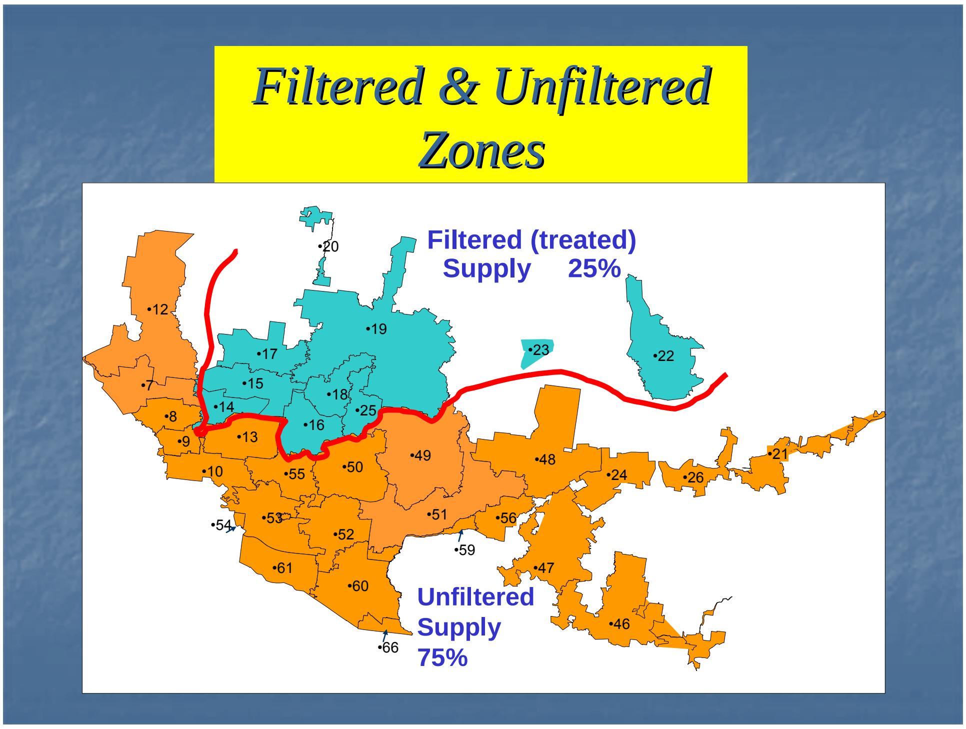

Figure 4 - Treated and untreated zones in Yarra Valley Water's area (Jayaratne A, 2006b)

75% percent of YVW's supply is from natural protected forested catchments located to the north and east of the city (Upper Yarra and Thomson reservoirs, see Figure 2). 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. This water will be stored further in reservoirs for up to 4 years allowing it to purify through settling and natural disinfection processing.
The water is also disinfected with chlorination[5], 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 (Yan Yean and Sugarloaf reservoir, see Figure *2*) is fully treated.
The chemicals added to this water are chlorine, fluoride, lime/soda ash (to raise pH), aluminium sulphate (alum) and poly electrolytes.
Alum and poly electrolytes are removed from the water as part of the treatment process before the water is distributed to customers.

Yarra Valley Water is also required by their licence and the Victorian Safe Drinking Water Regulations 2005 to comply with the microbiological standards and to monitor and report their compliances targeting the health parameters of the Australian Drinking Water Guidelines of the National Health and Medical Research Council of Australia (1996). (Yarra Valley Water, 2006c)

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

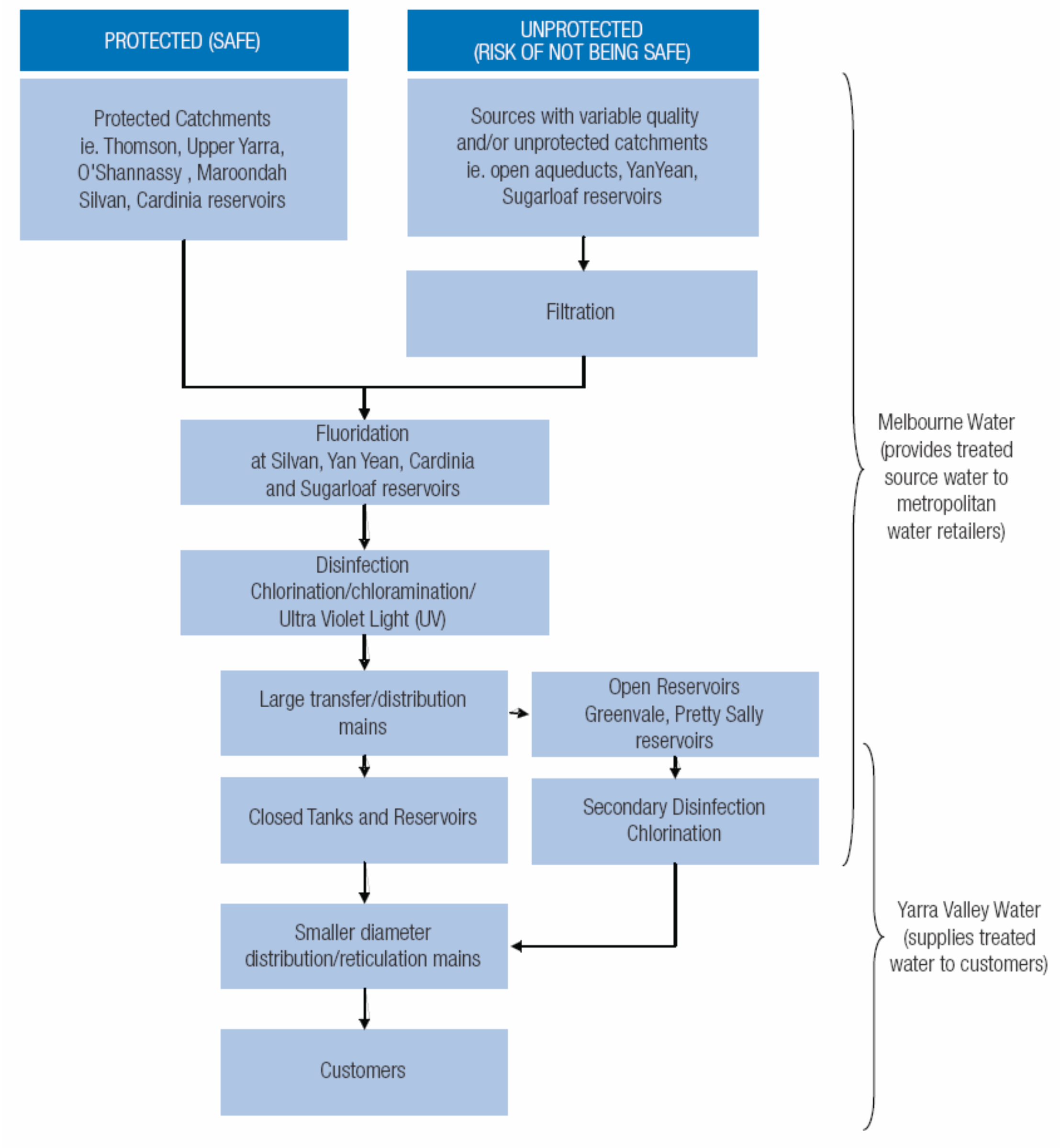

Figure 5 - From source to customer (Yarra Valley Water, 2006a)

Results to date indicate that the majority of particulate matter in Melbourne's water mains arises from source water (Prince et al. 2003).

Particles found within the water supply network around Melbourne are most likely from: the protected catchment upstream of treatment, or sloughing of bio films from within the pipes. Colour may origin from the presence of tannins or lignins produced by decaying plant material within the catchment storage. (Polychronopolous et al. 2003)

2.4 Customer complaints and mains cleaning program

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, see horizontal line in Figure 7.
By year 2013 the target is 3 complaints per 1000 customers.

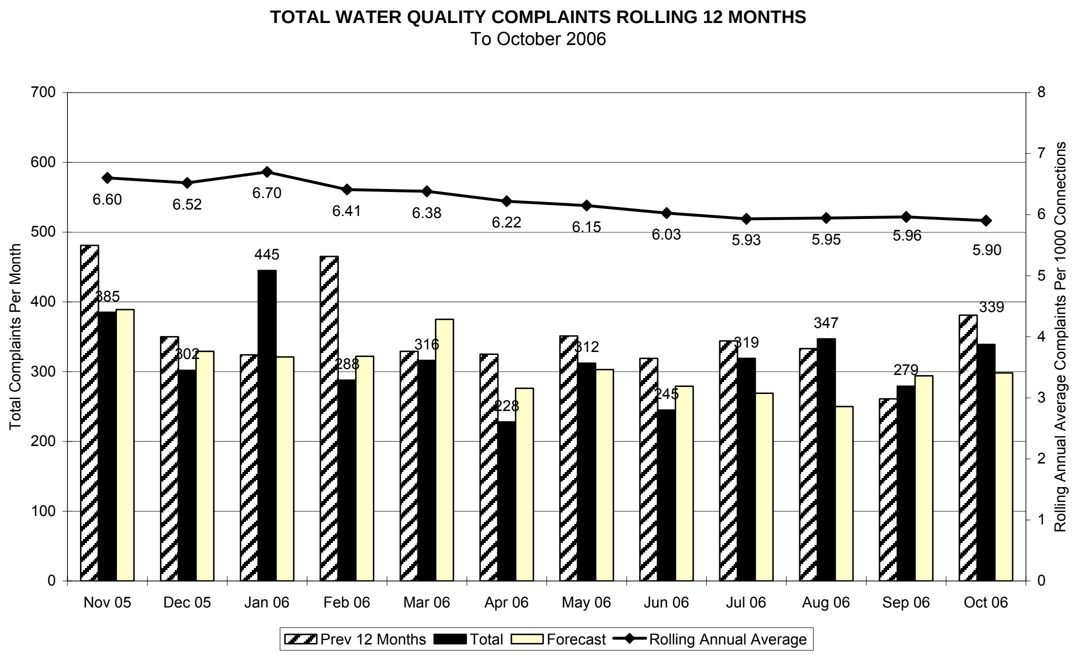

Figure 6 - Total complaints per Month and Rolling Annual Average of Yarra Valley Waters customer complaints, November 2005 until October 2006

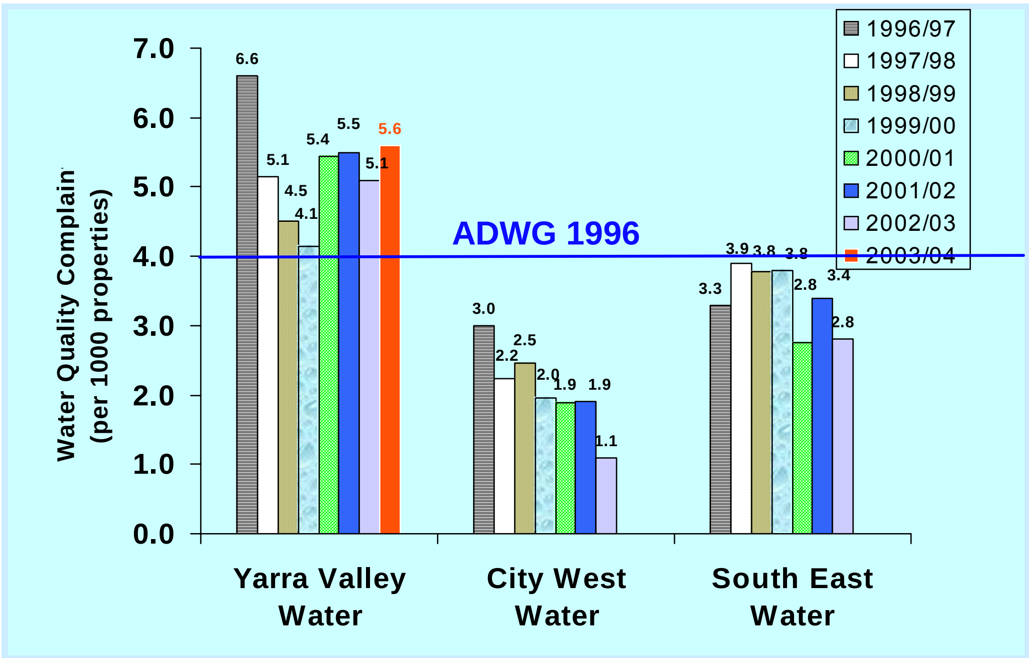

Figure 7 - Water quality complaints compared between the three retail companies in Melbourne (Yarra Valley Water, 2004). The Australian Drinking Water Guidelines (1996) recommends a customer complaint level of 4/1000.

Historically Yarra Valley Water has the highest water quality complaint results for Melbourne. Complaints from dead end streets contribute to about 20% of the dirty water complaints. This is significant considering only 10% of YVW's water mains are in dead end streets. (Yarra Valley water, 2004) The relationship between dead end streets and sediment load in mains is not further evaluated in this report.

In Melbourne there is a distinct seasonal and diurnal flow profile, due to large variations in summer and winter temperatures and customer behaviour (usage). South East Water Ltd, one of the other retail companies in Melbourne experienced that the dirty water customer complaints increased when the temperatures increased. Whether this trend was due to the increase in the volume of water used on hot days or due to the formation of dirty water by turbulent mixing with the increased pipe velocities has not yet been concluded. (Prince et al. 2001) The seasonal patterns should be considered when evaluating RPM measurement and their correlation to customer complaints.

When Yarra Valley Water plan their mains cleaning they select the area by ranking the number of complaints per 1000 connections and complaints/km. Further they thematically map complaints to identify hotspots and microbiological non-compliances. Thereafter the top (worst performing) zones are selected in order to clean 2800 km of water mains.

By using hydraulic models they identify areas within zones with low velocities and clean pipes where 95 % dry summer day peak velocity is lower than 0.2 m/s (low velocities meaning that there is no self cleaning in the system)

Analysis of complaints and pipe velocities using hydraulic models indicate that 80%-90% of complaints recorded are properties connected to water mains having velocities < 0.2 m/s. (Yarra Valley Water, 2004)

Yarra Valley Waters cleaning method is selected on pressure and size of the water main. Methods for cleaning pipes in the distribution network are for example flushing, swabbing, pigging and air scouring. About 60-70 % of the hydrants are used for flushing in an area. (Yarra Valley Water 2006b)

As previously mentioned Yarra Valley Water stopped their mains cleaning program in November 2002 due to water restrictions. The original water mains cleaning program used 90 % flushing and 10 % air scouring, cleaning up to a maximum of 1400 km per year. At this rate all zones would be cleaned, on average, every 6 years.

In addition to mains cleaning, around 3000 flushes are done per annum as a response to the customer complaints, where of about 75 % are related to dirty water. Reservoirs are cleaned when needed, on a frequency of 3-5 years and allows (on average) 10 tanks to be cleaned per year.

Unidirectional flushing is the preferred method of cleaning, due to its low cost. Yarra Valley Water flushes pipes with a diameter less than 225 mm, where residual pressure is larger than 50 m head.

Air scouring is used where flushing velocities can not be achieved and in areas where there is inadequate drainage to dispose any high volumes of water that flushing would cause. Air scouring is also sometimes used where significant problems with taste, odour or microbiology appear, since it is considered more effective to scour the pipes. Air scouring is used on pipes with a residual pressure less than 50 m and on pipes larger (or equal) to 150 mm regardless of pressure.

Swabbing is done on reticulation mains and on large mains based on risk assessment. (Yarra Valley Water, 2004)

3. Objectives

The Resuspension Potential Method as presented in this report is focusing on three major objectives. These objectives are set to help Yarra Valley Water work towards an improved mains cleaning program and thereby a reduction in the number of customer complaints. Since customer complaints are not a reliant indicator when establishing a mains cleaning program the RPM tool is being trialled.

Yarra Valley Water is interested in using the Resuspension Potential Method for unfiltered systems to:

1. Determine the effectiveness of the mains cleaning program

To achieve this, a measurement is required prior to mains cleaning and immediately after mains cleaning (preferably the next day).

2. Rank dirtiness of water quality zones/areas

The idea is to be able to compare different zones and areas within individual zones in order to prioritise which area/zone should be cleaned more often.

3. Predict zone cleaning frequency

With help from the results a frequency of cleaning can be established.

4. Methodology

4.1 Resuspension Potential Method (RPM)

The presence and mobility of loose sediments, irrespective of the origin, is what determines the discolouration risk. The Resuspension Potential Method (RPM) is based on measuring the capability of the sediment in a network to resuspend using a standard procedure of flushing, creating visually noticeable turbidity levels which are measured. The RPM is a standardised repeatable measurement method to determine the water quality response of a pipe. (Prince 2004)

During a controlled, normalized and moderate increase of the velocity in a pipe the turbidity is monitored.

The hydraulic shear stress resulting from the increase of velocity causes the sediment to resuspend. A practical restriction in this procedure is of course that the change in hydraulic regime only causes a moderate increase in shear stress to prevent too much increase in turbidity levels leading to actual complaints. (Vreeburg et al 2004b).

4.1.1 Practical performance of RPM

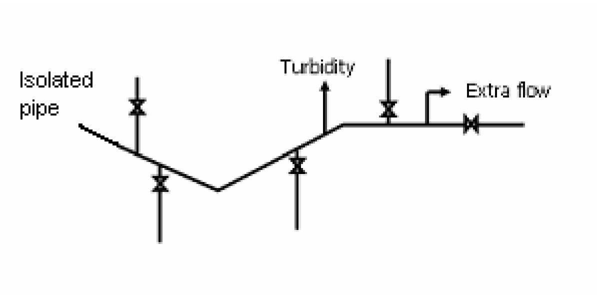

Figure 8 - Illustration of creating unidirectional flow (Vreeburg et al. 2004b).

