TE MATO VAI

07 November 2019

Re: Information to support approval to commission Te Mato Vai Stage 2

Dear Landowners,

This information pack has been prepared to support your decision about whether you approve the Cook Islands Government's (CIG) recent instruction to the PMU to begin commissioning the new intake water supply systems, known as Te Mato Vai Stage 2.

The CIG is committed to continuing the current consultation with all affected parties, and believes commissioning Te Mato Vai will enable better-informed decisions about the long term future of Rarotonga's public water supply. At the same time, the CIG is obliged to prevent additional significant costs, and job losses that will result if Te Mato Vai is further delayed.

The new system will be disinfected using chlorine before being connected, but no chlorine will be added to the drinking water supply at this stage. This reduced treatment system is described in the attached information pack.

Currently the public water supply is still connected to the old intake infrastructure. The commissioning process will connect the public water network into the newly constructed intake water treatment systems.

When connected, the public water supply will go through all steps of the new treatment system **except chemical disinfection (chlorination) of the water supply**. This means that while the water quality will be improved, **the public water supply will remain unsafe to drink without additional treatment** (such as boiling).

The Cook Islands Government considered the views of intake landowners, local leadership and the wider community before deciding to approve both disinfection of the new infrastructure and use of the 'coagulant' chemical, polyaluminium chloride (PACl). Information about PACl, the PACl alternatives we have considered, the disinfection process, and the conditions imposed on the work is provided in the information pack.

PACl will initially be introduced for a 6 month trial period. The coagulation process will be closely monitored during the trial. The monitoring reports will be used to inform Government and landowners' views on longer term PACl use.

Until a decision is made on disinfection (chlorination) To Tatou Vai and Ministry of Health will continue to test the public water supply for bacteria and monitor the community water stations to protect public health.

Kia manuia

The Te Mato Vai PMU

TE MATO VAI

Information Pack

Stage 2 Commissioning

November 2019

TE MATO VAI

Te Mato Vai Stage 2 Commissioning Conditions

The Cook Islands Government (CIG) has included the following mandatory conditions in their instructions to begin commissioning Te Mato Vai Stage 2.

When disinfecting the new infrastructure with chlorine, the contractor must:

- Meet the TMV Stage 2 project environmental conditions, and take all practical means to protect flora and fauna. This includes not discharging Calcium Hypochlorite (chlorine) into the environment.
- Not discharge water used to disinfect new infrastructure into the public water supply, and dispose of this water in accordance with the methodology referenced above.
- Give at least 48 hours written notice to the relevant landowners/representative of the valley intake that the contractor intends to carry out disinfection/shock dosing of facilities and equipment in their Valley.
- Allow one or more relevant landowners/representative to be present throughout the disinfection/shock dosing process and make reasonable steps to ensure that the landowners/representative are present.
- Not store any Calcium Hypochlorite or Sodium Thiosulphate in any intake valley at any time; and
- Remove all Calcium Hypochlorite or Sodium Thiosulphate used in the disinfection/shock dosing from the relevant Valley, on the same day as the disinfection/shock dosing.

When implementing PACl dosing, the contractor must:

- Follow a PACl dosing methodology approved by the CIG.
- Not discharge any settling tank 'product' (near clear water or sludge and water mix) to the stream or the scour ponds until landowners concerns and queries have been responded to, such that the CIG can instruct the emptying of the settling tanks as part of their operation and maintenance requirements.

When implementing AVG Backwash, the contractor must:

- Meet the TMV Stage 2 project environmental conditions, and take all practical steps to protect flora and fauna.

In addition, treatment plant performance and operation will be monitored, and monitoring results will be shared with landowners and responded to where necessary. Landowner concerns/ queries will be responded to, and actioned where necessary.

About Te Mato Vai Stage 2 Commissioning

About commissioning

What is 'commissioning'?

The public water supply that sends water to your taps has not yet been connected to the new water treatment system (Te Mato Vai). The water you get now is the same as it was before Te Mato Vai started.

'Commissioning' means we will disinfect all the new water system infrastructure, then connect it to the public water network that supplies Rarotonga's homes and businesses. As it gets connected, the public water supply will go through all steps of the new treatment system except chemical disinfection (chlorination) of the water supply.

Why can't it be commissioned without PACl?

If a water source is very clean, like groundwater, water treatment without a coagulant is possible. Coagulation is necessary in Rarotonga because stream water contains high levels of sediment and 'suspended solids', especially when it's rained. If a coagulant step was not used, the low water quality would likely cause the AVG filters to block, and we may not be able to operate the filters during and after heavy rain.

Will the full network be commissioned at once?

No, the intakes will be connected up progressively. We expect to connect the first sites before Christmas and the remaining sites early in the New Year.

Which intake will be commissioned first?

We will update landowners about which intake will be commissioned first as soon as we have confirmed this with our contractor.

When will the Matavera intake be commissioned?

The PMU will advise landowners and publish more information on the timing once confirmed with our contractor McConnell Dowell.

When will the other intakes be commissioned?

The PMU will advise landowners and publish more information on the timing once confirmed with our contractor McConnell Dowell. We will provide as much advance warning as possible.

What can the community expect when turning on their tap after commissioning?

The water may still appear muddy from time to time, and it will not be safe to drink. Residents are still advised to further treat their water – for example by boiling it – before using it for drinking or food preparation.

The water can only be made 'potable' (safe to drink) when the entire system has been disinfected and the water supply itself is also being disinfected to kill bacteria and viruses.

About PACl

What is PACl?

PACl is short for polyaluminium chloride. It's used in the water treatment process to make small particles of dirt etc. stick together and settle at the bottom of the tank.

PACl and filtration help remove harmful protozoa (for example giardia). PACl plays a key role in cleaning water, but is different from chlorine, which is a disinfectant.

What does PACl do?
PACl is used in a process called coagulation. Coagulation helps remove small particles of dirt and other contaminants, including harmful protozoa such as giardia. This is a slow mixing process. When

PACl is mixed with water, it combines with small particles of dirt and other contaminants, and settles at the bottom of the tank.

What about non-chemical coagulants?
The community suggested Moringa Oleifra seed as an alternative to chemical coagulants, but we've found it's unsuitable for use in Rarotonga.

The reasons for this include the fact that it's still untested for use in full-size water treatment systems, there are no established ways to get a regular, sufficient supply, and Rarotonga's humid climate would make it challenging to transport and store the seed without it spoiling (for example going mouldy).

In addition to our own research, To Tatou Vai has also conducted some laboratory testing of Moringa seed using local stream water. Unfortunately this testing found Moringa seed performed consistently worse than adding no chemicals at all, in both 'clean' and 'dirty' water conditions. It also has a very short shelf life before it decomposes and produces a strong smell of hydrogen sulfide. This fact alone excludes it from any future use on a large scale water treatment plant

When will PACl be used?
We will begin using PACl at the time each intake site is fully commissioned. Commissioning takes about one month per site.

How will it be stored?

We will be transporting, storing and handling PACl according to all the necessary health and safety standards. The PACl will be securely stored.

Is PACl necessary if we already have water filter tanks up at the intakes?
If a water source is very clean, like groundwater, water treatment without a coagulant is possible. Coagulation is necessary in Rarotonga because stream water contains high levels of sediment and 'suspended solids', especially when it rains. If a coagulant step was not used, the AVG filters would likely get blocked, and the filters may not operate at all during storms.

How much PACl is used?
The amount used will fluctuate depending on how much dirt is in the water, so the trial will provide us with more information on this. We will monitor and adjust the PACl dosage to suit the water quality and ensure we only use the minimum amount needed. The amount of PACl needed will be specific to the needs of each intake site, and potentially to each season.

Will there be any waste produced from the coagulation step?
Yes, the PACl combines with the dirt in the water and settles at the bottom of the sedimentation tank as a muddy 'sludge'.

Are there any health risks associated with this chemical?

PACl is safe to use when dosed correctly, and is widely used in other countries, including New Zealand and Australia. We will follow the standards set out in The Guidelines for Drinking-Water Quality Management for New Zealand.

What do you do with the PACl sludge?
We will follow standard practice, which is to move the sludge from the sediment tanks into purpose-built ponds, and then eventually to landfill.

How much PACl sludge will be generated each year?
We won't know how much sludge will be created until we trial the system. Even after this it will vary from year to year, as it depends on how much 'dirty' water is generated in the streams due to rainfall.

How will you manage PACl quantities and dosing?
To Tatou Vai staff are trained to operate the upgraded water system, which includes monitoring and testing to adjust the amount of PACl used. PACl is drip-fed into the water through an adjustable control valve. We will use the minimum amount necessary.

Are there any environmental impacts of disposing sludge at the landfill?
Landfill is the most environmentally responsible option, based on international best practice.

Disinfecting the new infrastructure with chlorine

Why do you need to disinfect the new infrastructure with chlorine?
It is standard practice to disinfect new infrastructure when connecting it to a water network. The construction work, and the people working on it, can contaminate a network. It is important to eliminate any potential contamination, as water supply authorities are obliged to do everything they can to protect public health.

What does it involve?
We will flush the pipes with chlorine to ensure the new connections do not contaminate the water supply. We do this before the system is connected, so none of the chlorine used will go into the public water supply.

After flushing, we will remove the chlorinated water and 'neutralise' the chlorine before disposing of it responsibly, in line with relevant industry guidelines.

Will there be chlorine in our water supply?
No - while the new system will be cleaned using chlorine, this is done before the new structures are connected into the water supply. No chlorine will be added to the water supply at this stage.

What exactly will you be using the chlorine on?
All new infrastructure constructed as part of the Te Mato Vai Project e.g. intake structures, settling tanks, pipes, filters and storage tanks etc. We will not be disinfecting the ring main or household pipes at this time.

Environment and health

How does PACl improve water quality?
It helps remove contaminants such as dirt and leaves, and also helps remove harmful protozoa which can make people sick.

