OPERATIONAL AND DESIGN CONSIDERATIONS FOR HIGH RATE CLARIFIERS IN THE SOUTH AFRICAN WATER TREATMENT INDUSTRY

Report to the
Water Research Commission

by

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EXECUTIVE SUMMARY

BACKGROUND

High rate processes are critical especially where capital spending cannot keep pace with the increasing water demand. Despite high rate clarification technologies being widely used in the first world nations for potable water treatment, these technologies are being scarcely used in developing countries. This may in part be due to a lack of knowledge or of knowledge dissemination on the performance capabilities, as well as the operational and maintenance requirements of high rate clarifiers. This study was initiated with the intention of contributing to bridging this knowledge gap.

AIMS

The aims of this project were:

- To contribute to the current understanding of the operational, maintenance and process requirements and limitations for high rate clarifiers, based on investigations conducted on a demonstration plant of the HR-CSAV type of high rate clarifier.
- To provide practical guidance on the selection, design and operation of high rate clarifiers, with particular reference to the investigations carried out on the demonstration model HR-CSAV.

METHODOLOGY

This study was undertaken by first conducting a literature review of the common high rate clarification technologies being used. The high rate clarifiers considered in this study were the HR-CSAV (a sludge blanket clarifier which uses a flocculant aid), ballasted sand processes and sludge recirculation processes. This was supported by plant visits undertaken to provide case studies for existing full scale facilities using these technologies, both in South Africa and abroad.

Chapter 2 contains the literature review and case study assessments.

In this study, the high rate clarification technology was evaluated based on investigations conducted on a demonstration unit. Due to budget constraints, only one of the available high rate clarifier technologies, the HR-CSAV – a patented technology developed by Pavel Polasek and Associates, was procured. Chapter 3 presents results from investigations conducted on a 500 m^3/day demonstration model HR-CSAV high rate clarifier. For comparison, the clarifier was operated at two water treatment facilities, one using an impounded raw water source with low raw water turbidity and the other using river water abstraction with more variable raw water turbidity of up to 157 NTU. In addition, for comparison the HR-CSAV demonstration model high rate clarifier was operated in parallel with conventional clarifiers (operating at 2 m/h).

Basic practical design considerations and operational guidelines for high rate clarifiers, based on the case study assessments, literature and on the outcome of investigations on the HR-CSAV clarifier are presented in Chapter 4.

RESULTS AND CONCLUSIONS

Results from the investigations on the HR-CSAV demonstration model high rate clarifier operating in parallel with conventional clarifiers (operating at 2 m/h) clearly showed that similar clarified water turbidity may be achieved by the high rate clarifier, which was operated at 7 m/h. Slow floc settling rates and an increase in settled water turbidity occured when using low turbidity raw water (i.e. < 25 NTU). The higher operating rates of the HR-CSAV and its sensitivity to the chemical dosages applied make it less forgiving to poor process monitoring and control compared to conventional clarifiers. The automation of chemical dosing systems, as is common for conventional processes, would allow for more prompt response to fluctuations in raw water quality.

It was very evident from the case studies and the operation of the demonstration model HR-CSAV clarifier that these high rate clarification processes are specialized technologies and therefore require more operator judgement and more instrumentation and control than conventional clarification processes. The intensive maintenance nature of these processes call for the regular presence of maintenance personnel and, in some instances, that stand-by treatment units be available during these maintenance shutdown periods. Therefore, the higher clarification rates achievable not only indicate significant cost savings, but also mean investment in a reliable asset management team and skilled operators which are fundamental for the successful operation of these units.

It is also understood that some of the mechanical challenges experienced with the HR-CSAV cannot be attributed entirely to the high rate technology. The selection of some components and equipment that made up the HR-CSAV demonstration plant was guided more by the available research budget than other life cycle considerations like ease of operation and maintenance, reliability and sustainability and other issues taken into account in the design of a full-scale water treatment process.

In general, the technology still holds promise as an attractive technology for developing countries to meet the growing potable water demands, provided that there is adequate training and local support services made available by the technology provider. This would to allow for the process to be successfully operated and maintained after installation.

GENERAL

The report will assist water treatment designers and water treatment practitioners particularly in South Africa to make informed decisions on the appropriateness of high rate clarification processes under local conditions. The project has met its objectives in providing a practical guideline on the selection, design

considerations and operation and maintenance implications associated with high rate clarification for potable water treatment.

RECOMMENDATIONS

This study did not fully address the operability of the other two clarifiers which were considered in the case study assessments, and also did not consider the economics, in terms of capital and life cycle costs, which are important in the planning and conceptual design processes. It is recommended that this be considered in future research work.

High rate clarification processes described and evaluated in this report are viable options for application in the South African potable water industry. It is recommended that water treatment practitioners and designers consider the application of this technology under the appropriate conditions.

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ACRONYMS & ABBREVIATIONS

Alum	Aluminium sulphate
G	Root mean squared velocity gradient (mixing intensity measured in s^{-1})
HR-CSAV	A type of high rate clarifier developed by Polasek and Associates
IHDS	Inline High Density Suspension process
LiCl	Lithium chloride
MLD	Mega-litres per day
OFA	Organic Flocculant Aid
WW	Waterworks

CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

The increasing demand for safe drinking water requires the installation of new treatment works or extensions to be made to existing systems, which are often restricted by space limitations and costs. In order to meet the backlogs in water delivery, especially in un-serviced areas in developing countries, it is becoming increasingly necessary to consider high rate treatment processes. A plethora of literature on high rate filtration processes is available, in publications such as Kawamura (1999) and Conley (1972), but less work has been conducted on high rate clarification processes, which are used in conjunction with subsequent filtration.

In conventional clarifiers, clarification rates up to 4 m/h (Baruth, 1998) are generally achieved, whereas in high rate processes, clarification rates of 14 m/h up to 80 m/h have been reported by suppliers of these technologies. The benefits of high rate clarification may be illustrated using the following typical example; a 4 m diameter conventional clarifier operating at an upflow rate of 4 m/h would produce 1.2 MLD of treated water. In contrast, a similar clarifier operating at a high upflow rate of 10 m/h would produce 3 MLD. With the increased cost of construction to achieve these throughputs in conventional processes, it has become critical that structures with smaller footprints be considered for future designs.

In the local South African context, high rate clarification is a relatively unexplored technology, even though it is being used extensively abroad in a wide range of municipal and industrial applications (Baruth, 1998). One of the likely reasons for this is due to the aforementioned lack of knowledge and knowledge dissemination about the technology. This study was initiated to contribute to bridging this knowledge gap.

1.2 PROJECT AIMS

The aims of this project were:

- To contribute to the current understanding of the operational, maintenance and process requirements and limitations of high rate clarifiers, based on investigations conducted on a demonstration model plant of the HR-CSAV type of high rate clarifier
- To provide practical guidance on the selection, design and operation of high rate clarifiers, with particular reference to the investigations carried out on the demonstration model HR-CSAV

1.3 SCOPE AND LIMITATIONS

In this study, the definition of high rate clarification was taken to be processes with upflow rates of 7 m/h and higher. The scope of work included:

- Operation of a HR-CSAV demonstration plant at a site using an impounded influent water source (i.e. the Hazelmere Waterworks)
- Operation of the HR-CSAV at a site using a variable quality raw water source, such as river water abstraction (i.e. the Umvoti Waterworks site)
- Conduct case study assessments of existing facilities using high rate clarifier technologies

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Clarification refers to solid-liquid separation processes. In its application in conventional potable water treatment processes, clarification is mainly aimed at reducing the solids content of water after coagulation and flocculation. Coagulation and flocculation aim at promoting the interaction of particles to form larger and faster settling aggregates. The clarification stage which follows is concerned with the settling and removal of these aggregates. In instances where the source water has a low turbidity and contains very little organic matter, treatment by direct filtration, where the clarification stage is omitted in the treatment process, is generally followed. This treatment option is more cost effective but reduces the overall reliability of the treatment process (Edzwald, 2011). For less pristine water sources, the conventional treatment train in which clarification and filtration occurs in separate units, is better followed.

2.1.1 Coagulation and flocculation

The coagulation process precedes clarification in the water treatment process. Ferric and aluminium salts are commonly used coagulants. During coagulation, a coagulant such as aluminium sulphate (alum) is rapidly mixed into the raw water. The dose of the coagulant is usually determined using a jar test (Sincero, 2003). It is critical to maintain the pH between 6.5 and 7.2, the range of minimum aluminium solubility to allow aluminium hydroxide floc formation (Ratnayaka, 2009).

The formation of hydrolytic products occurs in a very short period of time and therefore requires flash mixing for rapid and uniform dispersion of chemicals into the raw water. Once destabilisation has occurred, flocculation commences, where the chemically conditioned particles aggregate into flocs which can be subsequently removed during clarification. This is achieved by the controlled introduction of mixing energy to enable contact between particles for floc formation (Edzwald, 2011). The measure of the intensity of mixing is known as the velocity gradient, or G value, which is calculated using the following equation:

$$G = \sqrt{\frac{P}{\mu V}}$$

Where

G *velocity gradient, s^{-1}*

P *power dissipated, $kg.m^2s^{-3}$*

μ *viscosity of water, $kg.m^{-1}s^{-1}$*

V *volume of reactor, m^3*

Typically, the product of the G value for the flash mixing step and the flash mixing time used lies in the range of 500-1600 (Kawamura, 2000) and for slow mixing during flocculation G values in the range 10-70 s^{-1} (Kawamura, 2000) are generally used.

2.1.2 Clarification

The separation of flocs from water is generally achieved using gravity separation processes. The clarification process is usually sized based on the hydraulic loading rate (or upflow velocity). The upflow velocity is defined as:

$$V_s = \frac{Q}{A}$$

Where

V_s *upflow velocity, m/h*

Q *influent flow rate, m^3/h*

A *water surface area in settling tank, m^2*

Conventional clarifiers generally operate at surface loading rates of up to 4 m/h (Baruth, 1998). Clarified water quality in general deteriorates as the surface loading rate is increased (Edzwald, 2011). High rate clarification refers to processes which can be loaded at higher rates than typically used in conventional clarifiers. This higher rate results in the clarifier occupying a smaller footprint and reduced construction costs, compared to a conventional clarifier of the same throughput.

2.2 HIGH RATE CLARIFIERS

Clarification rate is a function of the rate of floc formation and the settling velocity of flocs (U.S. EPA, 2003). The high rate clarification processes generally follow the same type of chemical pre-treatment as in conventional treatment processes, but also includes some mechanism by which denser and faster settling flocs are formed. This results in lower settling times, and hence lowers hydraulic retention times and the size of process units. The main mechanisms used to achieve the higher rates are:

- Use of a ballasting agent: the deliberate addition of an inert ballasting agent, such as micro-sand (< 200 µm) or magnetite provides nuclei for the formation of dense and rapid settling flocs (Swain *et al.,* 2011). Micro-sand is recovered and recycled by separation from the sludge in a hydrocyclone.

- Sludge recirculation: at the start of the flocculation process, a portion of sludge is recycled and added to the coagulated mixture, which enhances inter-particle contact and facilitates more rapid formation of flocs (Edzwald, 2011).

- Use of a chemical flocculant aid: the addition of a chemical organic flocculant aid to a sludge blanket type of process in order to facilitate faster sedimentation of flocs.

A brief description of these three types of high rate clarification processes is covered in Section 2.2.1.

It is worth noting that inclined plates or tubes (see Figure 2-1) can be used to enhance the settling process and are generally also included in the design of high rate clarification processes. These inclined plates or tubes increase the available surface area for settling of flocs as water flows across the plates and also reduces the settling depth.

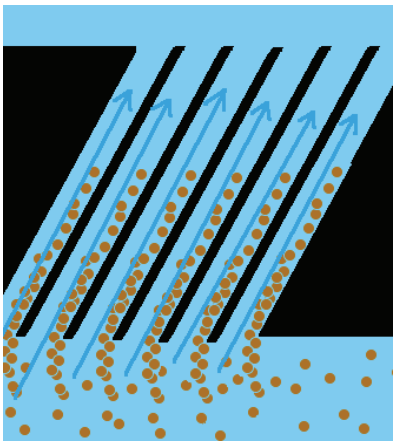


Figure 2-1: Schematic of lamella plates

2.2.1 Ballasted flocculation processes

Ballasted flocculation is a physical-chemical type of clarification process where a coagulant, flocculant and an inert ballasting agent (usually micro-sand or magnetite) is used to improve and accelerate floc formation and settling properties. This process is reported to operate up to 80 m/h for potable water applications (Veolia, 2007).

In this process pre-treatment of the raw water includes pre-screening of the influent water upstream of the high rate clarification unit to prevent particles larger than 3 mm from clogging the hydrocyclone. The clarifier system consists of four zones, viz. (Figure 2-2)

- Coagulation zone: Coagulation follows pre-screening, generally using aluminium sulphate (alum), which is rapidly mixed with incoming raw water in this zone of the clarifier

- Injection zone: The water then enters the injection zone of the clarifier. A ballasting agent, such as micro-sand or magnetite, and a polymer (usually an anionic polymer) is mixed in this zone. The destabilized particles bond to the micro-sand by polymer bridges. The ballasting agent thus serves as a ‘seed’ (or deposit point) and increases the surface area for inter-particle contact and agglomeration of flocs. It also acts as a weight (ballast) to promote rapid settling of agglomerated flocs

- Maturation zone: In the maturation zone, slow mixing promotes flocculation

- Settling zone: In the settling zone, the dense flocs, containing the ballasting agent, settle rapidly. Lamella plates are also sometimes used to facilitate floc settling. Clarified water overflows from the clarifier weir after passing the lamella plates. Sludge, containing the ballasting agent, is removed from the base of the clarifier using a scraper and is pumped to a hydrocyclone, where the ballasting agent is separated from the sludge. The ballasting agent is recycled and re-used and requires continuous topping-up due to losses during desludging.

The total retention time in this unit was reported to be up to 7 min (U.S. EPA, 2003).

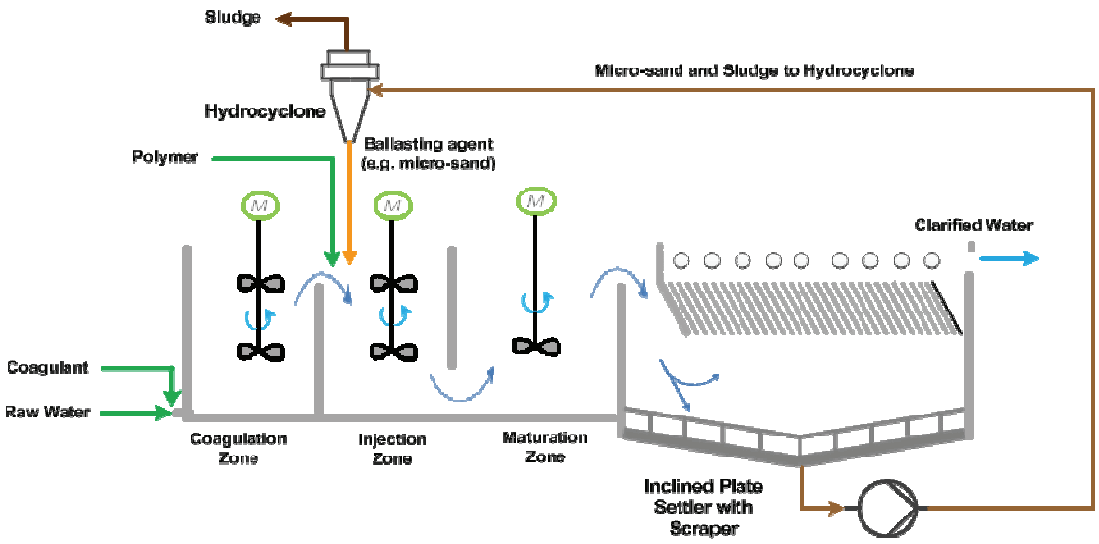


Figure 2-2: Schematic of the ballasted flocculation process

2.2.2 Sludge recirculation processes

This process is similar to the process using the ballasting agent; however, recycled sludge is used as a ballasting agent to form dense and rapidly settling flocs. The process is reported to be able to achieve surface loading rates of up to 40 m/h in potable water applications (Infilco Degremont, 2009). Figure 2-3 shows a schematic of the process.

The clarifier consists of the following zones:

Coagulation: The rapid mixing of a coagulant (such as alum) into the water.

Flocculation: This follows in the next compartment of the clarifier, with the introduction of a polymer and recycled settled sludge. The re-circulated sludge enhances the flocculation process and the polymer aids in densification of the coagulated particles. A draft-tube mixer is used to create a complete-mix flocculation zone (Clarifier Design Task Force, 2005). A plug flow transition zone then follows to condition the floc.

Settling: Flocculated water then enters the settling zone, where lamella plates facilitate the solid-liquid separation process. The settled flocs at the base of the clarifier form sludge. The sludge is removed using a scraper, and a portion of the sludge is recycled and reused.

The total retention time in this unit was reported in U.S. EPA (2003) to be up to 15 min.

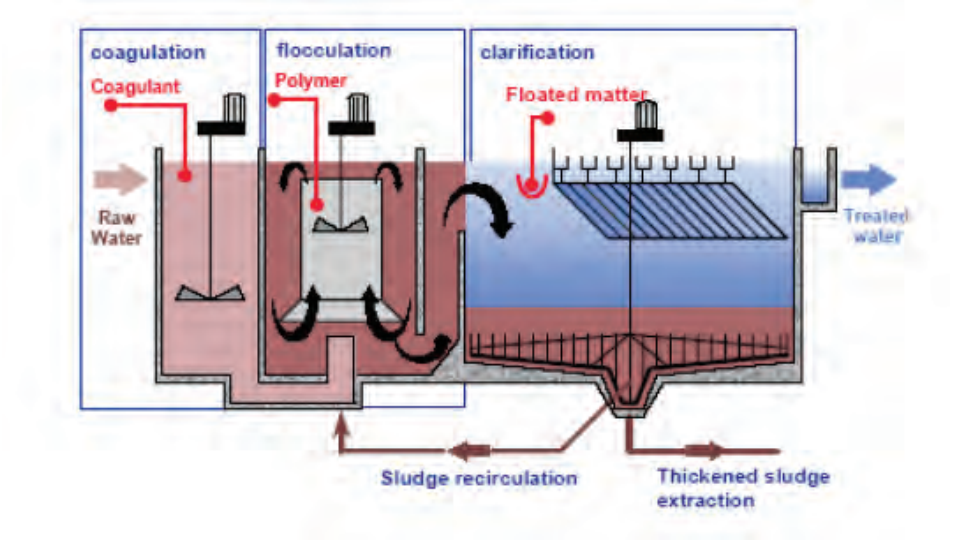


Figure 2-3: Schematic of the sludge recirculation process (Infilco Degremont, 2009)

2.2.3 Addition of flocculant aids

The HR-CSAV clarifier, developed by Polasek and Associates is reported to achieve settling rates up to 14 m/h. The use of extended rapid agitation during flocculation coupled with the addition of a chemical flocculant aid (anionic or non-ionic polyelectrolyte) enables the formation of large agglomerates with a higher sedimentation velocity. The technology was reported to be suitable for continuous operation under steady conditions (Polasek *et al*., 2005c) and requires the influent water turbidity to be more than 25 NTU in order to operate successfully. In this study, investigations were carried out on a demonstration model of the HR-CSAV clarifier.

Pre-treatment of the raw water includes the addition of a coagulant such as alum. Coagulated raw water enters the inner flocculation compartment of the clarifier, where further high intensity mixing is achieved. The flocculated water exits the bottom of the inner flocculation compartment via a perforated plate at the base of the compartment, and moves upwards through the outer sludge blanket compartment. An Organic Flocculant Aid (OFA) is added prior to the water entering the sludge blanket compartment. The expanding cone shape of this compartment reduces the velocity of the water flowing upwards. A fluidised sludge blanket, into which flocculant particles continuously deposit, is maintained in this compartment. The level of the floc blanket surface is controlled by removing solids via a sludge overflow weir. This excess sludge is deposited and removed from the sludge thickening compartment.

The separate compartments in the clarifier are shown in Figure 2-4. Further description of the compartments in this process is given below.

- Flocculation compartment: This compartment is fitted with a stirrer driven by a variable speed motor, which enables extended rapid mixing until the flocculation optimum is achieved. This process is referred to as the Inline High Density Suspension (IHDS) process (Polasek *et. al.* 2005b). With the increased duration and intensity of mixing during flocculation, high density aggregates with a compact inner structure are formed. At the bottom of the flocculation compartment there are deflector baffles which reduce the fast rotation of the water in the flocculation compartment prior to it entering the sludge blanket. An OFA is dosed at the bottom of this compartment, prior to it passing through the deflector baffles. The OFA is used to bridge the particles formed during the IHDS process.

- Sludge blanket compartment: When the aggregates formed by the IHDS process grow in size, the macro-aggregates formed have a higher settling velocity than that formed under conventional flocculation conditions. This Post-Orthokinetic Agglomeration (POA) process takes place in the fluidised sludge blanket. The sludge blanket compartment is located outside of the flocculation compartment. It is constructed as an inverted cone and is connected to the inner flocculation compartment via narrow slots through which flocculated water enters. The conical wall forms a submerged weir at which the level of the sludge blanket height is maintained.

- Sludge thickening compartment: On the outside of the sludge blanket compartment is the sludge thickening compartment, in which the excess sludge from the sludge blanket settles and is removed during the desludging process.

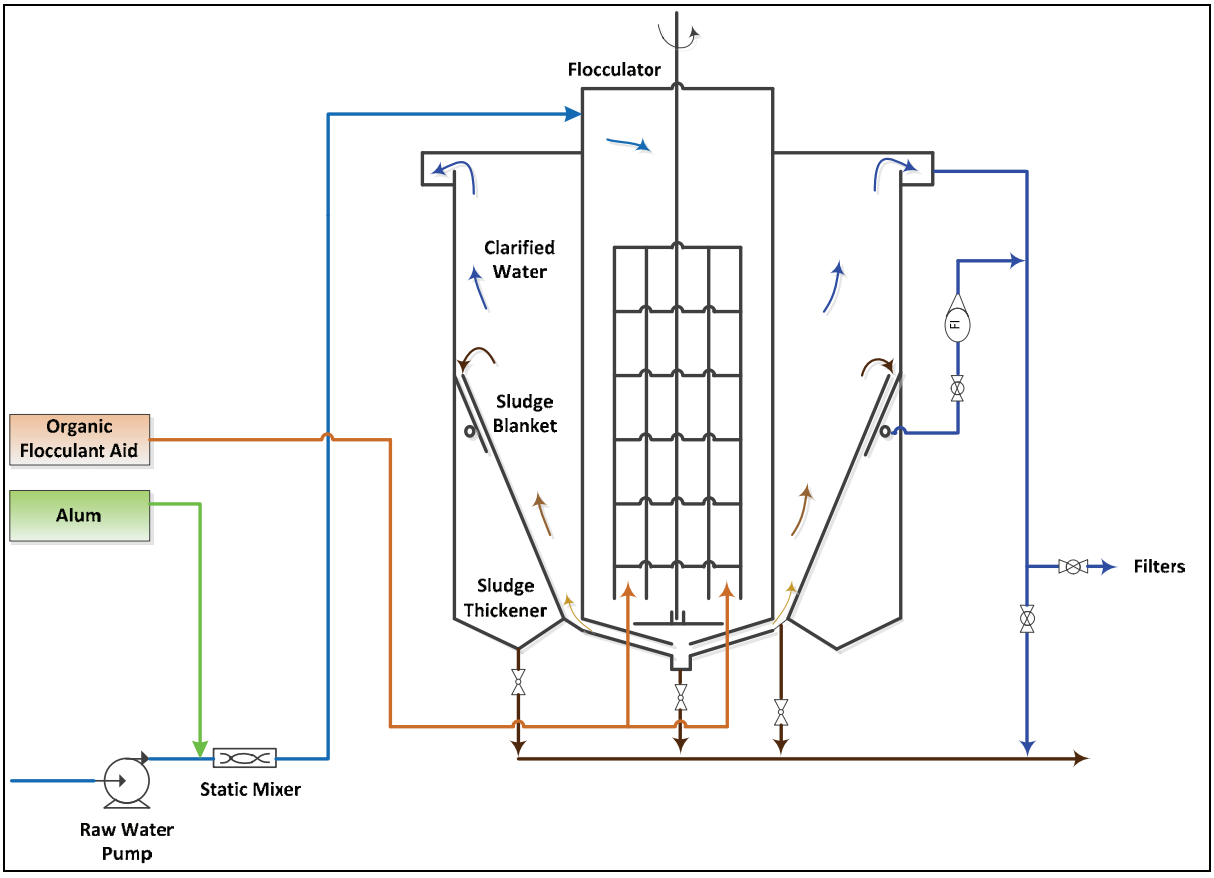


Figure 2-4: Schematic of the HR-CSAV clarifier

2.3 CASE STUDIES

Case study assessments of existing full-scale facilities making use of high rate clarifiers were undertaken, with the aim of gaining an understanding of the application of these technologies and the operational and maintenance experiences with each type of high rate clarification technology.

Technology providers were contacted to identify sites making use of ballasted flocculation, sludge recirculation and the HR-CSAV types of clarifiers. The sites which were shortlisted for the case studies are given below, and are followed by a detailed description:

- *Saulspoort Water Works (WW)*: A water treatment plant located in Bethlehem in the Eastern Free State in South Africa, utilising full scale HR-CSAV units as part of the process to produce potable water using water from a dam as a water source.

- *Tubatse Treatment Works*: A water treatment facility located in Mpumalanga in South Africa utilising the ballasted flocculation type of high rate clarifier as part of the treatment process for the production of process water for the Samancor plant. A combination of borehole water, plant effluent water, sewage and storm water are used as the raw water source.

- *Durban Water Recycling*: A wastewater recycling treatment facility in the south of Durban which uses sludge as a ballasting agent to achieve high clarification rates in its tertiary treatment processes to produce process water for various industries.

- *Sasol Synfuels Secunda*: The water treatment unit contains a sludge recirculation type of high rate clarifier which was installed for the treatment of water abstracted from a dam to produce process water for the Sasol facility.

- *Morsang sur Orge WW – France*: A water treatment facility located south of Paris which uses the sludge recirculation type of high rate clarifier technology in the treatment process for the production of potable water, using water abstracted from a river.

- *Mont Valerien WW*: A water treatment facility located in Paris, France which uses the sludge recirculation type of high rate clarifier technology in the treatment process for the production of potable water, using river water as a water source.

2.3.1 CASE STUDY 1: Saulspoort WW

The Saulspoort WW is a 40 MLD treatment process which supplies potable water to the Bethlehem community. The waterworks has four HR-CSAV clarifiers (two old clarifiers were installed when the plant was initially established and two additional clarifiers were installed when the plant was later upgraded). Figure 2-5 shows the key elements of the clarifier.

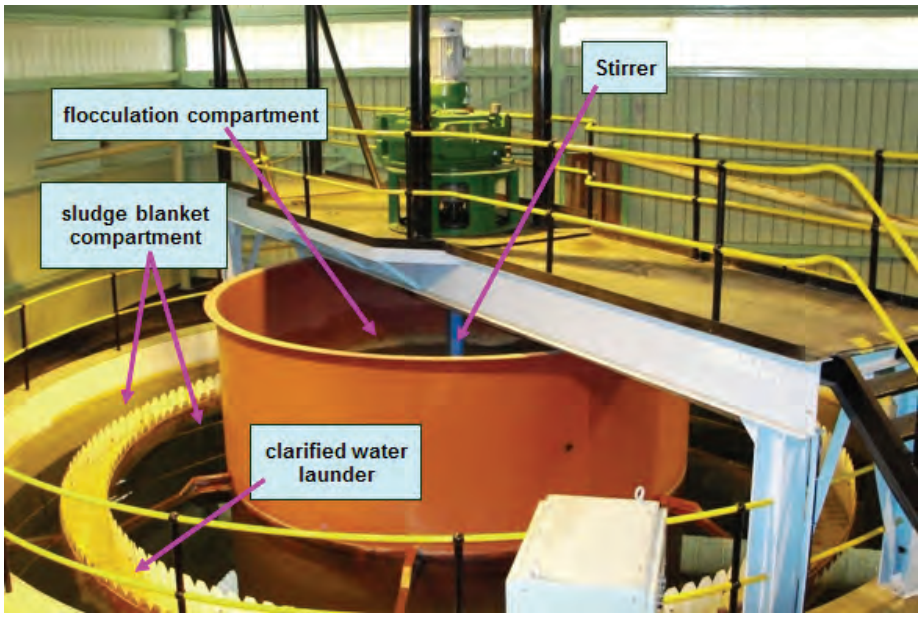


Figure 2-5: Key elements of the HR-CSAV clarifier in Bethlehem

In the Saulspoort process, raw water is split equally among the four HR-CSAV units. Coagulant dosing takes place at the splitter boxes. Lime dosing for pH correction also occurs at the splitter boxes. Clarified water from each of the four clarifiers is filtered and disinfected using chlorine gas. Figure 2-6 is a schematic of the process.

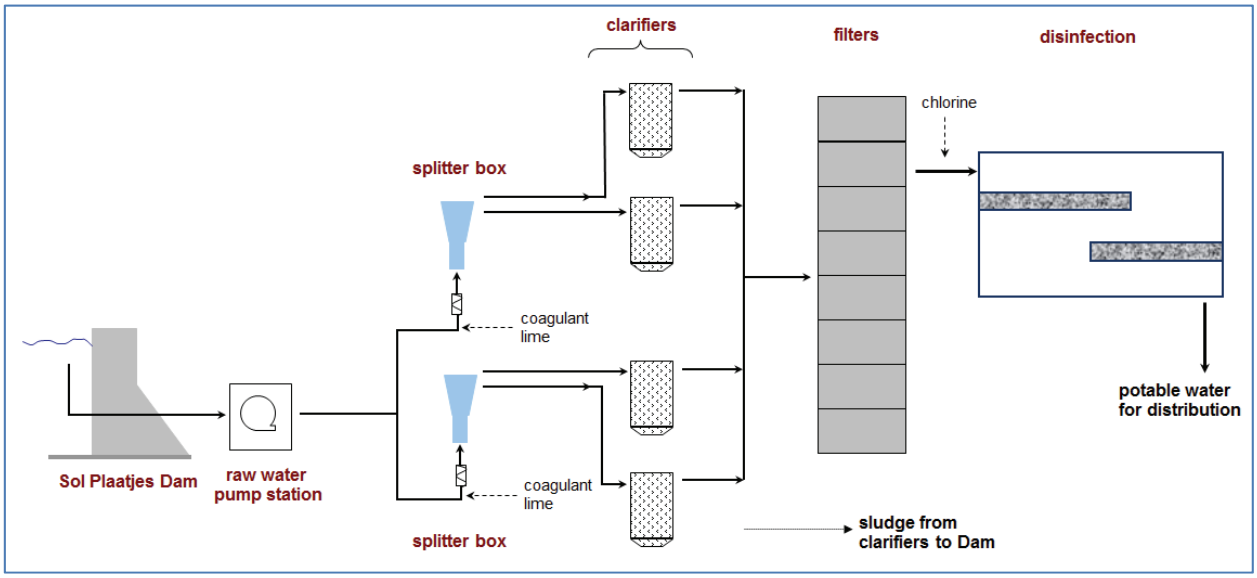


Figure 2-6: Schematic of the Saulspoort WW

These full-scale HR-CSAV type clarifiers are the same type which was used in the demonstration model investigations in this study. Both designs are in essence the same.