1. Isolate the pipe for which the discolouration risk is assessed by closing the valves that connect other feeding pipes with the pipe being evaluated. In this way a unidirectional flow is created, see Figure 8.

The minimum length of the isolated main should be 315 meters (see Appendix A for calculation).

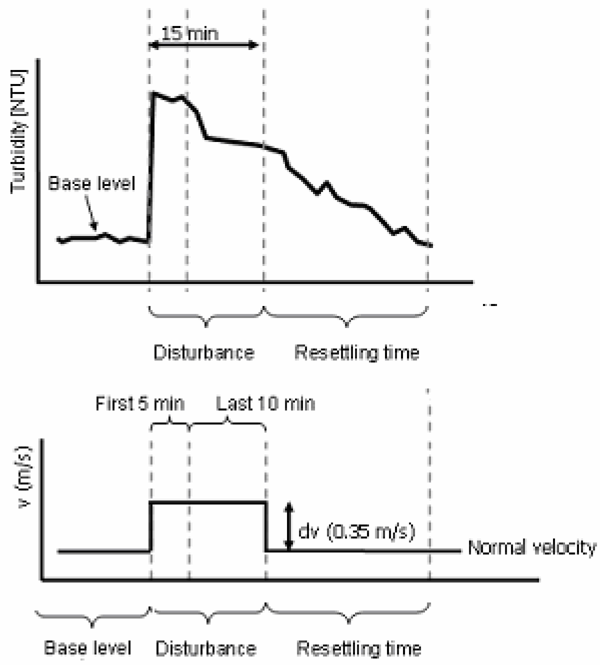

Figure 9 - Illustration of RPM performance (Vreeburg et al. 2004b).

2. Monitor the turbidity in the main pipe for some time (3-5 minutes) to determine the base level turbidity. This will give an indication of what the normal conditions of discolouration are in the pipe; see "Base level" in Figure 9.

3. Induce acceleration of the flow by opening a fire hydrant in such a way that the velocity in the pipe is increased with an additional 0.35 m/s on top of normal velocity and maintain this velocity during 15 minutes. The velocity of 0.35 m/s is empirically determined. Monitor the turbidity in the pipe during this disturbance, see Figure 9

4. After the 15 minutes disturbance reduce the velocity back to normal, continue the monitoring until the turbidity level is back to the starting level or until a predefined turbidity level or predefined resettling time is obtained, see "Resettling time" in Figure 9

The 15 minutes disturbance time, with a minimum of 315 meters is a recommendation. The disturbance time can be done for a shorter time which then corresponds to a shorter length required of the isolated main (to prevent water from other sources). For minimum required length and disturbance time see Appendix A.
It is not recommended to do a disturbance time shorter than 10 minutes since the results are likely to be insufficient for analysis.

The RPM is developed for smaller pipes ranging from 80 to 200 mm internal diameter. The velocity required to achieve the added 0.35 m/s is dependant on the internal diameter. For an 80 mm pipe this would be 1.76 l/s (6.3m^3/h) ranging up to 11.0 l/s (40m^3/h) for a 200 mm pipe. For a typical 100 mm pipe it would require a flow of 2.78 l/s (10m^3/h), see Appendix A for calculation.

It is not preferable to do RPMs on larger mains since only the top layer of the water is used in the pipe. The bottom layer is not flushed and this is where most of the sediments are accumulated. The sediments will only be removed if performing an

RPM using a large flow. A velocity greater than 0.35 m/s would be required to disrupt the bottom sediments, which is highly undesirable.
In smaller pipes all water is withdrawn from a pipe when an RPM is performed, meaning that the entire pipe is flushed and all easily removable sediments are removed.
Furthermore, larger pipes are often used as transport mains and the velocity in these pipes are more constant and no large fluctuations of velocity occur. Velocities are also higher and lower amounts of sediment will deposit.

The extra flow that is required to cause the increased velocity of 0.35 m/s will be obtained by opening the hydrant. If a calibrated standpipe is used (see Figure 10), the right flow will be achieved.
Using a flow control valve (ceramic plate or in Melbourne *Maric* valves) a constant flow during the disturbance will be maintained throughout the test, see Figure 10 (right). A risk when not using any ceramic plates is that when initially opening the hydrant an instant disturbing flow with often higher velocity than the desired one is obtained. This extra velocity will cause an extra resuspension of the sediment which is not optimal since the intention is only to clear the hydrant from debris and not cause any experimental disturbance.

Figure 10 - Example of standpipe setup and ceramic plates used in the Netherlands (left: Kjellberg, 2006; right: Vreeburg et al. 2004b)

The flow through the standpipe, causing the disturbance is monitored with a flow meter (water meter).
These flows should be registered because any deviation from the standard disturbance may cause a different shear stress on the sediment and therefore also a different effect on the turbidity.
Using well calibrated plates in the standpipe can eliminate the need for flow measurement. (Vreeburg et al. 2004b)

Figure 11 - Two different models of Dr. Lange turbidity meters (Kjellberg, 2006). This equipment can easily be attached inside the vehicle.

A number of different turbidity meters can be used to register the turbidity levels. In the Netherlands the Sigrist KT65 and the Dr.Lange Ultraturb (see Figure 11) are used. Comparison between the two concluded that the meters measure comparable turbidity patterns in turbulent solutions, but that the absolute values of turbidity are at different levels. (Slaats et al, 2000 cited in Vreeburg et al. 2004b)
These differences need to be taken into account when evaluating the results of the RPM measurements.

Figure 12 - A "theoretical" result of an RPM measurement

The results from the RPM measurements can be read as the turbidity pattern observed in the main. A typical appearance of a measurement can be seen in Figure 12 (also previously in Figure 9). In order to determine the discolouration risk four elements of the curve are important;

* Base level turbidity
* Initial increase in turbidity at the start of the hydraulic disturbance
* Development of turbidity during the hydraulic disturbance
* Resettling time and pattern to base (initial) turbidity level

Base turbidity level
The base level is the level before the hydraulic disturbance. The base level turbidity indicates the turbidity of the source water and gives information about the source of the sediment. Base line turbidity is also needed to determine the time for the turbidity to resettle after the disturbance is stopped.

Initial increase in turbidity
As soon as the velocity is increased with 0.35 m/s on top of normal velocity the turbidity will immediately rise to a certain level. This initial increase will give the instantaneous mobility of the sediment, resulting in peak turbidity.
The initial increase is also an indication of the maximum turbidity caused by a hydraulic incident.
The initial turbidity is caused by a loose layer of sediments that is immediately available when disturbance time starts. If the initial turbidity increases then the chance of noticing discolouration is higher.

Development of turbidity during the hydraulic disturbance
The disturbance is kept during 15 minutes to develop a stable level.
If the turbidity level stays at almost the same level, as the first five minutes, during the entire disturbance period, 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 is homogeneous.
In most cases the turbidity will drop during the 15 minutes disturbance time which can be explained as follows. (Vreeburg et al 2004b):

1. There is a relatively small amount of heavy sediments present that with the extra forces in acceleration of the flow will result in an initial whirling up of this heavy sediment (Blokker et al, 2003 cited in Vreeburg et al. 2004b)
This sediment will only lead to a small discolouration risk since it is settling even during the deviating hydraulic circumstances, making the significance of the sediments limited.

2. The isolated main is too short. A minimum length of 315 meters is required to avoid water being drawn from other sources upstream of the isolated pipe. This water will not have the same disturbance of 0.35 m/s since it is drawn from a looped network or from pipes with larger diameters.
If the disturbance time would be set to fewer minutes, for example 10 minutes, it would require a minimum isolated main of 210 meters (see Appendix A).

3. The measurement is done in for example a hilly area with local pockets of sediments trapped in depressions, meaning a non-homogeneous deposit over the length of the isolated main.

In all cases the level of turbidity following the first peak will determine the continued discolouration risk. The longer time this level is sustained the higher risk for customers to detect the discoloured water.

Resettling to base level, to predefined turbidity or turbidity after predefined time
When the additional induced velocity is stopped the sediments will start to resettle again. These turbidity levels are monitored until they reach the base level, a predefined turbidity or a turbidity after a predefined time.
After closing the hydrant it takes some time for the sediment to resettle to base level. If the turbidity level stays high during a longer time period, the risk of noticing the turbidity when filling a white basin (bathtub, bathroom sink, washing bin etc) will be larger meaning a higher risk of complaints from customers. (Vreeburg et al. 2004b)

4.1.2 Evaluation of RPM Curves

When evaluating results as shown in Figure 12, five aspects are considered and rated equally, each weighing 20 %. These aspects are:

* Absolute maximum value of turbidity during the first five minutes of disturbance
* Average value of turbidity during the first five minutes of disturbance
* Absolute maximum value of turbidity during the last ten minutes of disturbance
* Average value of turbidity during the last ten minutes of disturbance
* Time needed to resettle again to base level or predefined level of turbidity

The value found for each aspect is ranked according to a ranking table.

Table 2 and 3 give example of ranking tables used for the Sigrist and Dr.Lange turbidity meters used in the Dutch distribution system.

Table 2 - Evaluation table used for Sigrist turbidity meter (Vreeburg et al. 2004b)

Points Category	0	1	2	3
Absolute maximum first 5 minutes	< 0.3 NTU	0.3 – 1.0 NTU	1.0 – 2.4 NTU	> 2.4 NTU
Average first 5 minutes	< 0.3 NTU	0.3 – 1.0 NTU	1.0 – 2.4 NTU	> 2.4 NTU
Absolute max last 10 min	< 0.3 NTU	0.3 – 1.0 NTU	1.0 – 2.4 NTU	> 2.4 NTU
Average last 10 min	< 0.3 NTU	0.3 – 1.0 NTU	1.0 – 2.4 NTU	> 2.4 NTU
Time to clear	< 5 min	5 – 15 min	15 – 60 min	> 60 min

Table 3 - Evaluation table used for Dr. Lange turbidity meter (Vreeburg et al. 2004b)

Points Category	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 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

For each aspect a validation on a scale of 0 (zero) to 3 points is made;
0 (zero) is the lowest and best rating, also meaning no discolouration risk, and 3 is the highest or worst rating. The highest value or maximum discolouration risk is 15 (5 aspects each given 3 points).

Depending on which turbidity meter used, a calibrated scale adapted to the equipment must me made to rate the five aspects. (Vreeburg et al 2004b)
With a discolouration risk establish in this way, with relative figures, it can be made area-specific or specific for every company to develop its own levels of accepted discolouration limits.
For every situation and measuring equipment a ranking table should be made, depending on the turbidity meter and other local circumstances.

An example will be shown later in this report of an application made for the turbidity meter Yeokal 611 used by Yarra Valley Water. These ranking tables can, as mentioned before be adapted for different purposes. When using the RPM technique to prioritize different areas for an initial cleaning program, the maximum value can be adjusted to the outcomes of the measurements. By adjusting the ranges it is possible to distinguish very high degrees of discolouration risk enabling the desired prioritisation.

These ranking tables also create a weighing scale for a company to risk receiving increased customer complaints (high ranges set as acceptable on the limits in the ranking table) versus economical issues (if setting lower acceptable limits it requires a more frequent cleaning).

The ranking tables 2 and 3 would, if used in Australia, always result in dirty mains. The particle load in the distribution system varies between the Netherlands and Australia due to different treatment philosophies. In the Netherlands multiple barrier treatment without any chemical disinfection (chlorination) is applied, resulting in many treatment steps for surface water.
In the Netherlands the maximum allowed turbidity level in distributed water is set to 1 NTU while in Australia the maximum value is 5 NTU.
The Australian Drinking Water Guidelines (ADWG, 1996) recommend that turbidity in drinking water should be kept below 1 NTU to enable effective disinfection and below 5 NTU for aesthetic considerations. (Prince et al. 2001)

4.1.3 Cleaning frequency

By performing several RPMs in time and after plotting the overall RPM score as function of time the period between successive mains cleaning can be determined objectively and proactive cleaning actions can be taken.
In Figure 13 the general principle to determine this time period is given. In time several RPM measurements are taken and by assuming a constant water quality, the overall RPM score can be calculated. This score is plotted against time and when a main fouls an increase in the overall RPM score in time is observed. When the overall RPM score is exceeding the threshold level for cleaning the mains should be cleaned. Already from a few overall RPM scores the time period can be extrapolated when the supply zone is fed with a constant particle loading.

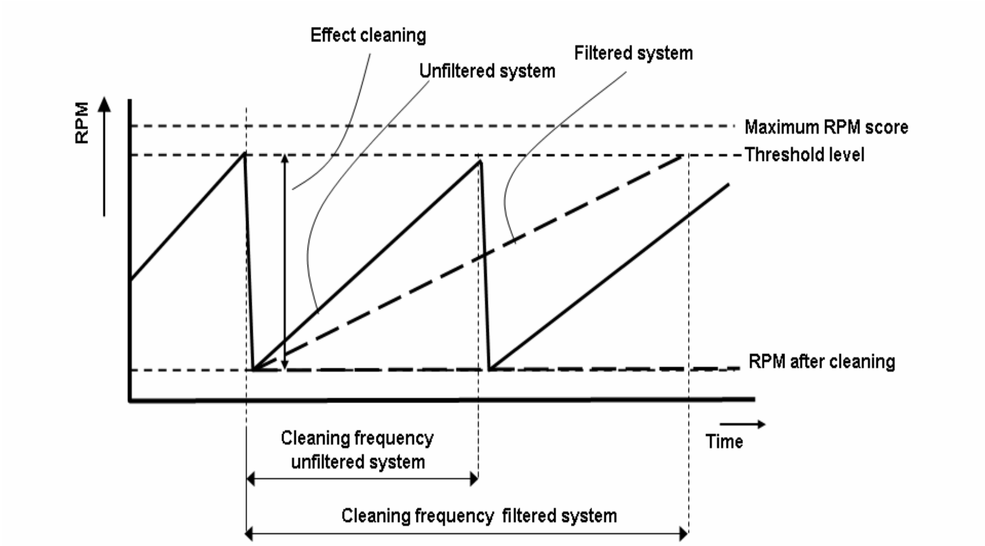

Figure 13 - Principle of using RPM measurement to determine cleaning frequency

4.2 Other sedimentation measuring models

There are a number of other models applied to analyse sediments and discoloured water around the world. In this report a few others will briefly be mentioned but the main focus is on the RPM.

4.2.1 Continuous monitoring of turbidity

The main parameter used is turbidity as a surrogate parameter for the amount of particles that is suspended in the water. The propagation of a natural variation of the turbidity level can be followed. Typical elements for the analysis are the base level of turbidity and the pattern during longer time. By monitoring the turbidity it can be established whether the incoming mass is equal to the outgoing mass which would mean that there is no net accumulation of sediment. Also meaning that if the mass out is less than the mass going in then there would be a build up of sediments in the system (Vreeburg et al. 2004a)

4.2.2 Mass Settling Potential (MSP)

Mass Settling Potential (MSP) gives an indication of the mass that can settle in a network. Experiments show that this can be up to 15-17 % of the dry solids that are available in the finished water. It is also concluded that the particle load in a network can be considerably decreased if the peaks of turbidity can be lowered. To accomplish this, improvement of the backwashing process and more time set to reinstall the washed filter during treatment would be of importance. (Vreeburg et al. 2004a)

4.2.3 Prediction and control Of Discolouration in Distribution Systems (PODDS)

The PODDS model is a water quality model developed for unlined systems.
The approach combines both deposition and wall attraction mechanisms. The PODDS model uses a conditioning hydraulic model and an event model but with a critical shear stress parameter requiring calibration by optimisation techniques and the self cleaning threshold is not taken into account. (Prince 2004)

The PODDS model describes the turbidity potential of attached layers at the pipe wall, the strengths of these layers which are influenced by the daily hydraulic regime of each pipe. The maximum shear stress during the day is responsible for the strength and the amount of fouling material that is eroded during a hydraulic event. (Vos 2005)

4.2.4 Particle Sediment Model (PSM)

The Particle Sediment Model developed by CRC (Cooperative Research Centre for Water Quality and Treatment; Australia) is based on the mechanism of gravitational settling and wall deposition. The PSM is used to predict the distribution of sediment over a network.

The model assumes that all particles entering the network come from the treatment plant and that no other processes contribute or sediment accumulation in pipes.
These are the concentration of particles from the treatment plant and the different characterization velocities for the sediment. (Vos 2005)

Jayaratne et al. 2004 showed after tests on a 100 mm clear PVC pipe, that the particles will settle with gravity if velocities are less than 0.07 m/s, and between 0.07 - 0.25 m/s the sediments will start to resuspend while between velocities of 0.25-0.6 m/s they will be moving completely.
If the particles do not start to move until velocities above 0.6 m/s there is likely manganese in the supply water. This model is on trial to be used by Yarra Valley Water to support the RPM and determine when mains cleaning is required.

5. Pre project practical research in the Netherlands

Before my work at Yarra Valley Water, Australia, I got acquainted with the RPM technique by visiting two water companies in the Netherlands.
Their RPM performances are very similar and they follow the method described in Chapter 4.
Both companies use Dr. Langes turbidity meter for their measurements and they both use a similar standpipe setup. Turbidity values are registered with a data logger every 10 seconds.

When performing the RPM measurements they apply different disturbance times. One company use 15 minutes with a minimum length of 315 m and the other one use 10 minutes disturbance with a required minimum length of the isolated main of 210 meters.

A flowmeter is used to determine the right flow and one of the companies also used ceramic plates to regulate the flow. Grab samples of the water were taken, to visually determine the discolouration *in situ*.

The water companies in the Netherlands use a computer package "Flush Planner", developed by Kiwa, to help prepare block flush plans using hydraulic models. The program makes it possible to determine exactly which valves to close when doing a cleaning action, to ensure that unidirectional flushing is achieved and a clear water front is used. Almost all of the Dutch water utilities use the RPM method, "Flush Planner" and online turbidity measurements to ensure that water mains are cleaned to an acceptable standard turbidity of less than 1 NTU.