Will the water be safe to drink?
No, because we are only commissioning the first three steps of the water treatment process (coagulation, sedimentation and filtration) we are not disinfecting the water. This means the water is still unsafe to drink without additional treatment such as boiling, to kill viruses and bacteria.

If you have any questions or concerns, please contact the PMU on 28851.

TE AU TAKAI'ANGA E 'A NOTE TAMA'ANGA ITE VAI

Ka akape'ea te au tu'anga ou ta te Te Mato Vai i akatu ite tama'anga ite turanga ote vai

KOTE NGAI KAKAPU'ANGA VAI

Ka riro teia ite arai ite au tita mama'ata mei te toka, te rakau ete vai atura kia kore e tae ki roto ite au paipa vai.

1

AKAOPU'ANGA ITE TITA ETE REPO

Aka'atea'anga ite au tita a mama'ata mai

Ko teia takai'anga, na te teima'a ote tita e pera te 'u'uti'anga a te kare o te enua (gravity) e aka'atea ite au tita mama'ata, (te repo, te rau rakau e te vai atura) na roto ite akaopu'anga i te reira ki raro ite tangikia.

Ka paru e ka noo teia au tita ki raro i te takere ote tangika.

2

KAPITIPITI'ANGA ITE TITA RIKIRIKI E PERA TE REPO

Ka aka'atea teia ite au tita rikiriki e pera te repo

Ko teia takai'anga koia ko te kapitipiti marie anga i te 'unga'unga tita ete repo kia petetue, ka tei'a'a i reira note paru ki raro i te tangika.

Ko teia takai'anga, kapiti ia atu ki te ta'au'anga ote vai, ka riro te reira i te takore atu i teia manumanu kino kote protozoa.

3

TA'AU'ANGA

Aka'atea'anga ite au repo rikiriki roa e pera te vari

Ka ta'anga'anga teia ravenga ite ona tea note ta'au'anga atu ite vai. Ka aka'atea'ia te repo ete vari i roto ite vai ki runga roa ite tangika, e kote vai tei to'au ia ka ake e ka noo te reira ki raro ite takere ote tangika.

Ko teia e pera te kapitipiti'anga ite tita ete repo i roto ite vai, ka riro te reira i te takore atu i te manumanu kikino koia te protozoa.

4

TA VAIRAKAU'ANGA

Ka riro te tavairakau'anga i te vai ite takore atu i te au manumanu kikino mei te bacteria ete virus.

Tuketuke te au ravenga meitaki atu/ ma kore kare e meitaki roa ana no te takore atu i teia au manumanu kikino.

Kare teia ravenga e ta'anga'anga'ia i teia 'eti'anga, no reira ka ananoo'ia kia tunu'ia te vai kia pupu i mua ake ka inu'ia ei te reira.

TANGIKA VAIRANGA'ANGA VAI MAMA'ATA

Ko teia au tangika katoatoa, ka mou ratou mei te 15 mirioni riters vai ite katoatoa.

I te tuatau ote vai mare, ka maka i teia au tangika ite orongo mai ite vai no tetai rua ra kite ki tangata o Rarotonga nei.

How the new Te Mato Vai system will clean our stream water

FOUR STEP TREATMENT PROCESS

COLLECTING WATER

The intake screen keeps rock, branches and larger material from getting into the water supply.

1

SEDIMENTATION

Removes 'solids'

This process uses gravity to remove solids (dirt, leaves etc) from water.

The solids settle on the bottom of the tank as sludge.

2

COAGULATION/ FLOCCULATION

Removes small particles and protozoa

This is a slow mixing process. It uses a 'coagulant' called polyaluminium chloride (PACl) to make small bits of dirt etc stick together and settle at the bottom of the tank.

This step, together with filtration, removes harmful protozoa (for example giardia).

3

FILTRATION

Removes small particles and protozoa (sand filters)

The filters use sand to further filter the water. Waste is removed from the top of the tank, and the filtered water is collected from the bottom.

This step further removes harmful protozoa.

4

DISINFECTION

Disinfection kills harmful bugs such as viruses and bacteria. There are a number of disinfection options; some are more effective than others.

This step will not be implemented yet, so water still needs to be boiled before drinking.

WATER STORAGE

These storage tanks hold up to 15 million litres of water. During drought periods, these tanks are able to supply two days of water to Rarotonga.

TE MATO VAI

Appendices

1. Follow-up Actions Table for Concerns of Selected Landowners from the 16th September 2019 Court Hearing
2. Information on alternative coagulation options including costs/risks/benefits (Follow up action item 2)
3. Information on PACL safety (Follow-up action items 4)
4. Information on residual aluminium content in sludge, PACl safety, environmental effects and monitoring/ management procedures, and sludge ponds design (Follow-up action items 3, 4 and 5)

TE MATO VAI

Appendix 1

Court Hearing (16th September 2019). Follow-up Actions Table for Concerns of Selected Landowners – (Updated 31/10/2019)

	DESCRIPTION	ACTION OWNER	ACTIONS	STATUS	DUE DATE
	PACL (Coagulation and sludge ponds)				
1	PACl EIA PMU and TTV will prepare TOR for NES. Following trial of PACL PMU and TTV will prepare a submission to NES. This is likely to be an addition to the TMV Stage 2 EIA and will cover PACl use, potential environmental effects and mitigation/monitoring procedures	TTV / PMU	PMU to prepare draft TOR for discussion with TTV and NES. Once TOR is agreed, TTV will seek an independent specialist to prepare the EIA submission. From TTV: TOR terms agreed by NES. Work has commenced on EIA. TTV yet to identify independent reviewer. PACL trial information will inform EIA.	PMU Complete TOR Agreed with NES TTV in progress	Estimate December '19
2	Provide information on alternative coagulation options including costs/risks/benefits	PMU	PMU to provide a brief summary of alternative coagulation options and why they recommended chemical coagulation (PACL) vs mechanical and other options PACL trial information will inform testing of alternatives.	Research information prepared TTV small trial underway	Estimate December '19
3	Residual aluminium (Al) content in sludge and potential effects • High level assessment of residual Al in sludge • Comparison with international standards etc. • Description of risk of Al leaching / discharge into environment (groundwater, stream) • Description of potential environmental effects	PMU	PMU is currently undertaking this high level PACl sludge effects assessment. The effects, volumes and residual sludge levels will be monitored and confirmed during trial to be conducted on PACL use	In progress	End October
4	Provide independent information on PACl safety, environmental effects and standard monitoring/ management procedures	PMU	PMU to collate international research on PACl safety and impacts	In progress	End October
5	Sludge ponds design • Adequacy of the design • Short term storage of sludge in ponds • Effects of rainfall, flooding, overflow/failure of ponds	PMU / MCD	PMU to prepare affidavit describing the pond design and management, addressing safety/environmental impact concerns	In progress	End October
6	Sludge ponds operation and disposal	TTV	TTV to prepare information on disposal processes and impacts. To be done in conjunction with EIA preparation.	In progress	Estimate December '19

Court Hearing (16th September 2019). Follow-up Actions Table for Concerns of Selected Landowners – (Updated 31/10/2019)

7	Provide information on why change from Alum to PACI - Provide environmental impact comparison - Cost and benefits of each to be provided	PMU	PMU to provide TTV with memo on the recommendation to switch from Alum to PACI. TTV have briefed landowners on PACI use and reasons for choosing it over alum.	Completed	
	Consultation				
8	More "meaningful" consultation to be undertaken with landowners once the above technical information is available	MOH / TTV	Consultation and impact of no disinfection to be led by MOH and TTV with support from NES, Agriculture and PMU technical specialists.	Not yet started	In 2020

Abbreviations List

Abbreviation	Meaning	Explanation
AC	Asbestos Cement	Old pipes that carried the water around the island. These have been replaced with polyethylene (PE) pipes.
CIG	Cook Islands Government	Elected government
EIA	Environmental Impact Assessment	Assesses the impact of a proposed activity on the environment before making the decision on whether to carry it out. It also develops a system to assess and measure impacts to avoid or minimise if it is decided to carry out the activity.
MCD	McConnell Dowell	Responsible for the design and construction of Stage 2 of the TMV project.
MFEM	Ministry of Finance and Economic Management	Oversees both TMV and MTVKTV projects to provide a consistent direction for Government policy and funding. The Ministry of Finance and Economic Management manages the contract for the Project Management Unit.
NES	National Environment Service	The Government department responsible for environmental regulations and assessment and monitoring projects that require permits under those regulations
PACI	Polyaluminium Chloride	Coagulation agent used to aid in the coagulation and flocculation step of the water treatment process.

Court Hearing (16th September 2019). Follow-up Actions Table for Concerns of Selected Landowners – (Updated 31/10/2019)

PMU	Project Management Unit	The team tasked with managing the
TOR	Terms of Reference	The TOR document outlines the purpose of an EIA submission and what should/should not be assessed
TTV	To Tatou Vai	Crown Entity established to operate and maintain Te Mato Vai assets after the project is complete.

TE MATO VAI

Appendix 2

Memorandum

01 November 2019

To	Lloyd Myles		
Copy to	TMV PMU, MFEM		
From	Scott Cairney	Tel	+64 27 289 4369
Subject	MISC No's. 41/2016 to 50/2016 – Follow-up Actions table for Concerns of Selected Landowners Item 2	Job no.	51/12504023

1 Background

This memorandum provides information on alternative coagulation options, including their respective risks, advantages and disadvantages. It also discusses the reasoning behind chemical coagulation being recommended instead of mechanical coagulation for the treatment of Rarotonga's water supply through the Te Mato Vai project.

A four-step treatment process is to be used: (1) sedimentation, (2) coagulation/flocculation, (3) filtration, and (4) disinfection. All four steps are necessary to achieve a potable water supply.