At the time of the site visit, the plant was operating at 27 MLD. Plant personnel indicated that operating above this throughput resulted in solids carry-over from the clarifier. The dimensions of the clarifier were

measured and the upflow rate was calculated to be 6.4 m/h at 27 MLD and 9.4 m/h at the design throughput of 40 MLD. The upflow velocity at the sludge blanket level was reported to be 11 m/h by Polasek *et al.,* (2002).

The clarifiers are desludged once a day during normal operation when the raw water turbidity is low (<10 NTU). If the clarified water turbidity increases beyond 10 NTU, desludging is then increased to twice daily. Sludge from these clarifiers is returned untreated to the Sol Plaatje Dam.

2.3.1.1 Chemicals

There are three different types of coagulants used at the Saulspoort WW, with each type dependent on the raw water turbidity:

- *Poly-Aluminium Chloride (PAC):* PAC was used when the raw water turbidity was less than 10 NTU
- *M70:* This coagulant was used for raw turbidity between 10 and 60 NTU. This chemical is also a type of PAC (Polasek *et al.,* 2002), however further information regarding the composition of this coagulant could not be obtained from the plant personnel.
- *Polyamine:* Polyamine was used when the raw water turbidity was higher than 60 NTU.

2.3.1.2 Monitoring

The plant laboratory is equipped for measuring turbidity, pH and chlorine. These determinands are measured by the Laboratory Technician at 4 hour intervals. Other determinands such as alkalinity, total hardness, conductivity and microbiological analyses are measured monthly at an external laboratory. In addition, jar tests are conducted by the Plant Technician on an ad-hoc basis. Grab samples taken from the old and new clarifiers showed the clarified water turbidity to be 6.49 NTU and 3.27 NTU respectively.

Figure 2-7 shows water quality data obtained from the plant. Clarified water turbidity spikes above 5 NTU are evident in the old clarifiers. These spikes were generally accompanied by sudden fluctuations in the raw water turbidity, which then necessitated a manual adjustment of the coagulant dosage.

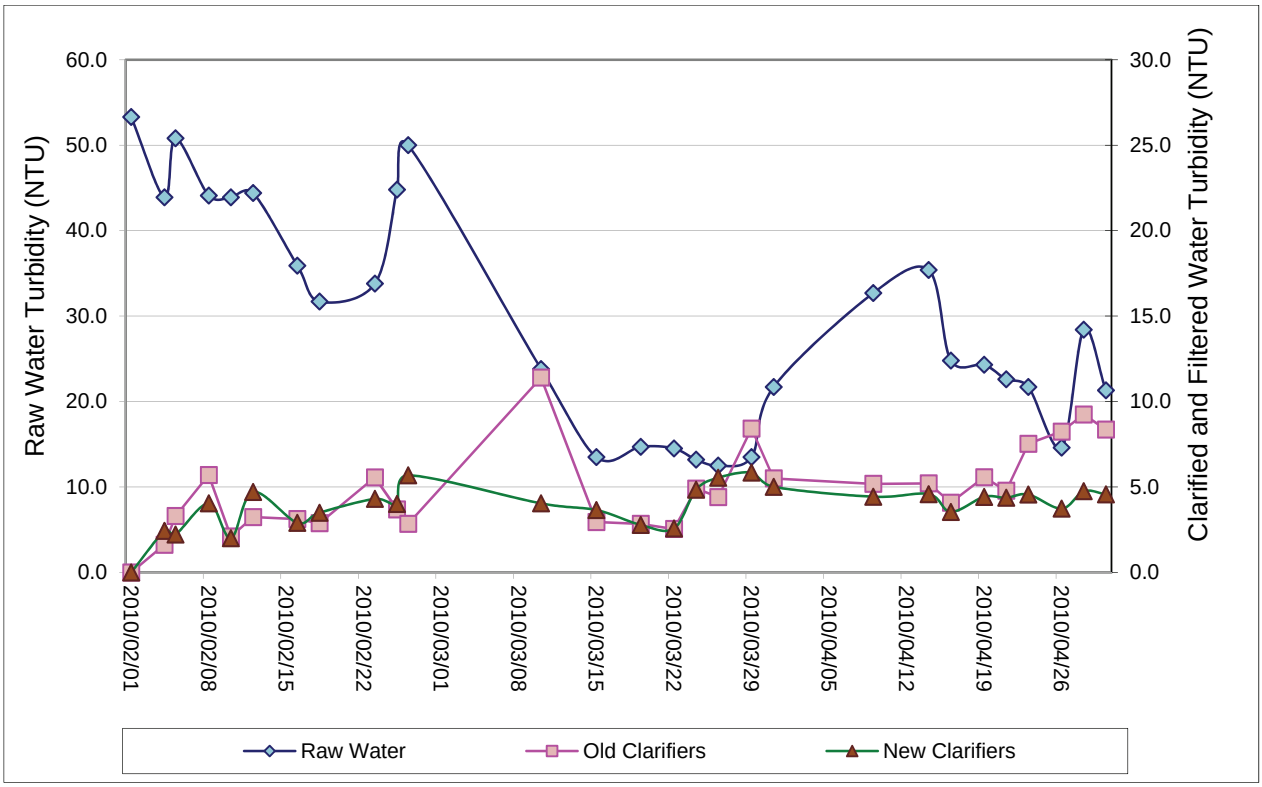


Figure 2-7: Clarified water quality data for Saulspoort WW

2.3.1.3 Maintenance Issues

Each clarifier is shut down once a week, for approximately half an hour, to clean accumulated flocs from the collection trough and other supporting structures. A major shutdown of two hour duration is undertaken fortnightly, where all four clarifiers are completely drained and cleaned. This indicates that these units require significant down-time for maintenance.

It was noted that two stirrer shafts had sheared off from the old clarifiers over a 10 year period. The shearing was caused by frequent rapid stirrer start-up and shut down. The two new high rate clarifier stirrers are controlled by a variable speed drive motor which allows for slow stirrer start-up and shut down, unlike the old clarifiers which have constant speed motors. This issue of shaft shear should therefore be minimised in the new units with prolonged usage.

2.3.2 CASE STUDY 2: Tubatse Treatment Works

Tubatse WW, owned by Samancor-Tubatse Ferrochrome, is a 4 MLD plant that utilises a ballasting agent to achieve high clarification rates. At the time of the site visit, the operation of the clarifier was being optimized, after recently being commissioned. Water sourced from boreholes, plant effluent, storm water and sewage is stored in a balancing dam prior to treatment and re-use as process water in the Samancor Ferrochrome Smelter plant. The plant was operating at 3.12 MLD at the time of the site visit.

Figure 2-8: High rate clarifiers at the Tubatse site

Ferric chloride is dosed as a coagulant in the treatment process. The clarification stage of the treatment process comprises two high rate clarifier units. One unit uses micro-sand (80-100 µm in diameter) as a ballasting agent and the other units use re-circulated sludge. The coagulated water is split in a ratio of 4:1 between the sand ballasted clarifier and the sludge re-circulation unit respectively.

A description of the ballasted sand process is given in Section 2.2.1. In the Tubatse process, the coagulated influent water is rapidly mixed after which an acrylamide co-polymer (HYDRAX 3930) and recycled micro-sand are used to facilitate floc formation. At start-up micro-sand is added to the injection tank at a concentration of 3 g/l, and is thereafter topped-up during operation to account for sand losses. It was highlighted by personnel on site that sand losses increases at higher throughputs. This is of significant importance as high sand losses will contribute to higher operating costs over time.

It was noted from discussions with the technology provider present on site that the process is very sensitive to the polymer and micro-sand dosages, which if not carefully controlled, can cause blockages in the hydrocyclone. Therefore, this process has a very narrow operating window and may require sophisticated plant dosage control to ensure smooth operation. The sludge generated is dewatered in a belt press prior to disposal to landfill. At the time of the site visit, the plant was achieving the required 10-15 NTU clarified water turbidity, which is then used as process water.

The main application of the sludge recirculation unit at the Tubatse WW process is for water softening. Here lime is added at the injection tank for pH adjustment in the range of 8.8 to 10. The retention time in each stage of this unit is three times greater than that of the sand ballasted unit, hence the reduced throughput through this unit, and results in a clarified water with a turbidity below 3 NTU.

Some of the process problems identified were blockages of pipelines caused by precipitation of lime, the deposition of lime on the lamella plates and the sludge re-circulation lines requiring frequent flushing. This poses further maintenance concerns as is the case for the HR-CSAV units and therefore may impact on

production and water quality. No technical design data (such as mixing intensities etc.) were available since these were deemed to be confidential.

2.3.2.1 Monitoring

There was no laboratory on site at the time of the site visit. However, the following parameters are being monitored:

- Raw water from the balancing dam is continuously monitored for turbidity with an on-line turbidimeter
- The balancing dam is sampled daily to measure Cr^{+6} levels
- Final clarified water from each of the clarifiers is tested for Cr^{+6} at 3 hour intervals using a hand-held test kit.
- pH and suspended solids analyses is conducted on the clarified water
- Suspended solids analyses is conducted, once per eight hour shift, on the content from the zone where micro-sand is added, and the micro-sand dosage adjusted accordingly

2.3.2.2 Start-up and Shutdown

The micro-sand ballasted clarifier process was being optimised at the time of the site visit. This unit required a slow start-up, whereas the sludge recirculation unit could be ramped up to the maximum operating capacity and sludge introduced into the system at start-up. This indicates that the sludge recirculation unit would take a minimal amount of time to reach its steady state operation as compared to the ballasted clarifier.

2.3.2.3 Maintenance Issues

No significant maintenance operations had been carried-out due to the plant still being in the commissioning phase at the time of the site visit. Some of the major maintenance requirements reported by the technology provider on site included frequent greasing of rotating equipment, cleaning of the lamella plates (with the frequency being dependent on the rate of deposition) and cleaning and calibration of on-line meters. In addition, the proper operation and maintenance of the hydrocyclone to avoid accumulation of organic material on the sand particles would be required (U.S. EPA, 2003).

2.3.3 CASE STUDY 3: Sasol Synfuels Secunda

The high rate clarifier at this plant was shut down during the time of the site visit due to an overnight power failure. As a result the operation of the clarifier could not be observed. The plant uses a sludge recirculation type of high rate clarifier, which is described in Section 2.2.2.

2.3.3.1 Monitoring

Daily laboratory measurements of the raw water turbidity, pH and conductivity were conducted. Clarified water was analyzed for turbidity at 3 hour intervals. In addition, the solids content of sludge was determined on an ad-hoc basis.

Figure 2-9 shows the historical water quality data. The target clarified water turbidity is 7 NTU. The influent raw water turbidity from the dam was quite variable, ranging between 35 NTU and 95 NTU, and the clarified

water turbidity data was very erratic and was found to be mostly higher than the required 7 NTU. These fluctuations could be as a result of poor operation of the unit. The main evidence supporting this was that the desludging frequency had been reduced (i.e. the required continuous desludging of the unit had been discontinued) as a result of sludge handling capacity difficulties being experienced at the site. As a consequence of this, a large amount of sludge was re-circulated and desludging was only carried out on an ad-hoc basis. The raw water turbidity from the dam also increased during the period of March to June 2010 (50-95 NTU) and as such created additional demand for sludge removal on the process. The overall impression is that the unit did not cope well over the entire period considered and that the recirculation sludge ratio and concentration must be frequently monitored and controlled to ensure effective operation.

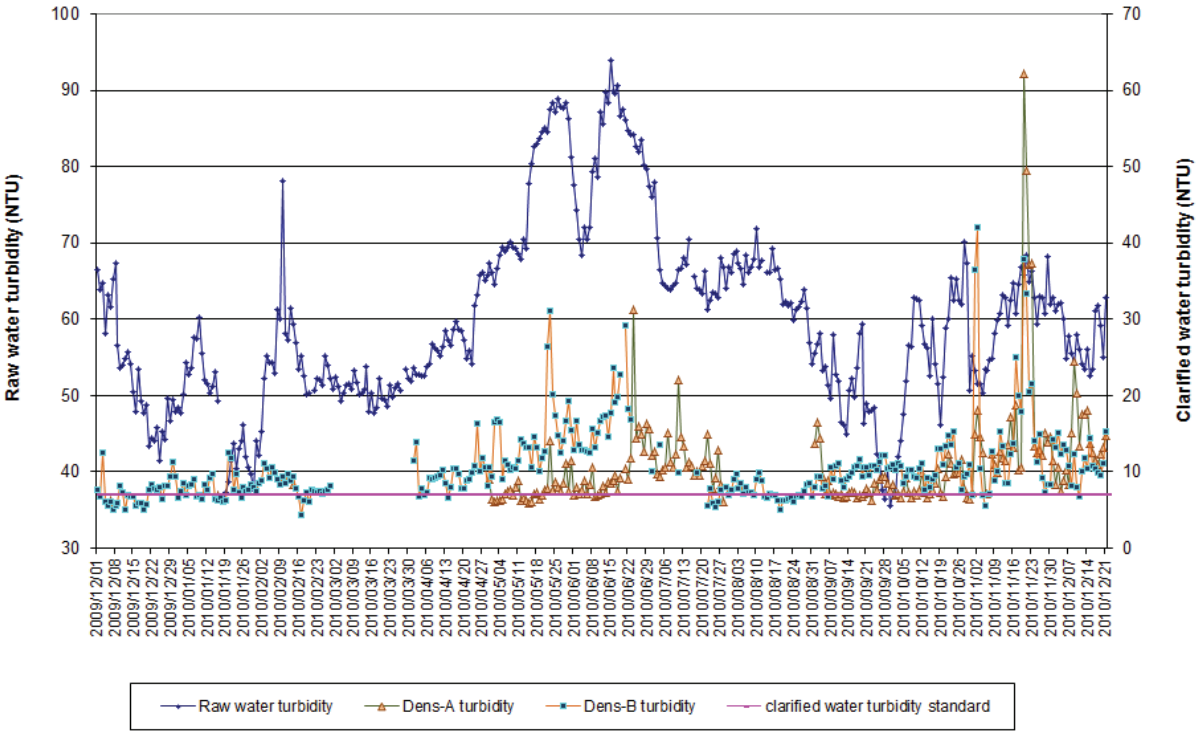


Figure 2-9: Water quality data for the Sasol clarifiers (December 2009 to December 2010)

Some of the process challenges experienced included blockages in the sludge lines and the high sludge concentration which resulted in the clarifier not performing optimally.

2.3.3.2 Maintenance Issues

The critical components on the clarifiers include the lamella packing, agitators and sludge pumping equipment. When the lamella packing required cleaning, one module was taken off-line for 2 hours for the clean-up. A more comprehensive shutdown takes place after every 2 years or sooner if the clarified water quality deteriorates significantly. This comprehensive shutdown is about a week in duration and involves cleaning of the entire unit. This duration between the comprehensive shutdown (2 years) would not be expected to pose additional burden on operational staff and on maintenance costs.

2.3.4 CASE STUDY 4: Durban Water Recycling (DWR)

Durban Water Recycling (DWR) treats domestic and industrial effluent from eThekwini Water Services for use as process water. The capacity of the treatment plant is 47.5 MLD, and includes a high rate clarifier operating at 14 m/h, which uses recycled sludge as a ballasting agent.

The incoming wastewater undergoes pre-treatment (i.e. screening, grit removal and primary sedimentation). Secondary treatment involved aeration and secondary clarification. The influent flow rate into the tertiary treatment plant containing the high rate clarifier units was controlled by first transferring the stream into a holding tank for storage.

The outflow from the holding tank is dosed with aluminium sulphate (typically 25 mg/l) prior to entering the clarifier. An anionic polyacrylamide (dosage controlled by feed flow rate) and recycled sludge are added in the clarifier. Approximately 15% of sludge generated was recycled. This recycle ratio was obtained on a trial and error basis, taking into consideration the floc settleability and clarified water turbidity.

During the initial operation of the high rate clarifier, a few modifications were made to the process. Visual observations and jar tests confirmed that the flash mixing impeller was shearing the floc in the flash mixing zone of the clarifier. A long channel and a hydraulic jump were therefore created to facilitate mixing of the coagulant into the water without floc shearing. In addition, the mixing of the polymer was also achieved using a hydraulic jump, prior to the water entering the clarifier where recycled sludge would be added. Figure 2-10 shows the modifications on the long flow channel and the hydraulic jumps for the DWR process.

2.3.4.1 Maintenance issues

General problems encountered included blockages on the sludge return line and accumulation of plastic material that have by-passed the screens on the lamella plates. Damage to the lamella plates during maintenance cleaning could easily occur due to poor accessibility. On-line meters, gearboxes and the sludge scraper were the main equipment requiring regular maintenance.

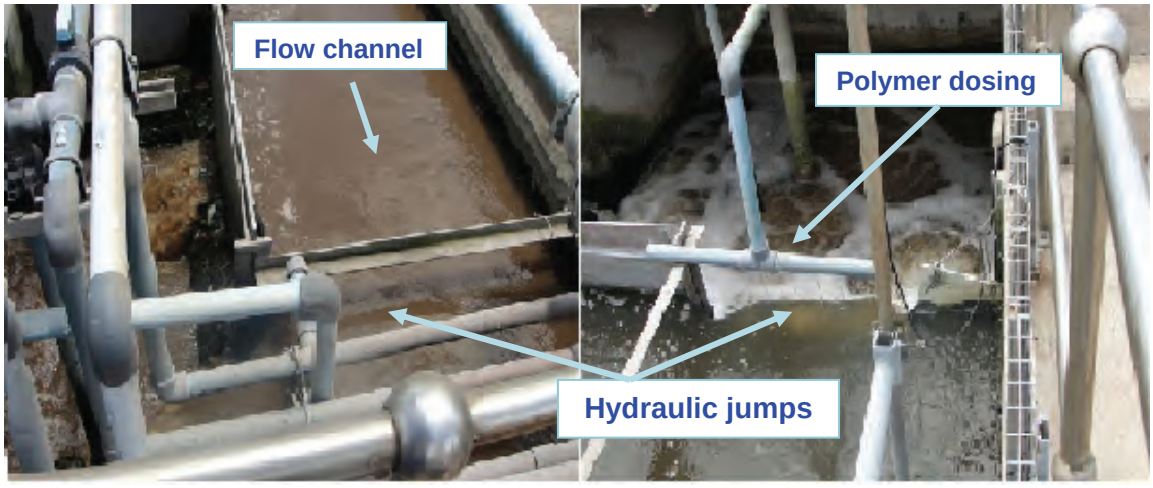


Figure 2-10: Modification to the DWR process

2.3.4.2 Monitoring

The clarified water turbidity was monitored using an on-line meter, with grab samples taken on an ad-hoc basis for turbidity and colour analyses. Chemical dosages were flow proportional. The flow balancing tank and extensive pre-treatment reduced fluctuations in the flow and quality of water to the high rate clarifier.

Figure 2-11 shows the clarified water turbidity from the clarifier for the period July 2010 to July 2011. The influent water to the clarifier at the DWR plant allowed for little variation as it was maintained on average at 5 NTU (maximum of 12 NTU and minimum of 2 NTU), which allowed for easier process control. The unit produced clarified water consistently below 1 NTU over the period.

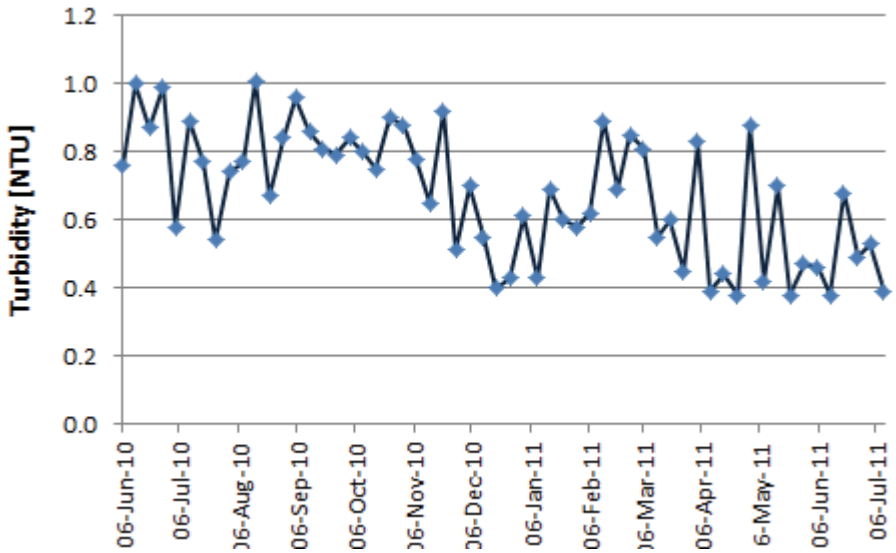


Figure 2-11: Historical clarified water turbidity for the clarifier (July 2010 to July 2011)

2.3.4.3 Start-up and Shutdown

The clarifier was shut down by switching off the raw water pump and the sludge recirculation pump. The unit can be switched off in this way for short periods of time without anaerobic conditions developing. Complete shutdown of the unit requires complete drainage of the content from the unit. During start-up, operation at a low flow rate (50 % capacity) is required and desludging only occurs when sludge has formed. It was reported that at a higher raw water turbidity, the sludge forms within 2 hours, whereas at low raw water turbidity, a day was required.

2.3.5 CASE STUDY 5: Morsang sur Orge Waterworks

The Morsang sur Orge waterworks is a 225 MLD plant that uses the sludge recirculation type of high rate clarifier technology. The source water was the River Seine, where on-line monitoring of quality takes place at a monitoring station. This serves to alert the plant of any changes in the resource quality, so that the required adjustments could be promptly made to the process. Due to the plant being located far upstream of urban and industrial areas, pollution impacts on the raw water are minimal.

The sludge recirculation high rate clarifier unit at the plant was installed in 1998, during an upgrade of the plant to 225 MLD, and can treat 81 MLD, at an upflow rate of 22 m/h. Due to the low water demand at the time of the site visit; the unit was operating at 9 m/h.

Pre-treatment involved screening, pH correction using sulphuric acid and coagulation using alum and a flocculation aid (an anionic polymer). Typical dosages of alum were 60 mg/L for low turbidity water (approximately 10 NTU) and 200 mg/L for high turbidity water (approximately 300 NTU) and dosages of 0.14-4 mg/L for the flocculant aid. The coagulated water is split, with one stream entering the sludge recirculation clarifier and the other stream entering a pulsator type of clarifier operating at 8 m/h. Hydraulic mixing along a length of pipe is provided for mixing of the coagulant and mechanical mixing is used for the polymer. A description of the sludge recirculation type of process is given in Section 2.2.2. It was noted that during periods of operation at a low flow rate, increased recirculation of sludge was carried out.

Some process challenges experienced included the coating of the lamella plates with sludge with the resultant effect of solids carryover. In these instances, the load on the filters would increase and increased frequency of backwashing was required. The clarifiers were covered to minimise temperature and wind effects during cold weather.

2.3.5.1 Maintenance Issues

It was noted that the clarifier unit was maintenance intensive, compared to conventional clarifiers, in particular the mechanical mixer and the scraper. The unit was cleaned weekly and was taken off-line once a month for more thorough maintenance cleaning during low demand periods where increased recycling of sludge was required. During these periods where the clarifier was being cleaned, the pulsator clarifier was used to meet the plants water clarification requirements.

The general maintenance intensive issues on the recirculation clarifiers are again noted as from the previous case studies. This will definitely impact on the operating costs.

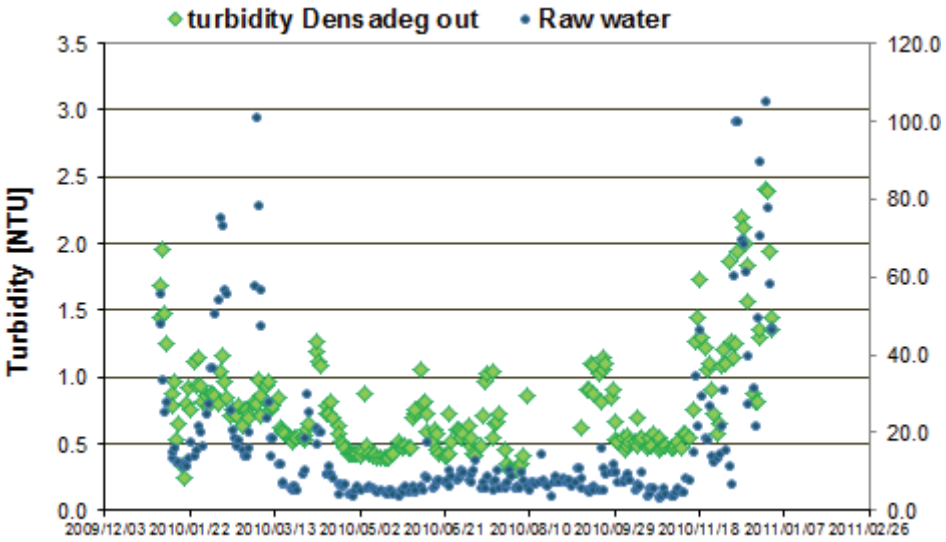
2.3.5.2 Monitoring

Continuous monitoring of the water quality from the River Seine takes place using an automatic sampling device, which triggers an alarm when changes beyond pre-set limits are recorded. This system allows for a forewarning to be sent to the control room, for the necessary process changes to be made. The on-line instrumentation was fitted with alarms to alert operational personnel of out-of-ranges on the plant.

Jar tests are conducted fortnightly and chemical dosages adjusted accordingly. When the clarified water turbidity increases beyond the required limit, solids analyses are conducted on sludge samples and the recycle ratio is adjusted accordingly.

Figure 2-12 shows the raw water and clarified water data from the high rate clarifier for the period of January 2010 to January 2011. The clarified water was maintained below 2.5 NTU, despite the raw water

turbidity varying between 0.5 NTU and 80 NTU. Clarified water turbidity results were consistently below 0.5 NTU from May 2010 to September 2010. The unit performed exceptionally well during the period considered.



* note that “Densadeg out” refers to the clarified water turbidity

Figure 2-12: Historical water turbidity (January 2010 to January 2011)

2.3.5.3 Start-up and Shutdown

The clarifier undergoes a gradual start-up (operation at low throughput) to allow for the formation of the sludge with solids content of 20-80 g/L. During the period of sludge blanket development, the clarified water quality is poor, which results in more frequent backwashing of filters due to the increased solids load.

2.3.6 CASE STUDY 6: Mont Valerien WW

The Mont Valerien WW is a 60 MLD plant used for the production of potable water. The plant utilizes the sludge recirculation type of high rate clarifier, operating at an upflow rate of 22 m/h.

Raw water drawn from the River Seine (2-250 NTU) undergoes screening and pre-ozonation. Alum is dosed (25 mg/L at a raw water turbidity of about 10 NTU to approximately 150 NTU, and 100 mg/L at turbidity higher than 150 NTU). The coagulated water then enters the sludge recirculation high rate clarifier.

The main causes of clarified water turbidity exceeding the plant’s control limits were due to problems with the maintenance intensive sludge scraper or as a result of flow changes due to the recycling of filter backwash water to the clarifier. Greater operator expertise is required for process monitoring and response to these changes in the process conditions.

The maintenance and monitoring requirements were the same as for the Morsang sur Orge Waterworks (see Section 2.3.5.1 and Section 2.3.5.2 respectively). Clarifier maintenance intervals are fortnightly cleaning of the clarifier and an annual shut down for complete maintenance and cleaning.

2.3.6.1 Start-up and Shutdown

The clarifiers are operated on a low flow rate during start-up. The duration of start-up is dependent on the raw water turbidity and can require 2 days or up to a week for the sludge blanket to develop. During short periods of shutdown (i.e. a few hours), the inflows and outflows can be stopped without draining the plant. This occurs during the fortnightly maintenance cleaning. The complete draining of the clarifier takes place during an annual shutdown where longer time periods are required for maintenance and cleaning.

2.4 CONCLUSIONS

It is evident from the case studies that high rate clarification processes are specialized technology requiring more operator judgement and more planned maintenance compared to conventional clarification processes. Therefore, these technologies are more suitable in applications where a reliable asset management team and skilled operators are available.

In terms of design, monitoring of the influent water and on-line meters provide early warning systems which allow for more prompt response to raw water and process variations. It is essential that the filtration system following this process be designed to handle additional solids load, since at start-up or at times of sudden change in the influent water quality, the clarified water quality may be poor for a period of time while the system adjusts to the changes. Frequent backwashing of filters may therefore be required during these periods. Stand-by clarifier treatment units may in certain instances be required since frequent cleaning/maintenance results in the units being offline for significant periods in a year. Sludge blockages were a common problem in these high rate clarifier units and thus may pose numerous problems for operational staff.

In the South African context, there was only one known potable water treatment works which made use of high rate clarification, viz. the Bethlehem Waterworks. The HR-CSAV type of clarifier was the technology used there. In this study, the HR-CSAV type of high rate clarifier was evaluated in more detail on a demonstration model plant. The results and conclusions drawn from this work are presented in the chapters which follow. Similar experimental work on the other two types of high rate clarifiers discussed in this chapter would provide useful information on the application of these technologies in potable water treatment in South Africa.

CHAPTER 3: INVESTIGATIONS USING THE DEMONSTRATION MODEL HR-CSAV CLARIFIER

3.1 INTRODUCTION

The HR-CSAV type of high rate clarifier is a patented technology, developed by Pavel Polasek. A description of this clarifier was given in Chapter 2 (Section 2.2.3). Experimental trials on a demonstration model HR-CSAV clarifier were conducted to investigate the performance and operational and maintenance requirements of this technology. The demonstration model clarifier was operated at two sites: Hazelmere WW which uses an impounded water source (turbidity range of 1.5 NTU to 40 NTU, at the time of the investigations), and Umvoti WW which abstracts water from the Umvoti river (turbidity range of 15 NTU to > 100 NTU, at the time of the investigations). This chapter presents the findings from the investigations conducted at both these sites.