Figure 14 - Measurement at Hydron in Flevoland, the Netherlands (Kjellberg 2006)

6. RPM procedure at Yarra Valley Water

Yarra Valley Water has taken approximately 500 RPM measurements at 150 different locations between 8/9/05-10/11/06

6.1 Prioritization – zones/areas

When Yarra Valley Water started their implementation of the Resuspension Potential Method they wrote a procedure of criteria used for finding measurement sites. The procedure stated that RPM sites were to be selected with a distance of 10 km apart, on selected streets where no previous bursts had been registered. A total number of 13 water quality zones were to be evaluated with the Resuspension Potential Method.

A number of staff at YVWs' Planning team worked with the selection of hydrants. For every measurement two hydrants were selected, on the same street or on nearby streets. One of the two hydrants was a reserve if there were problems with the other one.
When the RPM locations were chosen the selected hydrant numbers were handed over to the Project Management team submitting them to a map of the area. On the map it was also stated which valves to close to create a unidirectional flow.
The map for each RPM location was given to the contractor who performed the measurements.
A procedure on how to perform the measurement was also written when YVW started their RPM implementation, this was handed over to the contractor as well.

RPM measurements were to be taken one week prior to cleaning, immediately after cleaning, and subsequently at the following intervals after cleaning: one week, one month, two months, three months, six months, nine months and 12 months.
The time between successive RPM measurements at each site is different from the Kiwa recommended frequency of 12 months. Customization of the RPM technique is necessary in applying the method for Melbourne's unfiltered system. Since this method is still under research in Melbourne it can with time be evaluated which interval is the best to apply.

When the results were collected for a RPM the data was stored in a data logger. Approximately 6 measurements were taken per day most days of the week between 10 am - 4 pm.
Within days of the RPM measurements being recorded the values were transferred by the contractor to a lap top and further to a stationary computer. The measurements were formatted and further sent to the Water Quality Team for evaluation and analysis of the results. The first analysis of the results was performed in September 2006, a year after the initial measurements.

Out of the 35 water quality zones, RPM measurements have been performed in 13 zones.
In this report there will be an evaluation using the RPM results from 5 of these zones, see Figure 15. The reason why these five are chosen is partly due to time constraints in evaluating all of the 13. The zones that are evaluated consist of three zones supplied with unfiltered water, one zone that sometimes has fully filtered water (periodically unfiltered aswell) and one zone with blended water (filtered + unfiltered).

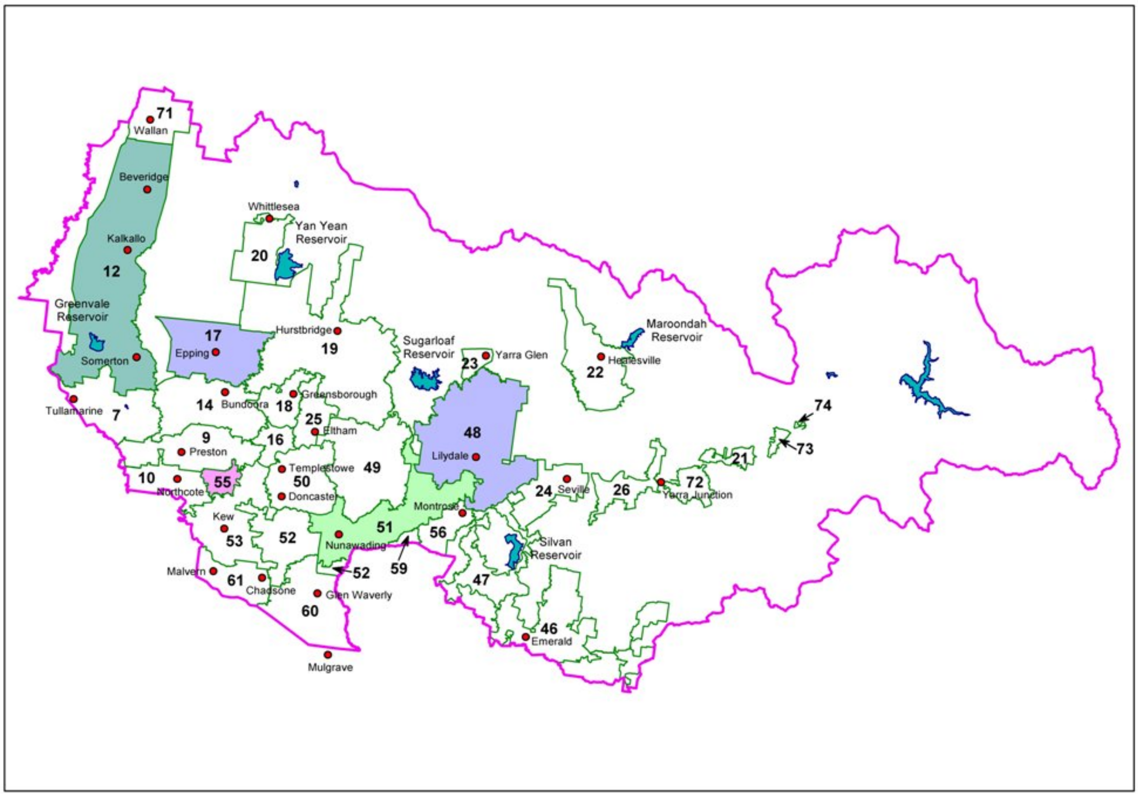

Figure 15 - The five zones (zone 12, 17, 48, 51 and 55) that are evaluated and their location (coloured zones)

It would have been of interest to do RPM measurements and evaluate results for yet another filtered zone and another zone with sometimes blended water. This has not been possible though since there are no measurements taken in zones with these premises other than the two already evaluated.

6.1.1 Croydon WQZ 51

Croydon is located in the south of Yarra Valley Waters supply system. It has an area of 72 km^2 and a total number of 53366 connections (55241 customers) (Jayaratne 2006[6])
The water supplied to the Croydon zone is unfiltered and comes from the Silvan reservoir.

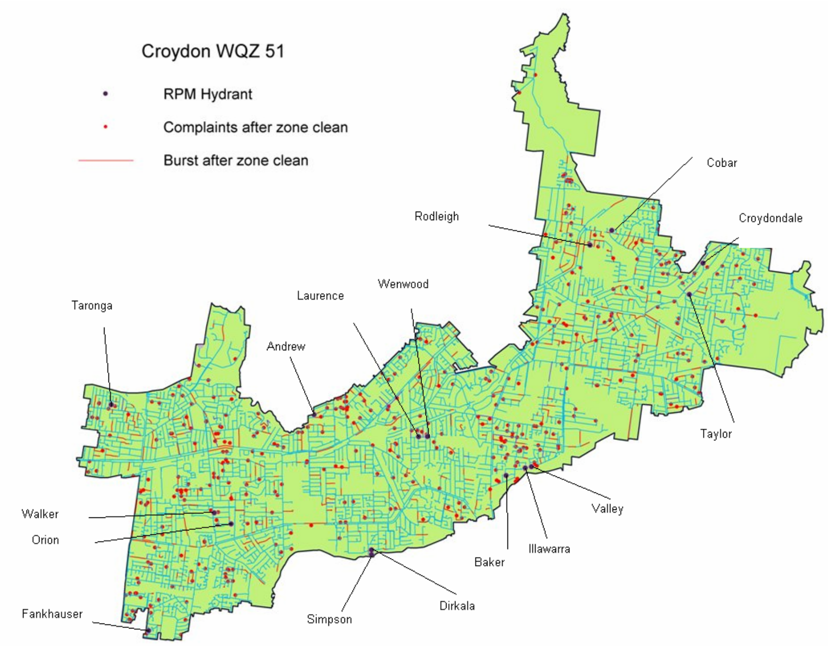

Figure 16 - Water quality zone 51, Croydon

A total number of 16 locations are selected for RPM measurements within the Croydon zone. Measurements are taken before mains cleaning (pre), 3 months after cleaning (some sites 4 months after), 6 months, 8 months and 11 months after cleaning.

Measurements are also taken 1 month and 2 months after cleaning but due to data logger problems this data is not accessible for evaluation.

On three of the locations there are also measurements taken one week after mains cleaning (Illawarra Cresent, Baker Road and Valley Court). However Valley Court does not have any pre measurement.

No measurements at all are taken on Taylor Street or Croydondale Drive due to inaccessibility and buried fittings. On Wenwood Street only one measurement is taken (19 July). Previous measurements could not be taken due to inaccessibility.

Figure 16 shows the number of customer complaints (based on dirty water) for a year, between September 2005-2006. The number of complaints are 492 giving a rate of 9/1000 customers. The zone was last cleaned at the end of October 2005.

Croydon was selected as an evaluation zone primarily because this zone contained most collected data.

6 Jayaratne Asoka, Power point presentation, Sri Lanka 2006

6.1.2 Epping WQZ 17

Epping has a total area of 36 km^2 with 16955 numbers of connections (22197 customers). (Jayaratne 2006[7])
This water quality zone is sometimes fully filtered with water coming from Yan Yean reservoir and sometimes unfiltered with a supply from Silvan reservoir. In the following time periods the water has been fully filtered:

5 October- 24 February 2004/2005
3 August – 31 January 2005/2006

When I left Yarra Valley Water on 1 December 2006, the Epping zone was supplied with water from the filtered Yan Yean and had been since 7 June same year.

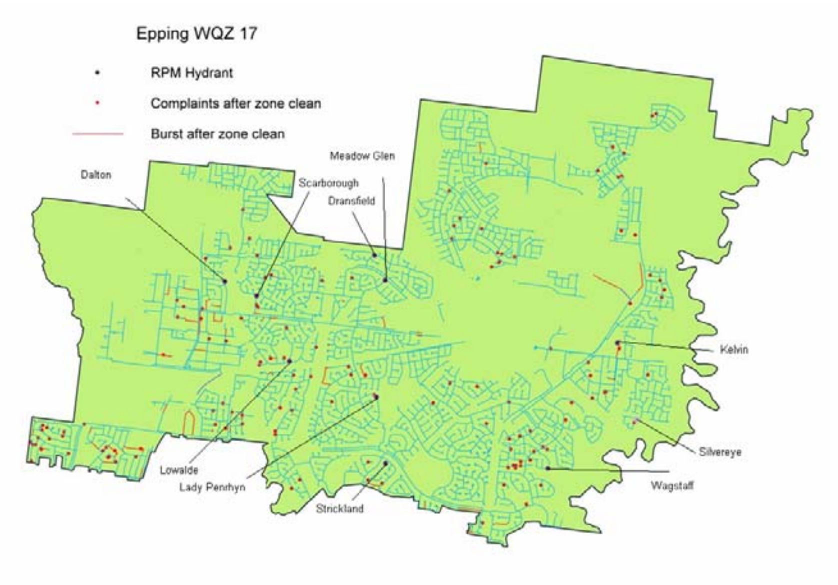

Figure 17- Water quality zone 17, Epping

Ten locations are selected for RPM measurements within the Epping zone. Measurements are taken before mains cleaning (pre), 6 months, 7 months and 8 months after cleaning.

Measurements are also taken 1 week, 1 month and 2 months after cleaning but due to data logger problems this data is not accessible for evaluation
No measurements at all are taken on Silvereye Plan (located to the east in Figure 17).

Figure 17 shows the number of customer complaints (based on dirty water) for a year, between September 2005-2006. The number of complaints are 195 giving a rate of 9/1000 customers. The zone was last cleaned by end of November 2005.

[7] Jayaratne Asoka, Power point presentation, Sri Lanka 2006

6.1.3 Bulleen WQZ 55

Bulleen has a total area of 12 km^2 and 24069 connections (23731 customers). (Jayaratne 2006[8])
The reason why Bulleen is one of the interesting zones to evaluate is because the water is supplied from both Silvan reservoir (unfiltered) and Sugarloaf reservoir (filtered). This means that filtered and unfiltered water are blended before the mixture is fed to the distribution system.

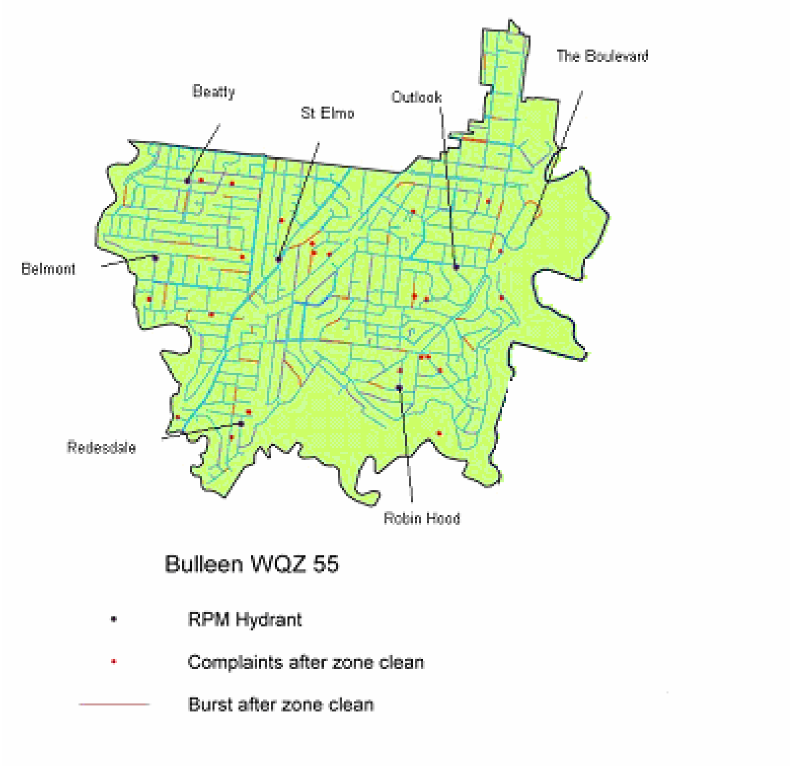

Figure 18 - Water quality zone 55, Bulleen

Seven locations are selected for RPM measurements in WQZ 55, Bulleen. Measurements are taken before mains cleaning (pre), 1 month, 2 months, 3 months and 6 months after cleaning.

Figure 18 shows the number of customer complaints (based on dirty water) for a year, between September 2005-2006. The number of complaints are 375 giving a rate of 16/1000 customers. The zone was last cleaned at the end of May 2006 which might explain the high complaint rate.

8 Jayaratne Asoka, Power point presentation, Sri Lanka 2006

6.1.4 Somerton WQZ 12

In Somerton with an area of 70 km^2 and 20492 connections (27849 customers) (Jayaratne 2006[9]) the number of customer complaints has decreased over the past year and that is the main reason to why this zone was evaluated further. The water is here supplied from the Silvan reservoir, meaning that it is unfiltered.

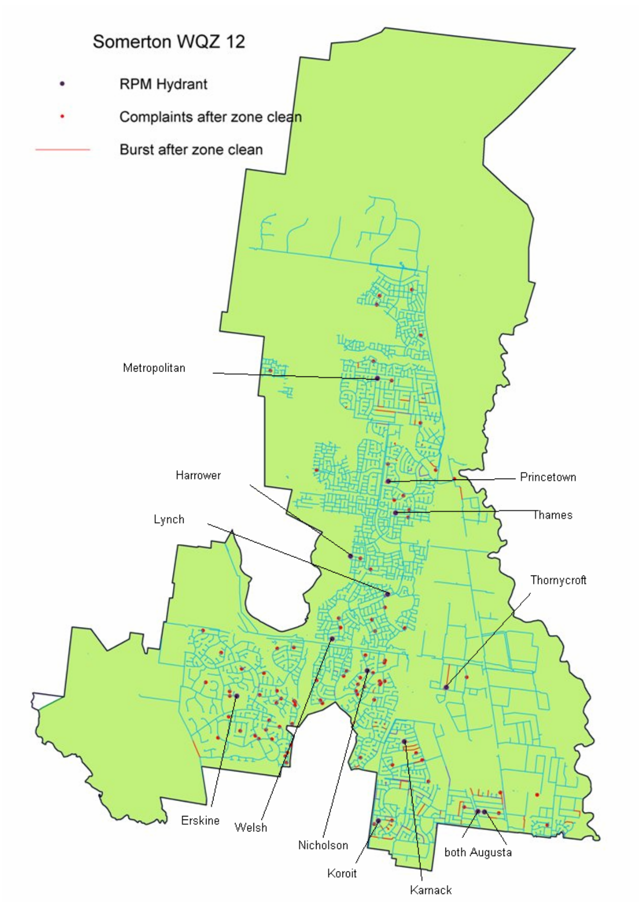

Figure 19 - Water quality zone 12, Somerton

Twelve locations are selected for RPM measurements in Somerton zone. Measurements are taken before mains cleaning (pre), 2 months and 9 months after cleaning. Measurements are also taken 1 week after cleaning but due to data logger problems this data is not accessible for evaluation.

On three of the locations (Thornycroft Street, Princetown Avenue and Metropolitan Avenue) the pre measurements could not be done. Also on Metropolitan Avenue the 9 months after cleaning measurement could not be taken. No measurements at all are taken on Welsh Court due to buried fittings.

Figure 19 shows the number of customer complaints (based on dirty water) for a year, between September 2005-2006. The number of complaints is 289 giving a rate of 10/1000 customers. The zone was last cleaned at the end of March 2006.

[9] Jayaratne Asoka, Power point presentation, Sri Lanka 2006

6.1.5 Lilydale WQZ 48

As a final investigation Lilydale zone with 77km^2 and 14860 connections (16044 customers) was evaluated (Jayaratne 2006[10]). This is also a zone which gets the water supply from the Silvan reservoir.