The second step, coagulation and flocculation, involves slowly mixing a chemical (coagulant) into the water, to enable small particles of dirt and suspended solids to clump together and sink to the bottom of the tank. Clear water is then discharged from the top water surface of the sedimentation tank into the next step of the treatment process. There is a limited range of chemicals that can be used for the coagulation process; typically these are aluminium sulfate (alum) or polyaluminium chloride (PACl). For the Te Mato Vai project, PACl has been chosen as the preferred coagulant because it is safer than alum, has a longer shelf life, and performed better in water quality tests.

PACl is required for the operation of the headworks site and is a critical component of the water treatment process. The chemical is only used in the coagulation and flocculation step, and the majority of the chemical will be removed by the settling tank and AVG filters because it mostly sticks to the sediments that are removed from the water. The level of residual PACl or dissolved Aluminium in the treated water supply is minimal.

2 Water Chemistry and Selection of Coagulant

The two primary chemical coagulant options are:

1) Aluminium sulphate (alum); and

2) Polyaluminium chloride (PACl).

Both chemicals are supplied as powder or granular form in 20kg bags, or in the case of alum also in 500kg bags. The chemicals can be safely stored in dry conditions in a normal shed.

Both chemicals are typically mixed as a 10% w/v solution prior to use and then drip fed, or added via a dosing pump, to the raw water at the inlet of the sedimentation tank which then enters the hydraulic flocculator. This initiates the flocculation process (formation of floc) followed by subsequent settlement of floc in the bulk part of the sedimentation tank. The flocculation process produces a low turbidity, low colour, low iron and manganese content water from the sedimentation tank that is then suitable for filtering through the sand filters before entering the distribution network.

An alternative organic coagulant is Moringa Oleifera Seed. This has also been assessed as part of this memo.

3 Site Specific Water Quality

Detailed in the **Detailed Design for Stage 2 Design Report – Part 1 (GHD, August 2016)** is test results of samples taken from potential water sources in August 2014.

Water samples from several sites under low to moderate rainfall conditions were tested for sediment settleability, turbidity and colour. Maximum settlement of sediment occurred in about 30 minutes and irrespective of the sediment loading the turbidity and colour of the supernatant was well within the acceptable range for normal coagulation. Trials using alum achieved good final water quality for the samples tested. Analytical results for samples from most intakes under dry weather conditions and some samples under moderate to heavy rain conditions, revealed that the alkalinity concentration in the water varied from acceptable for alum coagulation (for dry weather conditions) to low for some sites (under wet weather conditions).

Tests also showed that total alkalinity is low for Totokoitu, Taipara, Avana and Turangi. This means that coagulant dosing would need to be Polyaluminium Chloride or similar – not aluminium sulphate. Although aluminium sulphate is suitable for other sites (dry conditions), for the purposes of consistency, simple operation and logistics of supply, the same coagulant should be used across all sites.

Although the bench scale work was not extensive, the data from this work supports the premise that coagulant dose rates are not particularly sensitive to variable turbidity in settled water samples.

All parameters including colour and turbidity are marginal as to whether the water needs to be dosed with coagulant for colour during dry weather conditions. However, due to the speed of change of flows (and resulting sediment loading) it is likely that to achieve a consistent water output (without powered monitoring devices and control), coagulant will be required most (if not all) of the year. The decision to treat all the water all of the time (the sedimentation tank will not be needed for consistent periods of dry weather and the AVG would be kept operational) is to optimise water quality.

4 Aluminium Sulfate (Alum)

Alum	
Advantages	1) Cost of a kilogram of alum is low. 2) Dosing systems can be a simple drip-feed system or a dosing pump. 3) The same physical dosing system can be used for alum and PACL 4) Non-hazardous.
Disadvantages	1) Requires concurrent dosing of a polyelectrolyte and pH correction to be effective for TMV waters. These techniques increase the operating costs, require a higher skill level and are difficult to juggle manually. 2) Only is effective within a very narrow pH range (about 5.5- 6.5) 3) Effective removal of colour and turbidity needs good operational skills. The optimal dosing pH range for colour removal is different to the optimal pH range for turbidity removal.

	4) The floc formed tends to be buoyant and fragile, and is susceptible to temperature and density induced short-circuiting. 5) Prepared solutions are unstable and tend to stratify. 6) Dosing rates need to be regularly adjusted to match raw water quality – dry season can lead to lack of nuclei (dirt particles) in the water making it difficult to form floc using alum.
Risks	1) Mismatched dose rates may cause significant floc overflow to the sand filters resulting in the shutdown of the filters. 2) Under low to moderate turbidity conditions short-circuiting of floc may shorten filter runs. 3) Mistakes associated with dosing alum, polyelectrolyte and soda ash/lime may affect treated water pH leading to after-floc formation in the reservoir and network. 4) If any one of the dosing chemicals is not available under moderate to high turbidity conditions then the treatment plant will have to be closed down. 5) Over-dosing or under-dosing has the potential for the aesthetic guideline value of 0.1 g/m^3 for aluminium in treated water to be exceeded. Aluminium based deposits in watermains and in metal household connections can be uplifted by changes in water flow in pipes and give rise to discolouration complaints.

5 Polyaluminium Chloride (PACl)

PACl	
Advantages	1) Effective over a wide pH range from pH 5 to pH 8. 2) Non-acidic - so does not affect the main chemical characteristics of the water being treated. 3) Forms strong readily settleable floc. 4) Concurrent dosing of chemicals for pH correction and a polyelectrolyte are not required. 5) Develops about 2/3 less sludge when compared to alum. 6) Prepared solutions are stable for 4-5 months. 7) The same physical dosing system can be used for alum and/or PACl. 8) Non-hazardous in general use. 9) Equivalent PACl dose rate is about 1/3 that of alum for the same water quality situation. 10) Under normal operating conditions, filter runs should be longer and water quality will be better because of the improved floc formation and settling characteristics when using PACl. 11) Operating the treatment plants will be less stressful because PACl has a wider tolerance for coping with raw water quality changes than alum. 12) PACl does not leave an aluminium residual in treated waters.

Disadvantages	1) Per kilogram it is more expensive than alum – however to balance this increased cost, it requires a lower dosing rate and does not require any other pH adjustment.
Risks	1) The risks are similar to those outlined for alum, but because PACl has a wider tolerance for coping with water quality variations, problems due to operational matters are potentially less likely to happen and if they do the impacts will be more manageable.

6 Moringa Oleifera Seed

Moringa Oleifera Seed	
Advantages	1) Does not affect alkalinity and pH of the water, so concurrent dosing of chemicals for pH correction and a polyelectrolyte are not required. 2) Limited research suggests it is non-toxic and appears to have no harmful effect on aquatic life in small quantities.
Disadvantages	1) The seed of Moringa oleifera is known to have a bitter flavour. There is the possibility of this flavour transferring into the drinking water and affecting the taste of the drinking water. 2) As the Moringa oleifera seed is not a well-known and implemented coagulant for water treatment, it is likely to be difficult to obtain in large quantities sufficient for continuous treatment of water. There are unknown lead times for this quantity of product. 3) There is no standard dosing guideline for Moringa oleifera. 4) If grinding of the seed is to be done on the island, systems need to be designed and properly implemented to ensure consistency in the characteristics of the seed powder. 5) Uncertainty as to whether standard dosing systems are capable of functioning with Moringa oleifera as the coagulant. 6) Likelihood of contamination of the product by fungal or mould microorganisms.
Risks	1) The use of Moringa oleifera is nowhere near as developed as other traditional coagulants such as PACl and alum. There is a link between higher dosages of Moringa oleifera leading to increased hardness removal in water, however no standard dosage system. 2) To date, GHD has found no record of Moringa oleifera being used to treat water on a large scale in a treatment plant – so far, it appears that all research has been done at a laboratory scale. Therefore, there is no certainty that Moringa oleifera will successfully work as a coagulant for TMV waters. 3) As it is not a well-known and monitored water treatment chemical unlike alum and PACl, there is uncertainty in the ability to consistently monitor the quality of the product (i.e. it is not a substance that is widely approved and monitored by the US Food and Drug Administration (FDA)). This leads to the risk of adding in additional unwanted, unknown, and potentially harmful substances into the drinking water.

7 Conclusions

The following can be concluded:

1) Investigations and research have shown that TMV source water quality, particularly alkalinity, is not always high enough to support chemical reactions when alum is added to raw water. This is most apparent during high turbidity conditions, so concurrent dosing of a polyelectrolyte and a pH adjustment chemical such as soda ash, or lime, is required if alum is to be effective.
2) In order to deal with the variability of the alkalinity of the TMV source water the dosing system should be partially, or fully, instrumented. With no power at most of the TMV sites, limited back-up technical support in Rarotonga and the requirement to fully man the water treatment plants to support the instrumentation, alum has been determined to be not suitable for this set of plants.
3) PACl does not require concurrent dosing of a polyelectrolyte and pH adjustment chemical so offers significant advantages in terms of operation ease and ability to cope with a wider range of source water variations without the need to change dose rates as frequently as with alum.
4) PACl forms heavier denser floc with good settling characteristics so that the quality of water from the sedimentation tank onto the filters is normally expected to be of consistently better quality compared to alum treated water.
5) PACl provides more operational flexibility and has a comparable operational cost.
6) While there are some benefits to using Moringa Oleifera as an alternative coagulant for water treatment, ultimately its use as a coagulant has not been explored thoroughly in both academic research and in the water industry. As a result of this, there are multiple unknowns and risks that come with the implementation of Moringa Oleifera as a coagulant and therefore it is not recommended.

8 Recommendation

Potable grade (white) granular/powder Polyaluminium Chloride (PACl) is the recommended primary coagulant for the TMV water supply project treatment plants.