3.2 DESCRIPTION OF THE HR-CSAV DEMONSTRATION MODEL PLANT

The HR-CSAV demonstration model clarifier has a design capacity of 500 m^3/day, which equates to an upflow rate of 14.7 m/h. See Appendix A for clarifier dimensions. The plant comprised of the following:

- Raw water feed pump
- The HR-CSAV clarifier
- A container containing the control panel, the day tanks for the destabilization reagent and the Organic Flocculant Aid (OFA), dosing pumps and area for chemical storage (dry alum and OFA powders)
- Bulk alum and OFA makeup tanks (dissolution tanks)
- In-line mixer: to provide high intensity agitation required for the dispersion of alum into the raw water
- Softener and a softened water tank

A layout diagram for the process is shown in Figure 3-1. The clarifier and bulk chemical makeup tanks were located outside the container. The bulk tanks, fitted with mixers, were mounted on the roof of the container. The day tanks, situated in the container, allowed for the alum and OFA solutions to be gravity fed from the dissolution tanks to the day tanks.

A water softening unit, required for the preparation of the OFA solution, was located outside the container. Access to the top of the clarifier was provided by means of a stairway and platform mounted on the roof of the container.

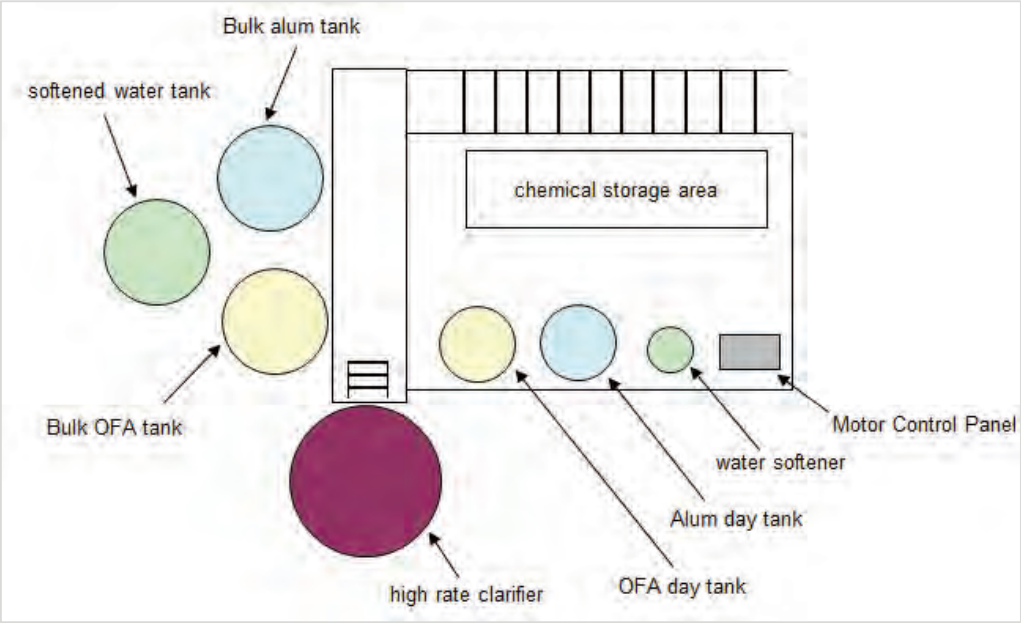


Figure 3-1: Layout diagram for the HR-CSAV demonstration model plant

A process flow diagram for the demonstration model plant is shown in Figure 3-2**.**

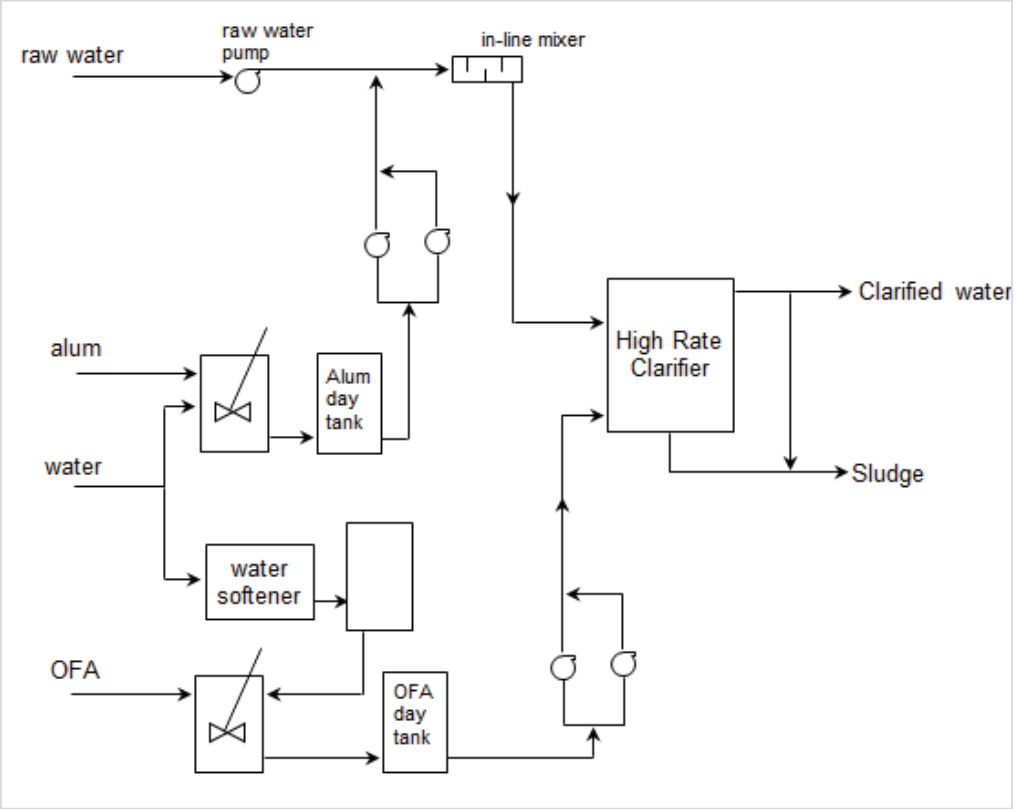


Figure 3-2: Process Flow Diagram for the HR-CSAV demonstration model clarifier process

3.3 EXPERIMENTAL TRIALS AT HAZELMERE WATERWORKS

The HR-CSAV demonstration model plant was first installed at the Hazelmere WW, located north of Durban. Raw water to the waterworks is abstracted from the Hazelmere Dam. A layout diagram showing the treatment train at Hazelmere WW and the location of the HR-CSAV in the process is shown in Figure 3-3.

The feed to the HR-CSAV was drawn off from the raw water pipeline to the waterworks, with clarified water being directed to filters at the waterworks and sludge generated being directed to the sludge treatment plant at the waterworks.

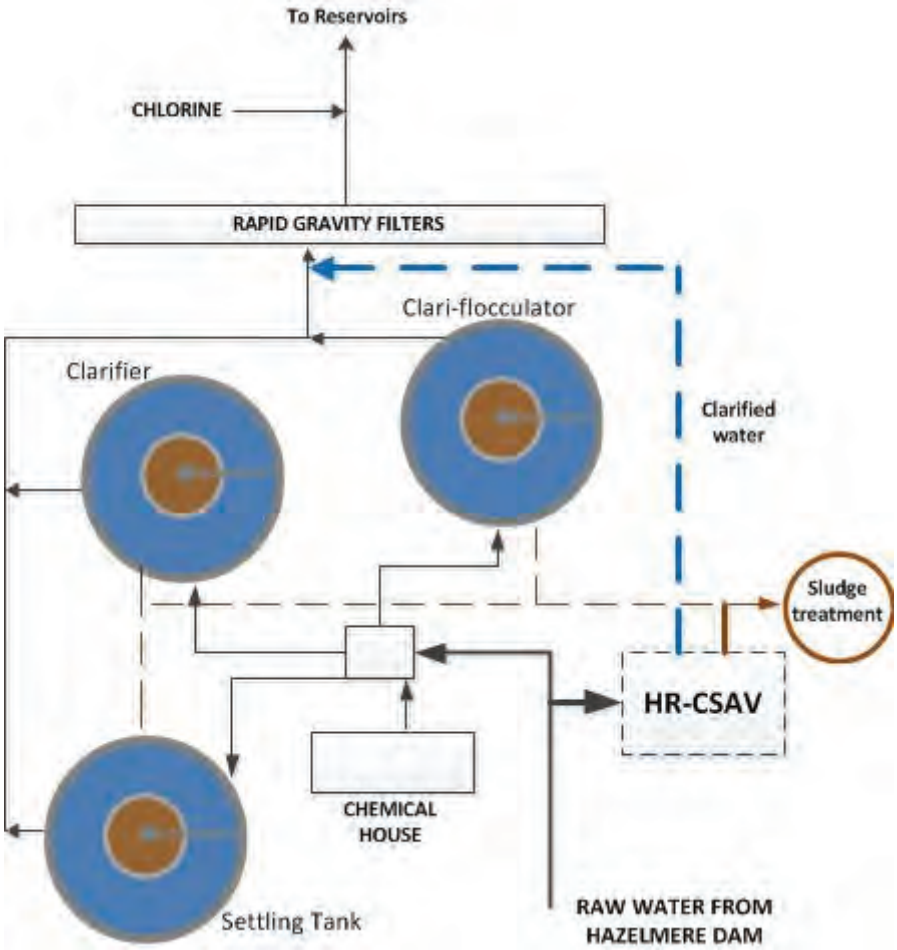
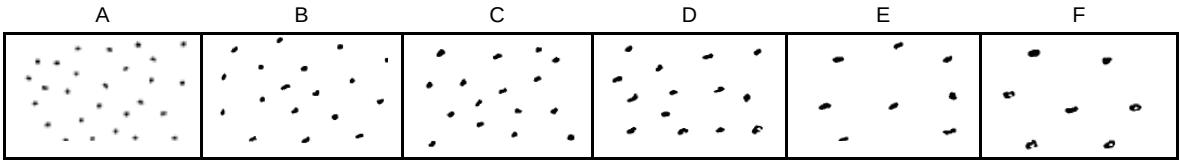


Figure 3-3: Layout diagram for the Hazelmere WW site

3.3.1 Plant optimisation studies at Hazelmere WW

Jar tests were conducted using the raw water from Hazelmere WW to estimate the alum and OFA dosages required when operating the HR-CSAV clarifier. Turbidity of the clarified water was used as an indicator of the efficiency of the process. Therefore, the chemical dosage at which maximum reduction in turbidity was attained was considered to be the optimum dosage. The methodology followed for the jar tests and raw data from the jar test experiments can be found in Appendix B and Appendix C, respectively.

Figure 3-4 gives the results obtained when applying the jar test procedure to the raw water (turbidity of approximately 5 NTU) to determine the optimum alum dose. No OFA was added in this experiment. An alum dosage of 20 mg/l was the minimum dosage required to achieve a minimum turbidity of 1 NTU. Flocs formed at this optimum alum dose were classified as D-type (see diagram below) and had moderate to slow settling velocities.



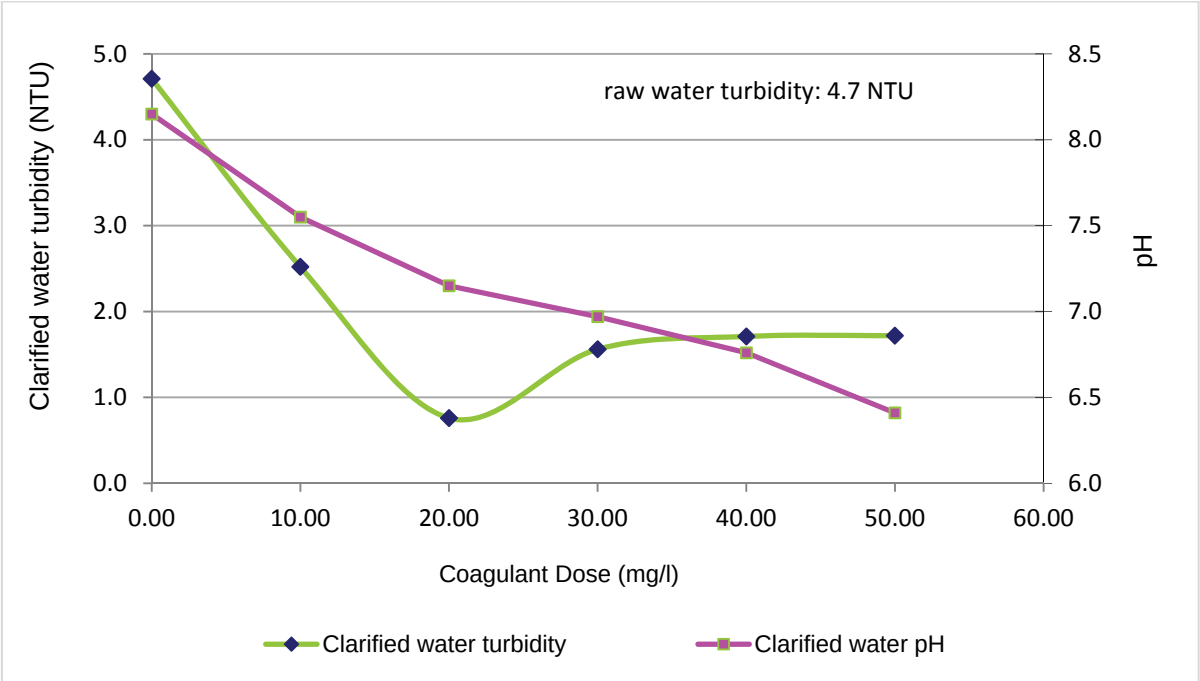


Figure 3-4: Jar test optimization of alum dosage for Hazelmere WW raw water

This optimum alum dose was then applied to the jar test to determine the optimum OFA dose as illustrated in Figure 3-5. An OFA dose of 0.25 mg/l was required to obtain the minimum turbidity. Flocs formed at this OFA dose were classified as D-type and had moderate to slow settling velocities.

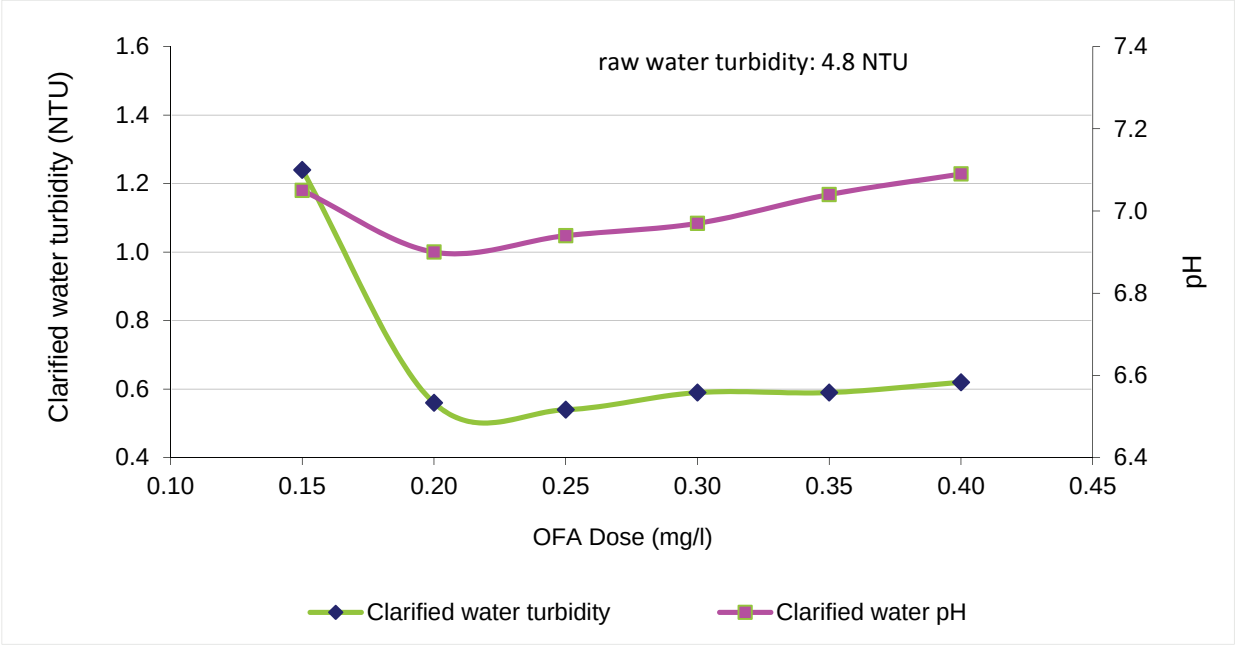


Figure 3-5: Jar test optimization of OFA dosage for Hazelmere WW raw water

High intensity mixing (G values of 125-380 s^{-1}) was evident in the flocculation compartment of the HR-CSAV. Further jar tests were therefore conducted in order to determine the effect of mixing intensity on the settleability of the flocs. The jar test procedure was modified to vary the G-value during the 2 minute mixing following addition of the coagulant. Slow mixing intensity and time in the jar test remained unchanged. The jar test optimised chemical doses were used in this experiment. Figure 3-6 shows the results obtained.

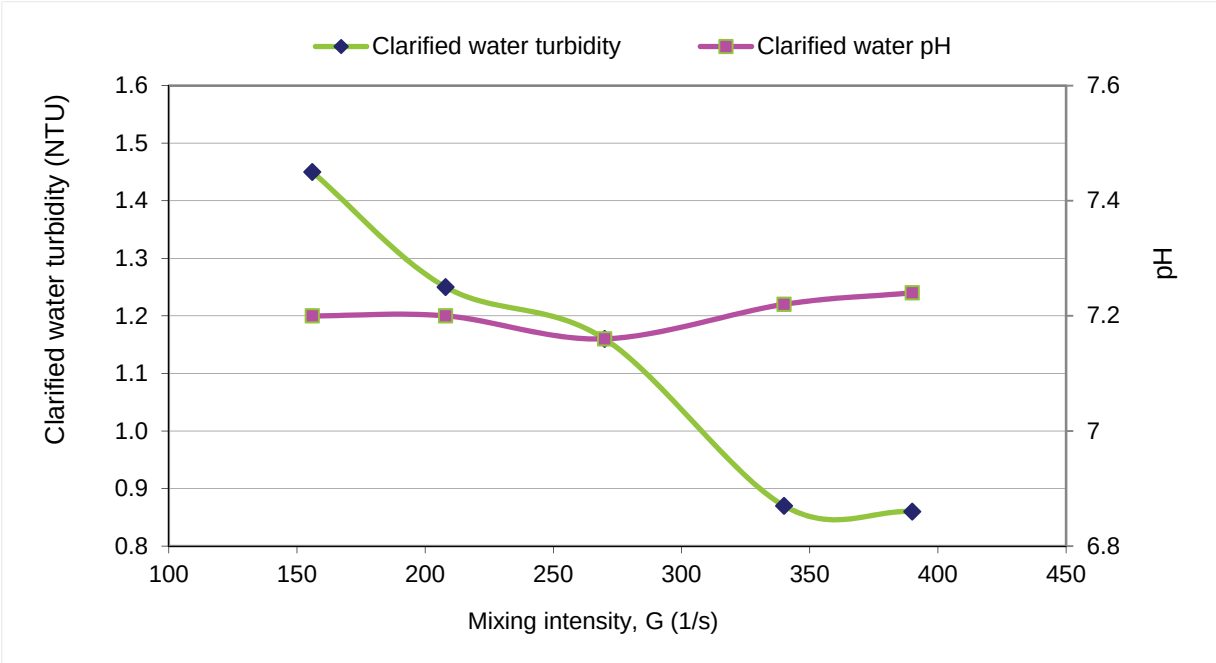


Figure 3-6: Jar test investigation on impact of mixing intensity

The results show that mixing intensity influenced the settleability of the flocs, and as the mixing intensity increased from 156 s^{-1} to 390 s^{-1} the clarified water turbidity improved from 1.5 NTU to 0.9 NTU. This high

intensity flocculation mixing in the Inline High Density Suspension (IHDS) process, described by Polasek *et. al.* (2005b), results in the formation of denser flocs with a compact inner structure, which enables faster settling of the flocs and hence improved clarified water turbidity. This confirmed that the high mixing intensity used in the flocculation compartment of the HR-CSAV would improve the settling rate of flocs.

3.3.2 Performance Evaluations of the demonstration model HR-CSAV at Hazelmere WW

The results from investigations conducted on the HR-CSAV demonstration model plant are presented in this section. The impact of varying the upflow rate, OFA dosage and the alum dosage on the performance of the clarifier were investigated. The measure of performance of the clarifier was the clarified water turbidity. Supernatent water from the sludge thickening compartment is combined with the clarified water in the HR-CSAV clarifier, and so the turbidity of the supernatent water from the sludge thickening compartment is therefore also presented. *As no online instrumentation was installed while the clarifier was located at Hazelmere WW, no samples were collected at night.*

Figure 3-7 shows the results obtained when the upflow rate was gradually increased. The jar test optimised alum and OFA dosages were applied throughout the investigation.

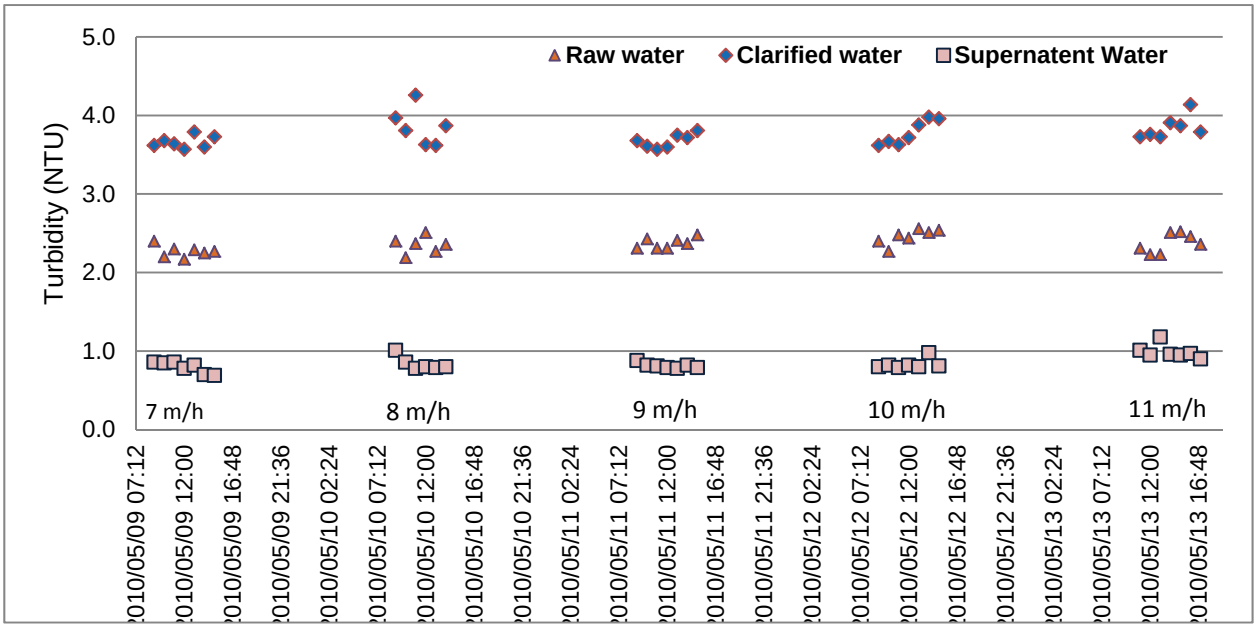


Figure 3-7: Effect of increasing the raw water flow rate on clarifier performance

It is clearly evident from the clarified water turbidity results that no solids separation occured even at the lowest upflow rate. It is however worthy to note that solids separation in the sludge thickening compartment was evident, as indicated by the supernatent water turbidity. The supernatent water, with a minmal flow rate of 600 L/h, has a longer settling time in the sludge settling compartment compared to the setttling time experienced by the clarified water. The results indicate that the poor clariifed water turbidity was due to the settling velocity of the flocs not being sufficient at the high upflow rates in the clarifier. The moderate to slow settling velocity flocs observed in the jar tests support these findings.

Figure 3-8 and Figure 3-9 show the results obtained when the OFA dose and the alum dose were each in turn gradually increased while the other kept constant at the jar test optimised dosage (dosage increments shown on graphs). The clarifier was operated at half the design capacity (i.e. 7 m/h) in these investigations. The results obtained also show no solids separation being evident in the clarifed water but separation of solids in the supernatent water from the sludge thickening compartment.

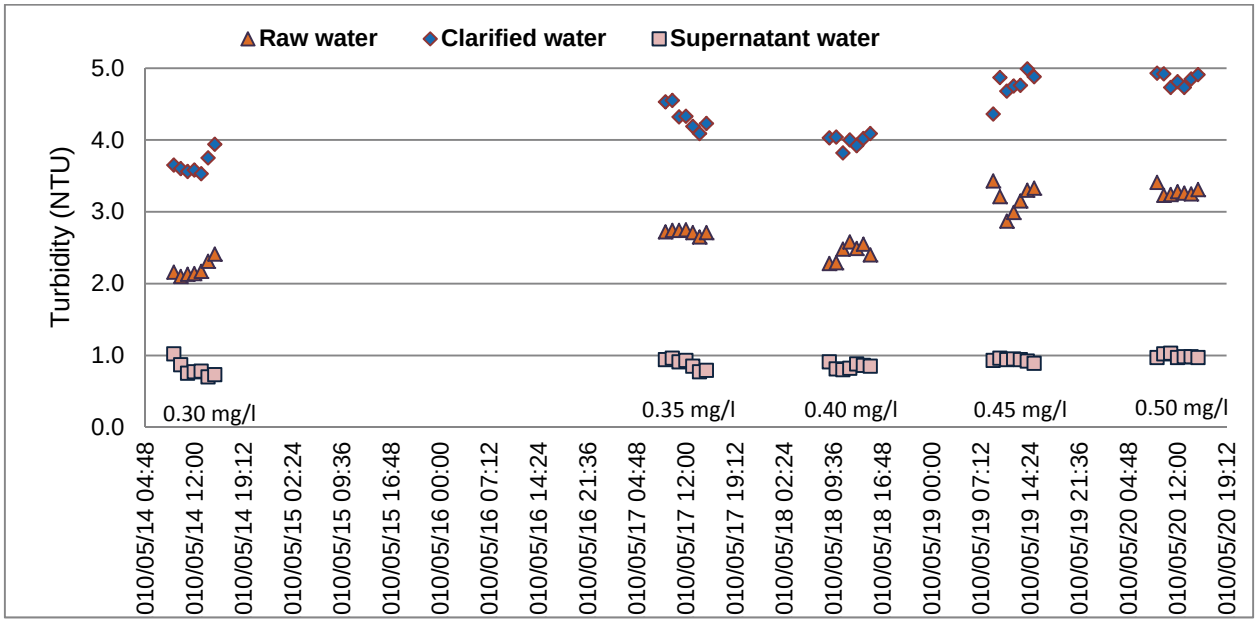


Figure 3-8: Effect of increasing the OFA dosage on the clarified water turbidity

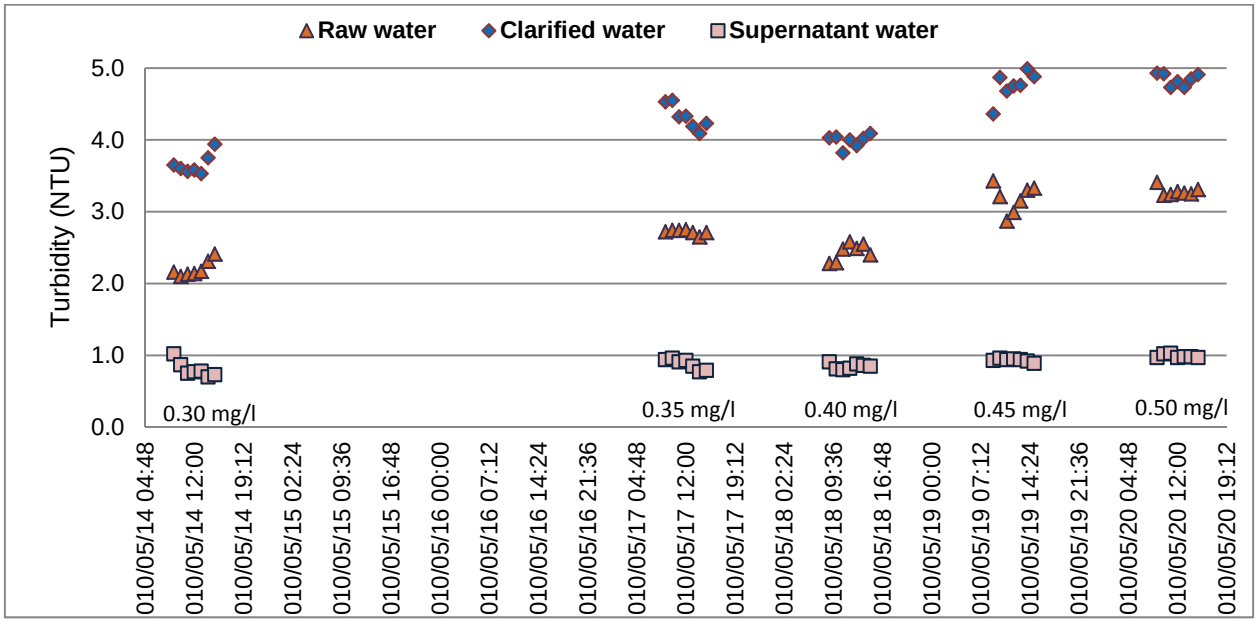


Figure 3-9: Effect of increasing the alum dosage on the clarified water turbidity

The poor performance at Hazelmere WW was potentially due to the slow settling velocity of the flocs, as observed in the jar tests, which resulted in solids carryover. Consultation with the Operation Manual for the HR-CSAV demonstration model plant indicated that the HR-CSAV plant works best at higher raw water turbidity (i.e. turbidity > 25 NTU). Following this, no further investigations were conducted at this site.

3.4 EXPERIMENTAL TRIALS AT UMVOTI WATERWORKS

The HR-CSAV clarifier was relocated to the Umvoti WW, situated in the Kwa-Dukuza region of KwaZulu-Natal. The raw water which is abstracted from the Umvoti River has a higher and more variable turbidity (ranging from 15 NTU to > 100 NTU) compared to the impounded water source at Hazelmere WW, and so ensured that the objective of testing the clarifier performance under these raw water quality conditions could be achieved.