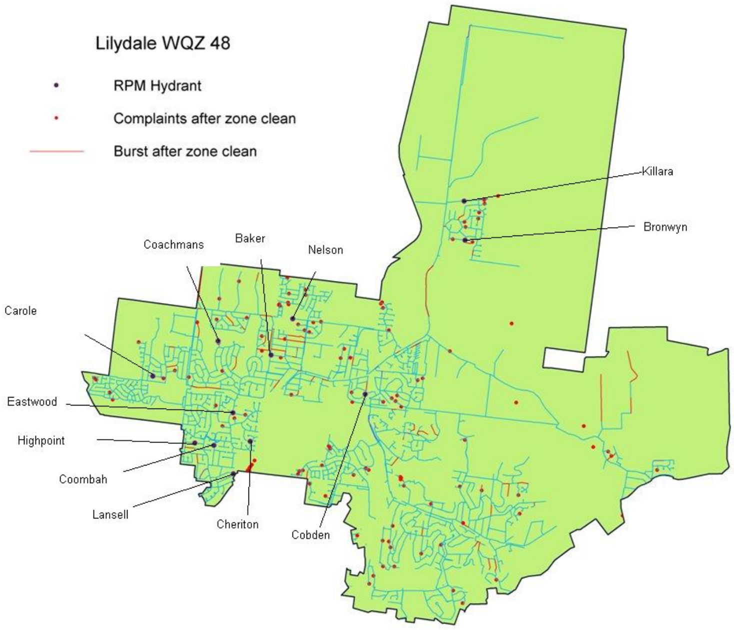

Figure 20 - Water quality zone 48, Lilydale

Twelve locations are selected for RPM measurements in Lilydale zone.
On three of the locations (Carole Avenue, Southern Cross and Coachmans Court) measurements are taken prior to mains cleaning.
Further measurements are taken 7 months, 10 months and 12 months after mains cleaning.
Only the 12 months measurement is done on Killara Road due to the fact that a main had to be been re-laid there in 2005. No measurements at all are done on Coombah Court, Lansell Road, Cheriton Drive and Highpoint Avenue.

Figure 20 shows the number of customer complaints (based on dirty water) for a year, between September 2005-2006. The number of complaints are 195 giving a rate of 12/1000 customers. The zone was last cleaned at the end of November 2005.

10 Jayaratne Asoka, Power point presentation, Sri Lanka 2006

6.1.6 Summary of the zones

Table 4 - Summarizing table of the five evaluated zones

Zone	Area (km^2)	Feed water (source and type)	Customers	Customer complaints*	Last cleaned
Croydon	72	Silvan, unfiltered	53366	9/1000	end of October 2005
Epping	36	Silvan and Yan Yean, sometimes filtered	22197	9/1000	end of November 2005
Bulleen	12	Silvan and Sugarloaf, blended	23731	16/1000	end of May 2006
Somerton	70	Silvan, unfiltered	16044	10/1000	end of March 2006
Lilydale	77	Silvan, unfiltered	27849	12/1000	end of November 2005

*September 2005-2006

A summarizing table is created to get a better overview of the five evaluated zones and their premises.

6.2 Equipment

6.2.1 Initial equipment

The setup of equipment used by Yarra Valley Water for RPM measurements September 2005 until start of October 2006 can be seen in Figure 21 and Figure 22.

Figure 21 - Equipment setup used by Yarra Valley Water (Kjellberg 2006)

Figure 22 - Placement of standpipe in hydrant (Kjellberg 2006)

A 63 mm aluminium standpipe is placed in the hydrant (visible behind hydrant lid in Figure 21). From the hydrant a transparent hose (30 cm) is connected with camlock fittings, see Figure 22. The purpose of the transparent hose is to make an initial visual judgement of the “dirtiness” of the water. It should be noted that this is a subjective observation.

From the transparent hose a Ø 50 hose is connected and at the end of this the flowmeter is connected. (Flowmeter is seen where the person in Figure 21 stands). The length of that part of the hose is 9 meters. After the flowmeter another 9 meter hose is attached and further connected to the turbidity meter.

To prevent air getting trapped in the turbidity unit it is placed on a 20 cm high wooden block. After the turbidity meter the water flows towards a drain.
The data logger, a Yeokal 611, connected to the turbidity meter is calibrated to log every minute and is activated when the RPM is started.

6.2.2 Improved equipment

After some improvements done by start of October the equipment is put together in a slightly different way, see Figure 23.

Figure 23 - Equipment placed in the trailer (Kjellberg 2006)

Everything is now placed in the trailer to avoid heavy work with carrying out all the equipment and after measurements replacing it in the trailer again. As well as reducing workload it will now also save some time at every location. The hatch by the end of the trailer is opened during measurements, and the hose seen in the picture is lead out that way.

The length of the hose (Ø 50) between the hydrant and the flow meter is now 4 meters allowing enough length for the trailer to be placed near the hydrant. After the flowmeter a 30 cm transparent hose is used, connected to the turbidity unit with elbow connections. From the turbidity unit a 2 meter Ø 50 is connected (also out from the back of the trailer) allowing the water to flow out to drainage. Both the turbidity unit and the flowmeter are placed in angle to avoid air bubbles getting trapped and having effect on the measurements.

The contractor, performing the measurement, also has a timer that he starts when disturbance time starts and stops after 15 minutes. Since there are events in the environment around the measurement that can cause interruption the timer is there to make it easier for the person in field to measure the disturbance correctly.

7. Results

All of the five zones are evaluated with the goal of answering the three objectives. In chapter 7 not all the results will be shown, but examples from different zones.

7.1 Usable and Non usable results

When analysing the results there are certain aspects which require consideration. The first evaluation consists of investigating all 13 zones to find out how many of the measurements can be used for further evaluation.
61 % of the RPMs done in the 13 zones are taken on mains with a minimum length of 315 meters and with a disturbance time of 15 minutes. Approximately 26 % of the results are done on streets with a length of 210 m (10 min disturbance) up to 315 meters.
The remaining 13 % are all measured on mains with a length shorter than 210 meters and these can not be used for further evaluation since a disturbance time less than 10 minutes will not be optimal for evaluation. Further analysis is not done on the total number of usable data from all the 13 zones.

A deeper analysis is performed on the five evaluated zones. Out of these zones there is following relationship between usable and non usable results:

Table 5 - Evaluation of results from the five analysed WQ zones

	Usable		Not usable		
	Disturbance time = 15 min	**Disturbance time = 10 - 14 minutes**	**Disturbance time < 10 min**	**Other measurements performed incorrectly***	**Total**
Number of measurements (-)	74	45	24	51	**194**
Percentage (%)	38	23	12	26	**100**

* By incorrectly performed, includes the RPMs measured with the wrong flow, problems with data logger etc. See Appendix B for details

As can be seen in Table 5 only 38 % of the RPMs were done in a correct way, with 15 minutes disturbance time. However is should be observed that out of these 38 % most RPMs were missing a resettling time, leaving it impossible to evaluate all 5 criterias mentioned in Chapter 4.1.2.

In order not to loose too much of other valuable information in the analysis, the measurements done with a total disturbance of 10 - 14 minutes were also further analysed. This summarized to a total of 61 % (61.3 % exactly) usable measurements. The remaining 38 - 39 percent is dismissed due to faults such as; RPMs measured with a disturbance time less than 10 minutes, wrong flow being applied on 150 mm mains, problems with data logger or other faults in measurements.

The wrong flow is said to have been applied between March 2006 and September 2006 on all mains ≥ 150 mm. To get a better understanding of what is considered as usable and non usable data; examples are described in section 7.1.1 – 7.1.2.

7.1.1 Non usable data

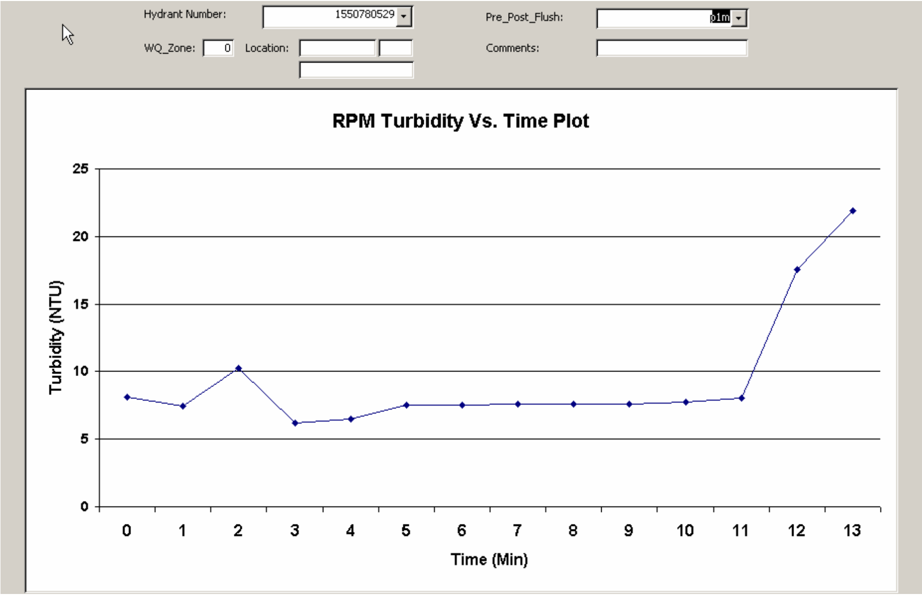

Figure 24 - Bulleen, Beatty Street. June 2006, 1 month after mains cleaning

The results shown in Figure 24 can have some different explanations. Since there are no records of the measurements more than the data some interpretation is required based on experience and literature knowledge.
The measurement is taken in June 2006 and according to information given by the contractor, who performed the measurement, the wrong flow has been applied in this main at this time of the year. This main is 150 mm in diameter and a flow of approximately 3 l/s has been applied instead of the 6 l/s flow that is required to create the right disturbance. When applying a lower flow than required the result will show an almost straight line and no clear start of the disturbance is visible. The reason for the peak by the end is likely due to that the data logger is still switched on when the measurement has been stopped and the peak is created by the drainage of the left over water in the hose.

One other interpretation, which is less unlikely than the first, but which could explain the appearance of the results in the graph is that the disturbance is not started until t = 11 min. For some reason the experiment is then stopped after only 2 minutes disturbance, so the peak by the end is the actual start of the disturbance. The small peak by t = 2 min would then indicate that it is a disturbance from the hydrant, which might not have been flushed properly beforehand.

Even if the exact event can only be guessed it can however be concluded that the result can not be used for further evaluation.

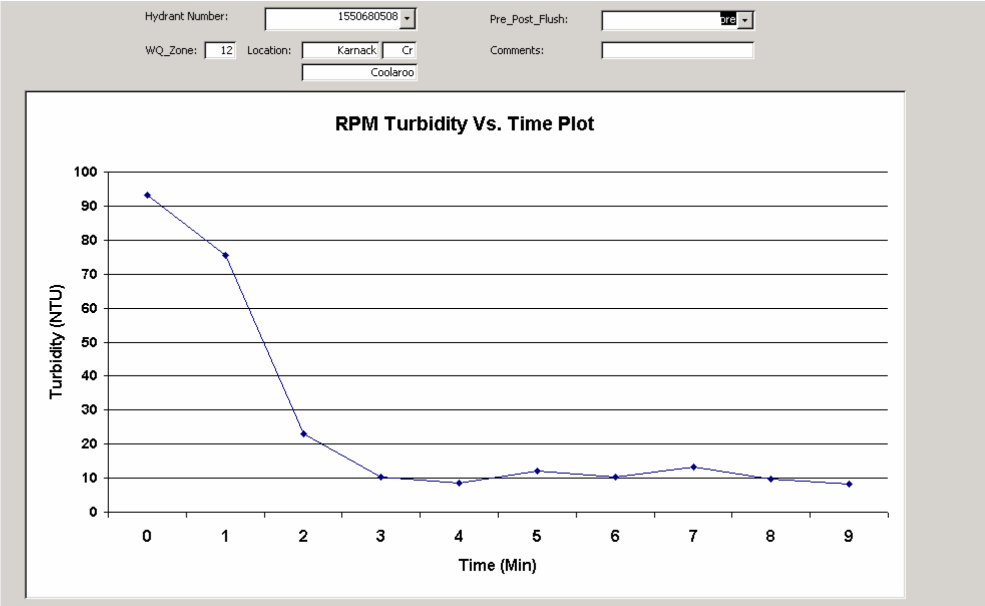

Figure 25 - Somerton, Karnack Cresent. March 2006, pre measurement

Another example of a result that can not be used for further analysis is shown in Figure 25. Here it can be seen that the data logger has not been switched on at the start of the experiment and only the last part of the peak is visible.
The measurement is also cut short at nine minutes.
It can be concluded that the turbidity is fairly high at around 94 NTU even though this might be the end of a peak, which can not be determined from this result. The turbidity resettles to a level of around 10 NTU which give some information about the source of the sediment. As mentioned in section 4.1.2 “Evaluation of graphs”, the Australian Drinking water Guidelines (ADWG, 1996) recommend that turbidity in drinking water should be kept below 1 NTU to enable effective disinfection and below 5 NTU for aesthetic considerations. (Prince et al. 2001)

7.2.2 Usable data

Examples of usable results that are further analysed can be seen in Figure 26 and 27. The main difference between the two examples, besides different locations is that Figure 26 shows a measurement taken with the initial equipment setup and Figure 27 shows with the improved setup. The procedure of performing a measurement had also been updated and improved between these two times.

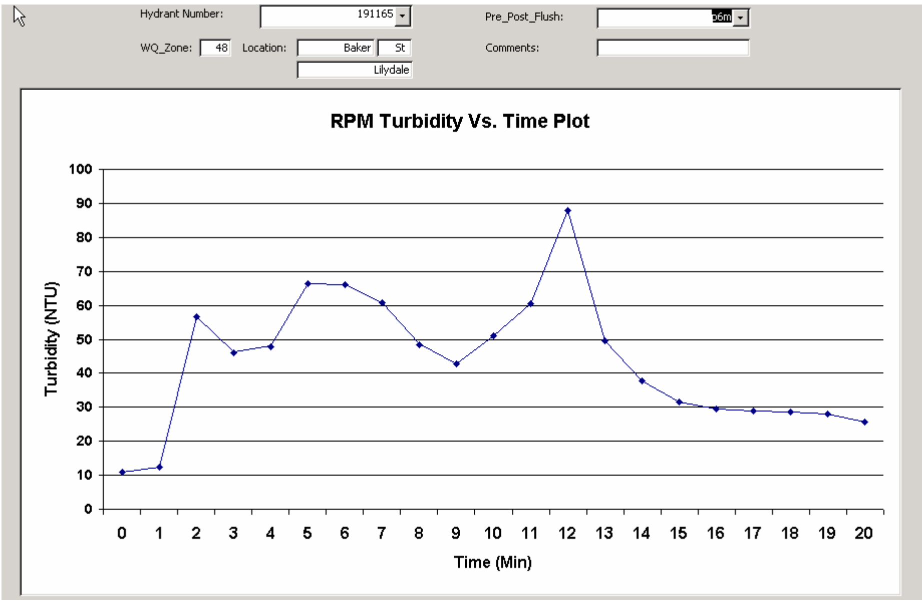

Figure 26 - Lilydale, Baker Street. April 2006, 7 months after mains cleaning

It can be seen in Figure 26 that the disturbance is kept on almost the same level as for the first five minutes meaning that there is considerable amount of sediment in the pipe and that the composition is homogenous. The highest peak reaches almost 90 NTU.

Even on the usable results there can be aspects that are not clear.

The base level is showing a value of approximately 10 NTU, however it is only measured for 1 minute so one can not be sure that this is showing the true information about the source of the sediment. The base level should have been measured during a couple of more minutes, to validate the level.

The resettling time has not been measured for long enough either since it can be seen that after t = 20 min it is still descending towards a lower value.

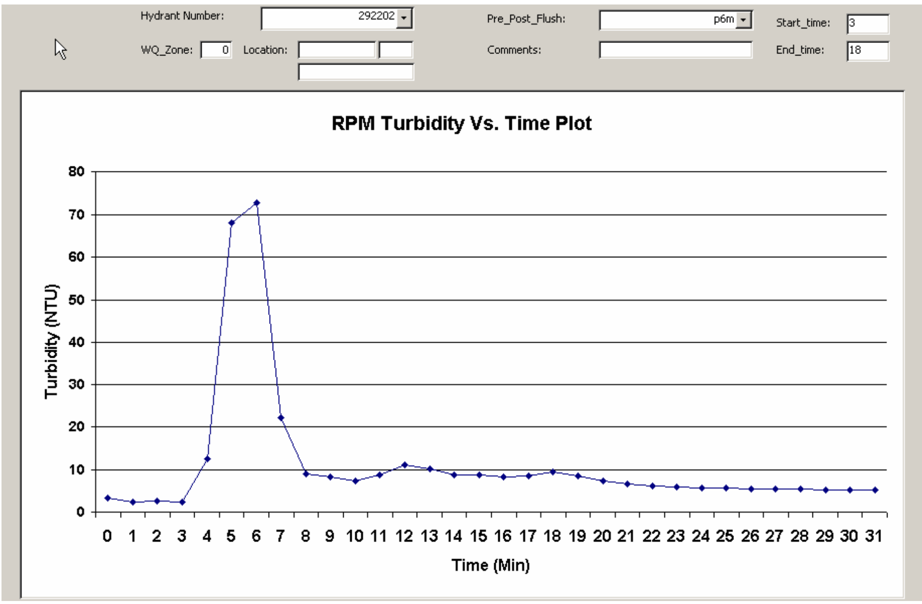

Figure 27 - Bulleen, Belmont Road. November 2006, 6 months after mains cleaning

The graph in Figure 27 has all the fundamental categories for evaluation. The baseline is measured long enough and clearly visible between t = 0 min to t = 3 min. The disturbance gives an initial high peak to about 73 NTU but goes relatively fast down again. This indicates that there is an initial whirl up of heavy sediment, a sediment load near the source of the hydrant. Since the peak resettles down to around 10 NTU and below, during the rest of the disturbance, there is relatively little heavy sediment in the remaining pipe and the discolouration risk is small.