Regards

Scott Cairney
Engineer to Contract – TMV Stage 2 / Project Director

TE MATO VAI

Appendix 3

Memorandum

1 November 2019

To	Lloyd Myles		
Copy to	TMV PMU, MFEM		
From	Scott Cairney	Tel	+64 27 289 4369
Subject	MISC No's. 41/2016 to 50/2016 – Follow up Actions Table for Concerns of Selected Landowners' items 4	Job no.	12/504023

1 Background

This memorandum is to provide independent information on the safety, environmental effects, and standard monitoring and management procedures for Polyaluminium Chloride (PACl).

PACl is commonly used as a coagulant for the treatment of drinking water. The chemical is supplied in powdered or granular form (can also be supplied in liquid form) in 20kg bags. It is then typically mixed as a 10% w/v solution prior to use and then drip fed, or added via a dosing pump, to the raw water at the inlet of a sedimentation tank (or clarifier) where it then enters a hydraulic flocculator. The hydraulic flocculator initiates the flocculation process (formation of floc) followed by subsequent settlement of floc in the bulk part of the sedimentation tank (or Clarifier). The flocculation process lowers turbidity, colour, iron and manganese content of the raw water by encouraging fine particulates, and in some cases dissolved metals, to clump together. The majority of these 'clumps' (Floc) particles sink to the bottom of the sedimentation tank and remain in the tank, however smaller floc particles can leave the sedimentation tanks and are then filtered out through sand filters (like the AVG's) before entering the distribution network. The flocculation process is also substantially reduces the amount of microbiological contamination prior to the disinfection process (but does not necessarily eliminate it)

2 Safety

Listed below are the relevant safety measures shown in the Safety Data Sheets (SDS) for both dry PACl (100% PACl, in dry powder form), and liquid PACl (30-60% PACl with the balance made up with water). These SDSs from Ixom are attached as **Appendix A** (Dry PACl), and **Appendix B** (liquid PACl).

Appropriate engineering controls:

- Store in a cool, dry place and ensure adequate ventilation (can include local exhaust ventilation); and,
- Keep containers closed when not in use and check regularly for spills.

Conditions for safe storage, including any incompatibilities:

- Store in plastic (PE, PP, PVC) or fibreglass containers/vessels. Corrosive to mild and stainless steels; and,
- Store away from incompatible materials (detailed in SDS).

Individual protection measures, such as Personal Protective Equipment (PPE):

- At a minimum, wear safety shoes, overalls, chemical goggles, and impervious gloves when handling PACl;
- For dry PACl, avoid skin and eye contact and breathing in dust. Avoid handling which leads to dust formation;
- For liquid PACl, avoid skin and eye contact and breathing in vapour, mists and aerosols;
- If determined by a risk assessment an inhalation risk exists, wear a dust mask/respirator meeting the requirements of AS/NZS 1715 and AS/NZS 1716;
- Always wash hands before smoking, eating, drinking or using the toilet; and,
- Wash contaminated clothing and other protective equipment before storage or re-use.

Accidental Release Measures: Personal precautions/Protective equipment/Methods and materials for containment and cleaning up:

- Wear protective equipment to prevent skin and eye contact and breathing in dust;

Accidental release measures: Emergency procedures/Environmental precautions:

- Clear area of all unprotected personnel;
- If contamination of sewers or waterways has occurred advise local emergency services.
- Contain - prevent run off into drains and waterways;
- Use absorbent (soil, sand or other inert material);
- Work up wind or increase ventilation to avoid breathing in dust;
- Slippery when spilt;
- Collect and seal in properly labelled containers or drums for disposal; and,
- Neutralise with lime or soda ash.

3 Environmental Effects (Ecotoxicity)

It is strongly advised that either undiluted, unneutralised, or large amounts of PACl not to have contact with ground water, water courses, sewage systems, or drainage ditches; and,

PACl discharge into aquatic environments can lower the pH value of the receiving waters. This acidified water has the potential to harm aquatic organisms. Dilution of the product can increase the pH value and reduce the risk of harm to receiving waters.

The actual dissolved aluminium concentration in the proposed release of "near clear water" from the settling tank or supernatant from the sludge pond cannot be reliably predicted. In theory, if this water has a low organics content, a turbidity <1 NTU and the pH is in the range 6 to 7.5, it is possible that the soluble aluminium will be <0.1 mg/L (as Al). The extent of toxicity risk for fish would therefore be expected to be low, but it is recommended that a suitable ecological study for the actual fish populations of interest be completed if concentration are determined to be higher than 0.1mg/L.

It is important to note that in the instance of elevated Al concentrations (i.e. above 0.2mg/L) that this does not necessarily result in toxicity. There are a few water chemistry parameters that can affect the bioavailability of Al in water, including pH, total hardness and dissolved organic carbon. These items will change and be different depending on the raw water characteristics at each site.

Additional to the water chemistry characteristics, duration of exposure also plays a role in the toxicity of Al in aquatic environments. This means that exposure to short durations of 'high' concentrations can be withstood by the environment without causing detrimental outcomes. This means that if during testing for

Al, 'high' concentrations are found, operations can be stopped until the concentrations can be lowered, thereby allow concentrations to dissipate while operations are adjusted to reduce any impact.

According to Auckland Regional Council TP227, "it is generally accepted that dissolved aluminium at a concentration between 0.050 and 0.100 mg/L with a pH between 6.5 –and 8.0 presents little threat of toxicity. However, at lower pH, the toxicity increases with an effect of possible major concern being the coagulation of mucus on the gills of fish."

4 Standard Monitoring and Management Practices (Process)

The most significant by-product of using PACl in the coagulant of drinking water is dissolved aluminium.

The World Health Organisation (WHO) have defined acceptable concentrations of aluminium in drinking water following treatment using aluminium based coagulants.

> *"The beneficial effects of the use of aluminium as a coagulant in water treatment are recognized. Taking this into account and considering the potential health concerns (i.e. neurotoxicity) of aluminium, a practicable level is derived based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants, to minimize aluminium levels in finished water. For large, well-operated and well-controlled plants, a residual aluminium concentration in the final water of 0.1 mg/l should be achievable. For smaller facilities, a residual concentration of 0.2 mg/l is a more reasonable expectation."*

In order to ensure these requirements are met, WHO states:

> *"A number of approaches are available for minimizing residual aluminium concentrations in treated water. These include use of optimum pH in the coagulation process, avoiding excessive aluminium dosage, sufficient mixing at the point of application of the coagulant, optimum mixing conditions for flocculation and efficient filtration of the aluminium floc (Letterman & Driscoll, 1988; WRc, 1997). Residual aluminium concentration is affected not only by obvious factors, such as operational conditions and raw water quality, but also by more obscure factors, such as water treatment plant capacity and the size of the water supplier (Ohno et al., 2009)."*

More detail can be found in Aluminium in Drinking-Water, Background Document for Development of *WHO Guidelines for Drinking-Water Quality* (WHO, 2010), attached as **Appendix C.**

It should also be noted that the Draft Cook Island Drinking Water Standards also has selected Guideline Value (GV) for the concentration of aluminium in the drinking water as 0.1mg/L.

Within New Zealand, the Standard for the Supply of PACl for Use in Water Treatment, Second Edition (Water New Zealand, 2013) is intended to provide purchasers, manufacturers and suppliers with the minimum requirements for PACl, including physical, chemical and testing requirements. This standard is attached as **Appendix D** and includes the following regarding methods of dosing:

> *"Polyaluminium chloride is dosed as a liquid solution. It is usually dosed via diaphragm pumps into a zone of high water turbulence to facilitate rapid mixing of the solution with the water. It is normal to pump the solution with additional dilution water into the water being treated in order to facilitate good mixing and rapid coagulation."*

The Guidelines for Drinking-Water Quality Management for New Zealand – Chapter 13: Treatment Processes, Coagulation (May 2019) are attached as **Appendix E** and includes the following regarding performance and control:

> *"The performance of coagulation and flocculation is dependent on a large number of factors, many of which are inter-related, making optimisation difficult. Source water characteristics, chemical dose rates, mixing conditions, flocculation times, the selection of chemicals and their order of addition,*

treatment rates, water temperature, can all affect performance. Control of pH and alkalinity is also essential to maintain performance."

5 Monitoring and Management Practices (Environment)

In New Zealand and Australia, in most cases sludge supernatant is recycled back to the inlet of the water treatment plant. This is achieved by pumping the supernatant back up to the head of the works prior to the dosing point. In this way, it is only the sludge that becomes waste product as the supernatant is recycled back into the "process" water and is ultimately consumed.

So, for discharges of PACl (or dissolved aluminium) to the environment (through Supernatant), there is no 'standard' practice'. However, we have identified one example of where sludge pond supernatant is discharged back into the environment and provides guidance on how a monitoring process may be arranged for the treatment plants on Rarotonga. This is at the Wairoa Water Treatment Plant (WTP) located in Frasertown, Wairoa District on the east coast of the North Island of New Zealand.