The layout of the HR-CSAV process is the same as that shown in Figure 3-1. A layout diagram showing the treatment train at Umvoti WW and the location of the HR-CSAV is shown in Figure 3.10

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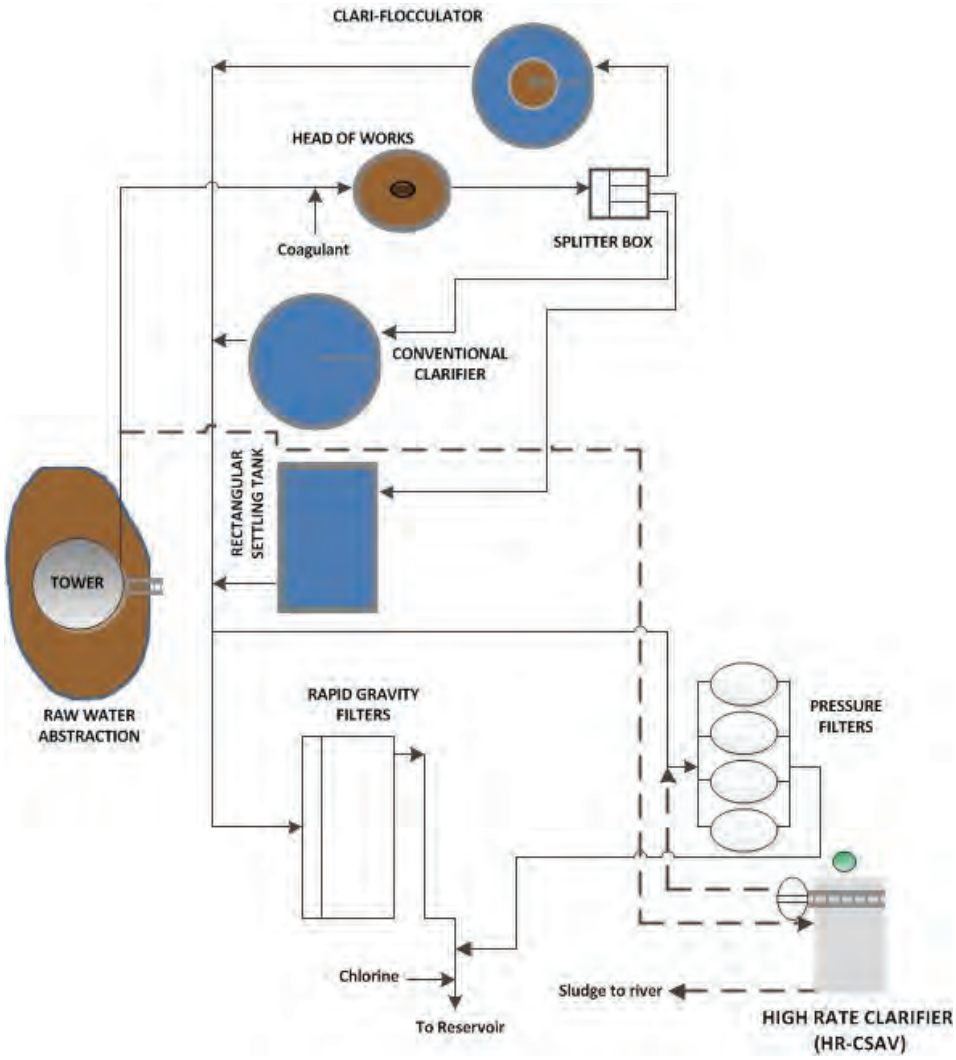


Figure 3-10: Layout drawing for the Umvoti WW site

3.4.1 Plant optimisation studies at Umvoti WW

The plant optimisation tests conducted on the HR-CSAV at the Umvoti WW included:

- Laboratory scale settling tests
- Jar tests
- Tracer test
- Mass balance

The results from these tests are presented in this section.

3.4.1.1 Settling tests

Laboratory scale settling rate experiments were conducted to confirm the effect of low and high raw water turbidity on the settleability of flocs. High and low turbidity raw water samples (14 NTU and 157 NTU respectively) from Umvoti WW were used in the investigations. Jar tests, using mixing conditions which simulated the HR-CSAV upflow rate of 7 m/h, were performed to determine the optimum dosages for alum and OFA. The jar test optimum chemical doses were then applied in settling trials. In the settling trials, samples were collected from a sample point at various time intervals after slow mixing and analysed for turbidity Fugire 3-11 presents the results giving the change in clarified water turbidity over time for the high and low raw water turbidity experiments.

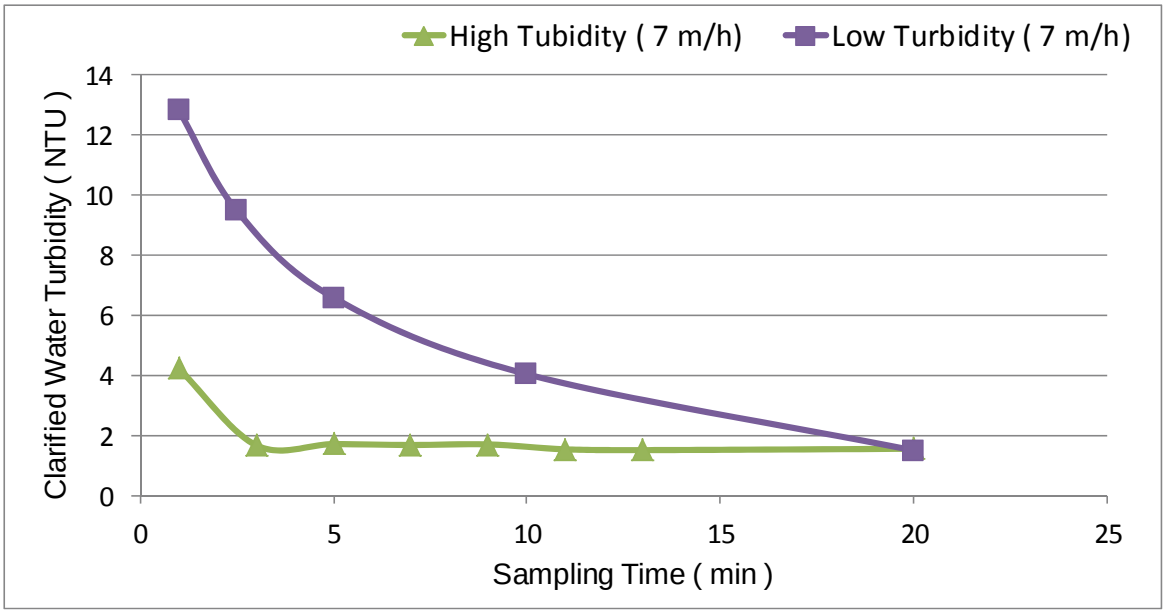


Figure 3-11: Settling rates for high and low raw water turbidity conditions

The results clearly show that faster solids separation is obtained at the higher raw water turbidity compared to the lower raw water turbidity. This confirms the potential cause of poor solid-liquid separation evident when operating at the low raw water turbidity at Hazelmere WW.

3.4.1.2 Jar tests

Jar test results were conducted using Umvoti WW raw water with the intention of examining the effect of various combinations of alum and OFA dosages on the clarified water turbidity. The jar test procedures followed are found in Appendix B.

The jar tests were conducted under the following conditions, at various combinations of OFA and alum dosages (note that slow mixing time remained unchanged at 15 minutes for all investigations):

- Using the standard jar test procedure
- Modifying the jar test procedure with extended high intensity mixing (i.e. increasing the high intensity mixing time from 2 min to 7.5 min)
- Increasing the high intensity mixing time further to 16 min

Jar tests varying the alum and OFA dose were conducted using raw water (turbidity 19-24 NTU) from Umvoti WW, as had been conducted on the raw water from Hazelmere WW. The standard jar test procedure was followed. Results are shown in Figure 3-12.

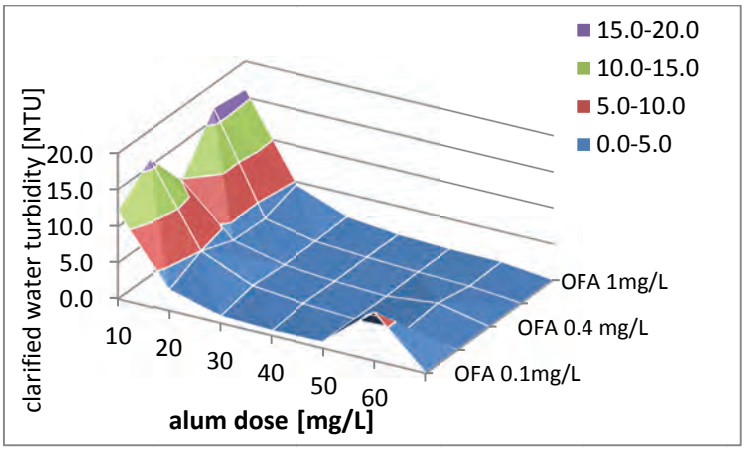


Figure 3-12: Jar test results, using the standard jar testing conditions, on the Umvoti raw water

It is evident that at alum dosages above 20 mg/L, clarified water turbidity of < 5NTU are achievable at all OFA dosages between 0.1 mg/L and 1 mg/L. An exception is at the alum dose of 60 mg/L at the low OFA dose of 0.1 mg/L, where a clarified water turbidity of 6.7 NTU was obtained. Small and slow settling flocs were evident at all combinations of alum and OFA dosages.

The jar test procedure was then modified to simulate the high intensity mixing conditions in the flocculation compartment of the HR-CSAV. In the modified jar test procedure, high intensity mixing was extended from 2 min to 7.5 min. The extended high intensity mixing time during flocculation, described by Polasek *et al.* (2005b) as the Inline High Density Suspension (IHDS) process, results in the formation of micro-flocs with a compact and dense inner structure, which enables the formation of faster settling macro aggregates upon addition of OFA. Results are shown in Figure 3-13.

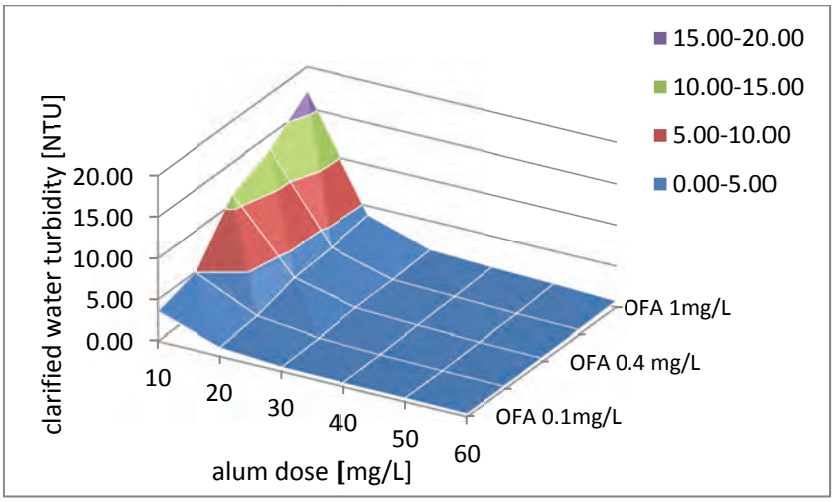


Figure 3-13: Jar test results on low turbidity raw water at 7.5 min flocculation time

In the extended high intensity mixing conditions, clarified water turbidity of less than 5 NTU was achieved at all OFA dosages between 0.1 mg/L and 1 mg/L, for alum dosages > 20 mg/L, as previously noted. However, at the alum dose < 20 mg/L, improved clarified water turbidity is evident compared to Figure 3-12.

In Figure 3-13, the poorer clarified water turbidity obtained at alum doses less than 20 mg/L, compared to higher alum doses, is indicative of insufficient coagulant being available for the destabilisation of particles, which causes a re-stabilisation effect at higher OFA dosages. The improved clarified water turbidity at 60 mg/L alum and 0.1 mg/L OFA is noted compared to that obtained in Figure 3-12.

It is however known that at a given velocity gradient, there will be a limited flocculation time beyond which floc particles will not grow due to continuous breakdown of larger flocs (Polasek, 2005b). To confirm this, further jar tests were conducted by increasing the high intensity mixing further to 16 min. The results from this investigation are shown in Figure 3-14 below.

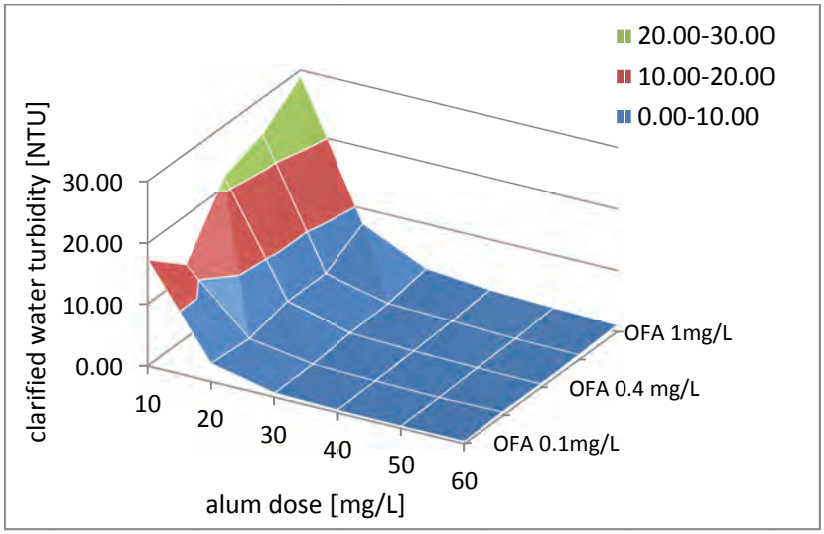


Figure 3-14: Jar test results on higher turbidity raw water at 16 min flocculation time

The improvement in clarified water turbidity noted at the low alum and OFA dosage in Figure 3-13 is absent here. This is potentially due to the breakdown of flocs at the extended high intensity mixing times. However, improved clarified water turbidity at all dosage combinations are observed here compared to using the short rapid mix time in the standard jar test procedure, shown in Figure 3-12.

In an attempt to distinguish between the effect of OFA and the impact of the extended high intensity mixing times, further jar tests were conducted using alum only. Results are presented in Figure 3-15.

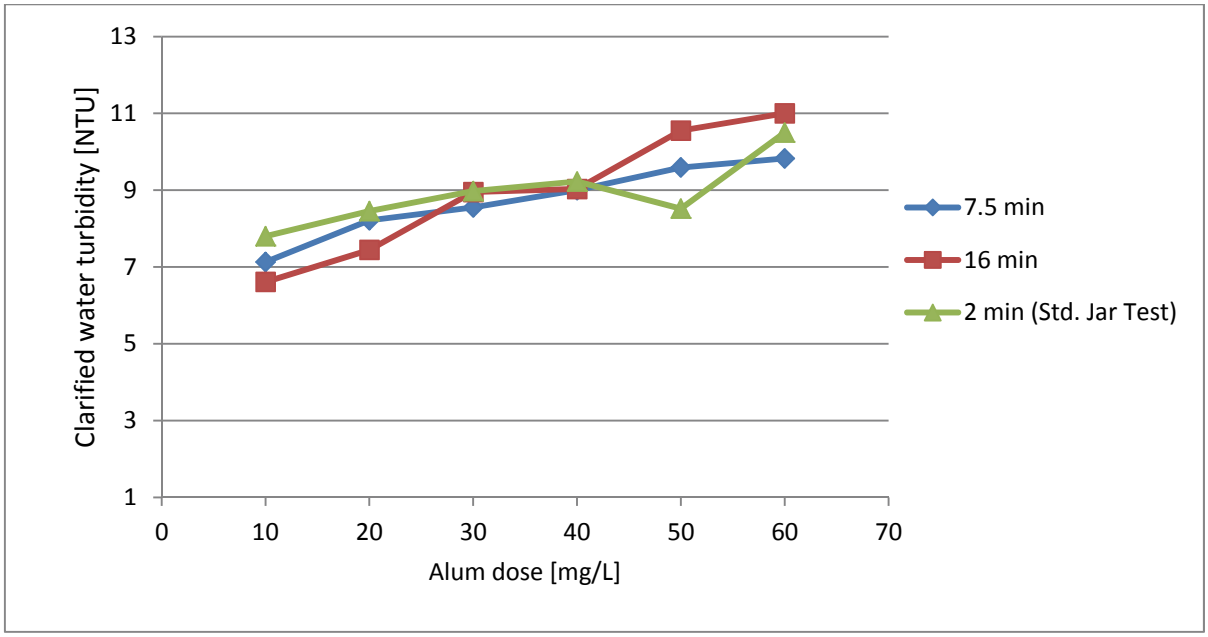


Figure 3-15: Jar test results when using alum only

Poor clarified water turbidity was obtained in all investigations using alum without OFA. The results clearly indicate even with the extended high intensity mixing in the aforementioned IHDS process, the low clarified water turbidity observed when using alum in combination with OFA are not yielded. This is due to the absence of OFA, which acts as a bridging agent for the aggregates formed during the IHDS process. These findings are in agreement with Polasek *et al.* (2005b) where it is stated that "*by improving the strength and hence the size of the formed aggregates, OFA facilitates improvement of their settleability*".

3.4.1.3 Tracer test

The performance of a process is greatly influenced by its hydraulic behaviour. An unfavourable hydraulic behaviour can lead to significant reduction in capacity and cause higher solids carryover. Therefore, a tracer analysis test was performed on the HR-CSAV clarifier using pulse addition of lithium chloride (LiCl). A mass of 32 g of LiCl was added within a few seconds to the inner flocculation compartment of the clarifier. Samples of clarified water was taken during the tracer test and analysed for lithium. The clarifier was operated at approximately half capacity (i.e. 240 m^3/day) and sampling was conducted over 120 minutes.

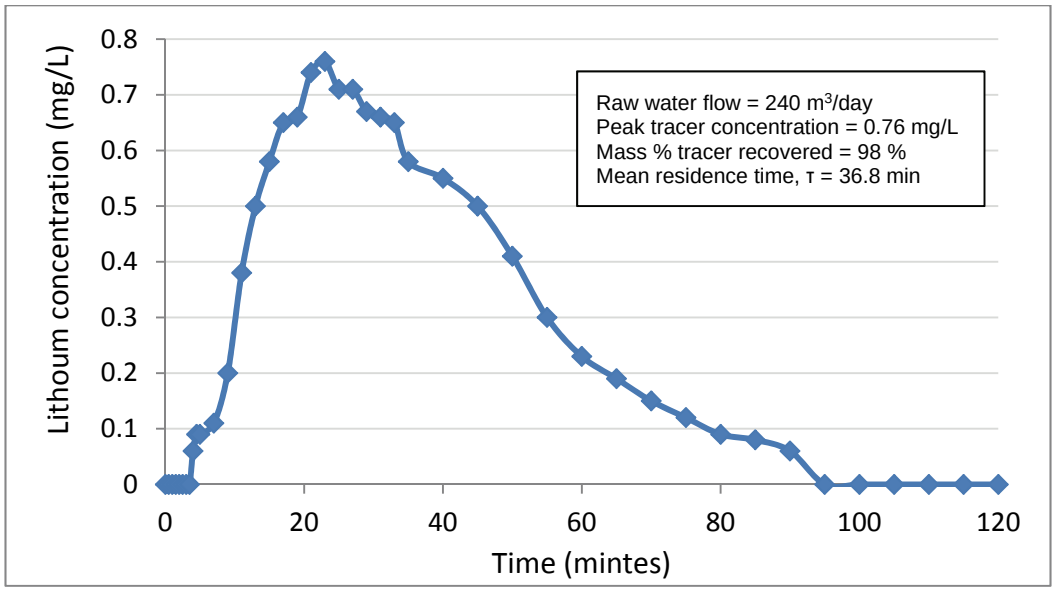


Figure 3-16: Tracer test response curve

Figure 3-16 gives the tracer response curve obtained. The shape of the tracer curve obtained from the pulse tracer test had an initial peak concentration followed by a steady decrease in the tracer concentration. The tracer profile showed that the peak lithium concentration of 0.76 mg/L was reached after approximately 23 minutes, thereafter decreasing until no tracer was detected.

An average residence time of 36.8 minutes was obtained, which is close to the theoretical residence time of 45.8 minutes. Integration of the area under the curve provided the cumulative lithium mass loading at the sample point. A tracer mass recovery of approximately 98% was thus calculated, indicating good hydraulic efficiency.

3.4.1.4 Solids Mass Balance

A solids balance was conducted over the HR-CSAV as shown in Figure 3-17. After a 24 hour operating period (following desludging) at 14 m/h, samples were taken of the raw water feed, alum feed, OFA feed, clarified water overflow and supernatant water flow. The plant was then desludged for approximately 1 minute and samples were taken of the sludge. All samples were analysed for total suspended solids (TSS).

As in any mass balance analysis, the law of conservation of mass was applied. The findings indicated that 14% of the influent solids were not accounted for. The main sources of this error were identified as follows:

- Fluctuations in the influent and clarified water turbidity during the 24 hour period were not accounted for, since the mass balance provides a snap shot of the conditions at the time of sampling after 24 hours of operation
- The sample of the sludge analysed would not be representative of all the sludge in the sludge thickening compartment due to non-homogeneity in terms of concentration in this compartment
- When desludging occurs approximately 40% of the sludge compartment volume (1.25 m^3) is removed. Therefore the measured sludge solid content does not solely represent the mass of solids accumulated in the thickening compartment during the 24 hour test period

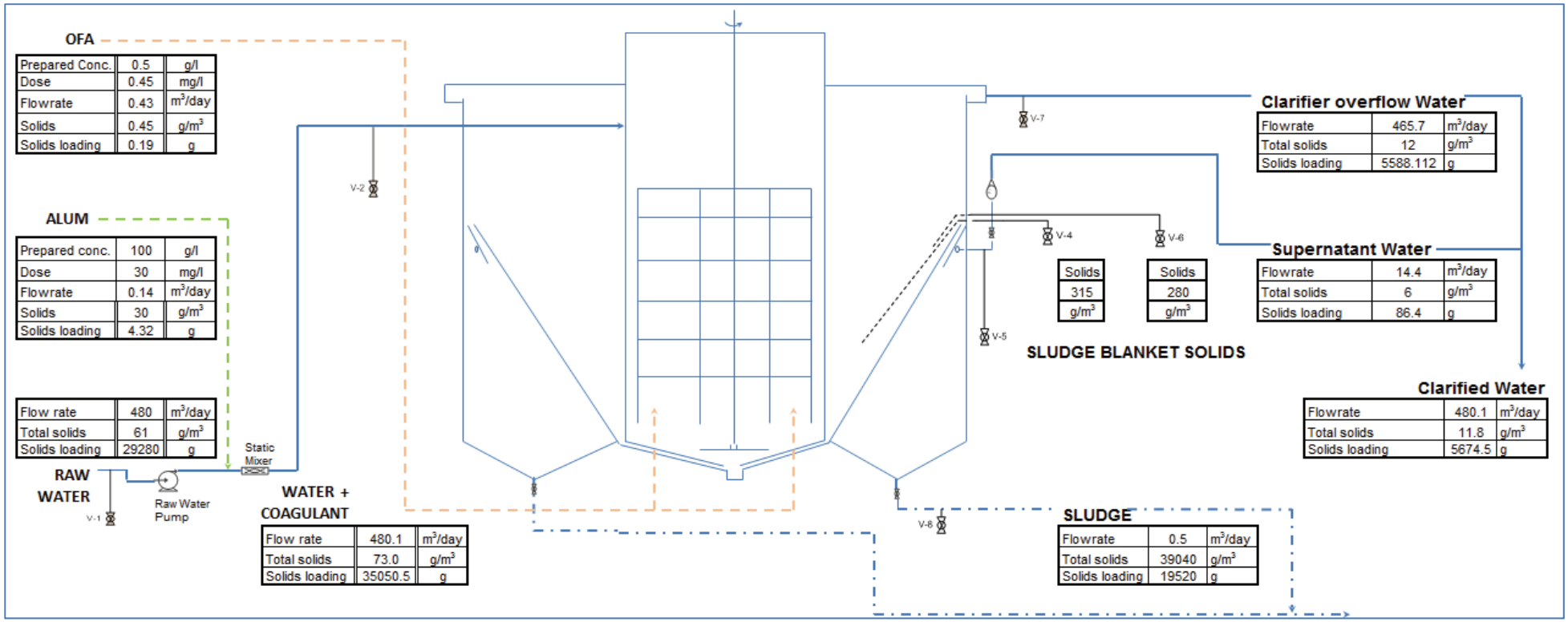


Figure 3-17: Solid mass balance analysis of the HR-CSAV

$$\boldsymbol{Total\ solids\ in = Total\ solids\ out}$$

$$(\boldsymbol{m_{raw\ water} + m_{alum} + m_{OFA}}) = (\boldsymbol{m_{clarified\ water} + m_{sludge}})$$

Where $\boldsymbol{m}$ **= solids loading determined, g = flow rate (m³/day) x TSS (g/m³) x 1 day**

$$(29280g + 4.32g + 0.19g) - (5675g + 19520) = 4090g$$

$$\%\ of\ influent\ solids\ not\ recovered = \frac{Mass\ not\ recovered}{Total\ solids\ in} * 100 = \frac{4090}{29284.5} * 100 = 14\%$$

3.4.2 Performance Evaluation of the demonstration model HR-CSAV at Umvoti WW

The results from operation of the HR-CSAV at Umvoti WW are presented in this section. The performance of the HR-CSAV clarifier was compared to two of the full scale clarifiers at Umvoti WW. The upflow rates of these full scale clarifiers are tabulated below.

Table 3-1: Upflow rates of full scale conventional clarifiers at Hazelmere WW

Clarifier type	Upflow rate
Clari-flocculator	2 m/h
Rectangular settling tank	1.5 m/h

Jar tests were conducted to determine the optimum chemical dosages to apply to the HR-CSAV and cascade tests were undertaken to further optimise chemical doses. The chemical dose control for the full-scale clariflocculators was via a streaming current detector.

The HR-CSAV was delsuged once daily during all plant trials.

Upon relocation to Umvoti WW, online instruments were installed for the continuous logging of data. It is also noted that due to operational challenges not associated with the high rate clarifier and intermittent power failures, continuous operation of the HR-CSAV was not possible.

3.4.2.1 Operation of the HR-CSAV at an upflow rate of 7 m/h

Figure 3-18 to Figure 3-20 show the performance of the HR-CSAV when operated at 7 m/h. The results obtained from the HR-CSAV when operated at 7 m/h indicate that the performance of the HR-CSAV followed similar trends to the conventional clarifiers at the Umvoti site which were being operated at a maximum of 2 m/h. Intermittent power failures resulted in the HR-CSAV being shut down. Figure 3-20 shows the deterioration in clarified water turbidity of the HR-CSAV upon power failure, whereas the conventional clarifiers were slower to respond. This indicates that although the HR-CSAV operated at more than three times the upflow rate of these conventional clarifiers, the unit is more sensitive to process upsets.