7.2 Evaluation of results

As mentioned in section 4.1.2 "Evaluation of graphs" there are five different aspects of the results that are considered in the standard RPM procedure and rated equally, weighing each 20 %.

Figure 28 - A theoretical result of an RPM measurement

For all RPM data of YVW only four aspects in all the graphic results can be rated since the resettling time very rarely is monitored and can therefore not be considered.
The first 5 minutes of disturbance can be found on all measurements. The "last 10 minutes" are in reality ranging between 5 minutes and 10 minutes depending on the total disturbance time measured.

The graphs that can be used are evaluated with a ranking table. The ranking table is made as an example of what can be reasonable for Yarra Valley Water to apply to their unfiltered water. The limits of the category are discussed with the persons involved in the RPM measurements at YVW.

Table 6 - Ranking table applied to Yarra Valley Waters systems, measured with a Yeokal 611

Points Category	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
Time to clear – not evaluated	-	-	-	-

The RPM score in the ranking table, Table 6, ranges from 0 (totally clean) to a maximum of 12 points. The persons at YVW, involved in this project, also discussed that when an RPM ranking of 10 points is reached the main needs to be cleaned.

The limits of the categories and the overall RPM ranking when cleaning is necessary can and should be adjusted when the RPM is in use for some time at YVW. The turbidity values are quite high and to reach YVW overall goal of 3 complaints per 1000 customers by 2013, more severe values should be used. For the moment as the RPM is still in use as a research tool, the values as given in Table 6 are used.

7.2.1 Effectiveness of mains cleaning program

The first objective is to investigate the effectiveness of mains cleaning. If an RPM measurement is be taken prior to and directly after mains cleaning the effectiveness of the mains cleaning can be evaluated.
Example is shown for Illawarra Cresent in Croydon, Figure 29 where an RPM have been measured before and after cleaning.

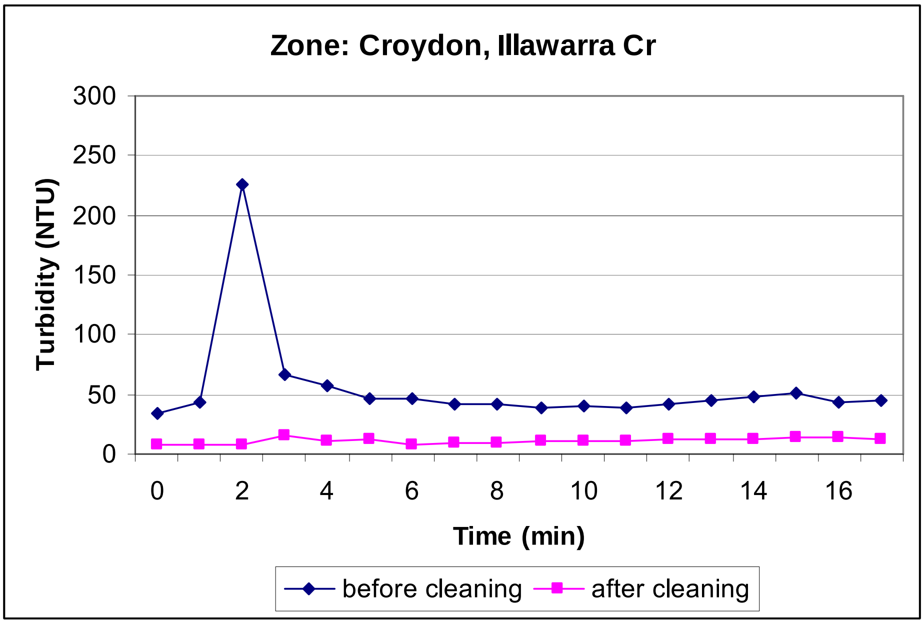

Figure 29 - Pre and post RPM-measurement to determine effectiveness of mains cleaning

With help from Table 6 it can be summarized that before mains cleaning the RPM curve has a total score of 8 points (out of maximum 12). Two weeks after mains cleaning another RPM is done which gives an overall rating of 4. The difference between the pre and post measurement indicates the effectiveness of mains cleaning.
In this example it can be concluded that the mains cleaning has not been sufficient since the value of post cleaning is 4 and the desired target should be 0 (zero) or possibly 1.

Unfortunately there are only two locations (out of totally 57 locations in the five zones) where the RPM has been performed prior to cleaning and directly after mains cleaning. The second result is illustrated in Figure 30.

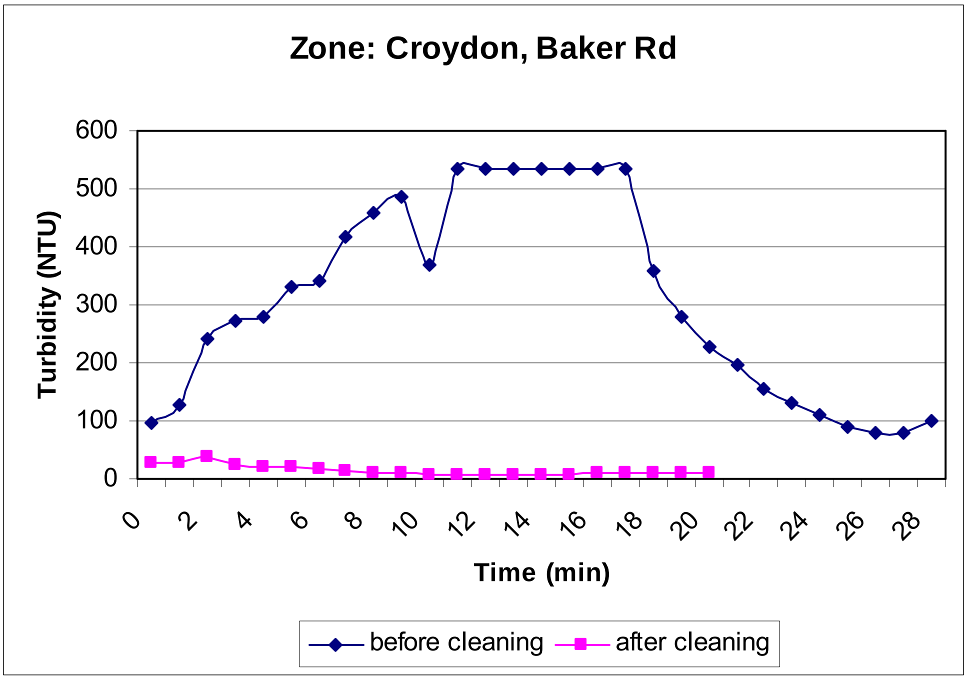

Figure 30 - Pre and post RPM-measurement to determine effectiveness of mains cleaning

With help from Table 6 it can be summarized that before mains cleaning the RPM curve has a total score of 12 points (out of maximum 12). It can clearly be seen in Figure 30 that there is a high sediment load in this main since the turbidity reaches a value of approximately 550 NTU and stays on very high turbidity levels throughout the entire disturbance period. It also stays on a very high level during the resettling period which indicates a presence of remaining sediment in the pipe.
Two weeks after mains cleaning another RPM is done which gives an overall rating of 3. The target should be 0 (zero) points or possibly 1.

Both examples in Figure 29 and Figure 30 can clearly be used to evaluate the effectiveness of mains cleaning.

7.2.2 Rating of mains and zones

The usable RPM data from the five zones are all evaluated and ranked following Table 6, see Appendix C for details.
The different locations within the zones are individually evaluated after their "dirtiness" and thereafter the zones are compared with each other.

As typical examples of individual RPM curves the curves of Taronga Road in the Croydon zone (unfiltered system) and Redesdale Road in Bulleen (blended system) are given in Figure 31 respectively Figure 32. An RPM measurement is performed prior to mains cleaning at both locations.
It can clearly be seen that there are high levels of turbidity observed on Taronga Court, ranging up to almost 450 NTU, while in on Redesdale Road the maximum turbidity does not reach 100 NTU.

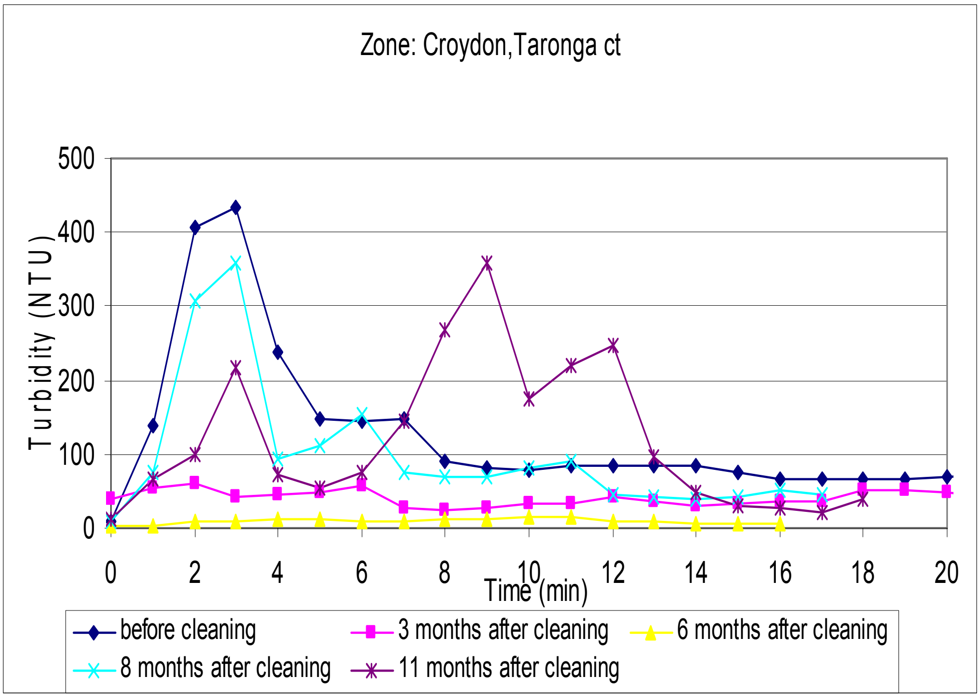

Figure 31 - RPM curve for Taronga Court in Croydon

With help from the ranking table, Table 6, Taronga Court would be given 12 points (on scale 0 points to 12) on the measurement taken prior to mains cleaning.
Three months after mains cleaning, on the same location, the maximum turbidity is almost 60 NTU and the overall rating score would be 7 points. After 6, 8 and 11 months another RPM is done and ratings can be seen in Table 7. A clear increase in the turbidity is observed. The overall RPM scores are 2, 11 and 12 points, respectively. This means that a large amount of sediment has been deposited in the main in the period between first and last measurements and this main need to be cleaned within one year. Also mains in the direct neighbourhood having similar pipe geometry have to be cleaned or at least an RPM has to be made to see if cleaning is required.

Table 7 - Ranking table for Taronga Court, Croydon, measured in turbidity unit (NTU)

	Pre[11]	p3m	p6m	p8m	p11m
max 5 (NTU)	434.6	58.8	10.9	359.4	217.7
average 5 (NTU)	228.6	50.8	8.7	159.2	110.9
max x-5[12] (NTU)	147.1	58.2	14.1	153.9	359.4
average x-5 (NTU)	102.8	34.8	10.1	77.4	161.4
RANK (points)	12	7	2	11	12

[11] Pre equals before mains cleaning and p3m means 3 months after (post) mains cleaning, p6m equals 6 months after mains cleaning etc.

[12] x-5 (in this case x equals 14 min). X variates from 10 to 14 since not all measurements were done with a disturbance time of 15 min in total.

It can be seen in Table 7 that the measurement 6 months after mains cleaning only has a score of 2. The reasons for this low value can be that there has been a cleaning in this main sometime after 3 months but before 6 months or that there has been a fire fighting event in the area or another sudden increase of water usage.

The same evaluation is done for Redesdale Road in Bulleen.

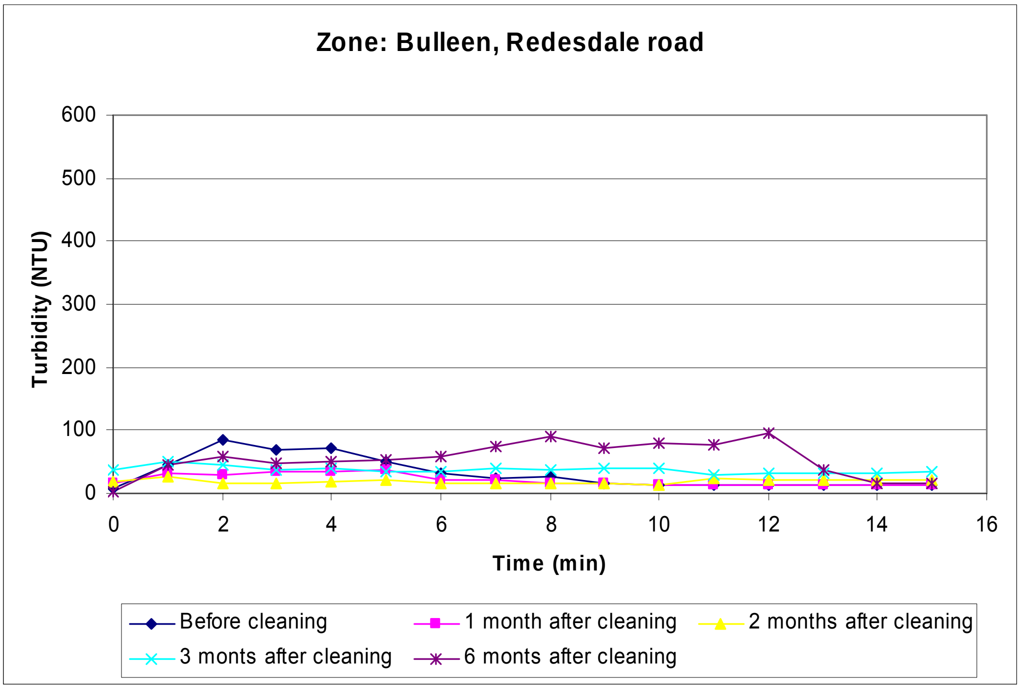

Figure 32 - RPM curve for Redesdale Road in Bulleen

Following ranking is obtained:

Table 8 - Ranking table for Redesdale Road, Bulleen, measured in turbidity unit (NTU)

	Pre	p1m	p2m	p3m	p6m
max 5 min (NTU)	72.3	36.8	26.3	50.5	57.1
average 5 min (NTU)	54.8	30.4	19.2	40.7	42.8
max 10 min (NTU)	51.4	51.4	23.5	40.1	95.9
average 10 min(NTU)	20.7	18.2	19.1	34.9	60.9
RANK (points)	7	5	4	5	7

The Redesdale road has a rating score of 7 prior to cleaning, see Table 8. RPMs are done after 1, 2, 3 and 6 months with rating scores of 5, 4, 5 and 7, respectively. A lower increase in overall RPM score is observed at this location and it is not necessary to clean this location after 6 months.
It can however not be determined when cleaning is required since no RPM data after 6 months are available yet.
A thing worth mentioning is that the rating one month after a main cleaning is already at 5 (of maximum 12) points, which might indicate that the cleaning has not been done sufficiently. Unfortunately there is not any measurement taken a week after mains cleaning which would confirm or deny this.

An individual evaluation like the examples shown above for Croydon and Bulleen is done for every location within the five zones.

One part of the second objective is to compare the zones with each other. This part is not totally possible to answer since the RPMs are done on such a different time interval that the existing usable results are not sufficient for comparison. When all the RPMs are done with the right procedure, they can be used to rank systems. At the moment it requires better and more experiments to achieve this goal.

Although there is not a fixed evaluation method to rank these differences there are still results that can be used to give a direction towards a comparison. Of course a fixed procedure is what should be applied but since this is not possible other parameters have been investigated to compare the zones.
In Table 9 to 10 the peak values of turbidities and total average turbidities in the five zones are evaluated.

Table 9 - Total average of measurement taken in each zone

	Category	Croydon n = 36	Epping n = 24	Bulleen n = 21	Somerton n = 17	Lilydale n = 21
AVERAGE	max 5 min	122.0	49.0	71.6	154.0	103.2
	average 5 min	63.1	30.3	39.0	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**

Table 10 - Maximum turbidity found during measurement

	Category	Croydon	Epping	Bulleen	Somerton	Lilydale
MAXIMUM	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	149.0	353.1	286.3	379.6
	average 10 min	498.0	64.2	72.1	137.6	156.0
	Average	**445.4**	**100.2**	**235.7**	**248.4**	**357.8**

The values of all RPM measurements (n) independent of time are added for each category and then the average is calculated for each category (ex. Croydon = 36 maximum values during the first five minutes of disturbance are added and then divided by 36 = 122.0).
A total average is also calculated as the sum of the categories divided by four (ex. Croydon, 122.0 + 63.1 + 84.9 + 60.3 = **82.6**)
With Table 9 is can be indicated that Epping has in general lower turbidity levels than the other zones. This would also be expected since this zone has sometimes filtered water. Bulleen with blended water also has a total average value, as expected, that is relatively low compared to Croydon, Lilydale and Somerton.
The highest average value of 109.4 is found in Somerton. The results from Somerton indicated less variation in high and low turbidity levels than for instance in Croydon which can explain this result.
Together with the average values it is interesting to investigate the highest measured value in the zones as well.
In Table 10 it can once again be seen 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.

As mentioned previously this evaluation only gives a direction and indication of the situation but that a fixed evaluation method should be applied when the results improve.