The control conditions for the Wairoa WTP that are set by the Hawkes Bay Regional Council are:

1. *The maximum discharge rate shall not exceed 28 L/s and the maximum volume discharged in any 24 hour period shall not exceed 600 m3.*
2. *Sampling conducted once every three months in 4 locations:*
    a) *In the tributary of the stream 20 m upstream from the point of discharge*
    b) *In the tributary of the stream 50 m downstream from the point of discharge*
    c) *In the stream 50 m downstream from the confluence with the tributary*
    d) *In the stream 20 m upstream from the confluence with the tributary*
3. *The samples are tested for dissolved aluminium, turbidity and pH*
4. *The dissolved aluminium results for sample (c) are compared to the ANZECC (2000) trigger value for dissolved aluminium of 0.055 mg/L in the receiving water.*
5. *If any result for samples taken at location (c) exceed the trigger, then the dissolved aluminium results from the other 3 locations are compared to determine if the discharge is the likely principal cause, or a likely significant contributor to the exceedance.*
6. *If it is determined that the discharge is the likely principal cause, or a likely significant contributor to the ANZECC trigger value exceedance, then the sampling required will be increased to once every month until 4 consecutive samples at location (c) are compliant.*
7. *The treatment plant produces a bi-annual report summarising the monitoring and sampling undertaken, critical analysis of compliance and potential adverse environmental effects and any recommendations.*
8. *The council can review and change the conditions of the consent annually.*

Applying this monitoring and management approach in the context of the Te Mato Vai Project, a proposed regime for Te Mato Vai could be adopted as follows:

1. *Sampling conducted once every week for 4 months of operation in 4 locations:*
    (a) *At the Intake structure*
    (b) *In settled water in the scour / backwash ponds*
    (c) *In the stream approximately 50m downstream of the discharge point from the scour / backwash pond*

    (d) *In the stream approximately 100m upstream of the discharge point into the lagoon*
    (e) *In the stream approximately half way between the treatment plant and the lagoon discharge point*

2. *The samples are tested for dissolved aluminium, turbidity and pH*
3. *The dissolved aluminium results for sample (c) are compared to the ANZECC (2000) trigger value for dissolved aluminium of 0.055 mg/L in the receiving water.*
4. *If any result for samples taken at location (c) exceed the trigger, then the dissolved aluminium results from the other locations are compared to determine if the discharge is the likely principal cause, or a likely significant contributor to the exceedance.*
5. *If it is determined that the discharge is the likely principal cause, or a likely significant contributor to the ANZECC trigger value exceedance, then alternative coagulants, or operational approaches will need to be developed to reduce the concentrations.*
6. *If after the 4 months of operation, results show Al concentrations are stable and below the ANZECC threshold, the sampling required will be decreased to once every month until 4 consecutive samples at location (c) are compliant. Then reduced to once every 6 months for perpetuity.*
7. *If an exceedance occurs in any test, then the testing regularity will revert to the next highest level of testing regularity until the issue is resolved.*
8. *The treatment plant produces a bi-annual report summarising the monitoring and sampling undertaken, critical analysis of compliance and potential adverse environmental effects and any recommendations.*
9. *The NES can review and change the conditions of the consent annually.*

Regards

Scott Cairney
Engineer to Contract – TMV Stage 2 / Project Director

Appendix A – Dry PACl MSDS

Safety Data Sheet

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name:	**DRY PAC**
Other name(s):	Polyaluminium chloride, PAC Solid
Recommended Use of the Chemical and Restrictions on Use	Water treatment chemical.
Supplier:	Ixom Operations Pty Ltd
ABN:	51 600 546 512
Street Address:	Level 8, 1 Nicholson Street Melbourne 3000 Australia
Telephone Number:	+61 3 9665 7111
Facsimile:	+61 3 9665 7937
Emergency Telephone:	**1 800 033 111 (ALL HOURS)**

Please ensure you refer to the limitations of this Safety Data Sheet as set out in the "Other Information" section at the end of this Data Sheet.

2. HAZARDS IDENTIFICATION

Not classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for transport by Road and Rail; NON-DANGEROUS GOODS.

This material is hazardous according to Safe Work Australia; HAZARDOUS SUBSTANCE.

Classification of the substance or mixture:
Acute Oral Toxicity - Category 4
Skin Irritation - Category 2
Eye Irritation - Category 2A

SIGNAL WORD: WARNING

Hazard Statement(s):
H302 Harmful if swallowed.
H315 Causes skin irritation.
H319 Causes serious eye irritation

Precautionary Statement(s):

Prevention:
P264 Wash hands thoroughly after handling.
P270 Do not eat, drink or smoke when using this product.
P280 Wear protective gloves / protective clothing / eye protection / face protection.

Response:
P301+P312 IF SWALLOWED: Call a POISON CENTER or doctor/physician if you feel unwell.
P330 Rinse mouth.
P302+P352 IF ON SKIN. Wash with plenty of soap and water.
P321 Specific treatment (see First Aid Measures on Safety Data Sheet).
P332+P313 If skin irritation occurs: Get medical advice/attention.
P362 Take off contaminated clothing and wash before reuse.
P305+P351+P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P337+P313 If eye irritation persists: Get medical advice/attention.

Storage:
No storage statements.

Disposal:
P501 Dispose of contents/container in accordance with local/regional/national/international regulations.

Poisons Schedule (SUSMP): None allocated.

3. COMPOSITION AND INFORMATION ON INGREDIENTS

Components	CAS Number	Proportion	Hazard Codes
Polyaluminium chloride	1327-41-9	100%	H302 H315 H319

4. FIRST AID MEASURES

For advice, contact a Poisons Information Centre (e.g. phone Australia 131 126; New Zealand 0800 764 766) or a doctor.

Inhalation:
Remove victim from area of exposure - avoid becoming a casualty. Remove contaminated clothing and loosen remaining clothing. Allow patient to assume most comfortable position and keep warm. Keep at rest until fully recovered. Seek medical advice if effects persist.

Skin Contact:
If skin or hair contact occurs, immediately remove any contaminated clothing and wash skin and hair thoroughly with running water. If swelling, redness, blistering or irritation occurs seek medical assistance.

Eye Contact:
If in eyes, hold eyelids apart and flush the eye continuously with running water. Continue flushing until advised to stop by a Poisons Information Centre or a doctor, or for at least 15 minutes.

Ingestion:
Rinse mouth with water. If swallowed, give a glass of water to drink. If vomiting occurs give further water. Seek medical advice.

Indication of immediate medical attention and special treatment needed:
Treat symptomatically.

5. FIRE FIGHTING MEASURES

Suitable Extinguishing Media:
Not combustible, however, if material is involved in a fire use: Media applicable to surrounding fire.

Specific hazards arising from the substance or mixture:
Non-combustible material. Decomposes on heating emitting toxic fumes including those of hydrogen chloride and aluminium oxide .

Special protective equipment and precautions for fire-fighters:
If safe to do so, remove containers from path of fire. Fire fighters to wear self-contained breathing apparatus and suitable protective clothing if risk of exposure to products of decomposition.

6. ACCIDENTAL RELEASE MEASURES

Emergency procedures/Environmental precautions:
Clear area of all unprotected personnel. If contamination of sewers or waterways has occurred advise local emergency services.

Personal precautions/Protective equipment/Methods and materials for containment and cleaning up:
Wear protective equipment to prevent skin and eye contact and breathing in dust. Avoid breathing in dust. Work up wind or increase ventilation. Contain - prevent run off into drains and waterways. Use absorbent (soil, sand or other inert material). Sweep up, but avoid generating dust. Collect in properly labelled containers, with loose fitting lids, for disposal. Neutralise with lime or soda ash.

7. HANDLING AND STORAGE

Precautions for safe handling:
Avoid skin and eye contact and breathing in dust. Avoid handling which leads to dust formation.

Conditions for safe storage, including any incompatibilities:
Store in a cool, dry, well ventilated place. Store in plastic (PE, PP, PVC) or fibreglass containers/vessels. Corrosive to mild and stainless steels. Store away from incompatible materials described in Section 10. Keep containers sealed as material may absorb moisture. Keep containers closed when not in use - check regularly for spills.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Control Parameters: No value assigned for this specific material by Safe Work Australia. However, Workplace Exposure Standard(s) for decomposition product(s):

Hydrogen chloride: Peak Limitation = 7.5 mg/m^3 (5 ppm)

As published by Safe Work Australia Workplace Exposure Standards for Airborne Contaminants.

Peak Limitation - a maximum or peak airborne concentration of a particular substance determined over the shortest analytically practicable period of time which does not exceed 15 minutes.

These Workplace Exposure Standards are guides to be used in the control of occupational health hazards. All atmospheric contamination should be kept to as low a level as is workable. These workplace exposure standards should not be used as fine dividing lines between safe and dangerous concentrations of chemicals. They are not a measure of relative toxicity.

Appropriate engineering controls:
Ensure ventilation is adequate and that air concentrations of components are controlled below quoted Workplace Exposure Standards. Keep containers closed when not in use.

If in the handling and application of this material, safe exposure levels could be exceeded, the use of engineering controls such as local exhaust ventilation must be considered and the results documented. If achieving safe exposure levels does not require engineering controls, then a detailed and documented risk assessment using the relevant Personal Protective Equipment (PPE) (refer to PPE section below) as a basis must be carried out to determine the minimum PPE requirements.

Individual protection measures, such as Personal Protective Equipment (PPE):
The selection of PPE is dependent on a detailed risk assessment. The risk assessment should consider the work situation, the physical form of the chemical, the handling methods, and environmental factors.

OVERALLS, SAFETY SHOES, CHEMICAL GOGGLES, GLOVES, DUST MASK.

Wear overalls, chemical goggles and impervious gloves. Avoid generating and inhaling dusts. If determined by a risk assessment an inhalation risk exists, wear a dust mask/respirator meeting the requirements of AS/NZS 1715 and AS/NZS 1716. Always wash hands before smoking, eating, drinking or using the toilet. Wash contaminated clothing and other protective equipment before storage or re-use.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state:	Solid
Colour:	Pale Yellow
Odour:	Weak
Solubility:	Soluble in water.
Specific Gravity:	0.85
Flash Point (°C):	Not applicable
Flammability Limits (%):	Not applicable
Autoignition Temperature (°C):	Not applicable
Solubility in water (g/L):	>300
Melting Point/Range (°C):	Not available
Decomposition Point (°C):	Not available
pH:	3.5 - 5.0 (1% aqueous solution)

10. STABILITY AND REACTIVITY

Reactivity:	Reacts with chlorates. Reacts with chlorites.
Chemical stability:	Stable under normal conditions of use. Hygroscopic: absorbs moisture or water from surrounding air.
Possibility of hazardous reactions:	Corrosive to metals .

Conditions to avoid:	Avoid exposure to moisture. Avoid exposure to heat, sources of ignition, and open flame.
Incompatible materials:	Incompatible with chlorates , chlorites .
Hazardous decomposition products:	Aluminium oxide. Hydrogen chloride.