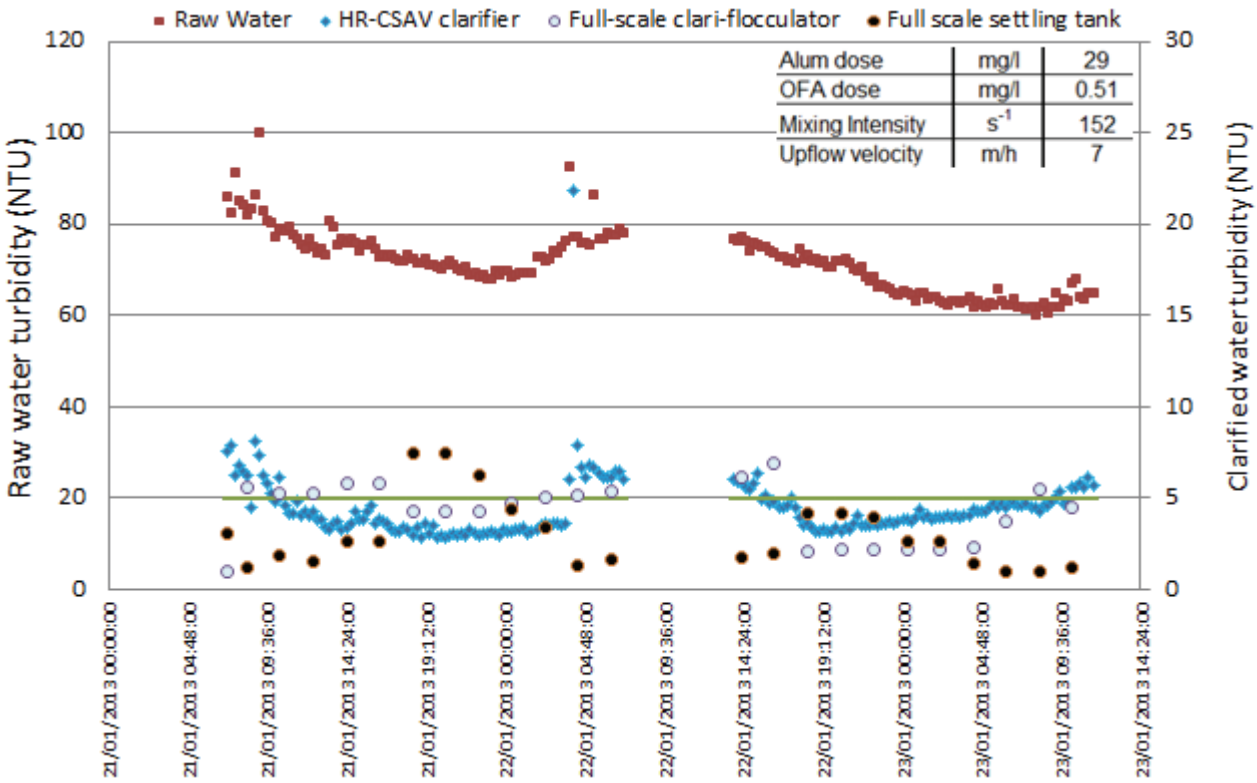


Figure 3-18: Operation of the HR-CSAV at 7 m/h (21-23 Jan '13)

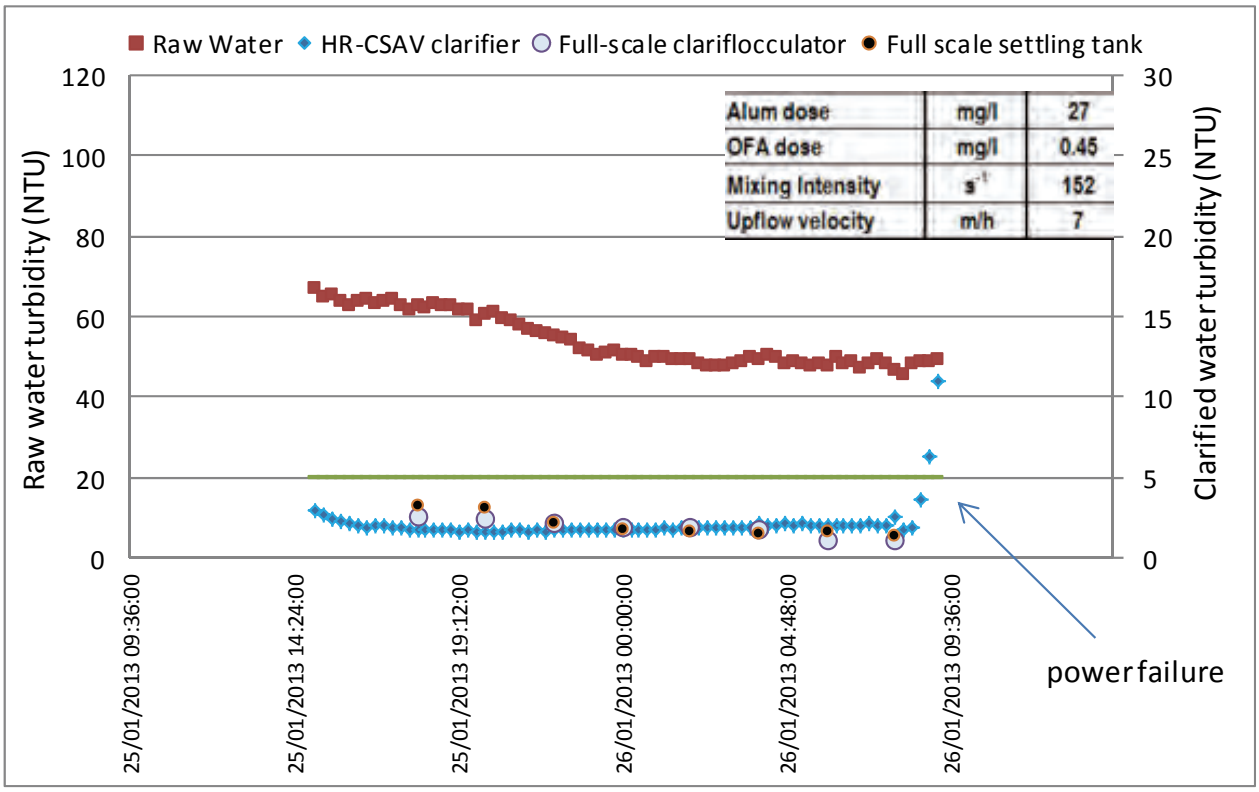


Figure 3-19: Operation of the HR-CSAV at 7 m/h (25-26 Jan '13)

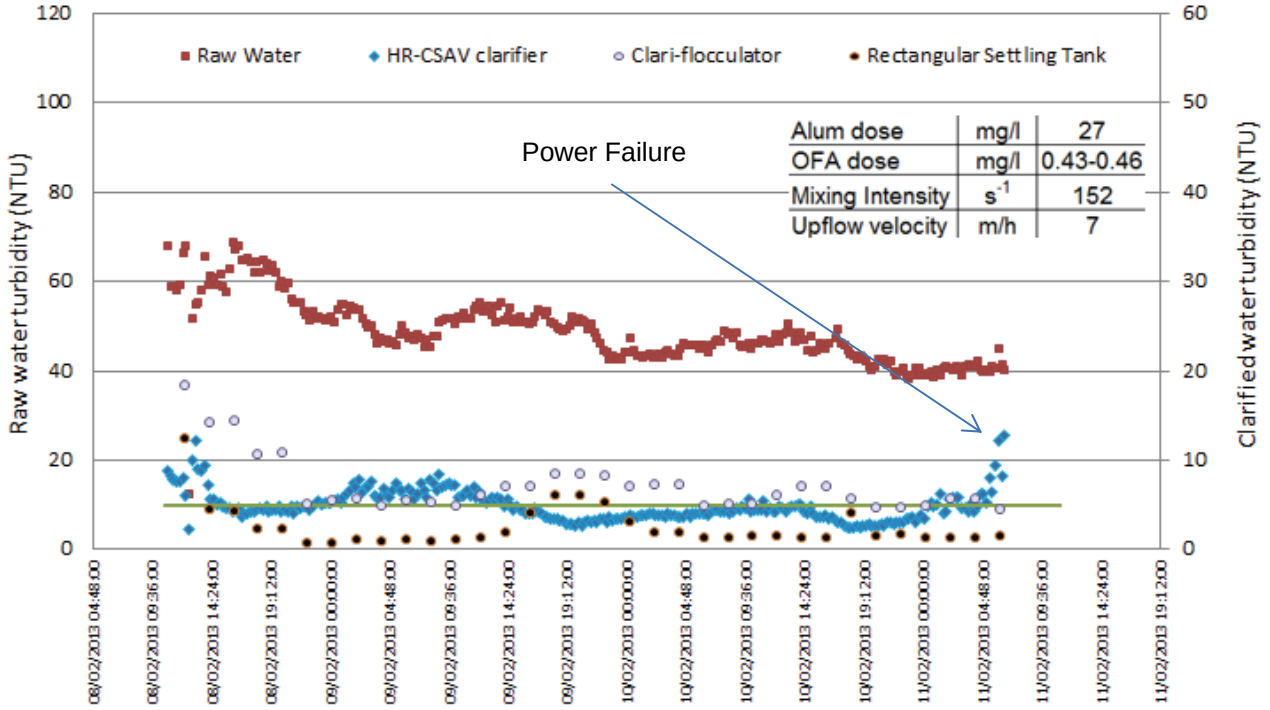


Figure 3-20: Operation of the HR-CSAV at 7 m/h (8-11 Feb '13)

3.4.2.2 Response of the HR-CSAV to variable raw water turbidity

Figure 3-21 shows the response of the HR-CSAV and the other conventional clarifiers at the Umvoti site to changes in the raw water turbidity.

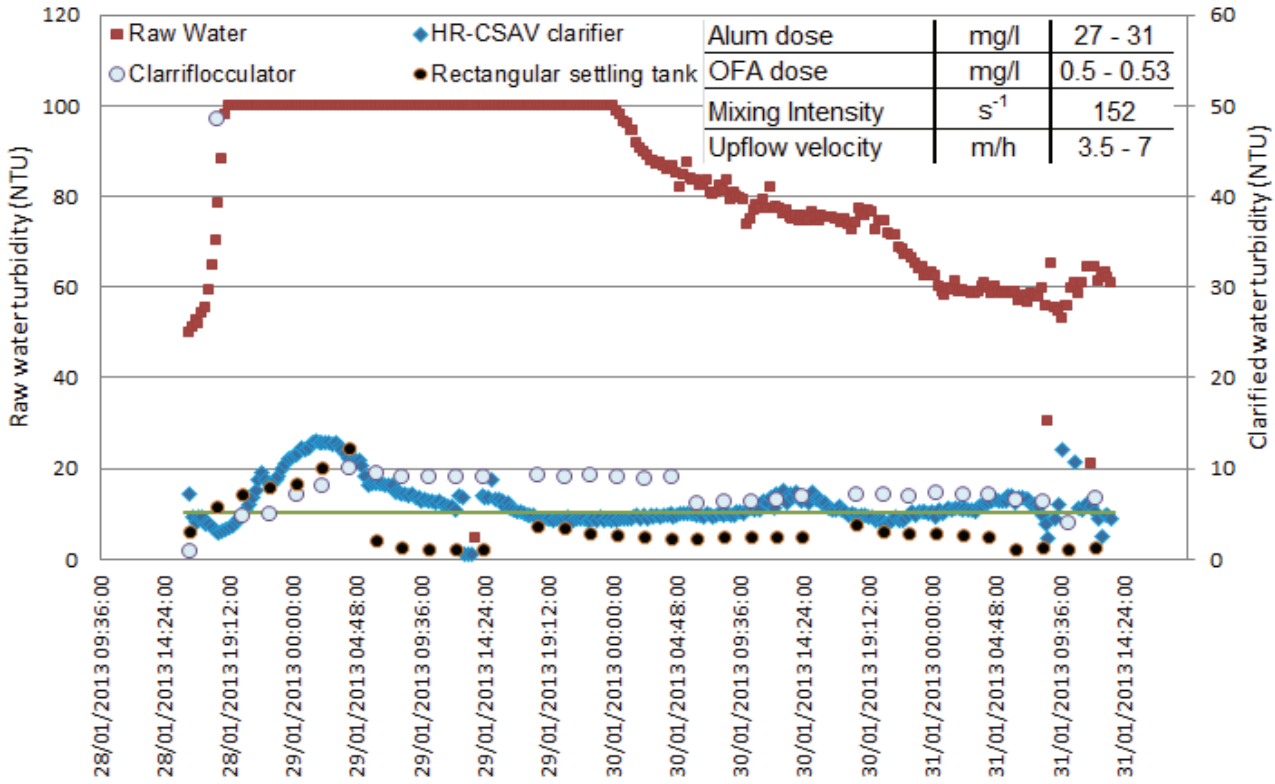


Figure 3-21: Response of the HR-CSAV to changes in raw water turbidity (28-31 Jan '13)

The first section of the graph shows the upflow rate varying between 3.5 m/h and 7 m/h. This was due to fluctuations in water demand at night compared to during the day, resulting in the clarifier influent throughout varying. The graph shows that the raw water turbidity started at 50 NTU, and then rapidly increased to 100 NTU. This rapid increase in turbidity resulted in a deterioration in the clarified water turbidity for the HR-CSAV and the other clarifiers at the Umvoti WW site. The coagulant dose for the other clarifiers at Umvoti is controlled automatically using a streaming current detector. The HR-CSAV coagulant dose is controlled manually. Whereas the settling tank adjusted fastest to the change in raw water turbidity, the response of the HR-CSAV and the clariflocculator was slower. In general, the HR-CSAV responded well to the gradual reduction in raw water turbidity from 100 NTU to 60 NTU. It is again noted that the HR-CSAV achieved comparable clarified water turbidity to the other full-scale clarifiers, despite being operated at 7 m/h compared to a maximum of 2 m/h for the other clarifiers. An increase in clarified water turbidity for the HR-CSAV towards the end of 31 Jan ’12 was as a result of one of the intermittent power failures at the site.

3.5 SUMMARY OF FINDINGS

- The raw water turbidity limitation on the HR-CSAV clarifier was confirmed upon operation of the clarifier at the two sites and from settling test results which showed that slow floc settling rates, and associated reduced turbidity reduction efficiency, occured when using low turbidity raw water (i.e. < 25 NTU). It is therefore recommended, based on these studies, that the clarifier be used in applications where the influent water turbidity exceeds 25 NTU.
- The HR-CSAV clarifier operating at an upflow velocity of 7 m/h was able to produce clarified water turbidity comparable to conventional full-scale clarifiers operating at 2 m/h when treating water with raw water turbidity > 25 NTU. Therefore, in terms of quality and throughput, the process shows great promise for treating water at higher surface loadings compared to conventional clarifier processes.
- The higher operating rates of the HR-CSAV and its sensitivity to the chemical dosages applied make it less forgiving to poor process monitoring and control compared to conventional clarifiers. The automation of coagulant dose control, by potentially using a streaming current detector and a flow meter for flow proportionate adjustments, would allow for more prompt responses to fluctuations in raw water turbidity. The frequency of desludging, which is dependent on the amount of influent solids, must be determined using a mass balance. In addition, operators would require detailed troubleshooting training to deal with process fluctuations.
- The maintenance intensive nature of the HR-CSAV was evident at both sites (i.e. Hazelmere WW and Umvoti WW), mainly in terms of planned maintenance requirements for the stirrer which operates continuously. In addition, potentially due to overdosing of OFA, the slots at the base of the clarifier, which connects the flocculation compartment to the sludge blanket compartment, became blocked. This required the clarifier be taken off-line for a day to be dismantled and cleaned.
- The continuous operation of the clarifier was also hindered with intermittent power failures. A back-up power supply (e.g. a standby generator) is a requirement for full-scale installations of this clarifier, as is typically required by most other conventional water treatment processes.

CHAPTER 4: DESIGN AND OPERATIONAL CONSIDERATIONS

4.1 INTRODUCTION

The three types of high rate clarifiers considered in this study (viz. ballasted flocculation processes, sludge recirculation processes and the HR-CSAV) were described in Chapter 2. This chapter provides practical operating and design guidelines, aimed at making those keen on considering the use of these sophisticated high rate clarification technologies in potable water treatment applications aware of some of the operational requirements and design considerations. This is critical especially under conditions in developing nations, where it is important to not impose first world technologies to individuals who are not adequately prepared for it. Monk *et al.,* (1984) summarises this aptly in stating, "*Design and engineering concepts must match a nations ability to build, operate, repair, and pay for them*."

It is noted that typically, once a decision is made to use high rate clarification technology, these units are generally procured pre-designed and fabricated from a supplier of the technology. Therefore, this section of the project is not an attempt to provide detailed technical design parameters, but instead to serve the purpose of providing a high rate clarifier selection guideline, giving criteria which are to be considered during the design phase. The knowledge and skills acquired from the operation of the HR-CSAV demonstration model plant enabled this technology to be considered in more detail compared to the other technologies, where information was limited to that obtained during study tours to existing full-scale installations using the technology and from literature sources.

The operating guidelines are limited to the HR-CSAV type of clarifier and are based on operational experiences on the demonstration model plant and on the site visit to the full-scale unit at Bethlehem Waterworks (see Section 2.3.1). Information pertaining to operation, monitoring and maintenance of the HR-CSAV after installation is presented. Operational considerations for the other two types of clarifiers were briefly described in the Case Study descriptions given in Chapter 2 and are not discussed here.

4.2 DESIGN CONSIDERATIONS

High rate clarification technologies have a number of benefits compared to conventional clarification processes by virtue of the higher clarification rates achievable. Ballasted flocculation processes have been reported to achieve up to 60 m/h (Veolia Water, 2007), sludge recirculation processes up to 40 m/h (Infilco Degremont, 2009) and the HR-CSAV up to 14.7 m/h (Polasek, 2005a) in potable water applications.

Some of the factors which are considered in this section include the influent water requirements, the treatment process requirements and utilities requirements. Selection criteria to be considered during the design phase are also tabulated.

4.2.1 Influent requirements

The high rate clarifier units are sensitive to the influent water turbidity as are conventional clarification processes. However, due to the higher operating rates, these units call for more prompt process adjustments when influent water quality fluctuates, as is typical in non-impounded water sources. Therefore on-going monitoring of the influent water quality is integral in providing early warning systems which will allow for the necessary process response to be implemented.

For the HR-CSAV type of high rate clarifier, it was critical for raw water turbidity to be higher than 25 NTU. This was confirmed during experimental trials on the demonstration model clarifier at the Hazelmere WW, where no solid liquid separation was evident at low raw water turbidity. The sensitivity of the performance of the HR-CSAV clarifier to the influent water turbidity was also marked at the full scale installation at the Bethlehem WW site where one of three different types of coagulants was selected based on the turbidity of the influent water. It is therefore imperative to examine water quality trends, and predict variations in raw water quality likely to occur, when considering including this type of clarifier as part of the treatment process.

The sludge recirculation and ballasted flocculation types of clarifiers don't have a constraint on the raw water turbidity but nevertheless also require prompt process adjustments following raw water fluctuations.

4.2.2 Process requirements

Pre-treatment: For each of the clarifiers considered, pH adjustment may be required to maintain the water pH between 6.5 and 7.2, the range of minimum aluminium solubility to allow aluminium hydroxide floc formation (Ratnayaka, 2009). It is also noted that the ballasted flocculation process required the pre-screening through a 6 mm screen, to prevent blockages of the hydrocyclone.

Chemicals: Chemical storage facilities must be adequately sized to allow for 15 or 30 days storage, depending on the size of the process. For the ballasted clarification process, this includes not only the coagulant, polymer and pH correction chemicals, but also storage space for the sand, which is typically dosed at 3 g/L.

In the HR-CSAV process, the coagulant and organic flocculant aid (OFA) chemicals required for the HR-CSAV can be made up in bulk mixed tanks and then transferred to smaller secondary feed tanks, which serve as day tanks. A storage tank for softened water from the ion exchange unit, which is required for the makeup of the OFA solution, is also required.

Process Monitoring: The presence of on-line instrumentation and adequate process monitoring to provide early-warning systems for changes to be made in the process will result in better performance. In particular, the monitoring of influent water quality and adjustment of coagulant dose accordingly are recommended.
The use of on-line turbidimeters, accompanied by data loggers, can be used for monitoring raw and clarified water turbidity, and is especially useful for troubleshooting purposes. Level sensors on chemical storage

tanks, or a transparent strip on the storage tank, would allow for monitoring of tank level. The monitoring of chemical dose rate can be achieved by installation of a sight glass with isolation valve.

It is noted that the reliance of online instrumentation for process monitoring and control implies that a good asset management team is indispensible for calibration of these meters, to ensure the accuracy of results.

The control of the chemical dosages would require jar tests to be conducted regularly. An on-site laboratory with the required equipment and trained process operators would be needed to conduct these analyses. Automatic chemical dose control can be achieved using a streaming current detector, which will allow for more prompt response to changes in chemical dose required. An on-line raw water flow meter is also useful to estimate flow-proportionate changes required in chemical dosage. The remote monitoring of the process could also be considered. These options in process automation do not eliminate the need for a high level of operator presence, to conduct weekly jar tests to confirm dosages, to make up chemical solutions and for troubleshooting purposes.

Other Requirements: It is essential that the filtration system following the clarification process be designed to handle additional solids load, since at start-up or in instances where the operator responses are slow, increased solids load in the clarified water may occur for a period of time while the system adjusts to the changes. During these periods, more frequent backwashing of filters may therefore be required.

In systems where the demand is relatively constant, a holding vessel located prior to clarification would allow for more constant flow rate to the high rate clarification process. This would minimise sudden fluctuations in flow rate causing sludge blanket instability and solids carryover and also eliminate the need for process adjustments associated with changes in flow rate. Clarifier intake pumps must however still be equipped with variable speed drives to allow for slow start (as low as 4 m/h upflow velocities) during start up and sludge blanket development, in addition to the full flow operating range requirements.

These units were found to be very maintenance intensive, with complete shutdown and cleaning of the units being required at least annually. Stand-by clarifier treatment units may in certain instances be required during these maintenance shutdown periods.

In climatic conditions where temperature fluctuates, either due to seasonal variations or due to day/night variations, insulation of the HR-CSAV would be required, to prevent turnover of the sludge blanket and the resultant deterioration in clarified water quality.

Lastly, durable equipment and systems are central to reduce emergency maintenance requirements. The stirrer in the flocculation compartment of the HR-CSAV demonstration model plant was found to be very maintenance intensive with many problems experienced resulting in significant downtime. The use of variable speed drives on the stirrer for the full scale HR-CSAV installation at Bethlehem WW allowed for slow start of the stirrer, and the resultant less frequent breaking of the stirrer shaft due to rapid stopping and starting.

4.2.3 Utilities requirements

Softened water is required for the preparation of the OFA solution. This would typically be generated using an ion exchange resin. Regeneration of the resin would typically be carried out on site, and therefore storage of the acids and bases required for regeneration would need to be provided for in the design.

The HR-CSAV requires continuous operation hence a steady power supply must be guaranteed. For short periods of service interruptions, standby power supply must be available. The use of a diesel or natural gas generator would be adequate in these instances. It is recommended that in instances where there are frequent power failures or in applications where frequent stopping and starting is required, the HR-CSAV not be considered. The experimental trials on the demonstration model plant at the Umvoti WW site, a rural location, were abounding with power failures, which rendered much downtime mainly associated with re-starting the unit once power was restored.

The fundamental use of gravity should be incorporated into the design where possible to reduce the energy demand, especially in rural applications. An example of this was the process modification to the DWR process (see Section 2.3.4) where the process was modified to include hydraulic jumps to achieve mixing.

4.2.4 Operation and Maintenance

Complex and sophisticated processes are generally more costly and complicated to operate and maintain. The three types of high rate clarifiers considered in this study are specialized technologies and, among other factors, require skilled and adequately trained operators in order to ensure optimal monitoring and operation.

A good maintenance support system is a key part of the successful operation of these processes. These units are very maintenance intensive, not only with regard to physical components (gearboxes, stirrers, hydrocyclone, pumps etc.) and monitoring instrumentation of the unit, but staff is also required for intermittent shut-down and flushing of the unit. Ballasted processes using sand may experience high wear rates on pumps and piping moving the sand and sludge (Clarifier Design Task Force, 2005). In addition, blockages in sludge pipes, and in the hydrocyclone for the ballasted flocculation process, were a common problem experienced with the three types of clarifiers considered and would require emergency maintenance systems in place.

Selection criteria to be considered are summarised in Table 4-1.

Table 4-1: Selection criteria for high rate clarifiers

Criteria	Type of high rate clarifier		
	Sand Ballasted Flocculation	**Sludge recirculation**	**HR-CSAV**
Influent water turbidity	Suitable at any influent water turbidity	Suitable at any influent water turbidity	Not suitable in applications where influent water turbidity < 25 NTU
Reported maximum upflow velocity	Potable water: up to 80 m/h	Potable water: up to 40 m/h	Potable water: up to 14 m/h
Total Retention Time	7 mins (U.S. EPA, 2003)	15 mins (U.S. EPA, 2003)	• Flocculation compartment: 8.5 min • Sludge blanket compartment: 4.5 min • Clarified water compartment: 2 min
Chemicals used	• Inorganic coagulant (alum/ferric chloride) • Polymer • Micro-sand (80-100 µm)	• Inorganic coagulant (alum/ferric chloride) • Polymer	• PAC at low influent water turbidity and a for influent water turbidity > 60 NTU • Alum can be used instead of PAC • Organic flocculant aid (polyacrylamide)
Level of skills required	Skilled operators are required	Skilled operators are required	Skilled operators are required.
Maintenance	Maintenance intensive equipment include: • Online instrumentation • Mechanical mixers • Sludge pump and hydrocyclone • Sludge scraper • Stirrers and stirrer gearbox • Lamella plates Comprehensive shutdown and cleaning of the unit required annually	Maintenance intensive equipment include: • Online instrumentation • Mechanical mixers • Sludge pump • Sludge scraper • Stirrers and stirrer gearbox • Lamella plates Comprehensive shutdown and cleaning of the unit required annually	Maintenance intensive equipment include: • Online instrumentation • Mechanical mixer • Regeneration of ion exchange unit Fortnightly complete shutdown and cleaning of the unit is required

Criteria	Type of high rate clarifier		
	Sand Ballasted Flocculation	**Sludge recirculation**	**HR-CSAV**
Monitoring requirements	Jar tests are used to optimise coagulant dosages. Influent and clarified water turbidity must be monitored and chemical dosage adjustments made based on jar tests. At minimum once daily analysis of micro-sand in the recycled stream is required. A dose rate for the sand of 3 g/L is typically used.	Jar tests are used to optimise coagulant dosages. Influent and clarified water turbidity must be monitored and chemical dosage adjustments made based on jar tests. Solids analyses on the recycled sludge are required, and the recycle ratio adjusted accordingly.	Jar tests are used to optimise chemical dosages. Influent and clarified water turbidity must be monitored and chemical dosage adjustments made based on jar tests. Solids monitoring of the sludge from the sludge blanket compartment is required.
Sludge generated	Sludge waste requires further dewatering	Concentrated sludge (20-80 g/L)	7.5% w/v sludge drained from the clarifier was achieved during demonstration plant trials
General	Requires 3 mm fine screen in order to avoid blocking of hydrocyclone		Ion exchange unit required water softening for OFA chemical make-up

4.3 OPERATING GUIDELINES FOR THE HR-CSAV HIGH RATE CLARIFIER

This section includes guidelines on commissioning, start-up and shut-down of the HR-CSAV type of high rate clarifier. Operating, maintenance and troubleshooting considerations are also given. The information given here is based on operation of the demonstration model HR-CSAV plant.

4.3.1 Commissioning, start-up and shut-down of the HR-CSAV

4.3.1.1 Commissioning

When starting up for the first time after installation, the HR-CSAV must be commissioned to confirm that the unit and associated infrastructure are operational and free from faults. This inspection would usually be preceded by a visual examination of all mechanical equipment which was specified in the design.

The commissioning process would typically be conducted in conjunction with the technology provider. As per general cold commissioning procedures, water is circulated through the system, in order to detect leaks and to check that all instrumentation, valves and equipment are functioning. Starting/Stopping and opening/closing of all mechanical equipment (i.e. pumps, valves etc.), including testing of sample points, must be conducted. The clarified water overflow weirs must be correctly levelled to ensure equal flow distribution through all V-notches. Snags identified here would need to be rectified prior to commencing hot commissioning.

The process treatment chemicals must be prepared and be available for use during hot commissioning. The jar test optimised chemical dosages must be obtained for the source water and be applied to the process. The clarifier must be operated at a low upflow rate (typically 4 m/h), with all clarified water being discharged to the sludge treatment facility while commissioning. The chemical dosing systems would be tested during this period. Upon completion of hot commissioning, snags identified would need to be addressed prior to commencing operation.

4.3.1.2 Start-up and Shut-down

Prior to start-up, chemicals must be made up. The jar test optimised chemical dosages to be applied to the plant must be determined. The clarifier should be operated continuously at a low upflow rate of 4 m/h, with clarified water being directed to the sludge treatment plant during the period of development of the sludge blanket. No desludging would take place. The duration for development of the sludge blanket is dependent on the solids content of the raw water and can range from 2-24 hours.

Once the required clarified water turbidity is obtained and sustained, this is an indication that the clarifier can now be operated at higher upflow rates. Clarified water flow can then be directed back into the treatment process. Changes made to the upflow rate must be done gradually, to prevent disruption of the sludge blanket.

The shut-down of the plant would usually follow the sequence where the chemical dosing pumps are switched off and then the raw water pump. The stirrer would also need to be switched off. The clarifier can then be drained, if the shut-down is for an extended period of time (i.e. more than 1 day). Chemicals in storage tanks would need to be discarded if the duration of the shut-down exceeds the shelf life of the chemicals. It is noted that this type of clarifier is more suited to steady continuous flow conditions, which is free from interruptions, and so plant shut downs should be avoided unless unnecessary.

4.3.2 Operation of the HR-CSAV

Plant operation requires the preparation of chemical solutions to pre-determined concentrations, process monitoring and optimisation and record keeping. A description of these is given below.

4.3.2.1 Process monitoring and optimisation

A number of parameters would need to be monitored and be used to optimise the process during plant operation. Turbidity is generally used as an indicator of performance of unit processes.

The performance of the clarifier should be monitored at 2 hour intervals as follows:

- The flow rate and turbidity to the plant should be monitored, confirming results obtained using online instrumentation with data loggers where these are used. Rotameters are a cheap method of measuring and controlling flow rate. Keeping a record of flow rates and turbidity is useful especially for troubleshooting.

  Changes in the aforementioned parameters must be accompanied by chemical dosing adjustments. As a general rule-of-thumb, a 10 NTU change in influent indicates adjustment of the chemical dose, as determined through jar tests. The flow proportioned automation of the chemical dose control can be achieved using online flow meters.

- Clarified water turbidity should be monitored, confirming results obtained using online instrumentation where these are used. Clarified water turbidity exceeding the required limit (typically 5 NTU) would signal the requirement for troubleshooting. In addition, depending on the duration and the amount of the increased solids load from the clarifier, the subsequent filtration process may require more frequent backwashing.

The following daily operational tasks and monitoring is required:

- The pH of the influent water and clarified water must be monitored, to determine the effectiveness of pH correction in maintaining the pH within the required range for the coagulant being used. This can be achieved using online instrumentation.

- The level on all chemical dosing tanks must be checked. Chemical dosing tanks which have a clear strip so that the level can be visually seen is an easy indicator of when tanks need to be

refilled. On more sophisticated operations, this can be achieved using a level sensor, with an alarm on reaching the low tank level limit.

- Jar tests would need to be conducted daily, or when raw water is from an impounded source at least once a week and each time there is rain in the catchment. Extending the rapid mixing in the jar test, as in the HR-CSAV, is more representative of the plant conditions.

- Dosing rate of all chemicals should be checked. At each chemical dosing system, a sight glass with an isolation valve will enable manual verification of chemical dosing rates.

- The flocculator mixer speed must be adjusted when flow rate is changed, to maintain the required mixing intensity. The supplier would typically provide the operator with a chart showing the required stirrer speed setting for various influent water flow rates.

Other process optimisation and monitoring considerations include:

- *Desludging*: The desludging frequency is dependent on the amount of incoming solids. It is recommended that a solids balance across the clarifier be conducted to determine the frequency and duration of desludging.
- *Softened water*: The water softening unit is used for the removal of water hardness. Softened water is required for the make-up of the OFA solution, since hardness in water can react with process chemicals and consequently reduce chemical efficiency in the coagulation process. A limit of water hardness of <10 mg/L is required, and must be checked, as per the recommendations in the operating manual, for when regeneration is required.
- *Temperature*: Temperature fluctuations (day/night or seasonal) can adversely affect the performance of the clarifier, by causing sludge blanket turnover. It is therefore useful to measure the temperature, which can be used for troubleshooting purposes, if inferior clarified water quality obtained is due to temperature fluctuations.
- *Solids in sludge blanket*: The total solids content of the sludge blanket and floc settleability gives an indication of the operation of the clarifier. This is useful at start-up, when developing the sludge blanket, and also during normal operation, since developing and maintaining the sludge blanket is key to the successful operation of the HR-CSAV.
- *Residual Al^{3+}*: When an inorganic coagulant such as alum is used, it is important to periodically measure it residual Al^{3+} in the clarified water and the sludge, since the presence of Al^{3+} has serious health implications.

4.3.2.2 Chemical handling and preparation

Details on the preparation, safety and storage of the chemicals used in the HR-CSAV process are given in Table 4-2.

Table 4-2: Chemical preparation, safety and storage

Chemical	Chemical Type	Preparation	Safety	Storage
Coagulant	Aluminium or ferric based coagulant (e.g. Alum)	Alum is purchased as either granular, powder or liquid. Depending on the size of a plant, alum may be used concentrated as purchased or diluted. Liquid alum can dissolve completely in water within 2 hours when properly mixed, compared to several hours for powdered alum to dissolve. It is important to note the grade of alum used, as poorer grades are not suitable for potable water treatment due to impurities present. Impurities often do not dissolve and often precipitate and cause blockages in pipelines over time. Alum stock solution preparation usually involves mixing the bulk quantity of alum into water level in a stirred tank.	It is easier and safer to handle liquid alum rather than powdered alum. The following PPE should be used when handling alum based coagulants: - safety shoes - chemical-resistant, impervious gloves - chemical splash-proof goggles	Dry alum powder must be stored in a dry place and must be resealed prior to re-storage. The expiration date must be checked to ensure the effectiveness of the chemical is not lost. Alum is usually prepared and stored in HDPE tanks. Once dissolved alum is very stable and can be used for one week.
Organic flocculant aid (OFA)	Anionic polyacrylamide, Bulab 5616 (Superfloc A110)	The OFA is commonly purchased as granular powder. It is essential that the preparation of the OFA solution be done carefully, to prevent quality problems. When	The following PPE should be used when handling OFA: - safety shoes - chemical-resistant,	The OFA powder must be kept in a dry place and must be resealed prior to re-storage, as it can be susceptible to caking in moisture.