7.2.3 Zone cleaning frequency

By plotting the overall RPM score from all the measurements as a function of time the period between successive mains cleaning can be determined objectively and pro-active cleaning actions can be taken. In *Methodology* Figure 13, the general principle to determine this time period is given.

In reality it appears a little different than in theory. Below follows the results from Croydon (unfiltered), Epping (sometimes filtered) and Bulleen (blended), see Figure 33.

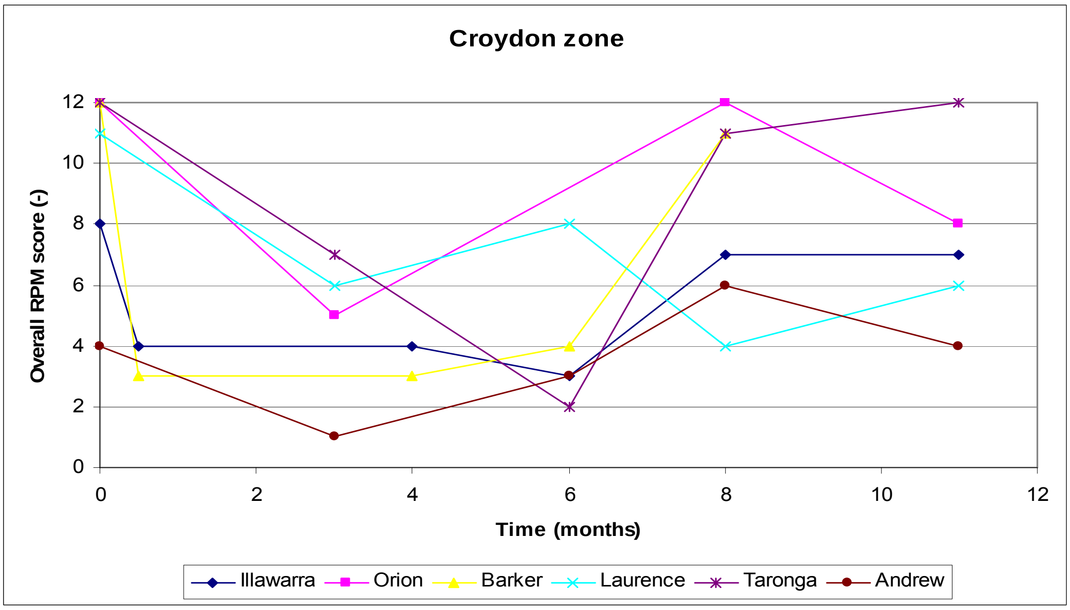

Figure 33 - Cleaning frequency for Croydon

It might seem difficult to establish when cleaning is required just by looking at Figure 33 since not all locations give similar results. However what can be established is that there is in most locations an increase in sediment loading between 6 and 8 months. By assuming that there would have been measurements done one week after cleaning (post RPM with a value of 2 points), the pattern can easier be distinguished. In Figure 34 this assumption is made. In Croydon a cleaning would be required in less than a year for many of the mains since they would pass the threshold level for cleaning individually set by the company. As an example the threshold level is set as 10 points in this evaluation.

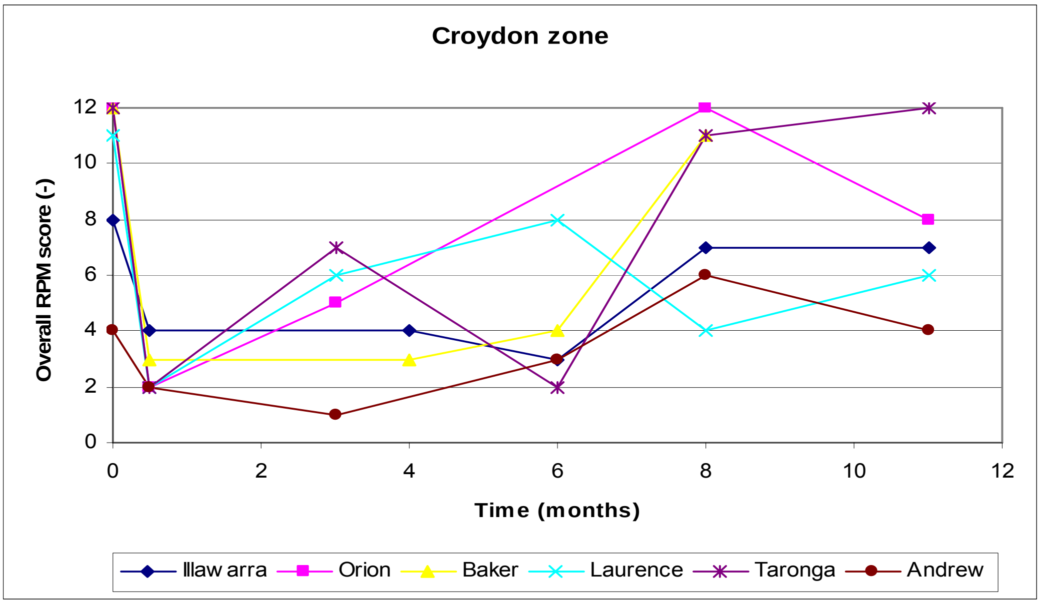

Figure 34 - Cleaning frequency for Croydon when presuming one week measurements

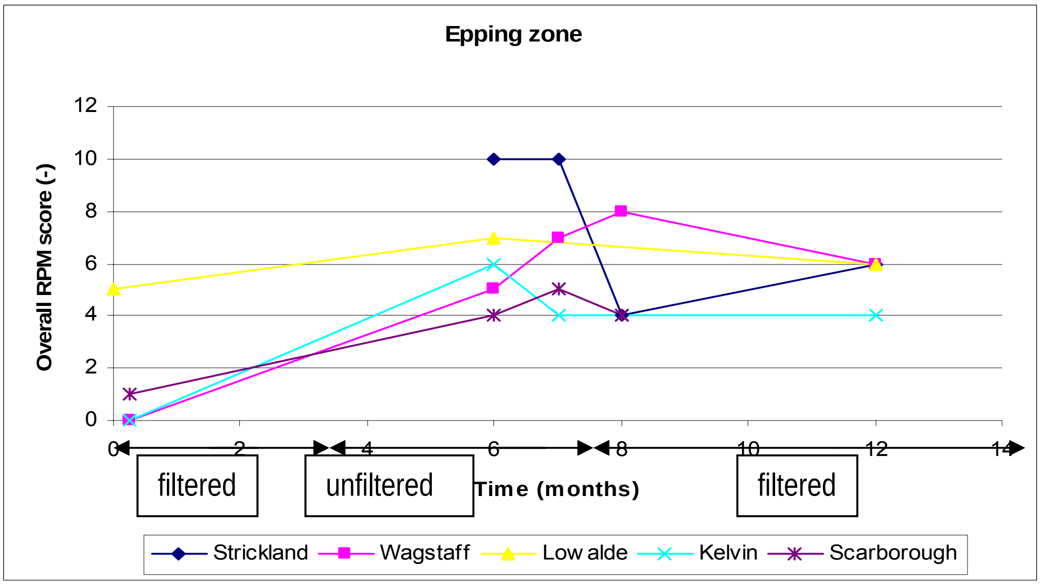

Figure 35 - Cleaning frequency for Epping

In the Epping zone which is a sometimes filtered zone (here filtered for post one week, 7 months, 8 months and 12 months after cleaning) it can clearly be seen that the systems fouls slower than in the Croydon zone. Unfortunately there are not measurements done after 12 months which will determine when cleaning will be required, but it is clearly seen that the system does not foul within one year.
The effect of having a filtered system is also clearly distinguished; the values tend to lie on a relatively stable level.
Unfortunately no RPM measurements are available within the first 6 months. In this period the water that is fed to the system change from filtered (first 3 months) to unfiltered (next 4 months). If a RPM had been done after 3 months probably a low result would have been found making Figure 35 even more clear.

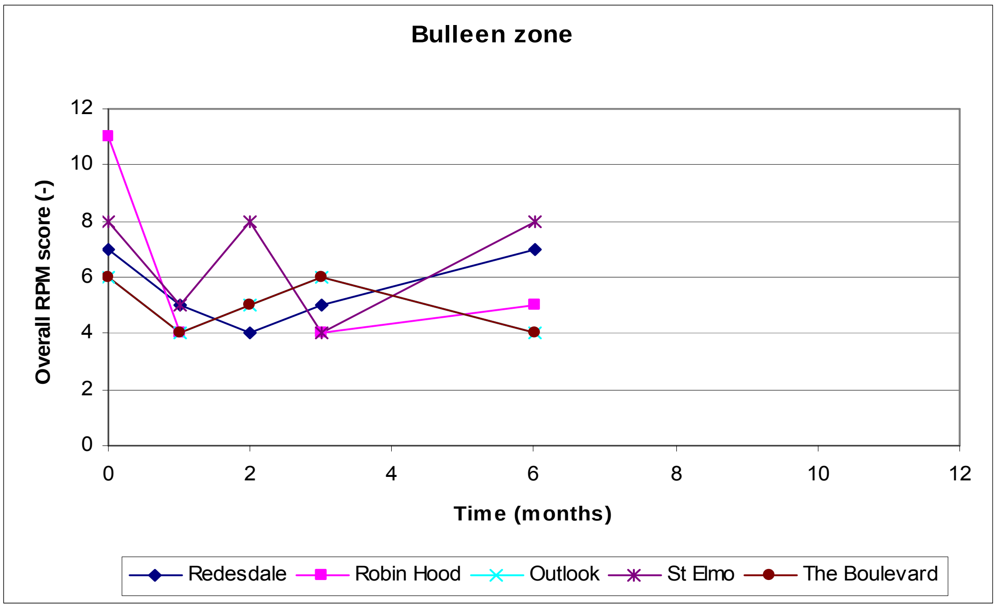

Figure 36 - Cleaning frequency for Bulleen

In the Bulleen zone which is a supply zone with blended water it is also clearly seen that the system does not foul within 6 months and likely a cleaning is not needed within one year. If cleaning is required within a year or not can at present time, unfortunately not be determined since no more measurements are taken after 6 months, see Figure 36.

The graphs for the other two unfiltered zones, Somerton and Lilydale can be found in Appendix D

As an overall picture of the cleaning frequencies in the zones, Figure 37 is created. However it should be observed that it is the total averaged values that are shown for each zone and not individual measurements.
The measurements from Somerton and Lilydale zones have been excluded since there are not sufficient measurements to represent these zones.

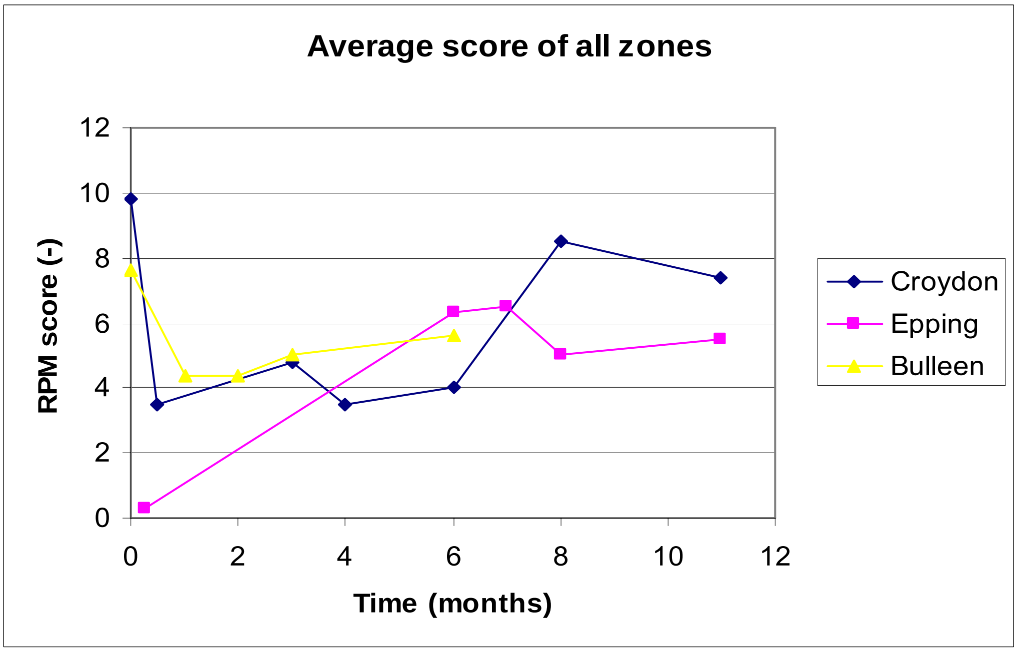

Figure 37 - Average values of all measurements in the five evaluated zones

In Croydon it can be concluded that there is an increase between 6 and 8 months also when taking the average of all results in this zone. The decrease after 8 months is likely due to an event in the system such as a burst, fire fighting event or other sudden increase of water, “cleaning” a main.

For Epping, as previously mentioned, it would have been of interest to take some measurements between mains cleaning and 6 months after, since there is a change between unfiltered and filtered water at this time. The peak in the Epping curve (after 6 months) is when unfiltered water is supplied to the network. When the filtered water is supplied again, around 7 months after mains cleaning, the average levels decrease.

Bulleen is also showing low values up till 6 months after mains cleaning.

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.
In example shown in Figure 38 and 39 it can clearly be distinguished that there is a fouling of certain locations between 6 and 8 months in the Croydon zone.

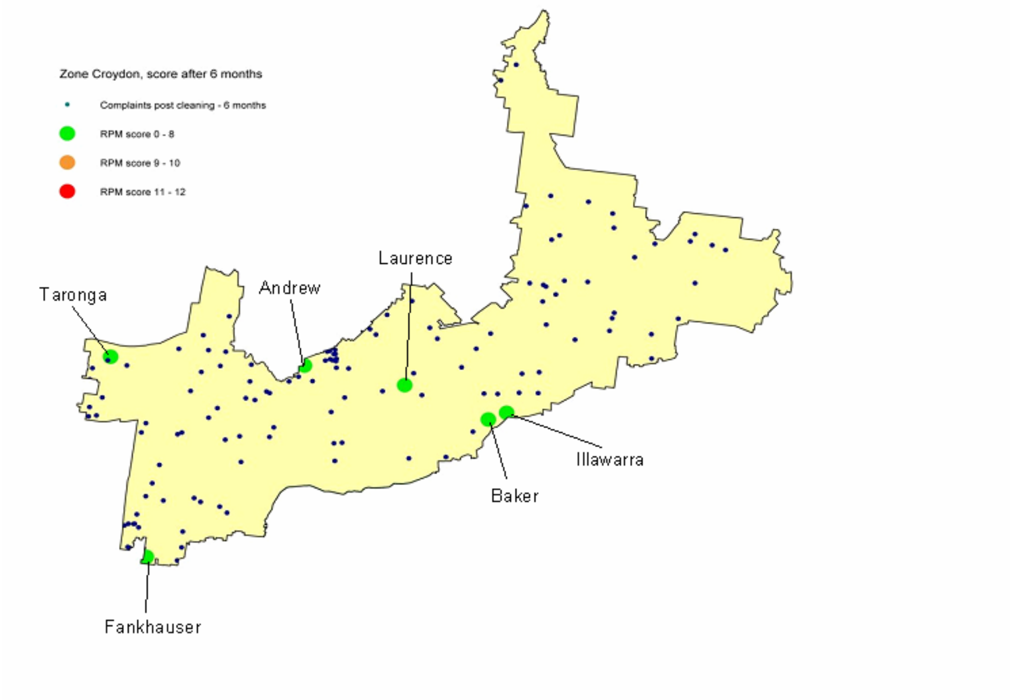

Figure 38 - Ranking of different locations in the Croydon zone, 6 months after mains cleaning

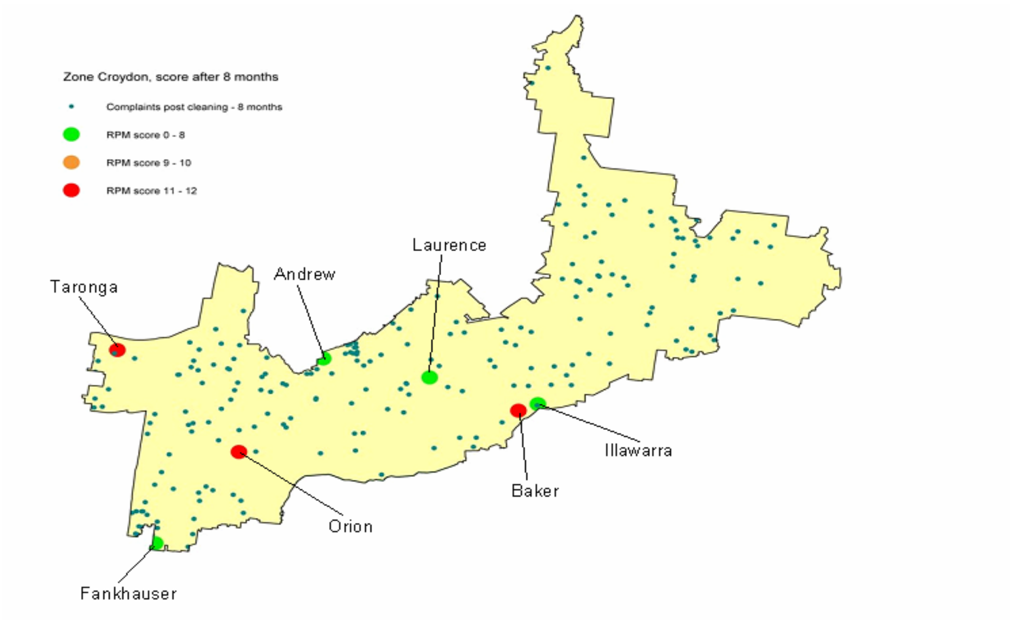

Figure 39 - Ranking of different locations in the Croydon zone, 8 months after mains cleaning

Six months after mains cleaning (Figure 38) all the locations still have a score of less than 8 points (green dot). Already 8 months after mains cleaning there are three

locations that all have reached a critical value of 11-12 points (red dot) which would require a new cleaning, see Figure 39.
The threshold level for required cleaning is set as 10 points in this evaluation.
It can also clearly be seen when comparing Figure 38 and Figure 39 how the number of customer complaints have increased between 6 and 8 months.
The reason why Orion Street can not be seen having any colour in Figure 38, is because there is no measurement taken at this location after 6 months.