11. TOXICOLOGICAL INFORMATION

No adverse health effects expected if the product is handled in accordance with this Safety Data Sheet and the product label. Symptoms or effects that may arise if the product is mishandled and overexposure occurs are:

Ingestion:	Swallowing can result in nausea, vomiting, diarrhoea, and abdominal pain.
Eye contact:	An eye irritant.
Skin contact:	Contact with skin will result in irritation.
Inhalation:	Breathing in dust may result in respiratory irritation.

Acute toxicity:
Oral LD50 (rat): 681 mg/kg.
Oral LD50 (mice): 316 mg/kg.

Chronic effects: No information available for the product.

12. ECOLOGICAL INFORMATION

Ecotoxicity	Avoid contaminating waterways.

13. DISPOSAL CONSIDERATIONS

Disposal methods:
Refer to Waste Management Authority. Dispose of contents/container in accordance with local/regional/national/international regulations.

14. TRANSPORT INFORMATION

Road and Rail Transport
Not classified as Dangerous Goods by the criteria of the Australian Dangerous Goods Code (ADG Code) for transport by Road and Rail; NON-DANGEROUS GOODS.

Marine Transport
Not classified as Dangerous Goods by the criteria of the International Maritime Dangerous Goods Code (IMDG Code) for transport by sea; NON-DANGEROUS GOODS.

Air Transport
Not classified as Dangerous Goods by the criteria of the International Air Transport Association (IATA) Dangerous Goods Regulations for transport by air; NON-DANGEROUS GOODS.

15. REGULATORY INFORMATION

Classification:
This material is hazardous according to Safe Work Australia; HAZARDOUS SUBSTANCE.

Classification of the substance or mixture:
Acute Oral Toxicity - Category 4
Skin Irritation - Category 2
Eye Irritation - Category 2A

Hazard Statement(s):
H302 Harmful if swallowed.
H315 Causes skin irritation.
H319 Causes serious eye irritation.

Poisons Schedule (SUSMP): None allocated.

This material is listed on the Australian Inventory of Chemical Substances (AICS).

16. OTHER INFORMATION

'Registry of Toxic Effects of Chemical Substances'. Ed. D. Sweet, US Dept. of Health & Human Services: Cincinatti, 2015.

This safety data sheet has been prepared by Ixom Operations Pty Ltd Toxicology & SDS Services.

Reason(s) for Issue:
Revised Primary SDS
Change in company details

This SDS summarises to our best knowledge at the date of issue, the chemical health and safety hazards of the material and general guidance on how to safely handle the material in the workplace. Since Ixom Operations Pty Ltd cannot anticipate or control the conditions under which the product may be used, each user must, prior to usage, assess and control the risks arising from its use of the material.

If clarification or further information is needed, the user should contact their Ixom representative or Ixom Operations Pty Ltd at the contact details on page 1.

Ixom Operations Pty Ltd's responsibility for the material as sold is subject to the terms and conditions of sale, a copy of which is available upon request.

Appendix B – Liquid PACl MSDS

Safety Data Sheet

1. IDENTIFICATION OF THE MATERIAL AND SUPPLIER

Product Name:	**LIQUIPAC (POLYALUMINIUM CHLORIDE)**
Other name(s):	Liquipac * Liquid PAC * Liquid polyaluminium chloride * PAC solution * Polyaluminium chloride solution * Liquipac 1210A
Recommended Use of the Chemical and Restrictions on Use	Flocculating agent for potable water and industrial water treatments.
Supplier:	Ixom Operations Pty Ltd (Incorporated in Australia)
NZBN:	9429041465226
Street Address:	166 Totara Street Mt Maunganui South New Zealand
Telephone Number:	+64 9 368 2700
Facsimile:	+64 9 368 2710
Emergency Telephone:	**0 800 734 607 (ALL HOURS)**

Please ensure you refer to the limitations of this Safety Data Sheet as set out in the "Other Information" section at the end of this Data Sheet.

2. HAZARDS IDENTIFICATION

Not classified as a Dangerous Good under NZS 5433:2012 Transport of Dangerous Goods on Land.

Classified as hazardous according to criteria in the HS (Minimum Degrees of Hazard) Regulations 2001.

SIGNAL WORD: WARNING

Subclasses:
Subclass 6.1 Category D - Substances which are acutely toxic.
Subclass 6.3 Category A - Substances that are irritating to the skin.
Subclass 6.4 Category A - Substances that are irritating to the eye.

Water Treatment Chemicals (Subsidiary Hazard) Group Standard 2006
Approval Number: HSR002684

Hazard Statement(s):
H302 Harmful if swallowed
H315 Causes skin irritation.
H319 Causes serious eye irritation.

Precautionary Statement(s):

Prevention:
P103 Read label before use.
P264 Wash hands thoroughly after handling.
P280 Wear protective gloves/protective clothing/eye protection/face protection.

Response:
P305+P351+P338 IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P337+P313 If eye irritation persists: Get medical advice/attention.

Storage:
No storage statements

Disposal:
P501 In case of a substance that is in compliance with a HSNO approval other than a Part 6A (Group Standards) approval, a label must provide a description of one or more appropriate and achievable methods for the disposal of a substance in accordance with the Hazardous Substances (Disposal) Regulations 2001. This may also include any method of disposal that must be avoided.

3. COMPOSITION AND INFORMATION ON INGREDIENTS

Components	CAS Number	Proportion	Hazard Codes
Polyaluminium chloride	1327-41-9	30-60%	H302 H315 H319
Water	7732-18-5	to 100%	-

4. FIRST AID MEASURES

For advice, contact a Poisons Information Centre (e.g. phone Australia 131 126; New Zealand 0800 764 766) or a doctor.

Inhalation:
Remove victim from area of exposure - avoid becoming a casualty. Remove contaminated clothing and loosen remaining clothing. Allow patient to assume most comfortable position and keep warm. Keep at rest until fully recovered Seek medical advice if effects persist.

Skin Contact:
If skin or hair contact occurs, immediately remove any contaminated clothing and wash skin and hair thoroughly with running water. If swelling, redness, blistering or irritation occurs seek medical assistance.

Eye Contact:
If in eyes, hold eyelids apart and flush the eye continuously with running water. Continue flushing until advised to stop by a Poisons Information Centre or a doctor, or for at least 15 minutes.

Ingestion:
Rinse mouth with water. If swallowed, give a glass of water to drink. If vomiting occurs give further water. Seek immediate medical assistance.

Indication of immediate medical attention and special treatment needed:
Treat symptomatically.

5. FIRE FIGHTING MEASURES

Suitable Extinguishing Media:
Not combustible, however, if material is involved in a fire use: Extinguishing media appropriate to surrounding fire conditions.

Specific hazards arising from the chemical:
Non-combustible material.

Special protective equipment and precautions for fire-fighters:
Decomposes on heating emitting toxic fumes, including those of hydrogen chloride . Fire fighters to wear self-contained breathing apparatus and suitable protective clothing if risk of exposure to products of decomposition.

6. ACCIDENTAL RELEASE MEASURES

Emergency procedures/Environmental precautions:
Clear area of all unprotected personnel. If contamination of sewers or waterways has occurred advise local emergency services.

Personal precautions/Protective equipment/Methods and materials for containment and cleaning up:
Slippery when spilt. Avoid accidents, clean up immediately. Wear protective equipment to prevent skin and eye contact. Contain - prevent run off into drains and waterways. Use absorbent (soil, sand or other inert material). Collect and seal in properly labelled containers or drums for disposal.

7. HANDLING AND STORAGE

Precautions for safe handling: Avoid skin and eye contact and breathing in vapour, mists and aerosols.

Conditions for safe storage, including any incompatibilities: Store in a cool, dry, well ventilated place. Store away from incompatible materials described in Section 10. Keep containers closed when not in use - check regularly for leaks.

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Workplace Exposure Standards: No value assigned for this specific material by the New Zealand Workplace Health & Safety Authority. However, Workplace Exposure Standard(s) for constituent(s):

Aluminium, as Al: Soluble salts WES-TWA 5 mg/m^3

As published by the New Zealand Workplace Health & Safety Authority.

WES - TWA (Workplace Exposure Standard - Time Weighted Average) - The eight-hour, time-weighted average exposure standard is designed to protect the worker from the effects of long-term exposure.

These Workplace Exposure Standards are guides to be used in the control of occupational health hazards. All atmospheric contamination should be kept to as low a level as is workable. These workplace exposure standards should not be used as fine dividing lines between safe and dangerous concentrations of chemicals. They are not a measure of relative toxicity.

Appropriate engineering controls:
Ensure ventilation is adequate and that air concentrations of components are controlled below quoted Workplace Exposure Standards. Keep containers closed when not in use.

If in the handling and application of this material, safe exposure levels could be exceeded, the use of engineering controls such as local exhaust ventilation must be considered and the results documented. If achieving safe exposure levels does not require engineering controls, then a detailed and documented risk assessment using the relevant Personal Protective Equipment (PPE) (refer to PPE section below) as a basis must be carried out to determine the minimum PPE requirements.

Individual protection measures, such as Personal Protective Equipment (PPE):
The selection of PPE is dependent on a detailed risk assessment. The risk assessment should consider the work situation, the physical form of the chemical, the handling methods, and environmental factors.

OVERALLS, SAFETY SHOES, CHEMICAL GOGGLES, GLOVES.

Wear overalls, chemical goggles and impervious gloves. Always wash hands before smoking, eating, drinking or using the toilet. Wash contaminated clothing and other protective equipment before storage or re-use.

If determined by a risk assessment an inhalation risk exists, wear a suitable mist respirator meeting the requirements of AS/NZS 1715 and AS/NZS 1716.