Chemical	Chemical Type	Preparation	Safety	Storage
		preparing the solution, the OFA is introduced while filling the mixed storage tank with softened water tank. When dissolving in softened water, each molecule of the OFA must be wetted. If the dry particles are not individually wetted, then undissolved globules, often called fish eyes, will form which are unusable in the treatment process. The mixing duration should be sufficient to completely dissolve the OFA (usually between 5-8 hours).	impervious gloves - chemical splash-proof goggles.	The expiration date must be checked to ensure that effectiveness is not lost.
Softened Water	< 10 mg/L hardness of water	Softened water is required for preparing the OFA solution. An ion-exchange resin can be used for this purpose. The chemicals required for regeneration of the ion-exchange resin may require storage on site. The supplier and O&M Manuals must be consulted.	PPE should be used: - safety shoes - chemical-resistant, impervious gloves - chemical splash-proof goggles.	Regeneration chemicals (usually acids/bases) must be stored separately in demarcated areas.

4.3.3 Maintenance requirements

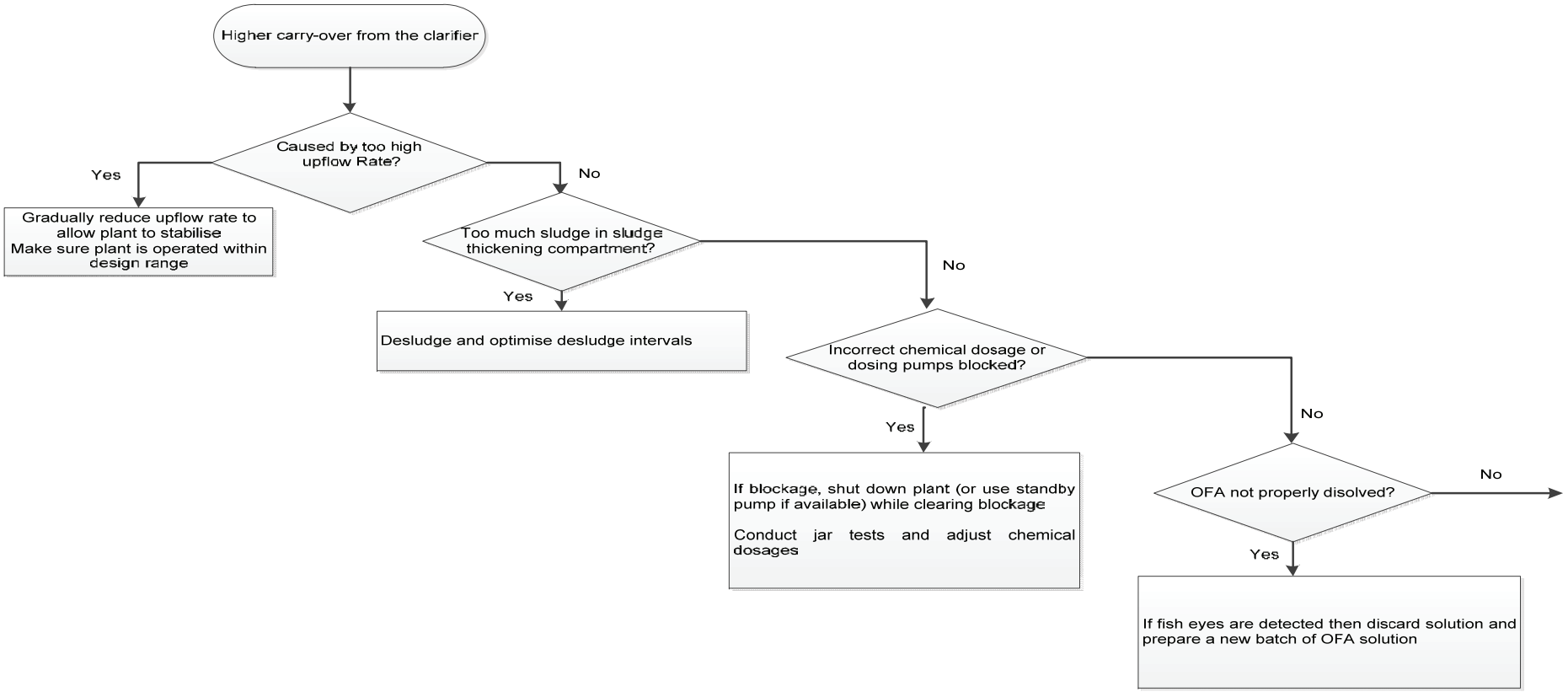
The maintenance requirements for the HR-CSAV are given in Table 4-3.

Table 4-3: Maintenance Requirement for the HR-CSAV clarifier

Equipment	Function	Common Problems	Maintenance Requirements	Planned or routine maintenance
Gearbox for the Stirrer	The gearbox controls the motor that drives the stirrer	Oil depletion	The frequency of checking and replacing the gearbox oil level with the required type of oil will be given the equipment Operations and Maintenance Manual. Generally, this is required once a month.	Planned maintenance
		Greasing	The frequency of greasing of bearings is usually weekly, but is dependent on visual observations of the amount of grease present or noise detected due to friction.	Routine maintenance
		Collapsing of thrust bearings	The gearbox can be very maintenance intensive due to its continual operation at high rotational speeds. Collapsing of bearings is usually identified by noise occurring. The gearbox is then stripped and bearings and associated coupling/sealing material are replaced.	Routine Maintenance
Online Instrumentation	Continuous monitoring of parameter (meters to measure turbidity, flow, pH, level in storage tanks, temperature)	Cleaning of sensors and calibration of meters	Cleaning of sensors on on-line equipment is required, the frequency being dependent on a number of process variables and the type of sensor being used (generally monthly cleaning of sensors). Calibration of on-line meters is required, at minimum once monthly.	Planned maintenance

Equipment	Function	Common Problems	Maintenance Requirements	Planned or routine maintenance
Chemical dosing pumps	Transfer of chemicals to water	Blockages Oil replacement	Chemical dosing pumps require periodic cleaning of suction and discharge non-return valves to remove particles that accumulate. Periodic lubrication oil replacement is required.	Planned Maintenance
Stirrers	Imparts mixing energy	Oil replacement	The stirrers on the mixing tanks, as well as the stirrer in the flocculation compartment of the HR-CSAV require oil change.	Planned Maintenance
Water Softener	Provides softened water, which is used as makeup water during preparation of the OFA	Exhausted resin requires regeneration	As the resin becomes exhausted with use, deterioration in the softened water quality may be evident. This would signal that regeneration of the resin is required.	Routine Maintenance
The HR-CSAV	Clarifies water	Deterioration in performance despite process being optimised	Complete shutdown and cleaning of the unit is required, the frequency dependant on the manner of operation and the influent water characteristics. Typically, fortnightly cleaning would be required.	Planned Maintenance

4.3.4 Troubleshooting



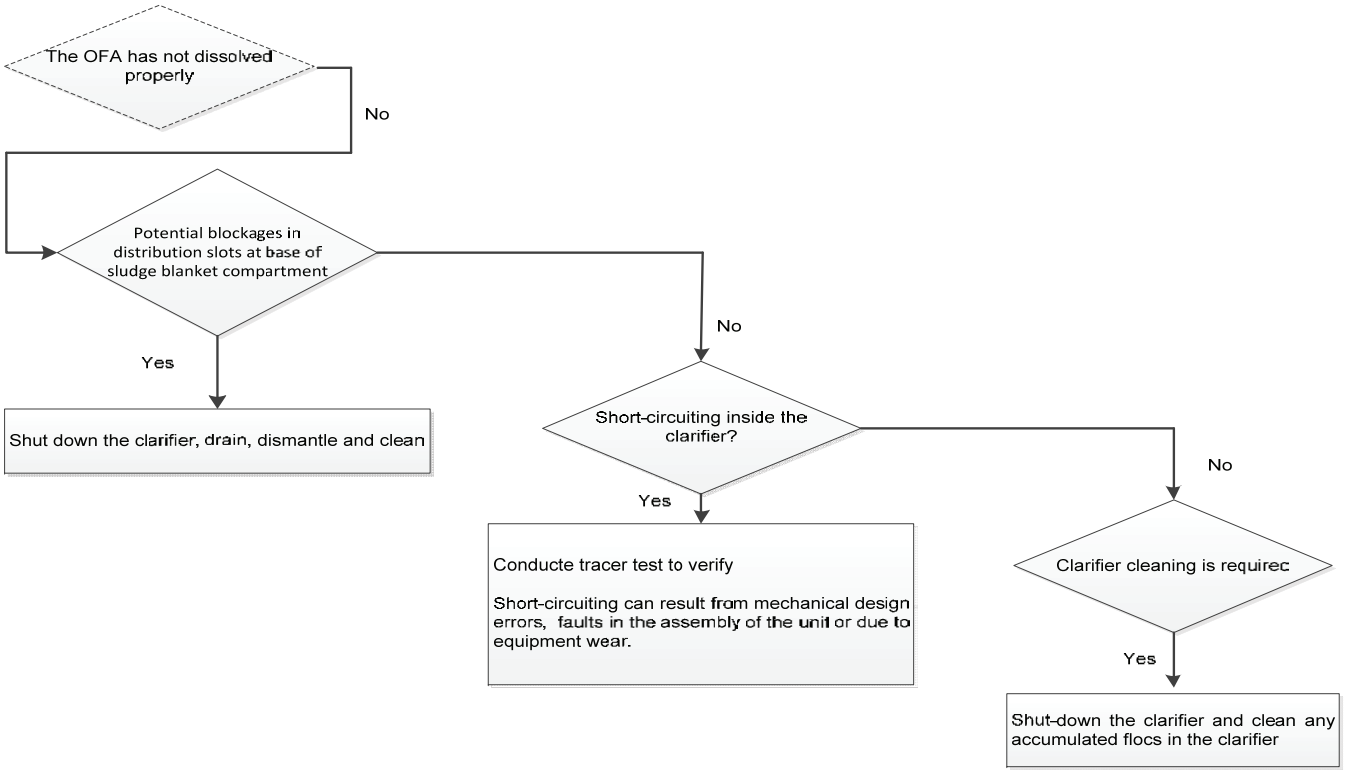


Figure 4-1: Troubleshooting flowchart for the HR-CSAV clarifier

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Results from the investigations on the HR-CSAV demonstration model clarifier clearly showed the sensitivity of the clarifier to raw water turbidity. Slow floc settling rates, and associated reduced turbidity reduction efficiency, occured when using low turbidity raw water (i.e. < 25 NTU), whereas clarified water turbidity comparable to conventional full-scale clarifiers operating at 2 m/h were achieved with the HR-CSAV clarifier operating at 7 m/h using high turbidity raw water (> 25 NTU). However, the higher operating rates of the HR-CSAV and its sensitivity to the chemical dosages applied make it less forgiving to poor process monitoring and control compared to conventional clarifiers. The automation of chemical dosing systems, as is common for conventional processes, would allow for more prompt response to fluctuations in raw water quality.

It was very evident from the case studies that these high rate clarification processes are specialized technologies and therefore require more operator judgement and more on-line instrumentation and control than conventional clarification processes. The maintenance intensive nature of these processes call for the regular presence of maintenance personnel and, in some instances, that stand-by treatment units be available during these maintenance shutdown periods. Therefore, the higher clarification rates achievable not only indicate significant cost savings, but also mean investment in a reliable asset management team and skilled operators which are fundamental for the successful operation of these units.

This study did not address the operability of the other two clarifiers which were considered in the case study assessments, and also did not consider the economics, in terms of capital and life cycle costs, which are important in the planning and conceptual design processes. It is recommended that this be considered in future research work. It is also understood that some of the mechanical challenges experienced with the HR-CSAV cannot be attributed entirely to the high rate technology. The selection of some components and equipment that made up the HR-CSAV demonstration plant was guided more by the available research budget than other life cycle considerations like ease of operation and maintenance, reliability and sustainability.

High rate clarification, however, still holds promise as an attractive option for meeting the growing potable water demands. In developing nations especially, adequate training provided by the technology provider and local support services will allow for the process to be understood, operated and maintained after installation. High rate clarification processes described and evaluated in this report are viable options for application in the South African potable water industry. It is recommended that water treatment practitioners and designers consider the application of this technology under the appropriate conditions.

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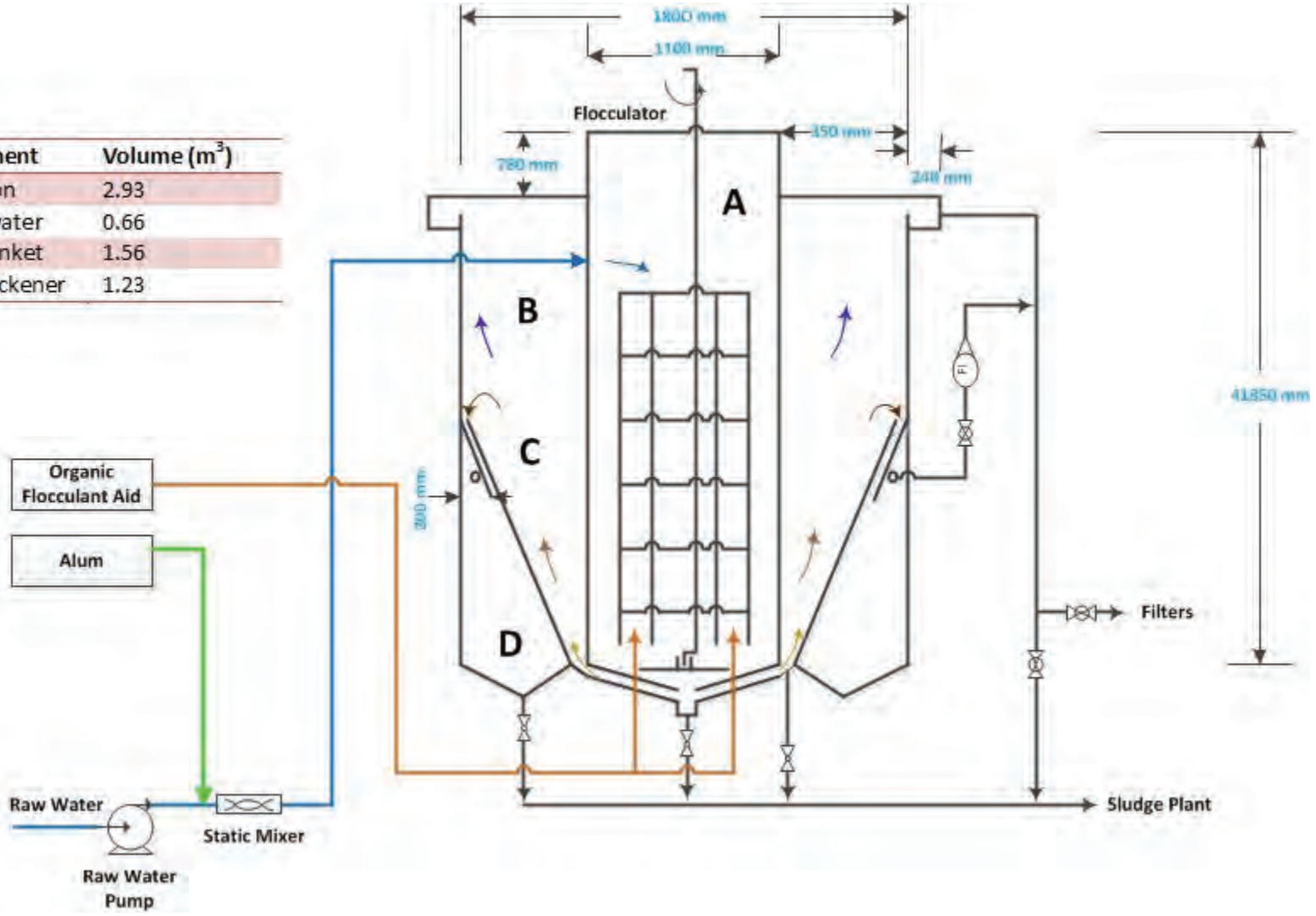
APPENDIX A: Clarifier Dimensions

Key:

Alphabet	Compartment	Volume (m^3)
A	Flocculation	2.93
B	Clarified water	0.66
C	Sludge Blanket	1.56
D	Sludge Thickener	1.23



APPENDIX B: Jar Test Methodology

Jar tests are an important process optimization tool used in the water industry. Jar tests assist in determining an estimate of the required coagulant dosages for effective aggregation-agglomeration of impurities in raw water. They can be an effective visual simulation tool for Water Works when applying similar jar test conditions to the plant (i.e. using identical water quality, chemical dosage concentrations, sequence of chemical dosing, reaction time and mixing intensity).

Jar Test Mixing Energy Calculations

Mixing Intensity/root mean square velocity gradient

$$\overline{G} = \sqrt{\frac{P}{V_{FC}\eta\mu}} \qquad (1)$$

Where $\overline{G}$ = mixing intensity or root mean square velocity gradient (s^{-1}),
V_{FC} = volume of flocculation or agglomeration compartment (m^3),
η = hydraulic efficiency of agglomeration compartment,
P = average shaft input power to water ($kg.m^2.s^{-3}$),
μ = dynamic viscosity of water ($kg.m^{-1}.s^{-1}$).

Laboratory chemical and equipment requirements

1) This procedure is based on aluminium sulphate solution concentration of 45-50% aluminium sulphate ($Al_2(SO_4)_3.18H_2O$). It is noted however that the alum solution being used at on the HR-CSAV must be used. 100g of the 45-50% alum solution must be measured
2) 0.5 g anionic polyacrylamide (Superfloc SF-A110) powder to make up the OFA solution
   Reagent chemicals supplied should be sampled and checked for quality
3) Jar testing apparatus consisting of six paddles and capable of housing 2 L beakers. The apparatus must be equipped with an adjustable speed counter (to permit a change in velocity gradient in the range $\overline{G}$ = 1-300 s^{-1}) should be used. Flat stirrer paddles are normally used, and it is recommended that the six-place laboratory stirrer be fitted with micro-ampere meter for measuring power input.
4) Six 2 L glass beakers (reaction vessels).
   Round 2 L beakers are preferred for HR-CSAV jar test application although square 2 L beakers can be used. These beakers should all be identical (shape, size and volume), allowing stirrers to be centred to minimize vortex formation. Note that glass beakers must be used instead of plastic beakers to minimise unsettled particles from sticking onto the sides of the beakers, thus influencing the clarified water turbidity.
5) De-ionized water
6) Turbidity meter
7) pH meter

8) magnetic stirrer
9) 1-5 ml auto pipette
10) 1 x stop watch
11) 1 x gram scale
12) Weighing boats
13) 6 x 500 ml conical flask, 2 x 1000 ml conical flasks, 2 x 1000 ml volumetric flask, 6 x 50 ml sampling beakers, 6 x filter papers

Preparation of reagents

0.5 g/l Superfloc SF-A110 (Organic Flocculent Aid, OFA)

- Measure and record the pH of de-ionized water.
- Pour 1000 ml of de-ionized water into a 1000 ml conical flask and place that on a magnetic stirrer.
- Switch on the magnetic stirrer. It is recommended that the heater be switched on and adjusted to the plant ambient temperature.
- Weigh 1 g of caustic granules and pour into the stirred de-ionised water.
- Weigh 0.5 g of Superfloc SF-A110 powder using a weighing boat and *slowly* pour the weighed mass into the continuously stirred de-ionized water.
- The slow pouring of the OFA (organic flocculent aid) is to prevent the formation of 'fish eyes'. The mixture should be allowed to mix for 4 to 5 hours to allow for complete homogenization.

100 g/l Aluminium Sulphate (Coagulant)

- Pour 500 ml of de-ionized water into an empty 1000 ml volumetric flask.
- Pour 222 ml of liquid aluminium sulphate solution into the half-full volumetric flask.
- Close the volumetric flask with a stopper and shake the mixture until it is well mixed. Then fill-up the volumetric flask with de-ionized water up to the 1000 ml mark.

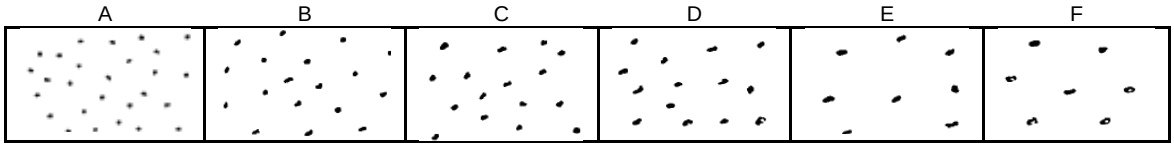
Jar test procedures

Determining the optimum alum dose

1. Number the empty 2 L beakers from 1-6 with a marker and centre them in ascending order under the 6-place laboratory stirrer.
2. Pour raw water up to the 2 L mark for all six beakers. Make sure the raw water sample is properly mixed before use.
3. Switch on the stirrer unit and adjust the stirrer revolution counter to 300 rpm to produce the required agitation intensity, $\overline{G}$.
4. Pipette 0.2 ml of the prepared aluminium sulphate solution into the 2 L beaker No. 2 using an auto pipette. Increase the dosage by 0.2 ml into each beaker in ascending order so that beaker No.6 has a volume of 1.0 ml. This step should be done as accurately and as quickly as possible so that the mixing

time in each beaker is almost the same. Note that beaker no.1 serves as a control and is therefore not dosed with alum, the alum dose from the second beaker to the last beaker would be from 10 mg/ to 50 mg/l.

5. Immediately after the dosing is finished start the stop watch, t = 0.
6. High Intensity mixing of alum should be set for 2 minutes, at t = 2 minutes lower the stirrer mixing speed to 40 rpm.
7. The duration of low intensity mixing is 12 minutes. Observe and note the size of the flocs formed in each beaker just before switching off the stirrer unit at t = 14 minutes.
8. The flocs are now allowed to settle for a maximum settling time of 15 minutes (t = 29 minutes). Observe and note the settling rate of flocs, e.g. slow, moderate, fast or very fast and the size of flocs formed, e.g. type A-F, A being the smallest size and F being the largest.



9. After the settling time has elapsed, sample 50 ml from the 2 L beakers using 50 ml sampling beakers and thereafter measure and record the clarified water turbidity for obtained from each beaker.
10. Thereafter, filter the remaining contents of each 2 L beaker into 500 ml conical flasks and measure the filtered water turbidity, pH and temperature for each beaker.

Determining the optimum OFA dose (if OFA is to be dosed in the HR-CSAV)

1. Repeat steps 1-3 from "*Determining the Optimum Alum Dose"* procedure, as given above.
2. Dose the optimum alum dose in all six 2 L beakers (as determined from the procedure for "*Determining the optimum alum dose")*. This step should be done as accurately and as quickly as possible so that the mixing time in each beaker is almost the same
3. Immediately after the dosing is complete, start the stop watch, t = 0
4. High Intensity mixing of alum should be set for 2 minutes.
5. After 2 minutes of high intensity mixing, immediately dose OFA from 10 mg/l to 60 mg/l (in 10 mg/l increments) from the first to the last beaker respectively. The desired alum-OFA high intensity mixing is 30 seconds but should not exceed 1 minute. *Note: this step should be done as accurately and as quickly as possible so that the mixing time in each beaker is almost the same*.
6. At t = 2.5 minutes lower the stirrer mixing speed to 40 rpm.
7. Repeat steps 7-10 in the procedure for "*Determining the Optimum Alum Dose"* but *note that the time milestones would increase by half a minute due to the added 30 seconds of the OFA high intensity mixing*.

Procedure for determining the optimum mixing intensity (when required)

1. Repeat steps 1-2 for "*Determining the Optimum Alum Dose"* procedure, as given above.
2. Switch on the stirrer unit and adjust the stirrer revolution counter to 140rpm for beaker No. 1, increasing the speed by 40rpm in each beaker in ascending order to vary the agitation intensity, $\overline{G}$, in each jar. Beaker No.5 will have a stirrer speed of 300rpm.
3. Dose the optimum alum dose in all six 2 L beakers (as determined from the procedure for "*Determining the Optimum Alum Dose")*. This step should be done as accurately and as quickly as possible so that the mixing time in each beaker is almost the same
4. Immediately after the dosing is complete, start the stop watch, t = 0
5. High Intensity mixing of alum should be set for 2 minutes.
6. After 2 minutes of high intensity mixing, immediately dose the optimum OFA dose in all six 2 L beakers (as determined from the procedure for "*Determining the optimum OFA dose")*. The desired alum-OFA high intensity mixing is 30 seconds but should not exceed 1 minute. This step should be done as accurately and as quickly as possible so that the mixing time in each beaker is almost the same
7. At t = 2.5 minutes lower the stirrer mixing speed to 40 rpm.
8. Repeat steps 7-10 in the procedure for "*Determining the optimum alum dose"* but *note that the time milestones would increase by half a minute due to the added 30 seconds of the OFA high intensity mixing*.

APPENDIX C: Raw Data for Plant Optimisation Trials

Jar tests at Hazelmere WW

DETERMINING OPTIMUM ALUMINIUM SULPHATE DOSAGE AT LOW RAW WATER TURBIDITY						
Date 2010/06/15						
Aluminium Sulphate (g/l)	100		OFA pH	12.76		
OFA Superfloc SF-A 110 (g/l)	0.5		Raw water pH	7.48		
De-ionised water pH	7.95		Raw water Turb. (NTU)	4.73		
Sample volume (l)	2					
Sample	**1**	**2**	**3**	**4**	**5**	**6**
$Al_2(SO_4)_3$ volume added (ml)	0	0.2	0.4	0.6	0.8	1
$Al_2(SO_4)_3$ dose (mg/l)	0	10	20	30	40	50
OFA SF-A 110 volume added (ml)	1	1	1	1	1	1
OFA SF-A 110 dosage (ml)	0.25	0.25	0.25	0.25	0.25	0.25
Clarified water turbidity (NTU)	4.71	2.52	0.76	1.56	1.71	1.72
Temperature ^{0}C	21.7	21.8	21.7	22.1	22.3	21.7
pH	8.15	7.55	7.15	6.97	6.76	6.41
Settling rate	no settling	slow	moderate	very slow	very slow	very slow
Block type	<A	C	D	B	B	B
Filtered water turbidity (NTU)	2.98	0.56	0.31	0.2	0.12	0.1

DETERMINING OPTIMUM OFA DOSAGE AT LOW RAW WATER TURBIDITY						
Date 2010/06/15						
Aluminium Sulphate (g/l)	100		OFA pH	12.76		
OFA Superfloc SF-A 110 (g/l)	0.5		Raw water pH	7.17		
De-ionised water pH	7.95		Raw water Turb. (NTU)	4.75		
Sample volume (l)	2					
Sample	**1**	**2**	**3**	**4**	**5**	**6**
OFA SF-A 110 volume added (ml)	0.6	0.8	1	1.2	1.4	1.6
OFA SF-A110 dosage (mg/l)	0.15	0.2	0.25	0.3	0.35	0.4
$Al_2(SO_4)_3$ volume added (ml)	0.4	0.4	0.4	0.4	0.4	0.4
$Al_2(SO_4)_3$ dosage (mg/l)	20	20	20	20	20	20
Settled turbidity (NTU)	1.24	0.56	0.54	0.59	0.59	0.62
Temperature ^{0}C	21.3	21.4	22.2	22.5	22.4	22.8
pH	7.05	6.9	6.94	6.97	7.04	7.09
Settling rate	mode-rate	mode-rate	mode-rate	mode-rate	mode-rate	moderate
Block type	C	D	D	D	D	D
Filtered turbidity (NTU)	0.3	0.37	0.31	0.27	0.28	0.23

EFFECT OF VARYING MIXING INSTENSITY ON TURBIDITY AT LOW RAW WATER TURBIDITY

Date 2010/07/06

Aluminium Sulphate (g/l)	100		OFA pH	12.45
OFA Superfloc SF-A 110 (g/l)	0.5		Raw water pH	7.41
De-ionised water pH	7.07		Raw water Turb. (NTU)	5.3
Sample volume (l)	2			
Lime (g/l)	1			

Sample	**1**	**2**	**3**	**4**	**5**
$Al_2(SO_4)_3$ volume added (ml)	0.4	0.4	0.4	0.4	0.4
$Al_2(SO_4)_3$ dosage (mg/l)	20	20	20	20	20
OFA SF-A 110 volume added (ml)	1	1	1	1	1
OFA SF-A 110 dosage (mg/l)	0.25	0.25	0.25	0.25	0.25
Lime volume added (ml)	8	8	8	8	8
Lime dosage (mg/l)	4	4	4	4	4
Stirrer speed (rpm)	140	180	220	260	300
Mixing intensity, G (s^{-1})	156	208	270	340	390
Settled turbidity (NTU)	1.45	1.25	1.16	0.87	0.86
Residual Aluminium (mg/l Al^{3+})	0.065	0.068	0.07	0.075	0.073
Temperature ^0C	21.2	21	21.3	21.4	21.4
pH	7.2	7.2	7.16	7.22	7.24
Settling rate	moderate	fast	fast	Very fast	Very fast
Block type	C/D	D	D	D	D
Filtered turbidity (NTU)	0.24	0.25	0.24	0.21	0.18

Settling Tests at Umvoti WW

Settling rate test at 7 m/h during low raw water turbidity at Umvoti WW			
Aluminium Sulphate/Alum dose(mg/l)		30	
OFA Superfloc SF-A 110 dose (mg/l)		0.1	
Raw water turbidity (NTU)		14	
Raw water pH		7.73	
Sample time (min)	Settling distance (cm)	Settling velocity (cm/min)	Average Turbidity (NTU)
1	10	10	12.83
2.5	10	4	9.48
5	10	2	6.58
10	10	1	4.03
20	10	0.5	1.49

Settling rate test at 7 m/h during high raw water turbidity at Umvoti WW			
Aluminium Sulphate/Alum dose(mg/l)		50	
OFA Superfloc SF-A 110 dose (mg/l)		0.4	
Raw water turbidity (NTU)		157	
Raw water pH		7.27	
Sample time (min)	Settling distance (cm)	Settling velocity (cm/min)	Average Turbidity (NTU)
0	10	0	69.3
1	10	10	4.22
3	10	3.3	1.67
5	10	2.0	1.7
7	10	1.4	1.67
9	10	1.1	1.69
11	10	0.91	1.53
13	10	0.77	1.50
20	10	0.5	1.55