The relationship between customer complaints and RPM measurement is not further evaluated in this report.

8. Discussion

8.1 Equipment

It is of course essential to have good equipment and to have a standard setup which is always followed; otherwise one can not compare the results with each other.

8.1.1 Initial equipment

The initial setup used from the start of the experiment until start/mid of October 2006 is not optimal.

The camlocks fitted on each end of the transparent hose tend to burst during high flows (6 l/s) which disrupt the entire measurement. The original idea with the transparent hose is to give a possibility to directly visualise the colour of the water coming from the hydrant. However, since this hose is never cleaned it soon loose its effect due to all the particles that eventually cover the walls inside the hose and take away the visibility. It is also a subjective measure.

Accountable problems which will occur during an RPM measurement are for example, data logger failure, battery breakdown or hoses bursting. Failure with the data logger is one of the key problems causing many of the results to be inaccessible.

Another problem with the previous setup is the length of the hoses. With a total length of 18 meters it takes time for the water to travel from the hydrant to the turbidity unit and for the turbidity to be measured, creating a retention time in the system and possible settling of particles along the way.

8.1.2 Improved equipment

The improved equipment also improves the results. As well as improved results it also creates a better environment for the person performing the RPMs. No heavy carrying of equipment and a system that is more easily attended than before.

In addition to adding extra batteries and a data logger, to avoid possible breakdown during a day of measurements, the timer has also turned out to be an essential detail during an RPM. What is often not considered is the interest from the public when performing an RPM, especially in Australia where strict water restriction are introduced. To keep full control of the created disturbance time, a timer set for 15 minutes is optimal.

8.2 Procedure

In this project the communication between engineers, flush planners and contractors needed improvement. Many of the results have been dismissed due to measurements being conducted in the wrong way caused by communication problems between people. This should not be an issue that have such a great effect on a projects result.

The procedure improved along the way and so did the communication and feedback between YVWs staff which by start/mid of October lead to better results.

Yarra Valley Water will in collaboration with Delft University of Technology and Kiwa Water Research continue with the RPM program. The first evaluation of data has shown to be very useful in finalising the procedure for RPM measurement.

8.3 Experimental results

The usage of customer complaints to identify discolouration risk is important but as a quantification tool it is not suitable.

When comparing the different customer complaints in the five evaluated zones, see Chapter 6.2 it can be seen that Bulleen, despite having blended water has the highest number of customer complaints, 16 per 1000 customers. The reason for this is likely that the mains cleaning program is done very late compared to in the other zones. In Bulleen it is done in May compared to in October and November for the other zones.
It can also be found that Croydon and Epping have the same amount of customer complaints, 9/1000 customers during the same time period of a year and with only one months difference in mains cleaning. This is interesting since Croydon is an unfiltered zone and Epping is a sometimes filtered zone and "ought" to have fewer complaints
When an area receive no or very few complaints it is tempting to judge this area as having lower risk, when this may have no bearing on the actual amount of incidences of discolouration that have occurred in the system. It is not recommended that complaints should be used to confirm or validate areas at risk of discoloured water events. A customer complaint is a subjective measurement which is neither reliable nor reproducible.

One of the objectives that this method has been applied for is to investigate the effectiveness of mains cleaning. To do this it is essential that a measurement is taken prior to and post mains cleaning. In this report it is concluded that this has only been done at 2 locations out of 57. It is enough to see that the RPM works as a tool with only two measurements but the goal should of course be to investigate the locations and not the tool.
The Resuspension Potential Method has shown to be an efficient tool when determining the requirement of a mains cleaning, however one should be careful when performing an RPM too often. 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 measuring location is destroyed in that sense that the easily resuspendable part of the sediment is removed. Performing an RPM too often is therefore not useful. If between two consecutive RPMs there is a constant overall 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.
This phenomenon can be seen in Chapter 7.2.2 for Redesdale Road where measurements have been done after one, two and three months. These all have a value of 5, 4 and 5 respectively which might indicate that the measurements have been taken too frequently.
Yarra Valley Waters original idea has been to collect RPM data one week prior to cleaning, immediately after cleaning, and subsequently at the following intervals after cleaning: one week, one month, two months, three months, six months, nine months and 12 months.
With this frequency there might be a destruction of the sediment and two measurements taken at different times might have the same value when being ranked.

9. Conclusions

The Resuspension Potential Method applied in this report is an objective and reproducible method which has for the first time been trialled in an unfiltered supply system. In the last year (2005-2006) approximately 500 RPM measurements have been done by a contractor for Yarra Valley Water in Melbourne.

9.1 Equipment

During an RPM measurement, as with any other experiment, there are always factors that play essential role in determining the reliability and trustworthiness of the results. There are also issues with the turbidity meter and the flowmeter where the reading becomes erratic due to entrapment of air.

The new setup where the equipment is placed in the trailer improved a number of key issues such as for example the problem with air. Both the turbidity unit and the flowmeter are placed on an angle preventing air from disturbing the turbidity readings.

The hoses are shortened leading to less retention time in the system and thereby more accurate turbidity readings. The trailer is also better equipped with more batteries to prevent measurements from being disturbed if failure occurs.

9.2 Procedure

The equipment issues are all technical problems which can easily be resolved. Unfortunately since the RPM is a new tool for Yarra Valley Water some experiments have partly been compromised due to communication problems between engineers, flush planners and contractors. As a result not all initial experiments have been done according to protocol, resulting in experiments that can not be used in this evaluation but they however provide valuable information for understanding the deposition and resuspension process in the distribution network.

The lack in ability to communicate and give feedback turned out to be a very essential issue during the time of evaluation. Feedback is part of the communication and very important to give to everyone involved. This will improve the progress of the project and keep the interest for it alive.

Through the evaluation performed at Yarra Valley Water it is shown that this model is applicable even for an unfiltered supply system.

The communication between engineers, flush planners and contractors, which is very essential for success when running a project, has been improved and intensified, so that even more useful data will become available with time.

9.3 Experimental results

When evaluating the results only 61 % of all the measurements (500) taken between 2005/2006 in 13 zones are done with the right length of 315 meter and a disturbance time of 15 minutes. Out of the13 water quality zones, 5 are thoroughly evaluated. It can be concluded that in these 5 zones 38 % are completed loosely according to procedure, most of them missing a resettling time. In order not to loose too much valuable information another 23 % of the results measured with a disturbance time between 10 -14 minutes are evaluated.

When applying the RPM a ranking table is created based on all the turbidity results achieved from the evaluated five zones. The ranking table is in this report made as an example to show how this method can be applied to Yarra Valley Waters distribution system. In the future these values can come to change since they are to be set by the company itself.

The RPM measurements are used by Yarra Valley Water to achieve a triple objective.
When a measurement is done prior and after the mains cleaning it can easily be assessed if the main is cleaned as explained in chapter 7. Unfortunately there are only two measurements that contain both a pre measurement and a post measurement (performed 2 weeks after mains cleaning) which make it difficult to see the trend in the entire system. However it can still be shown with only two good results that this method works to apply. In both these results it is clear that the RPM can be used as a tool to evaluate the effectiveness of the mains cleaning program.

For the second objective, to rank dirtiness of water quality zones/areas each measurement and street within the five zones is scored following the criteria of the ranking table.
By performing several RPM measurements in time it can be observed if in a main an easily resuspendable sediment layer is present. If so, the main needs to be cleaned. If not, no cleaning is required yet and within several months a new RPM measurement is necessary.
One part of the second objective is to compare the zones with each other. This part is not totally possible to answer since the RPMs are done on such a different time interval that the existing usable results are not sufficient for comparison. When all the RPMs are done with the right procedure, they can be used to rank systems. At the moment it requires better and more experiments to achieve this goal. An evaluation has however been performed giving a direction towards a comparison.
The results in these investigated parameter clearly show that an unfiltered zone have higher turbidity levels than a filtered or blended zone.

For the third objective, to determine a cleaning frequency three examples are shown for the Croydon, Epping and Bulleen zone, three zones with different premises.
By following the overall 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.
What can be determined with the existing data is that an unfiltered zone fouls faster than a filtered or blended zone. The trend for Croydon is reaching a threshold for cleaning much faster than the other zones.

10. Recommendations

10.1 Future equipment

Further improvements can still be done regarding the equipment. It would be wise to connect a flow reader or pressure gauge to the system. In that way it can instantly be monitored which flow is being used which will be a contributing part in the analysis.

It will also be an improvement to connect the orifice plates to regulate the flow and avoid all possible disturbance caused when the hydrant is being ‘cracked’. A problem with the initial and improved equipment is the instant regulation of the flow. When the person taking a measurement switches on the hydrant he/she will not know the exact flow going out and this might lead to a higher induced velocity than the 0.35 m/s.

The data logger used today is measuring every minute and can not be calibrated to measure in a smaller time interval. It would be better to have a data logger measuring every 10 seconds and every turbidity step would be monitored. However if Yarra Valley Water decides to change to another data logger the ranking table used for the Yeokal 611 will have to be re-evaluated.

10.2 Procedure

There are always improvements that can be done and this is still a tool under research which requires full attention when performed and analysed.

When applying the method it is very important that the procedure is well documented so more or less anyone can follow. The procedure should be explained to everyone involved by someone with sufficient previous experience, all to prevent mistakes from being done.

It is essential to have a strict protocol to follow which will make sure that the measurements are comparable.

To make the environment for the contactor better, a sheet or form can be developed. This sheet shall contain all the essential parameters such as, which flow to use, pipe diameter, disturbance time etc. This will make it easier for the person in field to register every measurement and also help the analyser in his/her work. On the sheet, remarks can be written down about the equipment when something is not working properly or general notes of other observations. There should be a direct feedback on these reports and the results.

This project is a teamwork which requires attention and feedback from everyone involved. It is of high importance for participants working with the RPM to go out in field and learn how to take RPM measurements, to easier understand the results and how to evaluate them.

A recommendation is to either send the selected persons on a course or that the people involved are trained by experts at site.

It is also important that more than one person is trained to perform an RPM since there is often a certain rotation amongst personal.

Knowledge will lead to better performance and better results. The RPM is still a research tool that needs careful supervision.

Analysis of the results takes time and should be performed as soon as possible so that strengths and weaknesses in the application of the method can be found and improved.

Evaluation should be done directly after measurements and will also lead to a faster check up; which is required to make sure that the performance of the method is done correctly.

10.3 Experimental results

Yarra Valley Water have in the past year been taking measurement in 13 different zones. This is not recommended since the RPM is still a research tool and fewer zones should be evaluated to first create a model. When the model works then the method can be applied to more zones.

When selecting an RPM site some aspects should be considered. It is wise to choose location with similar circumstances close to each other. Choose mains with same pipe diameter, street mains that supply approximately same amount of people (same number of connections) or have continuous quality of feed water.

Two RPM locations should however not be chosen each at the end of the same main, which has been done on some of the measurements that are analysed in this report.

After choosing a main with similar circumstances an interval of measurements can be done on the connecting mains. For instance on one of the streets measurements can be taken at time 0 (prior to mains cleaning), 3 months, 6 months, 9 months and finally 12 months after mains cleaning. On another one of the streets the 3 month measurement is skipped, and on another street the 3 and 6 months measurement is not done, and so on. By applying this model one can determine the right frequency for cleaning just by using different measurement intervals.

The RPM measurements are not used as a quantification tool to determine the sediment load in the network. When all RPMs are done according to procedure a quantifiable method besides the ranking system can be applied.

An overall quantification evaluation method can be developed, like the “area under curve” method.

By using the results obtained by an RPM measurement, the area under the curve can be calculated and together with the maximum turbidity during that experiment the different locations can be compared with each other. It is important not to disregard the maximum turbidity since graphs can have the same area under the curve but have different shapes. Without the maximum turbidity it does not say anything about the distribution of sediments during the disturbance, see Figure 40.

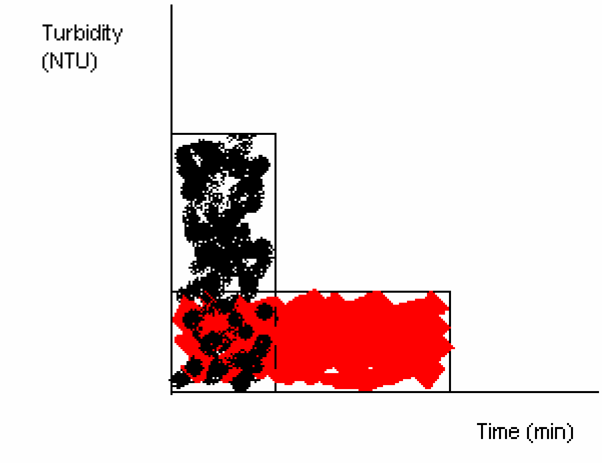

Figure 40 - An illustration of “Area under curve”

As seen in Figure 40, both blocks represent an equal area and are symbolising the result from two different measurements. By just looking at the area of the blocks these both locations would be ranked as having equally much sediment. However the maximum turbidity needs to be considered to determine if it is a considerable amount of sediments leading to a high discolouration risk in the pipe (red block) or just an initial while up of heavy sediments leading to a small discolouration risk (black block).

In this report there are no main analysis done on any possible relationship between the RPM results and corrosion of pipes, customer complaints or dead end mains. This is something that can be of interest to evaluate in the future. The relationship between customer complaints and RPM results are of importance for YVWs future work with this tool. During the time of my analysis at YVW it was found that no complaints had been filed at any of the RPM locations on the day of an RPM measurement or within 3 days after.

10.4 Other recommendations

It is of importance to always learn more and increase the knowledge. Therefore it is a recommendation that Yarra Valley Water contacts other water companies where the RPM is being implemented to share their experiences and to gain more knowledge. It is highly recommended that even with different treatment philosophies it would be wise of YVW to contact Dutch water companies to learn more and also to ask for details about equipment.

This would help YVW in their future progress with developing the Resuspension Potential Method for their systems.

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APPENDIX A

Calculation of minimum required length

Determining flow that corresponds to a specific pipe diameter

Table 1- Calculation of minimum length

Calculation model, examples	Pipe diameter (mm)	100	150	225		
	Area (m^2)	0.00785	0.01767	0.03976		(d^2)/4*pi
	Velocity (m/s)	0.35	0.35	0.35		
	Flow (m^3/s)	0.00275	0.00619	0.01392		Q = V*A
	Flow (m^3/h)	9.90	22.27	50.10		
	Volume during 15 min (ideal)	2.47	5.57	12.52		Q(m^3/h)*0.25h
	Length	315	315	315		L = V/A

Example: If the RPM measurement is done with a disturbance time of 15 minutes, the minimum required length of the isolated main is 315 meters. This would for a 100 mm pipe require a flow of 2.8 l/s and for a 150 mm pipe the flow should be 6.2 l/s.

If the disturbance time is chosen to a time less than 15 minutes it also requires a shorter length of the main being isolated.
In following table, Table 2, the length required corresponding to a certain disturbance time is calculated. This example shows the calculations for a 100 mm pipe, with the only difference in calculations from a 150 mm pipe being the volume of water required.

Table 2 - Minimum required length of isolated main.

Time (min)	Time (h)	Volume(m^3)	Length (m)
15	0.25	2.47	315
14	0.23	2.31	294
13	0.22	2.14	273
12	0.20	1.98	252
11	0.18	1.81	231
10	0.17	1.65	210
9	0.15	1.48	189
8	0.13	1.32	168
7	0.12	1.15	147
6	0.10	0.99	126
5	0.08	0.82	105
4	0.07	0.66	84

*It is not advisable to perform RPM measurements with less than 10 minutes of disturbance time since it might not give a sufficient monitoring of the development of turbidity during disturbance.

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Example: If the RPM measurements are being done with a 10 minutes disturbance time the length of the isolated main is only required to be minimum 210 meters to avoid water being drawn from other sources.