9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state:	Clear Liquid
Colour:	Pale Amber
Odour:	Mild
Solubility:	Soluble in water.
Specific Gravity:	1.20 @20°C (at 10.1% Al2O3)
Relative Vapour Density (air=1):	Not available
Vapour Pressure (20 °C):	Not available
Flash Point (°C):	Not applicable
Flammability Limits (%):	Not applicable
Autoignition Temperature (°C):	Not applicable
Boiling Point/Range (°C):	Not available
Decomposition Point (°C):	Not available
pH:	2.8 +/- 0.3 @25°C
Freezing Point/Range (°C):	-12.0 (approx.)

10. STABILITY AND REACTIVITY

Reactivity:	Reacts with calcium hypochlorite. Reacts with alkalis. Slowly corrodes metals. Reacts with cyanides.
Chemical stability:	Stable under normal ambient and anticipated storage and handling conditions of temperature and pressure.
Possibility of hazardous reactions:	Can react with calcium hypochlorite , alkalis , metals , cyanides .
Conditions to avoid:	None known.
Incompatible materials:	Incompatible with calcium hypochlorite , alkalis , metals , cyanides .
Hazardous decomposition products:	Hydrogen chloride

11. TOXICOLOGICAL INFORMATION

No adverse health effects expected if the product is handled in accordance with this Safety Data Sheet and the product label. Symptoms or effects that may arise if the product is mishandled and overexposure occurs are:

Ingestion:	Swallowing can result in nausea, vomiting, diarrhoea, and gastrointestinal irritation.
Eye contact:	An eye irritant.
Skin contact:	Contact with skin will result in irritation.
Inhalation:	Breathing in mists or aerosols may produce respiratory irritation.

Acute toxicity: No LD50 data available for the product. However, for constituent(s)
POLYALUMINIUM CHLORIDE:
Oral LD50 (rat): 681 mg/kg.
Oral LD50 (mice): 316 mg/kg.

Chronic effects: No information available for the product.

12. ECOLOGICAL INFORMATION

Ecotoxicity	Avoid contaminating waterways.

13. DISPOSAL CONSIDERATIONS

Disposal methods:
Refer to local government authority for disposal recommendations. Dispose of material through a licensed waste contractor. Normally suitable for disposal at approved land waste site.

14. TRANSPORT INFORMATION

Road and Rail Transport
Not classified as a Dangerous Good under NZS 5433:2012 Transport of Dangerous Goods on Land.

Marine Transport
Not classified as Dangerous Goods by the criteria of the International Maritime Dangerous Goods Code (IMDG Code) for transport by sea; NON-DANGEROUS GOODS.

Air Transport
Not classified as Dangerous Goods by the criteria of the International Air Transport Association (IATA) Dangerous Goods Regulations for transport by air; NON-DANGEROUS GOODS.

15. REGULATORY INFORMATION

Classification:
Classified as hazardous according to criteria in the HS (Minimum Degrees of Hazard) Regulations 2001.

Subclasses:
Subclass 6.1 Category D - Substances which are acutely toxic.
Subclass 6.3 Category A - Substances that are irritating to the skin.
Subclass 6.4 Category A - Substances that are irritating to the eye.

Water Treatment Chemicals (Subsidiary Hazard) Group Standard 2006
Approval Number: HSR002684

Hazard Statement(s):
H302 Harmful if swallowed.
H315 Causes skin irritation.
H319 Causes serious eye irritation.

16. OTHER INFORMATION

'Registry of Toxic Effects of Chemical Substances'. Ed. D. Sweet, US Dept. of Health & Human Services: Cincinatti, 2016.

Reason(s) for Issue:
5 Yearly Revised Primary SDS

This SDS summarises to our best knowledge at the date of issue, the chemical health and safety hazards of the material and general guidance on how to safely handle the material in the workplace. Since Ixom Operations Pty Ltd cannot anticipate or control the conditions under which the product may be used, each user must, prior to usage, assess and control the risks arising from its use of the material.

If clarification or further information is needed, the user should contact their Ixom representative or Ixom Operations Pty Ltd at the contact details on page 1.

Ixom Operations Pty Ltd's responsibility for the material as sold is subject to the terms and conditions of sale, a copy of which is available upon request.

Appendix C – Aluminium in Drinking Water

WHO/HSE/WSH/10.01/13
English only

Aluminium in drinking-water

Background document for development of
WHO *Guidelines for Drinking-water Quality*

Aluminium in Drinking-water
Background document for development of WHO *Guidelines for Drinking-water Quality*

© World Health Organization 2010

All rights reserved. Publications of the World Health Organization can be obtained from WHO Press, World Health Organization, 20 Avenue Appia, 1211 Geneva 27, Switzerland (tel.: +41 22791 3264; fax: +41 22 791 4857; e-mail: bookorders@who.int). Requests for permission to reproduce or translate WHO publications—whether for sale or for non-commercial distribution—should be addressed to WHO Press at the above address (fax: +41 22 791 4806; e-mail: permissions@who.int).

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the World Health Organization concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. Dotted lines on maps represent approximate border lines for which there may not yet be full agreement.

The mention of specific companies or of certain manufacturers' products does not imply that they are endorsed or recommended by the World Health Organization in preference to others of a similar nature that are not mentioned. Errors and omissions excepted, the names of proprietary products are distinguished by initial capital letters.

All reasonable precautions have been taken by the World Health Organization to verify the information contained in this publication. However, the published material is being distributed without warranty of any kind, either expressed or implied. The responsibility for the interpretation and use of the material lies with the reader. In no event shall the World Health Organization be liable for damages arising from its use.

The named authors alone are responsible for the views expressed in this publication.

Preface

One of the primary goals of the World Health Organization (WHO) and its Member States is that "all people, whatever their stage of development and their social and economic conditions, have the right to have access to an adequate supply of safe drinking water." A major WHO function to achieve such goals is the responsibility "to propose ... regulations, and to make recommendations with respect to international health matters ...."

The first WHO document dealing specifically with public drinking-water quality was published in 1958 as *International Standards for Drinking-water*. It was subsequently revised in 1963 and in 1971 under the same title. In 1984–1985, the first edition of the WHO *Guidelines for Drinking-water Quality* (GDWQ) was published in three volumes: Volume 1, Recommendations; Volume 2, Health criteria and other supporting information; and Volume 3, Surveillance and control of community supplies. Second editions of these volumes were published in 1993, 1996 and 1997, respectively. Addenda to Volumes 1 and 2 of the second edition were published in 1998, addressing selected chemicals. An addendum on microbiological aspects reviewing selected microorganisms was published in 2002. The third edition of the GDWQ was published in 2004, the first addendum to the third edition was published in 2006 and the second addendum to the third edition was published in 2008. The fourth edition will be published in 2011.

The GDWQ are subject to a rolling revision process. Through this process, microbial, chemical and radiological aspects of drinking-water are subject to periodic review, and documentation related to aspects of protection and control of public drinking-water quality is accordingly prepared and updated.

Since the first edition of the GDWQ, WHO has published information on health criteria and other supporting information to the GDWQ, describing the approaches used in deriving guideline values and presenting critical reviews and evaluations of the effects on human health of the substances or contaminants of potential health concern in drinking-water. In the first and second editions, these constituted Volume 2 of the GDWQ. Since publication of the third edition, they comprise a series of free-standing monographs, including this one.

For each chemical contaminant or substance considered, a lead institution prepared a background document evaluating the risks for human health from exposure to the particular chemical in drinking-water. Institutions from Canada, Japan, the United Kingdom and the United States of America (USA) prepared the documents for the fourth edition.

Under the oversight of a group of coordinators, each of whom was responsible for a group of chemicals considered in the GDWQ, the draft health criteria documents were submitted to a number of scientific institutions and selected experts for peer review. Comments were taken into consideration by the coordinators and authors. The draft documents were also released to the public domain for comment and submitted for final evaluation by expert meetings.

During the preparation of background documents and at expert meetings, careful consideration was given to information available in previous risk assessments carried out by the International Programme on Chemical Safety, in its Environmental Health Criteria monographs and Concise International Chemical Assessment Documents, the International Agency for Research on Cancer, the Joint FAO/WHO Meetings on Pesticide Residues and the Joint FAO/WHO Expert Committee on Food Additives (which evaluates contaminants such as lead, cadmium, nitrate and nitrite, in addition to food additives).

Further up-to-date information on the GDWQ and the process of their development is available on the WHO Internet site and in the current edition of the GDWQ.

Acknowledgements

The update of Aluminium in Drinking-water, Background document for development of WHO *Guidelines for Drinking-water Quality* (GDWQ), was prepared by Mr J.K. Fawell, United Kingdom, to whom special thanks are due. This original background document was published in the addendum to the second edition in 1998.

The work of the following working group coordinators was crucial in the development of this document and others contributing to the fourth edition:

Dr J. Cotruvo, J. Cotruvo Associates, USA (*Materials and chemicals*)
Mr J.K. Fawell, United Kingdom (*Naturally occurring and industrial contaminants* and *Pesticides*)
Ms M. Giddings, Health Canada (*Disinfectants and disinfection by-products*)
Mr P. Jackson, WRc-NSF, United Kingdom (*Chemicals – practical aspects*)
Professor Y. Magara, Hokkaido University, Japan (*Analytical achievability*)
Dr Aiwerasia Vera Festo Ngowi, Muhimbili University of Health and Allied Sciences, United Republic of Tanzania (*Pesticides*)
Dr E. Ohanian, Environmental Protection Agency, USA (*Disinfectants and disinfection by-products*)

The draft text was discussed at the Expert Consultation for the fourth edition of the GDWQ, held on 9–13 November 2009. The final version of the document takes into consideration comments from both peer reviewers and the public. The input of those who provided comments and of participants at the meeting is gratefully acknowledged.