Tracer Test Data

Raw water flow rate	m^3/d	480
Mass lithium chloride used	g	32
RESULTS		
Sample	**Time (min)**	**Measured Li concentration (mg/l)**
0	0	0
1	0.5	0
2	1	0
3	1.5	0
4	2	0
5	2.5	0
6	3	0
7	3.5	0.06
8	4	0.09
9	4.5	0.09
10	5	0.11
11	7	0.2
12	9	0.38
13	11	0.5
14	13	0.58
15	15	0.65
16	17	0.66
17	19	0.74
18	21	0.76
19	23	0.71
20	25	0.71
21	27	0.67
22	29	0.66
23	31	0.65
24	33	0.58
25	35	0.55
26	40	0.5
27	45	0.41
28	50	0.3
29	55	0.23
30	60	0.19
31	65	0.15
32	70	0.12
33	75	0.09
34	80	0.08
35	85	0.06
36	90	0
37	95	0
38	100	0
39	105	0
40	110	0
41	115	0
42	120	0
Raw water (background)		0
Desludge1		0
Desludge 2		0
Desludge 3		0

Jar tests at Umvoti WW

JAR TEST WITH HIGH MIXING INTENSITY FOR 2 MINS					
alum dose (mg/l)	OFA dose 0.1 mg/l	OFA dose 0.2 mg/l	OFA dose 0.4 mg/l	OFA dose 0.6 mg/l	OFA dose 1.0 mg/l
	Clarified water turbidity (NTU)				
10	12.1	16.1	9.85	16.7	16.1
20	2.82	4.97	3.25	3.07	4.6
30	0.94	1.88	1.58	1.64	1.85
40	0.67	1.2	1.02	1.16	1.12
50	0.83	0.79	0.68	0.82	0.85
60	6.72	1.08	1.51	0.6	0.78

JAR TEST WITH HIGH MIXING INTENSITY FOR 7.5 MINS					
alum dose (mg/l)	OFA dose 0.1 mg/l	OFA dose 0.2 mg/l	OFA dose 0.4 mg/l	OFA dose 0.6 mg/l	OFA dose 1.0 mg/l
	Clarified water turbidity (NTU)				
10	3.55	5.01	11.2	13.3	17.1
20	1.02	1.53	2.88	3.24	3.87
30	0.51	0.71	1.05	1.15	1.51
40	0.43	0.53	0.75	0.92	1.22
50	0.42	0.42	0.58	0.68	1.02
60	0.33	0.38	0.47	0.57	0.72

JAR TEST WITH HIGH MIXING INTENSITY FOR 16 MINS					
alum dose (mg/l)	OFA dose 0.1 mg/l	OFA dose 0.2 mg/l	OFA dose 0.4 mg/l	OFA dose 0.6 mg/l	OFA dose 1.0 mg/l
	Clarified Turbidity (NTU)	Clarified Turbidity (NTU)	Clarified Turbidity (NTU)	Clarified Turbidity (NTU)	Clarified Turbidity (NTU)
10	17.2	11.9	21.8	24.2	29
20	2.92	2.42	3.94	3.95	7.51
30	0.62	0.78	1.32	1.55	2.7
40	0.38	0.58	0.88	1.25	1.75
50	0.32	0.4	0.68	0.88	1.35
60	0.36	0.58	0.56	0.75	1.06

APPENDIX D: Raw Data from HR-CSAV Plant Trials

Plant Trials at Hazelmere WW

Effect of increasing the raw water flow on the clarified & supernatant water turbidity at Hazelmere WW						
Date	**Raw water turbidity (NTU)**	**Clarified water turbidity (NTU)**	**Supernatant water turbidity (NTU)**	**Flow rate (l/h) /1000**	**OFA dosage (mg/l)**	**Alum dosage (mg/l)**
2010/05/09 09:00	2.4	3.62	0.86	10	0.25	21.79
2010/05/09 10:00	2.2	3.68	0.85	10	0.22	18.45
2010/05/09 11:00	2.3	3.64	0.86	10	0.25	18.45
2010/05/09 12:00	2.17	3.57	0.78	10	0.25	24.60
2010/05/09 13:00	2.29	3.79	0.82	10	0.25	18.45
2010/05/09 14:00	2.25	3.6	0.7	10	0.25	24.60
2010/05/09 15:00	2.27	3.73	0.69	11	0.25	16.77
2010/05/10 09:00	2.4	3.97	1.01	11	0.26	20.78
2010/05/10 10:00	2.19	3.81	0.86	11	0.25	21.57
2010/05/10 11:00	2.37	4.26	0.78	11	0.25	22.36
2010/05/10 12:00	2.51	3.63	0.8	11	0.28	16.77
2010/05/10 13:00	2.27	3.62	0.79	11	0.25	22.36
2010/05/10 14:00	2.36	3.87	0.8	12	0.25	22.36
2010/05/11 09:00	2.31	3.68	0.88	12	0.24	21.48
2010/05/11 10:00	2.43	3.61	0.82	12	0.25	22.36
2010/05/11 11:00	2.31	3.57	0.81	12	0.25	22.36
2010/05/11 12:00	2.31	3.6	0.79	12	0.25	22.36
2010/05/11 13:00	2.41	3.75	0.78	12	0.23	22.36
2010/05/11 14:00	2.37	3.72	0.82	12	0.25	16.77
2010/05/11 15:00	2.48	3.81	0.79	14	0.24	21.96
2010/05/12 09:00	2.4	3.62	0.8	14	0.24	18.13
2010/05/12 10:00	2.27	3.67	0.82	14	0.23	21.08
2010/05/12 11:00	2.48	3.63	0.79	14	0.24	17.57
2010/05/12 12:00	2.44	3.72	0.82	14	0.24	17.57
2010/05/12 13:00	2.56	3.88	0.8	14	0.26	21.96
2010/05/12 14:00	2.51	3.98	0.98	14	0.26	21.96
2010/05/12 15:00	2.54	3.96	0.81	15	0.26	16.40
2010/05/13 11:00	2.31	3.73	1.01	15	0.26	20.50
2010/05/13 12:00	2.23	3.76	0.95	15	0.26	20.50
2010/05/13 13:00	2.23	3.73	1.18	15	0.26	20.50
2010/05/13 14:00	2.51	3.91	0.96	15	0.26	16.40
2010/05/13 15:00	2.52	3.87	0.95	15	0.24	20.50
2010/05/13 16:00	2.46	4.14	0.97	15	0.26	20.50
2010/05/13 17:00	2.36	3.79	0.9	10	0.31	18.45

Effect of increasing the OFA dosage on the turbidity of the clarified & supernatant water turbidity at Hazelmere WW						
Date	**Raw water turbidity (NTU)**	**Clarified water turbidity (NTU)**	**Supernatant water turbidity (NTU)**	**Flow rate (l/h) /1000**	**OFA dosage (mg/l)**	**Alum dosage (mg/l)**
2010/05/14 09:00	2.16	3.65	1.02	10	0.30	23.83
2010/05/14 10:00	2.1	3.6	0.87	10	0.31	24.60
2010/05/14 11:00	2.13	3.56	0.75	10	0.31	18.45
2010/05/14 12:00	2.14	3.58	0.77	10	0.31	18.45
2010/05/14 13:00	2.17	3.53	0.78	10	0.31	18.45
2010/05/14 14:00	2.31	3.75	0.7	10	0.31	18.45
2010/05/14 15:00	2.41	3.94	0.73	10	0.34	18.45
2010/05/17 09:00	2.72	4.53	0.94	10	0.34	24.51
2010/05/17 10:00	2.74	4.55	0.96	10	0.34	24.60
2010/05/17 11:00	2.74	4.32	0.91	10	0.34	18.45
2010/05/17 12:00	2.75	4.33	0.93	10	0.34	24.60
2010/05/17 13:00	2.71	4.19	0.85	10	0.34	18.45
2010/05/17 14:00	2.65	4.09	0.77	10	0.34	18.45
2010/05/17 15:00	2.71	4.23	0.79	10	0.40	18.45
2010/05/18 09:00	2.28	4.03	0.91	10	0.38	23.58
2010/05/18 10:00	2.29	4.04	0.81	10	0.39	21.01
2010/05/18 11:00	2.48	3.82	0.8	10	0.40	18.45
2010/05/18 12:00	2.58	4	0.82	10	0.40	18.45
2010/05/18 13:00	2.49	3.92	0.88	10	0.40	18.45
2010/05/18 14:00	2.55	4.02	0.86	10	0.37	24.60
2010/05/18 15:00	2.4	4.09	0.85	10	0.40	24.60
2010/05/19 09:00	3.43	4.36	0.93	10	0.42	23.58
2010/05/19 10:00	3.21	4.87	0.96	10	0.40	18.45
2010/05/19 11:00	2.87	4.68	0.94	10	0.43	24.60
2010/05/19 12:00	2.99	4.75	0.95	10	0.43	24.60
2010/05/19 13:00	3.15	4.76	0.94	10	0.46	18.45
2010/05/19 14:00	3.3	4.99	0.92	10	0.46	18.45
2010/05/19 15:00	3.33	4.88	0.89	10	0.46	18.45
2010/05/20 09:00	3.41	4.93	0.97	10	0.499	23.23
2010/05/20 10:00	3.23	4.92	1.02	10	0.492	18.45
2010/05/20 11:00	3.24	4.73	1.03	10	0.492	18.45
2010/05/20 12:00	3.28	4.81	0.97	10	0.494	24.60
2010/05/20 13:00	3.26	4.73	0.98	10	0.492	18.45
2010/05/20 14:00	3.25	4.85	0.98	10	0.492	18.45
2010/05/20 15:00	3.31	4.91	0.97	10	0.246	30.75

Effect of increasing the alum dosage on the clarified & supernatant water turbidity at Hazelmere WW						
Date	**Raw water turbidity (NTU)**	**Clarified water turbidity (NTU)**	**Supernatant water turbidity (NTU)**	**Flow rate (l/h) /1000**	**OFA dosage (mg/l)**	**Alum dosage (mg/l)**
2010/05/21 09:00	3.05	4.68	1.1	10	0.268	23.92
2010/05/21 10:00	3.06	4.69	1.03	10	0.277	24.60
2010/05/21 11:00	3.02	4.89	1.1	10	0.246	24.60
2010/05/21 12:00	3.06	4.68	1.02	10	0.246	24.60
2010/05/21 13:00	3.06	4.83	0.96	10	0.246	24.60
2010/05/21 14:00	3.09	4.75	1.05	10	0.246	24.60
2010/05/21 15:00	3.12	4.82	1.01	10	0.246	30.75
2010/05/25 09:00	3.44	5.25	1.21	10	0.269	27.98
2010/05/25 10:00	3.48	5.6	1.23	10	0.185	24.60
2010/05/25 11:00	3.42	5.49	1.22	10	0.246	30.75
2010/05/25 12:00	3.6	5.57	1.3	10	0.246	24.60
2010/05/25 13:00	3.52	5.45	1.31	10	0.246	30.75
2010/05/25 14:00	3.62	5.36	1.2	10	0.246	30.75
2010/05/27 09:00	4.12	6.41	1.5	10	0.244	29.38
2010/05/27 10:00	4.15	6.48	1.59	10	0.246	36.90
2010/05/27 11:00	4.2	6.38	1.51	10	0.246	36.90
2010/05/27 12:00	4.06	6.41	1.56	10	0.246	36.90
2010/05/27 13:00	4.19	6.54	1.57	10	0.246	36.90
2010/05/27 14:00	4.26	6.69	1.48	10	0.246	36.90
2010/05/27 15:00	4.36	6.6	1.48	10	0.246	43.05
2010/06/01 09:30	5.78	9.47	2.6	10	0.248	36.90
2010/06/01 10:30	5.85	9.47	2.57	10	0.246	43.05
2010/06/01 11:30	6.04	9.76	2.73	10	0.246	43.05
2010/06/01 12:30	6.26	9.92	3.05	10	0.246	43.05
2010/06/01 13:30	6.31	10.2	3.21	10	0.246	43.05
2010/06/01 14:30	6.4	10.3	3.38	10	0.246	43.05
2010/06/01 15:30	6.35	11	3.28	10	0.246	49.20
2010/06/02 09:00	6.37	11.2	4.91	10	0.247	42.93
2010/06/02 10:00	6.22	11.6	4.65	10	0.246	49.20
2010/06/02 11:00	6	11.8	4.77	10	0.246	49.20
2010/06/02 12:00	5.88	11.5	5.27	10	0.246	49.20
2010/06/02 13:00	5.87	11.6	5.44	10	0.246	49.20
2010/06/02 14:00	6.11	11.7	5.4	10	0.246	49.20
2010/06/02 15:00	6.32	12	5.52	10	0.246	49.20

Plant Trials at Umvoti WW

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
21/01/2013 07:06:29	7.55	85.86
21/01/2013 07:21:29	7.87	82.38
21/01/2013 07:36:29	6.25	91.15
21/01/2013 07:51:29	6.78	84.89
21/01/2013 08:06:29	6.43	84.13
21/01/2013 08:21:29	6.22	82.08
21/01/2013 08:36:29	4.51	83.55
21/01/2013 08:51:29	8.15	86.46
21/01/2013 09:06:29	7.34	99.86
21/01/2013 09:21:29	6.20	82.83
21/01/2013 09:36:29	5.82	80.87
21/01/2013 09:51:29	5.24	80.16
21/01/2013 10:06:29	4.84	77.41
21/01/2013 10:21:29	6.07	78.75
21/01/2013 10:36:29	4.60	78.30
21/01/2013 10:51:29	4.12	79.18
21/01/2013 11:06:29	4.16	77.82
21/01/2013 11:21:29	4.77	76.68
21/01/2013 11:36:29	3.99	75.63
21/01/2013 11:51:29	4.26	74.52
21/01/2013 12:06:29	4.02	76.96
21/01/2013 12:21:29	4.30	74.87
21/01/2013 12:36:29	3.84	73.81
21/01/2013 12:51:29	3.77	74.35
21/01/2013 13:06:29	3.37	73.24
21/01/2013 13:21:29	3.26	80.58
21/01/2013 13:36:29	3.57	79.30
21/01/2013 13:51:29	3.70	75.40
21/01/2013 14:06:29	3.25	76.72
21/01/2013 14:21:29	3.42	75.97
21/01/2013 14:36:29	3.59	76.83
21/01/2013 14:51:29	4.20	75.90
21/01/2013 15:06:29	3.83	74.29
21/01/2013 15:21:29	3.79	75.48
21/01/2013 15:36:29	4.29	75.43
21/01/2013 15:51:29	4.53	76.30
21/01/2013 16:06:29	3.54	74.45
21/01/2013 16:21:29	3.79	72.78
21/01/2013 16:36:29	3.71	73.21
21/01/2013 16:51:29	3.63	72.84
21/01/2013 17:06:29	3.28	73.33
21/01/2013 17:21:29	3.12	72.46
21/01/2013 17:36:29	3.16	72.00
21/01/2013 17:51:29	3.35	72.12
21/01/2013 18:06:29	3.22	73.11
21/01/2013 18:21:29	2.88	72.57
21/01/2013 18:36:29	3.32	71.58
21/01/2013 18:51:29	2.77	71.35
21/01/2013 19:06:29	3.63	72.15
21/01/2013 19:21:29	3.07	71.23

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
21/01/2013 19:36:29	3.44	71.01
21/01/2013 19:51:29	2.87	70.70
21/01/2013 20:06:29	2.89	70.08
21/01/2013 20:21:29	2.86	70.84
21/01/2013 20:36:29	2.91	71.81
21/01/2013 20:51:29	3.08	70.97
21/01/2013 21:06:29	2.90	70.11
21/01/2013 21:21:29	3.01	69.61
21/01/2013 21:36:29	2.96	70.75
21/01/2013 21:51:29	3.22	68.75
21/01/2013 22:06:29	3.03	69.38
21/01/2013 22:21:29	2.96	68.42
21/01/2013 22:36:29	3.05	68.67
21/01/2013 22:51:29	3.06	67.84
21/01/2013 23:06:29	3.14	68.07
21/01/2013 23:21:29	3.09	69.55
21/01/2013 23:36:29	2.98	69.01
21/01/2013 23:51:29	3.28	69.59
22/01/2013 00:06:29	3.12	69.72
22/01/2013 00:21:29	3.14	68.28
22/01/2013 00:36:29	3.23	68.91
22/01/2013 00:51:29	3.24	69.08
22/01/2013 01:06:29	3.36	69.35
22/01/2013 01:21:29	3.08	69.50
22/01/2013 01:36:29	3.12	69.47
22/01/2013 01:51:29	3.28	72.90
22/01/2013 02:06:29	3.47	72.64
22/01/2013 02:21:29	3.58	72.11
22/01/2013 02:36:29	3.50	72.22
22/01/2013 02:51:29	3.60	73.97
22/01/2013 03:06:29	3.59	73.88
22/01/2013 03:21:29	3.49	74.86
22/01/2013 03:36:29	3.59	76.20
22/01/2013 03:51:29	6.02	92.50
22/01/2013 04:06:29	21.88	77.31
22/01/2013 04:21:29	7.90	77.39
22/01/2013 04:36:29	6.64	76.06
22/01/2013 04:51:29	6.13	75.84
22/01/2013 05:06:29	6.75	75.35
22/01/2013 05:21:29	6.71	86.29
22/01/2013 05:36:29	6.36	76.80
22/01/2013 05:51:29	6.11	76.64
22/01/2013 06:06:29	6.14	78.07
22/01/2013 06:21:29	6.17	77.61
22/01/2013 06:36:29	6.47	77.62
22/01/2013 06:51:29	6.43	79.13
22/01/2013 07:06:29	6.06	78.20
22/01/2013 13:45:23	5.97	76.58
22/01/2013 14:00:23	5.87	76.52
22/01/2013 14:15:23	5.92	77.01
22/01/2013 14:30:23	5.59	76.19
22/01/2013 14:45:23	5.43	74.23

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
22/01/2013 15:00:23	5.84	75.93
22/01/2013 15:15:23	6.36	75.54
22/01/2013 15:30:23	4.93	74.91
22/01/2013 15:45:23	5.14	75.09
22/01/2013 16:00:23	4.73	74.23
22/01/2013 16:15:23	4.78	73.87
22/01/2013 16:30:23	4.50	72.65
22/01/2013 16:45:23	4.50	72.73
22/01/2013 17:00:23	4.62	71.81
22/01/2013 17:15:23	4.97	72.18
22/01/2013 17:30:23	4.44	71.43
22/01/2013 17:45:23	3.95	74.50
22/01/2013 18:00:23	3.49	72.39
22/01/2013 18:15:23	3.56	73.27
22/01/2013 18:30:23	3.42	72.05
22/01/2013 18:45:23	3.11	72.30
22/01/2013 19:00:23	3.14	71.31
22/01/2013 19:15:23	3.24	71.97
22/01/2013 19:30:23	3.19	70.67
22/01/2013 19:45:23	3.20	70.83
22/01/2013 20:00:23	3.34	71.92
22/01/2013 20:15:23	3.16	71.88
22/01/2013 20:30:23	3.34	72.38
22/01/2013 20:45:23	3.28	71.47
22/01/2013 21:00:23	3.56	70.33
22/01/2013 21:15:23	4.03	69.70
22/01/2013 21:30:23	3.47	70.40
22/01/2013 21:45:23	3.47	68.49
22/01/2013 22:00:23	3.48	67.60
22/01/2013 22:15:23	3.56	68.38
22/01/2013 22:30:23	3.45	66.19
22/01/2013 22:45:23	3.57	66.83
22/01/2013 23:00:23	3.55	66.00
22/01/2013 23:15:23	3.66	65.93
22/01/2013 23:30:23	3.57	64.69
22/01/2013 23:45:23	3.70	64.30
23/01/2013 00:00:23	3.83	65.51
23/01/2013 00:15:23	3.84	65.05
23/01/2013 00:30:23	3.72	64.41
23/01/2013 00:45:23	3.88	63.36
23/01/2013 01:00:23	4.31	65.02
23/01/2013 01:15:23	3.91	64.92
23/01/2013 01:30:23	3.98	63.71
23/01/2013 01:45:23	3.79	64.21
23/01/2013 02:00:23	3.94	64.19
23/01/2013 02:15:23	3.96	63.00
23/01/2013 02:30:23	3.92	62.68
23/01/2013 02:45:23	4.01	62.29
23/01/2013 03:00:23	3.92	63.10
23/01/2013 03:15:23	3.99	63.19
23/01/2013 03:30:23	3.88	62.53
23/01/2013 03:45:23	3.99	63.24

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
23/01/2013 04:00:23	4.06	64.05
23/01/2013 04:15:23	4.34	61.85
23/01/2013 04:30:23	4.29	63.00
23/01/2013 04:45:23	4.22	62.06
23/01/2013 05:00:23	4.27	61.70
23/01/2013 05:15:23	4.49	62.62
23/01/2013 05:30:23	4.64	62.36
23/01/2013 05:45:23	4.45	65.79
23/01/2013 06:00:23	4.69	62.96
23/01/2013 06:15:23	4.42	62.46
23/01/2013 06:30:23	4.71	62.31
23/01/2013 06:45:23	4.71	63.59
23/01/2013 07:00:23	4.54	61.64
23/01/2013 07:15:23	4.56	61.79
23/01/2013 07:30:23	4.68	61.46
23/01/2013 07:45:23	4.42	61.83
23/01/2013 08:00:23	4.51	59.91
23/01/2013 08:15:23	4.21	61.88
23/01/2013 08:30:23	4.60	62.63
23/01/2013 08:45:23	4.57	60.68
23/01/2013 09:00:23	4.79	61.88
23/01/2013 09:15:23	5.05	65.01
23/01/2013 09:30:23	5.36	61.76
23/01/2013 09:45:23	4.64	63.79
23/01/2013 10:00:23	4.65	63.20
23/01/2013 10:15:23	5.54	67.06
23/01/2013 10:30:23	5.53	68.12
23/01/2013 10:45:23	5.79	64.23
23/01/2013 11:00:23	5.58	63.78
23/01/2013 11:15:23	6.11	65.04
23/01/2013 11:30:23	5.72	64.84
25/01/2013 15:00:37	2.96	67.02
25/01/2013 15:15:37	2.61	65.11
25/01/2013 15:30:37	2.36	65.42
25/01/2013 15:45:37	2.20	63.85
25/01/2013 16:00:37	2.08	62.96
25/01/2013 16:15:37	2.04	63.62
25/01/2013 16:30:37	1.92	64.09
25/01/2013 16:45:37	1.96	63.21
25/01/2013 17:00:37	1.95	63.71
25/01/2013 17:15:37	1.92	64.38
25/01/2013 17:30:37	1.82	62.55
25/01/2013 17:45:37	1.79	61.75
25/01/2013 18:00:37	1.71	62.55
25/01/2013 18:15:37	1.76	62.31
25/01/2013 18:30:37	1.71	63.02
25/01/2013 18:45:37	1.66	62.94
25/01/2013 19:00:37	1.69	62.92
25/01/2013 19:15:37	1.65	61.49
25/01/2013 19:30:37	1.72	61.56
25/01/2013 19:45:37	1.59	58.88

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
25/01/2013 20:00:37	1.62	60.31
25/01/2013 20:15:37	1.64	61.10
25/01/2013 20:30:37	1.64	59.65
25/01/2013 20:45:37	1.69	59.08
25/01/2013 21:00:37	1.66	57.95
25/01/2013 21:15:37	1.61	56.89
25/01/2013 21:30:37	1.69	56.19
25/01/2013 21:45:37	1.64	55.47
25/01/2013 22:00:37	1.76	54.99
25/01/2013 22:15:37	1.77	54.81
25/01/2013 22:30:37	1.67	54.07
25/01/2013 22:45:37	1.73	52.24
25/01/2013 23:00:37	1.73	51.56
25/01/2013 23:15:37	1.76	50.11
25/01/2013 23:30:37	1.70	50.64
25/01/2013 23:45:37	1.77	51.27
26/01/2013 00:00:37	1.74	50.14
26/01/2013 00:15:37	1.78	50.19
26/01/2013 00:30:37	1.75	50.06
26/01/2013 00:45:37	1.79	48.93
26/01/2013 01:00:37	1.78	50.02
26/01/2013 01:15:37	1.81	50.04
26/01/2013 01:30:37	1.77	49.18
26/01/2013 01:45:37	1.82	49.31
26/01/2013 02:00:37	1.90	49.29
26/01/2013 02:15:37	1.89	48.23
26/01/2013 02:30:37	1.89	47.48
26/01/2013 02:45:37	1.86	47.75
26/01/2013 03:00:37	1.80	47.59
26/01/2013 03:15:37	1.90	48.24
26/01/2013 03:30:37	1.83	48.90
26/01/2013 03:45:37	1.90	49.85
26/01/2013 04:00:37	2.09	49.23
26/01/2013 04:15:37	1.95	50.15
26/01/2013 04:30:37	2.05	49.85
26/01/2013 04:45:37	2.18	48.34
26/01/2013 05:00:37	2.03	48.84
26/01/2013 05:15:37	2.10	48.36
26/01/2013 05:30:37	2.06	47.83
26/01/2013 05:45:37	2.04	48.47
26/01/2013 06:00:37	1.99	47.43
26/01/2013 06:15:37	2.03	50.02
26/01/2013 06:30:37	2.05	48.10
26/01/2013 06:45:37	2.01	48.94
26/01/2013 07:00:37	2.00	47.23
26/01/2013 07:15:37	2.09	48.20
26/01/2013 07:30:37	2.06	49.14
26/01/2013 07:45:37	2.05	48.45
26/01/2013 08:00:37	2.55	46.63
26/01/2013 08:15:37	1.76	45.73
26/01/2013 08:30:37	1.82	48.14
26/01/2013 08:45:37	3.58	48.88

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
26/01/2013 09:00:37	6.25	48.70
26/01/2013 09:15:37	10.98	49.27
08/02/2013 10:50:16	8.87	68.01
28/01/2013 16:16:11	7.22	49.81
28/01/2013 16:31:11	4.70	50.93
28/01/2013 16:46:11	4.13	52.56
28/01/2013 17:01:11	4.60	51.84
28/01/2013 17:16:11	4.67	54.32
28/01/2013 17:31:11	3.84	55.37
28/01/2013 17:46:11	3.79	59.38
28/01/2013 18:01:11	3.41	64.62
28/01/2013 18:16:11	3.07	70.35
28/01/2013 18:31:11	2.88	78.27
28/01/2013 18:46:11	3.07	88.38
28/01/2013 19:01:11	3.21	98.13
28/01/2013 19:16:11	3.47	99.85
28/01/2013 19:31:11	3.68	99.85
28/01/2013 19:46:11	4.08	99.85
28/01/2013 20:01:11	4.37	99.85
28/01/2013 20:16:11	4.84	99.85
28/01/2013 20:31:11	5.41	99.85
28/01/2013 20:46:11	6.05	99.85
28/01/2013 21:01:11	6.75	99.85
28/01/2013 21:16:11	7.65	99.85
28/01/2013 21:31:11	8.80	99.85
28/01/2013 21:46:11	9.50	99.85
28/01/2013 22:01:11	8.81	99.85
28/01/2013 22:16:11	8.36	99.85
28/01/2013 22:31:11	8.31	99.85
28/01/2013 22:46:11	8.80	99.85
28/01/2013 23:01:11	9.18	99.85
28/01/2013 23:16:11	9.93	99.85
28/01/2013 23:31:11	10.55	99.85
28/01/2013 23:46:11	11.13	99.85
29/01/2013 00:01:11	11.35	99.85
29/01/2013 00:16:11	11.58	99.85
29/01/2013 00:31:11	11.65	99.85
29/01/2013 00:46:11	12.20	99.85
29/01/2013 01:01:11	12.15	99.85
29/01/2013 01:16:11	12.23	99.85
29/01/2013 01:31:11	12.77	99.85
29/01/2013 01:46:11	13.02	99.85
29/01/2013 02:01:11	12.89	99.85
29/01/2013 02:16:11	12.90	99.85
29/01/2013 02:31:11	12.86	99.85
29/01/2013 02:46:11	12.81	99.85
29/01/2013 03:01:11	12.66	99.85
29/01/2013 03:16:11	12.91	99.85
29/01/2013 03:31:11	12.48	99.85
29/01/2013 03:46:11	12.12	99.85
29/01/2013 04:01:11	11.78	99.84

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
29/01/2013 04:16:11	11.17	99.84
29/01/2013 04:31:11	10.99	99.84
29/01/2013 04:46:11	10.89	99.85
29/01/2013 05:01:11	10.81	99.85
29/01/2013 05:16:11	10.32	99.85
29/01/2013 05:31:11	9.22	99.85
29/01/2013 05:46:11	8.21	99.85
29/01/2013 06:01:11	8.37	99.85
29/01/2013 06:16:11	8.30	99.85
29/01/2013 06:31:11	8.32	99.85
29/01/2013 06:46:11	8.39	99.85
29/01/2013 07:01:11	8.15	99.85
29/01/2013 07:16:11	8.18	99.85
29/01/2013 07:31:11	8.20	99.85
29/01/2013 07:46:11	7.39	99.85
29/01/2013 08:01:11	7.35	99.85
29/01/2013 08:16:11	7.17	99.85
29/01/2013 08:31:11	7.20	99.85
29/01/2013 08:46:11	6.96	99.85
29/01/2013 09:01:11	7.15	99.85
29/01/2013 09:16:11	6.72	99.85
29/01/2013 09:31:11	6.79	99.85
29/01/2013 09:46:11	6.51	99.85
29/01/2013 10:01:11	6.55	99.85
29/01/2013 10:16:11	6.34	99.85
29/01/2013 10:31:11	6.34	99.85
29/01/2013 10:46:11	6.20	99.85
29/01/2013 11:01:11	6.33	99.85
29/01/2013 11:16:11	6.12	99.85
29/01/2013 11:31:11	6.02	99.85
29/01/2013 11:46:11	5.85	99.85
29/01/2013 12:01:11	5.86	99.85
29/01/2013 12:16:11	5.42	99.85
29/01/2013 12:31:11	7.08	99.85
29/01/2013 12:46:11	6.77	99.85
29/01/2013 13:01:11	0.63	99.85
29/01/2013 13:16:11	0.59	99.85
29/01/2013 13:31:11	0.59	99.85
29/01/2013 13:46:11	49.93	4.66
29/01/2013 14:01:11	49.93	99.86
29/01/2013 14:16:11	7.08	99.85
29/01/2013 14:31:11	6.84	99.85
29/01/2013 14:46:11	6.75	99.85
29/01/2013 15:01:11	8.81	99.85
29/01/2013 15:16:11	6.59	99.85
29/01/2013 15:31:11	6.70	99.85
29/01/2013 15:46:11	6.46	99.85
29/01/2013 16:01:11	5.90	99.85
29/01/2013 16:10:04	6.28	99.85
29/01/2013 16:25:04	5.71	99.85
29/01/2013 16:40:04	5.45	99.85
29/01/2013 16:55:04	5.33	99.85