APPENDIX B

Evaluation of usable and non usable measurements

Table 3 - Complete evaluation of data

OK – usable
Graph results are not reliable, not using
too short disturbance time, not using
wrong flow applied, not using

Zone	No. of sites	RPM time (min)	pre	p1w /p2w	P1m	p2m	p3m	p4m	p5m	P6m	p7m	p8m	p9m	p10m	p11m	p12m
Croydon	16															
	Fankhauser Dr.	11														
	Taronga Ct	14														
	Andrew St	14														
	Laurence Gv	10														
	Wenwood St	14														
	Simpson Ct	8														
	Rodleigh St	8														
	Illawarra Cr	15														
	Orion St	15														
	Walker Ave	15														
	Baker Rd	15														
	Cobar Ct	4														
	Dirkala Av	8														
	Valley Ct	7														
	Croydondale	no measurements														
	Taylor	no measurements														
Epping	10															
	Dalton Rd	15														
	Scarborough Rd	12														
	Lowalde Dr	15														
	Dransfield Way	15														
	Meadow Glen Dr	15														
	Lady Penrhyn Way	15														
	Wagstaff Dr	15														
	Kelvin Gr	11														
	Strickland Ave	15														
	Silvereye Pl	no measurements														
Bulleen	7															
	Beatty St	15														

	Belmont Rd	8
	Redesdale Rd	15
	Robin Hood Rd	15
	Outlook Dr	15
	St. Elmo Rd	15
	The Boulevard	12
Somerton	12	
	Erskine Ct	13
	Augusta Av	15
	Karnack Cr	15
	Thornycroft St	15
	Nich olson Cr	15
	Harrower St	14
	Thames Way	14
	Princetown Av	15
	Metropolitan Av	15
	Lynch Pl	15
	Koroit Av	15
	Welsh	no measurements
Lilydale	12	
	Carole Av	13
	Southern Cross	15
	Coachmans Ct	15
	Eastwood Cr	15
	Nelson Rd	15
	Baker St	15
	Cobden Cr	12
	Bronwyn St	15
	Coombah Ct	no measurements
	Lansell Rd	no measurements
	Cheriton Dr	no measurements
	Highpoint Av	no measurements

APPENDIX C

Individual ranking score for every location

ZONE : CROYDON

Table 4 – Ranking table for Croydon

Street	**15 min disturbance data**							
		Pre	p2w	p3m	p4m	p6m	p8m	p11m
Illawarra	max 5	225.8	15.6		19.5	30.1	359.4	258.8
	average 5	81.0	10.6		15.5	17.1	91.9	76.2
	max 10	51.8	14.3		16.7	13.3	42.7	33
	average 10	43.4	11.9		11.5	8.8	27.2	31.2
	RANK	8	4		4	3	7	7
Orion	max 5	231.7		85			359.4	98.4
	average 5	158.9		21.5			183.8	44.8
	max 10	254.5		25			117.2	109.2
	average 10	220.0		15.9			106.1	60.7
	RANK	12		5			12	8
Walker	max 5	12.2						41.5
	average 5	9.0						33.8
	max 10	24.3						34
	average 10	12.6						26.2
	RANK	3						4
Baker	max 5	418.7	36.5		13.2	34.3	199.9	no data
	average 5	314.1	24.7		10.5	20.4	99.2	
	max 10	534.9	17.3		10.5	28.2	359.4	
	average 10	498.0	9.8		8.3	16.8	309.5	
	RANK	12	3		3	4	11	
Street	**10-14 min disturbance**							
		pre	p1w	p3m	p4m	p6m	p8m	p11m
Laurence x = 10min	max 5	297.6		54.7		144.1	15.3	81.6
	average 5	132.6		30.8		75.4	12.0	46.0
	max x-5	170.7		75.6		80.2	16.5	90.3
	average x-5	98.4		36.0		26.7	15.0	39.5
	RANK	11		6		8	4	6
Fankhauser x = 11min	max 5	not using		12.5		18.2	36.0	21.3
	average 5			9.2		17.1	23.4	17.9
	max x-5			7.7		16.6	38.1	21.1
	average x-5			6.8		14.1	24.9	17.5
	RANK			1		4	4	4
Taronga x = 14 min	max 5	434.6		58.8		10.9	359.4	217.7
	average 5	228.6		50.8		8.7	159.2	110.9
	max x-5	147.1		58.2		14.1	153.9	359.4
	average x-5	102.8		34.8		10.1	77.4	161.4
	RANK	12		7		2	11	12

Andrew x = 14 min	max 5	29.9			9.4	20.6	95.8	35.2
	average 5	25.7			8.1	10.7	59.3	31.5
	max x-5	26.6			12.0	10.5	40.3	30.4
	average x-5	13.8			8.4	5.1	38.1	21.4
	RANK	4			1	3	6	4

Street	**Dismissed data/streets**							
		pre	p1w	p3m	p4m	p6m	p8m	p11m
Valley x = 7 min	max 5		18.3		10.3	15.5	152.7	
	average 5		12.4		7.5	12.4	102.6	
	max x-5		13.2		10.3	16.2	126.1	
	average x-5		12.8		9.0	14.8	82.2	
Simpson x = 8 min	max 5			92.5		37.4	53.1	45.9
	average 5			72.6		21.3	29.7	28.8
	max x-5			92.5		16.6	22.5	29.9
	average x-5			81.6		13.8	18.7	23.6
Rodleigh x = 8 min	max 5	534.9			5.2			99.3
	average 5	296.6			3.9			64.3
	max x-5	268.9			7.2			36.5
	average x-5	221.3			6.3			54.5
Dirkala x = 8 min	max 5	59.8		54.9		16.5	20.5	38.9
	average 5	50.1		44.1		10.9	14.6	24.9
	max x-5	64.4		57.6		16.5	21.8	35.7
	average x-5	55.0		51.3		13.1	18.0	29.3
Cobar x = 4 min	3 measurements, none usable, too short time							
Wenwood 15 min	max 5							359.4
	average 5							197.1
	max 10							117.2
	average 10							44.8

ZONE : EPPING

Table 5 – Ranking table for Epping

Street		15 min disturbance data					
		Pre	p1w	p6m	p7m	p8m	p12m
Strickland	Max 5			118.7	100.7	42.7	57.5
	average 5			68.8	55.3	34.3	32.2
	Max 10			149.0	102.5	38.7	59.6
	average 10			64.2	56.0	35.9	28.7
	RANK			10	10	4	6
Wagstaff	Max 5		7.4	52.2	52.4	56	50.8
	average 5		6.4	38.0	46.1	28.0	26.0
	Max 10		7.3	45.4	146.2	107.5	56.7
	average 10		6.1	31.3	48.3	51.0	39.5
	RANK		0	5	7	8	6
Lowalde	Max 5	41.7		92.3			96.7
	average 5	29.5		53.5			37.3
	Max x-5	59.7		80.5	not using	not using	55.7
	average x-5	48.6		35.7			23.1
	RANK	5		7			6
Street		**10-14 min disturbance**					
		pre	p1w	p6m	p7m	p8m	p12m
Kelvin x = 11 min	Max 5		6.6	57.6	28.9	46.9	27.4
	average 5		4.4	42.2	25.2	37.7	19.5
	Max x-5		7.1	54.8	38	36.1	20.3
	average x-5		4.7	31.3	22.9	24.1	12.7
	RANK		0	6	4	4	4
Scarborough x = 12 min	Max 5	20.6		20.3	33.5	17.4	
	average 5	7.8		16.3	12.7	15.7	
	Max x-5	7.4		15.4	62.1	38.6	no data
	average x-5	5.7		15.4	11.4	18.1	
	RANK	1		4	5	4	
Street		**Dismissed data/streets**					
		pre	p1w	p6m	p7m	p8m	p12m
Dalton	Max 5	72.5		23.6	33.5		6.4
	average 5	19.6		19.8	22.7		4.9
	Max x-5	18.7		22.5	62.1	not using	6.3
	average x-5	15.1		14.0	50.4		5.9
Dransfield	Max 5			17.7	14.2	90.6	38.5
	average 5			16.0	13.5	40.0	26.4
	Max 10		not using	42.2	35.7	83.5	108.5
	average 10			29.4	13.6	52.8	47.7

Meadow Glen	Max 5	77.8		not using	not using	32.8	4.4
	average 5	25.2				28.2	1.6
	Max 10	50.8				29.7	0.9
	average 10	22.7				24.7	0.8
Lady Penrhyn	none performed correctly						

ZONE : BULLEEN

Table 6 – Ranking table for Bulleen

Street		**15 min disturbance data**				
		pre	P1m	p2m	p3m	p6m
Redesdale	max 5	72.3	36.8	26.3	50.5	57.1
	average 5	54.8	30.4	19.2	40.7	42.8
	max 10	51.4	51.4	23.5	40.1	95.9
	average 10	20.7	18.2	19.1	34.9	60.9
	RANK	7	5	4	5	7
Robin Hood	max 5	359.4	48.7	not using	24.4	46.8
	average 5	158.4	36.2		13.3	28.2
	max 10	116.0	33.4		38.8	70.3
	average 10	56.0	26.4		19.9	30.9
	RANK	11	4		4	5
Outlook	max 5	94.4	17.9	59.3	40.4	40.3
	average 5	36.7	12.8	31.7	30.5	18.0
	max 10	51.4	18.6	39.1	100.8	18
	average 10	38.4	12.6	33.8	47.5	16.0
	RANK	6	4	5	6	4
St Elmo	max 5	210.8	59.2	118.3	37.3	71.3
	average 5	53.5	24.1	67.7	27.3	37.8
	max 10	73.4	28.7	56.7	21.3	353.1
	average 10	46.1	24.4	49.7	20.5	72.1
	RANK	8	5	8	4	8
Street		**10-14 min disturbance**				
		Pre	p1m	p2m	p3m	p6m
The Boulevard	max 5	53.1	35.4	43.7	51.4	62.3
	average 5	39.5	25.0	35.4	39.4	33.8
	max x-5	82.1	37.4	44.3	35.8	48.6
	average x-5	53.1	33.1	42.1	27.4	47.3
	RANK	6	4	5	6	4
Street		**Dismissed data/streets**				

Beatty		pre	p1m	p2m	p3m	p6m
	max 5 average 5 max x-5 average x-5	not using	not using	not using	not using	not using

Belmont		pre	p1m	p2m	p3m	p6m
	max 5	not using	217.4	75.7	37.2	72.7
	average 5		77.8	40.3	21.8	31.1
	max x-5		57.1	39.5	20.3	8.9
	average x-5		55.8	32.9	20.3	8.4

ZONE : SOMERTON

Table 7 – Ranking table for Somerton

Street		**15 min disturbance data**		
		Pre	p2m	p9m
Augusta	max 5	359.4	72.3	5.3
	average 5	209.9	45.7	3.8
	max 10	284.4	223.3	4.5
	average 10	45.2	137.6	2.9
	RANK	10	9	0
Lynch	max 5	59.7	168.8	248.6
	average 5	38.2	121.6	177.0
	max 10	75.5	153.2	156.5
	average 10	54.4	119.7	111.8
	RANK	7	12	12
Koroit	max 5	299.1	267.1	137.2
	average 5	210.2	139.7	82.8
	max 10	177.9	63.4	225.2
	average 10	85.4	57.8	94.4
	RANK	11	10	10
Street		**10-14 min disturbance**		
		Pre	p2m	p9m
Erskine x = 13 min	max 5	34.7	46.4	61.9
	average 5	20.6	27.6	38.6
	max x-5	33.1	22.9	30.8
	average x-5	10.8	17.3	26.6
	RANK	4	4	5

Harrower x = 14 min	max 5	302.2	165.9	106.4
	average 5	194.4	74.4	32.5
	max x-5	286.3	174.1	20
	average x-5	105.8	80.4	14.6
	RANK	12	10	6
Thames x = 14 min	max 5	71.7	110.3	105.5
	average 5	46.3	61.0	82.0
	max x-5	54.2	57.5	93.1
	average x-5	35.1	35.9	49.6
	RANK	6	8	9

Street		**Dismissed data/streets**		
		Pre	p2m	p9m
Karnack	max 5	not using	207.6	193.6
	average 5		134.3	112.0
	max 10		141.2	100.3
	average 10		64.2	47.9
Thornycroft	max 5		13.1	2.6
	average 5		11.9	1.8
	max x-5		15.7	1.7
	average x-5		11.6	1.4
Nicholson	max 5	122.6	not using	5.8
	average 5	71.5		4.5
	max 10	73.0		6.1
	average 10	34.4		4.7
Princetown	max 5		55.4	82.9
	average 5		43.3	61.4
	max 10		46.9	60.6
	average 10		42.2	30.2
Metropolitan	max 5		not using	
	average 5			
	max 15			
	average 15			

ZONE : LILYDALE

Table 8 – Ranking table for Lilydale

Street		15 min disturbance data			
		Pre	p7m	p10m	p12m
Southern Cross	max 5	194.3	102.2	44.4	98.3
	average 5	122.9	44.6	35.8	33.3
	max 10	379.6	54.4	76.6	15.2
	average 10	132.8	29.8	33.9	5.7
	RANK	12	7	5	4
Coachmans	max 5	534.9	116.1	253.4	39.4
	average 5	360.5	60.2	134.9	30.0
	max 10	251.5	103.0	57.9	51.4
	average 10	156.0	35.0	35.6	37.1
	RANK	12	9	9	5
Baker	max 5		66.6	21.9	33.4
	average 5		49.4	16.4	22.1
	max x-5		87.9	17.7	42.6
	average x-5		51.5	15.5	29.5
	RANK		7	4	4
Bronwyn	max 5		69.9	39.7	15.2
	average 5		50.2	33.5	11.2
	max x-5		151.0	39.2	14.6
	average x-5		106.4	32.5	10.2
	RANK		9	4	3

Street		10-14 min disturbance			
		pre	p7m	p10m	p12m
Carole x = 13 min	max 5	23.8	179.6	40.9	10
	average 5	16.7	45.8	30.9	8.2
	max x-5	20.2	27.2	36.2	9.9
	average x-5	12.3	21.7	31.8	6.3
	RANK 2	4	6	4	0
Cobden x = 12 min	max 5		33.3	112.5	136.9
	average 5		12.2	43.0	85.5
	max x-5		64.7	140.6	302.0
	average x-5		15.5	110.2	123.2
	RANK 2		5	10	11

Street		Dismissed data/streets		
		p7m	p10m	p12m
Eastwood	max 5 average 5 max x-5 average x-5	no data	no data	no data

APPENDIX D

Cleaning frequency for Somerton and Lilydale

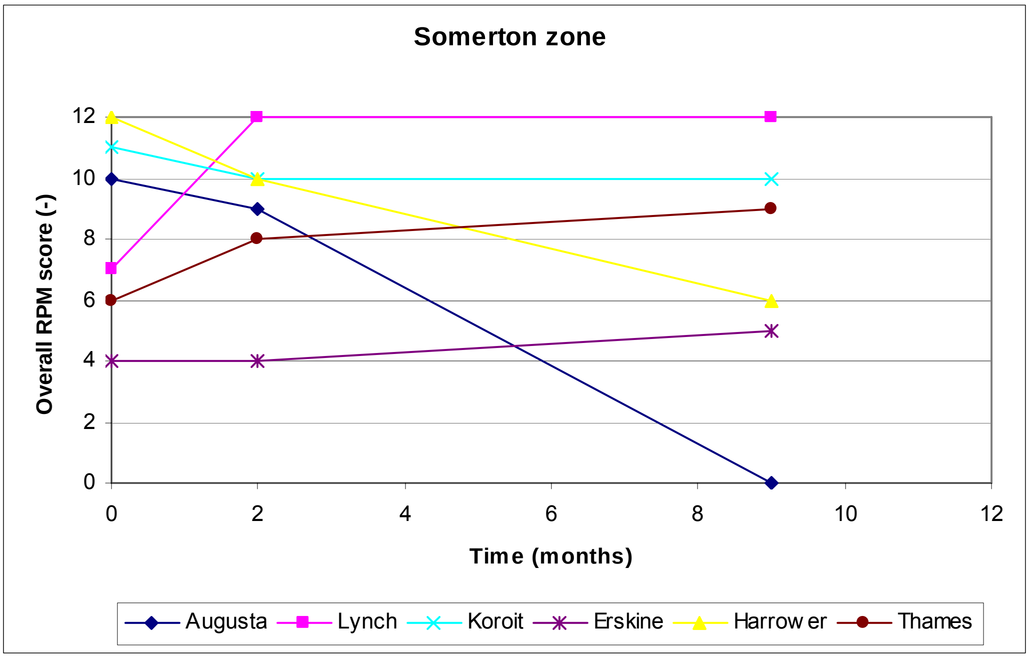

Figure 1 – Cleaning frequency for Somerton

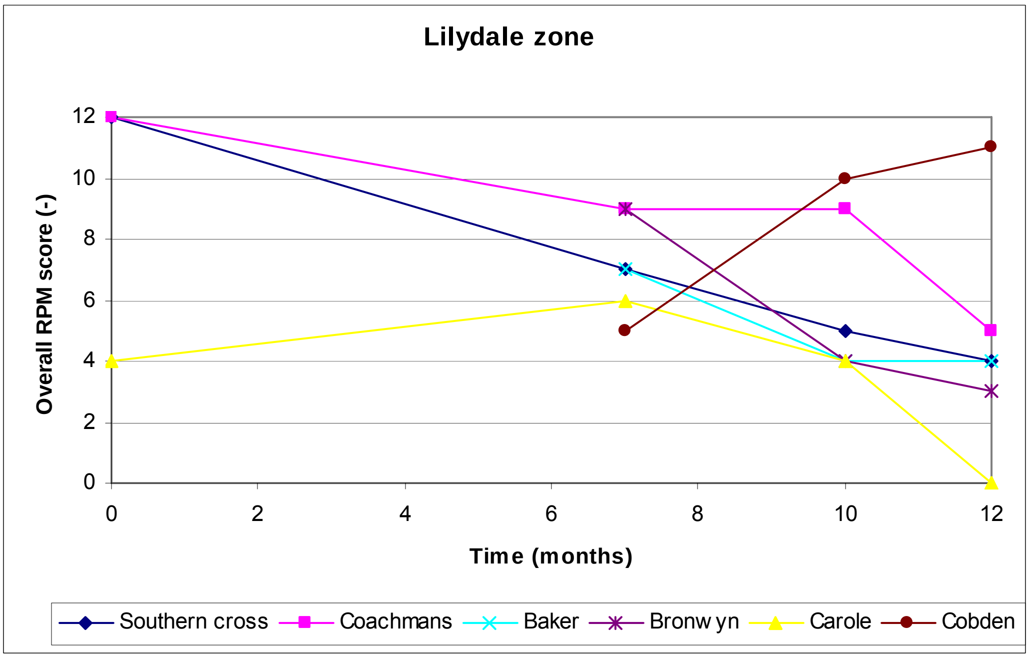

Figure 2 – Cleaning frequency for Lilydale