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
29/01/2013 17:10:04	5.22	99.85
29/01/2013 17:25:04	4.95	99.85
29/01/2013 17:40:04	4.84	99.85
29/01/2013 17:55:04	4.80	99.85
29/01/2013 18:10:04	4.82	99.85
29/01/2013 18:25:04	4.53	99.85
29/01/2013 18:40:04	4.45	99.85
29/01/2013 18:55:04	4.48	99.85
29/01/2013 19:10:04	4.44	99.85
29/01/2013 19:25:04	4.50	99.84
29/01/2013 19:40:04	4.29	99.85
29/01/2013 19:55:04	4.42	99.85
29/01/2013 20:10:04	4.55	99.85
29/01/2013 20:25:04	4.37	99.85
29/01/2013 20:40:04	4.59	99.85
29/01/2013 20:55:04	4.50	99.85
29/01/2013 21:10:04	4.26	99.85
29/01/2013 21:25:04	4.41	99.85
29/01/2013 21:40:04	4.44	99.85
29/01/2013 21:55:04	4.46	99.85
29/01/2013 22:10:04	4.35	99.85
29/01/2013 22:25:04	4.35	99.85
29/01/2013 22:40:04	4.39	99.85
29/01/2013 22:55:04	4.17	99.85
29/01/2013 23:10:04	4.66	99.85
29/01/2013 23:25:04	4.36	99.85
29/01/2013 23:40:04	4.43	99.85
29/01/2013 23:55:04	4.20	99.85
30/01/2013 00:10:04	4.51	99.85
30/01/2013 00:25:04	4.26	98.83
30/01/2013 00:40:04	4.40	97.98
30/01/2013 00:55:04	4.45	96.24
30/01/2013 01:10:04	4.37	95.95
30/01/2013 01:25:04	4.53	94.28
30/01/2013 01:40:04	4.57	94.52
30/01/2013 01:55:04	4.86	91.81
30/01/2013 02:10:04	4.51	90.61
30/01/2013 02:25:04	4.81	89.73
30/01/2013 02:40:04	4.46	89.02
30/01/2013 02:55:04	4.85	87.98
30/01/2013 03:10:04	4.67	87.67
30/01/2013 03:25:04	4.81	87.19
30/01/2013 03:40:04	4.74	87.38
30/01/2013 03:55:04	4.78	86.74
30/01/2013 04:10:04	4.84	85.73
30/01/2013 04:25:04	5.00	85.97
30/01/2013 04:40:04	4.65	86.78
30/01/2013 04:55:04	4.94	84.96
30/01/2013 05:10:04	5.13	82.05
30/01/2013 05:25:04	5.02	84.74
30/01/2013 05:40:04	5.10	87.59
30/01/2013 05:55:04	5.03	84.12

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
30/01/2013 06:10:04	5.06	83.53
30/01/2013 06:25:04	4.93	83.61
30/01/2013 06:40:04	4.77	82.48
30/01/2013 06:55:04	4.69	82.30
30/01/2013 07:10:04	5.07	83.70
30/01/2013 07:25:04	4.88	80.95
30/01/2013 07:40:04	4.72	80.48
30/01/2013 07:55:04	4.77	80.94
30/01/2013 08:10:04	4.95	82.55
30/01/2013 08:25:04	4.91	81.18
30/01/2013 08:40:04	4.97	83.52
30/01/2013 08:55:04	4.87	79.27
30/01/2013 09:10:04	4.83	80.82
30/01/2013 09:25:04	5.34	80.03
30/01/2013 09:40:04	5.15	79.82
30/01/2013 09:55:04	5.01	79.16
30/01/2013 10:10:04	5.46	73.76
30/01/2013 10:25:04	5.65	74.90
30/01/2013 10:40:04	5.39	76.82
30/01/2013 10:55:04	6.06	77.91
30/01/2013 11:10:04	5.35	77.10
30/01/2013 11:25:04	6.48	79.25
30/01/2013 11:40:04	6.24	77.37
30/01/2013 11:55:04	6.76	81.99
30/01/2013 12:10:04	5.66	77.23
30/01/2013 12:25:04	7.20	77.82
30/01/2013 12:40:04	6.76	77.17
30/01/2013 12:55:04	7.59	76.24
30/01/2013 13:10:04	6.13	76.77
30/01/2013 13:25:04	7.24	75.39
30/01/2013 13:34:17	6.90	74.88
30/01/2013 13:49:17	7.47	75.80
30/01/2013 14:04:17	6.62	74.69
30/01/2013 14:19:17	6.45	75.87
30/01/2013 14:34:17	6.53	75.27
30/01/2013 14:49:17	6.30	74.62
30/01/2013 15:04:17	7.30	76.60
30/01/2013 15:19:17	6.70	75.19
30/01/2013 15:34:17	6.56	74.70
30/01/2013 15:49:17	6.13	75.75
30/01/2013 16:04:17	6.20	75.46
30/01/2013 16:19:17	5.57	75.25
30/01/2013 16:34:17	5.38	75.24
30/01/2013 16:49:17	5.52	74.92
30/01/2013 17:04:17	5.76	75.11
30/01/2013 17:19:17	5.37	74.21
30/01/2013 17:34:17	5.29	74.81
30/01/2013 17:49:17	4.90	73.76
30/01/2013 18:04:17	5.07	72.59
30/01/2013 18:19:17	4.85	74.10
30/01/2013 18:34:17	4.63	77.38
30/01/2013 18:49:17	4.90	76.10

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
30/01/2013 19:04:17	4.89	75.73
30/01/2013 19:19:17	4.61	76.97
30/01/2013 19:34:17	4.60	76.48
30/01/2013 19:49:17	4.33	72.61
30/01/2013 20:04:17	4.20	74.47
30/01/2013 20:19:17	4.17	74.42
30/01/2013 20:34:17	3.93	74.66
30/01/2013 20:49:17	4.10	71.71
30/01/2013 21:04:17	4.34	71.57
30/01/2013 21:19:17	4.68	71.29
30/01/2013 21:34:17	4.24	68.85
30/01/2013 21:49:17	4.23	68.32
30/01/2013 22:04:17	4.49	67.15
30/01/2013 22:19:17	4.85	67.26
30/01/2013 22:34:17	5.24	66.37
30/01/2013 22:49:17	4.82	65.04
30/01/2013 23:04:17	5.26	63.96
30/01/2013 23:19:17	5.27	64.37
30/01/2013 23:34:17	5.24	62.58
30/01/2013 23:49:17	5.01	62.43
31/01/2013 00:04:17	5.29	63.15
31/01/2013 00:19:17	4.73	62.40
31/01/2013 00:34:17	5.40	60.09
31/01/2013 00:49:17	4.98	58.84
31/01/2013 01:04:17	5.29	58.12
31/01/2013 01:19:17	5.71	59.68
31/01/2013 01:34:17	5.42	59.13
31/01/2013 01:49:17	5.63	61.44
31/01/2013 02:04:17	5.56	58.79
31/01/2013 02:19:17	5.42	59.47
31/01/2013 02:34:17	5.55	58.90
31/01/2013 02:49:17	5.41	59.06
31/01/2013 03:04:17	5.37	58.63
31/01/2013 03:19:17	5.18	58.40
31/01/2013 03:34:17	5.89	58.79
31/01/2013 03:49:17	5.82	60.16
31/01/2013 04:04:17	6.14	60.85
31/01/2013 04:19:17	6.29	59.56
31/01/2013 04:34:17	6.50	58.56
31/01/2013 04:49:17	6.53	59.97
31/01/2013 05:04:17	6.32	59.04
31/01/2013 05:19:17	6.33	58.65
31/01/2013 05:34:17	6.36	58.73
31/01/2013 05:49:17	6.93	58.67
31/01/2013 06:04:17	6.95	58.71
31/01/2013 06:19:17	6.28	58.82
31/01/2013 06:34:17	6.79	57.00
31/01/2013 06:49:17	6.76	57.83
31/01/2013 07:04:17	6.67	57.95
31/01/2013 07:19:17	6.60	56.59
31/01/2013 07:34:17	5.98	58.34
31/01/2013 07:49:17	5.93	58.16

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
31/01/2013 08:04:17	5.79	57.59
31/01/2013 08:19:17	4.88	59.73
31/01/2013 08:34:17	3.92	55.95
31/01/2013 08:49:17	2.30	30.52
31/01/2013 09:04:17		
31/01/2013 09:19:17	4.47	55.30
31/01/2013 09:34:17	6.04	54.51
31/01/2013 09:49:17	12.12	53.12
31/01/2013 10:04:17		
31/01/2013 10:19:17		
31/01/2013 10:34:17		
31/01/2013 10:49:17	10.77	60.98
31/01/2013 11:04:17	5.72	58.62
31/01/2013 11:19:17	5.52	61.05
31/01/2013 11:34:17	6.05	99.88
31/01/2013 11:49:17		
31/01/2013 12:04:17	5.79	21.10
31/01/2013 12:19:17	5.18	64.38
31/01/2013 12:34:17	4.41	61.46
31/01/2013 12:49:17	2.44	62.18
31/01/2013 13:04:17	4.85	63.36
31/01/2013 13:19:17	4.94	61.96
31/01/2013 13:34:17	4.52	61.05
08/02/2013 11:05:16	8.31	59.06
08/02/2013 11:20:16	7.94	59.11
08/02/2013 11:35:16	7.59	58.28
08/02/2013 11:50:16	7.64	59.16
08/02/2013 12:05:16	8.08	66.56
08/02/2013 12:20:16	6.11	68.16
08/02/2013 12:35:16	2.24	12.39
08/02/2013 12:50:16	9.94	51.82
08/02/2013 13:05:16	12.24	54.89
08/02/2013 13:20:16	9.05	55.53
08/02/2013 13:35:16	8.77	58.26
08/02/2013 13:50:16	9.49	65.69
08/02/2013 14:05:16	7.29	59.50
08/02/2013 14:20:16	5.66	61.17
08/02/2013 14:35:16	5.56	61.08
08/02/2013 14:50:16	5.04	59.42
08/02/2013 15:05:16	5.34	61.73
08/02/2013 15:20:16	4.80	58.88
08/02/2013 15:35:16	4.62	57.91
08/02/2013 15:50:16	4.59	62.78
08/02/2013 16:05:16	4.36	68.85
08/02/2013 16:20:16	4.46	67.21
08/02/2013 16:35:16	4.57	68.08
08/02/2013 16:50:16	3.73	64.75
08/02/2013 17:05:16	4.08	64.81
08/02/2013 17:20:16	4.15	65.22
08/02/2013 17:35:16	4.22	64.56
08/02/2013 17:50:16	4.20	62.23

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
08/02/2013 18:05:16	4.46	64.32
08/02/2013 18:20:16	4.66	61.92
08/02/2013 18:35:16	4.56	64.80
08/02/2013 18:50:16	4.79	63.93
08/02/2013 19:05:16	4.36	62.39
08/02/2013 19:20:16	4.39	63.62
08/02/2013 19:35:16	4.46	62.11
08/02/2013 19:50:16	4.84	58.93
08/02/2013 20:05:16	4.29	60.30
08/02/2013 20:20:16	4.38	58.58
08/02/2013 20:35:16	4.36	59.77
08/02/2013 20:50:16	4.86	56.14
08/02/2013 21:05:16	4.10	55.42
08/02/2013 21:20:16	4.87	55.39
08/02/2013 21:35:16	4.62	55.19
08/02/2013 21:50:16	4.83	53.48
08/02/2013 22:05:16	4.90	52.65
08/02/2013 22:20:16	4.54	51.51
08/02/2013 22:35:16	4.81	53.51
08/02/2013 22:50:16	5.27	51.79
08/02/2013 23:05:16	5.44	52.02
08/02/2013 23:20:16	5.01	51.86
08/02/2013 23:35:16	5.23	51.58
08/02/2013 23:50:16	5.26	51.92
09/02/2013 00:05:16	5.32	52.32
09/02/2013 00:20:16	5.46	51.17
09/02/2013 00:35:16	5.65	53.58
09/02/2013 00:50:16	5.36	54.93
09/02/2013 01:05:16	5.95	55.00
09/02/2013 01:20:16	6.33	52.68
09/02/2013 01:35:16	6.72	54.62
09/02/2013 01:50:16	7.44	54.18
09/02/2013 02:05:16	6.96	53.87
09/02/2013 02:20:16	7.83	53.66
09/02/2013 02:35:16	6.50	51.67
09/02/2013 02:50:16	7.02	50.48
09/02/2013 03:05:16	7.10	49.66
09/02/2013 03:20:16	7.70	50.08
09/02/2013 03:35:16	6.05	48.07
09/02/2013 03:50:16	5.95	46.27
09/02/2013 04:05:16	5.79	47.26
09/02/2013 04:20:16	6.76	46.56
09/02/2013 04:35:16	6.01	46.83
09/02/2013 04:50:16	5.87	46.09
09/02/2013 05:05:16	6.73	46.62
09/02/2013 05:20:16	7.48	45.69
09/02/2013 05:35:16	6.58	48.27
09/02/2013 05:50:16	6.67	50.21
09/02/2013 06:05:16	5.75	48.48
09/02/2013 06:20:16	6.85	47.52
09/02/2013 06:35:16	6.42	47.71
09/02/2013 06:50:16	5.57	47.22

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
09/02/2013 07:05:16	6.34	48.03
09/02/2013 07:20:16	7.46	47.35
09/02/2013 07:35:16	6.67	45.41
09/02/2013 07:50:16	5.82	46.87
09/02/2013 08:05:16	7.88	45.29
09/02/2013 08:20:16	7.35	47.72
09/02/2013 08:35:16	6.74	47.95
09/02/2013 08:50:16	8.49	50.98
09/02/2013 09:05:16	6.97	51.39
09/02/2013 09:20:16	7.20	51.91
09/02/2013 09:35:16	7.48	51.59
09/02/2013 09:50:16	7.20	51.73
09/02/2013 10:05:16	7.25	50.69
09/02/2013 10:20:16	5.86	52.17
09/02/2013 10:35:16	6.10	51.93
09/02/2013 10:50:16	6.14	52.97
09/02/2013 11:05:16	6.65	51.83
09/02/2013 11:20:16	6.01	51.59
09/02/2013 11:35:16	6.95	53.66
09/02/2013 11:50:16	5.77	54.52
09/02/2013 12:05:16	6.39	55.27
09/02/2013 12:20:16	5.47	53.34
09/02/2013 12:35:16	5.35	53.53
09/02/2013 12:50:16	5.52	54.66
09/02/2013 13:05:16	5.92	52.65
09/02/2013 13:20:16	5.41	51.18
09/02/2013 13:35:16	5.94	54.51
09/02/2013 13:50:16	5.63	55.48
09/02/2013 14:05:16	4.78	51.32
09/02/2013 14:20:16	5.75	52.32
09/02/2013 14:35:16	5.06	54.14
09/02/2013 14:50:16	4.41	50.80
09/02/2013 15:05:16	4.88	51.92
09/02/2013 15:20:16	4.45	52.32
09/02/2013 15:35:16	4.41	51.04
09/02/2013 15:50:16	4.05	51.11
09/02/2013 16:05:16	4.00	50.42
09/02/2013 16:20:16	4.01	51.02
09/02/2013 16:35:16	4.59	52.10
09/02/2013 16:50:16	4.34	53.94
09/02/2013 17:05:16	4.09	53.37
09/02/2013 17:20:16	3.75	52.68
09/02/2013 17:35:16	3.68	53.52
09/02/2013 17:50:16	3.56	50.87
09/02/2013 18:05:16	3.51	50.72
09/02/2013 18:20:16	3.52	49.84
09/02/2013 18:35:16	3.26	49.39
09/02/2013 18:50:16	3.32	49.00
09/02/2013 19:05:16	2.96	49.46
09/02/2013 19:20:16	2.81	50.32
09/02/2013 19:35:16	2.88	52.05
09/02/2013 19:50:16	2.72	51.00

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
09/02/2013 20:05:16	3.08	51.80
09/02/2013 20:20:16	2.63	51.49
09/02/2013 20:35:16	3.08	51.04
09/02/2013 20:50:16	3.22	49.44
09/02/2013 21:05:16	3.07	50.54
09/02/2013 21:20:16	3.19	48.53
09/02/2013 21:35:16	3.17	47.41
09/02/2013 21:50:16	3.45	46.43
09/02/2013 22:05:16	3.38	44.61
09/02/2013 22:20:16	3.17	44.31
09/02/2013 22:35:16	3.60	42.84
09/02/2013 22:50:16	3.29	43.51
09/02/2013 23:05:16	3.41	42.80
09/02/2013 23:20:16	3.46	42.87
09/02/2013 23:35:16	3.43	42.51
09/02/2013 23:50:16	3.73	44.22
10/02/2013 00:05:16	3.66	44.31
10/02/2013 00:20:16	3.79	47.50
10/02/2013 00:35:16	3.77	44.65
10/02/2013 00:50:16	3.73	43.50
10/02/2013 01:05:16	3.83	43.65
10/02/2013 01:20:16	3.93	43.03
10/02/2013 01:35:16	3.96	43.38
10/02/2013 01:50:16	4.09	43.81
10/02/2013 02:05:16	4.15	43.25
10/02/2013 02:20:16	3.82	43.05
10/02/2013 02:35:16	3.82	43.72
10/02/2013 02:50:16	3.95	43.07
10/02/2013 03:05:16	3.69	44.23
10/02/2013 03:20:16	4.10	44.54
10/02/2013 03:35:16	3.82	43.90
10/02/2013 03:50:16	3.91	43.58
10/02/2013 04:05:16	3.69	43.34
10/02/2013 04:20:16	3.74	45.18
10/02/2013 04:35:16	3.77	46.41
10/02/2013 04:50:16	4.09	45.71
10/02/2013 05:05:16	3.76	45.92
10/02/2013 05:20:16	4.11	45.81
10/02/2013 05:35:16	3.98	45.76
10/02/2013 05:50:16	3.98	45.18
10/02/2013 06:05:16	4.09	45.99
10/02/2013 06:20:16	4.15	45.01
10/02/2013 06:35:16	3.93	44.29
10/02/2013 06:50:16	4.27	45.66
10/02/2013 07:05:16	4.46	46.45
10/02/2013 07:20:16	4.42	47.01
10/02/2013 07:35:16	4.36	46.71
10/02/2013 07:50:16	4.27	48.83
10/02/2013 08:05:16	4.76	48.47
10/02/2013 08:20:16	4.04	48.18
10/02/2013 08:35:16	4.29	47.42
10/02/2013 08:50:16	4.76	48.70

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
10/02/2013 09:05:16	4.55	45.75
10/02/2013 09:20:16	4.88	45.34
10/02/2013 09:35:16	4.72	45.43
10/02/2013 09:50:16	5.64	46.35
10/02/2013 10:05:16	4.32	45.11
10/02/2013 10:20:16	4.45	46.37
10/02/2013 10:35:16	4.54	46.08
10/02/2013 10:50:16	4.50	47.07
10/02/2013 11:05:16	5.52	47.06
10/02/2013 11:20:16	4.31	46.62
10/02/2013 11:35:16	4.57	46.10
10/02/2013 11:50:16	4.35	46.54
10/02/2013 12:05:16	4.32	48.13
10/02/2013 12:20:16	4.90	46.60
10/02/2013 12:35:16	4.70	48.37
10/02/2013 12:50:16	4.32	48.66
10/02/2013 13:05:16	4.59	50.69
10/02/2013 13:20:16	4.83	48.50
10/02/2013 13:35:16	4.91	46.75
10/02/2013 13:50:16	5.16	46.95
10/02/2013 14:05:16	5.15	48.57
10/02/2013 14:20:16	4.28	46.97
10/02/2013 14:35:16	4.12	44.82
10/02/2013 14:50:16	4.79	47.80
10/02/2013 15:05:16	4.16	44.28
10/02/2013 15:20:16	3.74	44.67
10/02/2013 15:35:16	3.72	46.35
10/02/2013 15:50:16	3.62	45.95
10/02/2013 16:05:16	3.79	45.02
10/02/2013 16:20:16	3.56	46.10
10/02/2013 16:35:16	3.68	96.30
10/02/2013 16:50:16	3.18	47.47
10/02/2013 17:05:16	3.01	49.42
10/02/2013 17:20:16	2.99	46.20
10/02/2013 17:35:16	2.59	45.98
10/02/2013 17:50:16	2.54	44.74
10/02/2013 18:05:16	2.49	43.70
10/02/2013 18:20:16	2.50	43.27
10/02/2013 18:35:16	2.63	42.74
10/02/2013 18:50:16	2.58	43.53
10/02/2013 19:05:16	2.63	43.18
10/02/2013 19:20:16	2.69	42.17
10/02/2013 19:35:16	2.83	40.93
10/02/2013 19:50:16	2.72	40.40
10/02/2013 20:05:16	2.63	41.12
10/02/2013 20:20:16	2.72	42.79
10/02/2013 20:35:16	2.95	42.19
10/02/2013 20:50:16	2.72	42.49
10/02/2013 21:05:16	3.04	41.57
10/02/2013 21:20:16	3.10	42.10
10/02/2013 21:35:16	2.88	39.89
10/02/2013 21:50:16	3.04	39.10

Date/Time	Clarified Water (NTU)	Raw Water (NTU)
10/02/2013 22:05:16	3.16	39.74
10/02/2013 22:20:16	3.12	40.50
10/02/2013 22:35:16	3.43	39.26
10/02/2013 22:50:16	3.45	38.48
10/02/2013 23:05:16	3.71	38.94
10/02/2013 23:20:16	3.16	40.78
10/02/2013 23:35:16	3.61	40.54
10/02/2013 23:50:16	3.92	39.16
11/02/2013 00:05:16	3.53	38.95
11/02/2013 00:20:16	4.94	39.63
11/02/2013 00:35:16	5.18	39.96
11/02/2013 00:50:16	4.86	38.68
11/02/2013 01:05:16	5.13	40.21
11/02/2013 01:20:16	6.27	39.25
11/02/2013 01:35:16	4.16	40.78
11/02/2013 01:50:16	4.30	40.93
11/02/2013 02:05:16	5.58	40.78
11/02/2013 02:20:16	5.95	40.34
11/02/2013 02:35:16	5.91	41.02
11/02/2013 02:50:16	5.80	40.74
11/02/2013 03:05:16	4.57	39.25
11/02/2013 03:20:16	4.63	40.93
11/02/2013 03:35:16	4.25	41.30
11/02/2013 03:50:16	5.16	41.23
11/02/2013 04:05:16	4.34	41.01
11/02/2013 04:20:16	4.84	42.15
11/02/2013 04:35:16	6.23	40.21
11/02/2013 04:50:16	6.27	39.90
11/02/2013 05:05:16	5.24	40.46
11/02/2013 05:20:16	8.10	39.74
11/02/2013 05:35:16	6.44	41.06
11/02/2013 05:50:16	9.35	40.51
11/02/2013 06:05:16	12.28	44.88
11/02/2013 06:20:16	8.25	41.54
11/02/2013 06:35:16	12.77	40.17
11/02/2013 06:50:16	17.61	40.37
11/02/2013 07:05:16	12.14	40.88
11/02/2013 07:20:16	12.54	42.43
11/02/2013 07:35:16	13.48	41.12
11/02/2013 07:50:16	9.89	40.45
11/02/2013 08:05:16	10.76	39.76
11/02/2013 08:20:16	10.52	40.72
11/02/2013 08:35:16	21.02	40.82
11/02/2013 08:50:16	20.01	42.40
11/02/2013 09:05:16	17.21	43.42
11/02/2013 09:20:16	15.50	44.72
11/02/2013 09:35:16	17.34	44.18
11/02/2013 09:50:16	11.58	43.29
11/02/2013 10:05:16	15.55	44.60
11/02/2013 10:20:16	14.65	44.00
11/02/2013 10:35:16	15.31	42.63
11/02/2013 10:50:16	27.22	52.09

Umvoti WW full scale clarifier			
Date	Raw Turb	Clariflocculator clarified water (NTU)	Settling Tank Clarified Water (NTU)
21/01/2013 10:00:00	82.7	5.25	1.84
21/01/2013 12:00:00	80.2	5.21	1.48
21/01/2013 14:00:00	75	5.77	2.57
21/01/2013 16:00:00	74.3	5.79	2.6
21/01/2013 18:00:00	71.9	4.24	7.42
21/01/2013 20:00:00	70.2	4.26	7.4
21/01/2013 22:00:00	68.8	4.3	6.22
22/01/2013 00:00:00	68.5	4.66	4.38
22/01/2013 02:00:00	67.9	5.06	3.38
22/01/2013 04:00:00	67.6	5.1	1.27
22/01/2013 06:00:00	66.1	5.32	1.6
22/01/2013 14:00:00	79.4	6.11	1.76
22/01/2013 16:00:00	77.6	6.87	1.95
22/01/2013 18:00:00	64.6	2.1	4.13
22/01/2013 20:00:00	64.2	2.12	4.1
22/01/2013 22:00:00	64	2.14	3.87
23/01/2013 00:00:00	88.3	2.17	2.65
23/01/2013 02:00:00	88.1	2.19	2.62
23/01/2013 04:00:00	87.4	2.22	1.45
23/01/2013 06:00:00	55.4	3.66	0.98
23/01/2013 08:00:00	54.7	5.41	0.99
23/01/2013 10:00:00	55.1	4.52	1.22
25/01/2013 18:00:00	52	2.52	3.14
25/01/2013 20:00:00	48.4	2.34	3.08
25/01/2013 22:00:00	48.1	2.1	2.07
26/01/2013 00:00:00	45.2	1.91	1.77
26/01/2013 02:00:00	42.1	1.84	1.58
26/01/2013 04:00:00	40.2	1.71	1.45
26/01/2013 06:00:00	46.2	1.02	1.53
26/01/2013 08:00:00	44.6	1.11	1.34
08/02/2013 12:00:00	58.3	11.1	12.7
08/02/2013 14:00:00	57	12.1	4.66
08/02/2013 16:00:00	56.3	12.2	4.41
08/02/2013 18:00:00	56.5	7.48	2.54
08/02/2013 20:00:00	56.8	7.52	2.44
08/02/2013 22:00:00	40.3	7.59	0.88
09/02/2013 00:00:00	42.8	8.56	0.98
09/02/2013 02:00:00	44.6	8.76	1.23
09/02/2013 04:00:00	38.8	6.3	1.12
09/02/2013 06:00:00	47.2	9.77	1.28
09/02/2013 08:00:00	46.4	6.6	1.19
09/02/2013 10:00:00	46.9	9.41	1.34
09/02/2013 12:00:00	38.6	10.36	1.49
09/02/2013 14:00:00	39.8	11.23	2.11
09/02/2013 16:00:00	47.9	11.3	4.19
09/02/2013 18:00:00	49.6	11.1	6.23
09/02/2013 20:00:00	47.5	8.07	6.22
09/02/2013 22:00:00	36.3	7.19	5.42

Umvoti WW full scale clarifier			
Date	Raw Turb	Clariflocculator clarified water (NTU)	Settling Tank Clarified Water (NTU)
10/02/2013 00:00:00	38.9	7.29	3.19
10/02/2013 02:00:00	41.7	7.37	2.16
10/02/2013 04:00:00	38.6	7.34	2.1
10/02/2013 06:00:00	55.6	12.6	1.5
10/02/2013 08:00:00	54.8	128	1.53
10/02/2013 10:00:00	53.1	12.1	1.6
10/02/2013 12:00:00	56.7	14.7	1.63
10/02/2013 14:00:00	51.8	11.21	1.56
10/02/2013 16:00:00	50.7	13.31	1.48
10/02/2013 18:00:00	46.5	7.52	4.2
10/02/2013 20:00:00	38.2	7.59	1.75
10/02/2013 22:00:00	37.7	7.63	1.88
11/02/2013 00:00:00	37.4	7.88	1.42
11/02/2013 02:00:00	37	8.28	1.48
11/02/2013 04:00:00	36.6	8.31	1.51
11/02/2013 06:00:00	39.7	7.18	1.67
11/02/2013 08:00:00	40.8	7.21	1.4
11/02/2013 10:00:00	35.6	7.51	1.48
28/01/2013 18:00:00	71.3	48.7	5.79
28/01/2013 20:00:00	73.4	4.88	7.13
28/01/2013 22:00:00	76.5	5.03	7.88
29/01/2013 00:00:00	78.8	7.16	8.28
29/01/2013 02:00:00	80.3	8.12	10.11
29/01/2013 04:00:00	82.4	10.2	12.2
29/01/2013 06:00:00	82.8	9.48	2.1
29/01/2013 08:00:00	83.2	9.22	1.4
29/01/2013 10:00:00	79.4	9.18	1.2
29/01/2013 12:00:00	77.8	9.14	1.12
29/01/2013 14:00:00	76.4	9.17	1.1
29/01/2013 16:00:00	75.2	9.21	1.06
29/01/2013 18:00:00	137	9.31	3.64
29/01/2013 20:00:00	88.6	9.09	3.4
29/01/2013 22:00:00	85.9	9.34	2.89
30/01/2013 00:00:00	90.3	9.22	2.77
30/01/2013 02:00:00	89.7	8.91	2.51
30/01/2013 04:00:00	85.4	9.16	2.32
30/01/2013 06:00:00	76.3	6.31	2.41
30/01/2013 08:00:00	76.8	6.47	2.51
30/01/2013 10:00:00	75.4	6.5	2.53
30/01/2013 12:00:00	75	6.54	2.57
30/01/2013 14:00:00	72.4	7.02	2.6
30/01/2013 16:00:00	70		
30/01/2013 18:00:00	69.2	7.14	3.8
30/01/2013 20:00:00	73.7	7.25	3.17
30/01/2013 22:00:00	70.9	7.07	2.98
31/01/2013 00:00:00	69.4	7.35	2.85
31/01/2013 02:00:00	71.7	7.29	2.69
31/01/2013 04:00:00	72.3	7.13	2.47
31/01/2013 06:00:00	65	6.54	1.22

Umvoti WW full scale clarifier			
Date	Raw Turb	Clariflocculator clarified water (NTU)	Settling Tank Clarified Water (NTU)
31/01/2013 08:00:00	62.4	6.37	1.24
31/01/2013 10:00:00	51.3	4.02	1.18
31/01/2013 12:00:00	53.6	6.85	1.32