The WHO coordinators were Mr R. Bos and Mr B. Gordon, WHO Headquarters. Ms C. Vickers provided a liaison with the International Programme on Chemical Safety, WHO Headquarters. Mr M. Zaim, WHO Pesticide Evaluation Scheme, Vector Ecology and Management, WHO Headquarters, provided input on pesticides added to drinking-water for public health purposes.

Ms P. Ward provided invaluable administrative support at the Expert Consultation and throughout the review and publication process. Ms M. Sheffer of Ottawa, Canada, was responsible for the scientific editing of the document.

Many individuals from various countries contributed to the development of the GDWQ. The efforts of all who contributed to the preparation of this document and in particular those who provided peer or public domain review comments are greatly appreciated.

Acronyms and abbreviations used in the text

AAS	atomic absorption spectrometry
DNA	deoxyribonucleic acid
FAO	Food and Agriculture Organization of the United Nations
JECFA	Joint FAO/WHO Expert Committee on Food Additives
LD_{50}	median lethal dose
LOAEL	lowest-observed-adverse-effect level
LOEL	lowest-observed-effect level
NOAEL	no-observed-adverse-effect level
NOEL	no-observed-effect level
PTWI	provisional tolerable weekly intake
USA	United States of America
WHO	World Health Organization

Table of contents

1. GENERAL DESCRIPTION

1.1 Identity

Aluminium is the most abundant metallic element and constitutes about 8% of Earth's crust. It occurs naturally in the environment as silicates, oxides and hydroxides, combined with other elements, such as sodium and fluoride, and as complexes with organic matter.

Compound	Chemical Abstracts Service Registry No.	Molecular formula
Aluminium	7429-90-5	Al
Aluminium chloride	7446-70-0	$AlCl_3$
Aluminium hydroxide	21645-51-2	$Al(OH)_3$
Aluminium nitrate (anhydrous)	13473-90-0	$Al(NO_3)_3$
Aluminium nitrate (nonahydrate)	7784-27-2	$Al(NO_3)_3 \cdot 9H_2O$
Aluminium oxide	1344-28-1	Al_2O_3
Aluminium sulfate	10043-01-3	$Al_2(SO_4)_3$

1.2 Physicochemical properties (Lide, 1993)

Property	Al	$AlCl_3$	$Al(OH)_3$	$Al(NO_3)_3$	Al_2O_3	$Al_2(SO_4)_3$
Melting point (°C)	660	190	300	72.8 (n)	2072	770 (d)
Boiling point (°C)	2467	262 (d)	–	135 (n) (d)	2980	–
Density at 20 °C (g/cm^3)	2.70	2.44	2.42	1.72 (n)	3.97	2.71
Water solubility (g/l)	(i)	69.9	(i)	734 at 20 °C 673 (n)	(i)	31.3 at 0 °C

d, decomposes; i, insoluble; n, nonahydrate

1.3 Organoleptic properties

Use of aluminium salts as coagulants in water treatment may lead to increased concentrations of aluminium in finished water. Where residual concentrations are high, aluminium may be deposited in the distribution system. Disturbance of the deposits by change in flow rate may increase aluminium levels at the tap and lead to undesirable colour and turbidity (Ainsworth, Oliphant & Ridgway, 1980). Concentrations of aluminium at which such problems may occur are highly dependent on a number of water quality parameters and operational factors at the water treatment plant, such as coagulation pH and coagulant dose.

1.4 Major uses

Aluminium metal is used as a structural material in the construction, automotive and aircraft industries, in the production of metal alloys, in the electric industry, in cooking utensils and in food packaging. Aluminium compounds are used as antacids, antiperspirants and food additives (ATSDR, 2008). Aluminium salts are also widely used in water treatment as coagulants to reduce organic matter, colour, turbidity and microorganism levels. The process usually consists of addition of an aluminium salt (often sulfate) at optimum pH and dosage, followed by flocculation, sedimentation and filtration (Health Canada, 1993).

1.5 Environmental fate

Aluminium is released to the environment mainly by natural processes. Several factors influence aluminium mobility and subsequent transport within the environment. These include chemical speciation, hydrological flow paths, soil–water interactions and the composition of the underlying geological materials. Acid environments caused by acid mine drainage or acid rain can cause an increase in the dissolved aluminium content of the surrounding waters (WHO, 1997; ATSDR, 2008).

Aluminium can occur in a number of different forms in water. It can form monomeric and polymeric hydroxy species, colloidal polymeric solutions and gels, and precipitates, all based on aquated positive ions or hydroxylated aluminates. In addition, it can form complexes with various organic compounds (e.g. humic or fulvic acids) and inorganic ligands (e.g. fluoride, chloride and sulfate), most but not all of which are soluble. The chemistry of aluminium in water is complex, and many chemical parameters, including pH, determine which aluminium species are present in aqueous solutions. In pure water, aluminium has a minimum solubility in the pH range 5.5–6.0; concentrations of total dissolved aluminium increase at higher and lower pH values (CCME, 1988; ISO, 1994).

2. ENVIRONMENTAL LEVELS AND HUMAN EXPOSURE

2.1 Air

Aluminium enters the atmosphere as a major constituent of atmospheric particulates originating from natural soil erosion, mining or agricultural activities, volcanic eruptions or coal combustion. Atmospheric aluminium concentrations show widespread temporal and spatial variations. Airborne aluminium levels range from 0.0005 $\mu g/m^3$ over Antarctica to more than 1 $\mu g/m^3$ in industrialized areas (WHO, 1997).

2.2 Water

The concentration of aluminium in natural waters can vary significantly depending on various physicochemical and mineralogical factors. Dissolved aluminium concentrations in waters with near-neutral pH values usually range from 0.001 to 0.05 mg/l but rise to 0.5–1 mg/l in more acidic waters or water rich in organic matter. At the extreme acidity of waters affected by acid mine drainage, dissolved aluminium concentrations of up to 90 mg/l have been measured (WHO, 1997).

Aluminium levels in drinking-water vary according to the levels found in the source water and whether aluminium coagulants are used during water treatment. In Germany, levels of aluminium in public water supplies averaged 0.01 mg/l in the western region, whereas levels in 2.7% of public supplies in the eastern region exceeded 0.2 mg/l (Wilhelm & Idel, 1995). In a 1993–1994 survey of public water supplies in Ontario, Canada, 75% of all average levels were less than 0.1 mg/l, with a range of 0.04–0.85 mg/l (OMEE, 1995). More recently, in drinking-water treatment systems in Canada that have surface water sources and use aluminium salts, the mean total aluminium concentration was estimated to be 101 μg/l. Mean concentrations for the different provinces varied from 20.0 to 174 μg/l (Environment Canada & Health Canada, 2010). In a large monitoring programme in 1991 in the United Kingdom, concentrations in 553 samples (0.7%) exceeded 0.2 mg/l (MAFF, 1993). In a survey of 186 community water supplies in the United States of America (USA), median aluminium concentrations for all finished drinking-water samples ranged from 0.03 to 0.1 mg/l; for facilities using aluminium sulfate coagulation, the median level was 0.1 mg/l, with a maximum of 2.7 mg/l (Miller et al., 1984). In another survey in the USA, the average aluminium concentration in treated water at facilities using aluminium sulfate coagulation ranged from 0.01 to 1.3 mg/l, with an overall average of 0.16 mg/l (Letterman & Driscoll, 1988; ATSDR, 2008).

2.3 Food

Aluminium is present in foods naturally or from the use of aluminium-containing food additives. The use of aluminium cookware, utensils and wrappings can increase the amount of aluminium in food; however, the magnitude of this increase is generally not of practical importance. Foods naturally high in aluminium include potatoes, spinach and tea. Processed dairy products, flour and infant formula may be high in aluminium if they contain aluminium-based food additives (Pennington & Schoen, 1995; WHO, 1989, 1997).

Adult dietary intakes of aluminium have been reported in several countries: Australia (1.9–2.4 mg/day), Finland (6.7 mg/day), Germany (8–11 mg/day), Japan (4.5 mg/day), the Netherlands (3.1 mg/day), Sweden (13 mg/day), Switzerland (4.4 mg/day), the United Kingdom (3.9 mg/day) and the USA (7.1–8.2 mg/day). Intakes of children 5–8 years old were 0.8 mg/day in Germany and 6.5 mg/day in the USA. Infant intakes of aluminium in Canada, the United Kingdom and the USA ranged from 0.03 to 0.7 mg/day (WHO, 1997).

2.4 Estimated total exposure and relative contribution of drinking-water

Aluminium intake from foods, particularly those containing aluminium compounds used as food additives, represents the major route of aluminium exposure for the general public, excluding persons who regularly ingest aluminium-containing antacids and buffered analgesics, for whom intakes may be as high as 5 g/day (WHO, 1997).

At an average adult intake of aluminium from food of 5 mg/day and a drinking-water aluminium concentration of 0.1 mg/l, the contribution of drinking-water to the total oral exposure to aluminium will be about 4%. The contribution of air to the total exposure is generally negligible.

3. KINETICS AND METABOLISM IN LABORATORY ANIMALS AND HUMANS

In experimental animals, absorption of aluminium via the gastrointestinal tract is usually less than 1%. The main factors influencing absorption are solubility, pH and chemical species. Organic complexing compounds, notably citrate, increase absorption. Aluminium absorption may interact with calcium and iron transport systems. Aluminium, once absorbed, is distributed in most organs within the body, with accumulation occurring mainly in bone at high dose levels. To a limited but as yet undetermined extent, aluminium passes the blood–brain barrier and is also distributed to the fetus. Aluminium is eliminated effectively in the urine in experimental animals (WHO, 1997).

In humans, aluminium and its compounds appear to be poorly absorbed, with levels of absorption of up to about 1% (Priest et al., 1998; Stauber et al., 1998; Priest 2004). The mechanism of gastrointestinal absorption has not yet been fully elucidated. Variability results from the chemical properties of the element and the formation of various chemical species, which is dependent upon the pH, ionic strength, presence of competing elements (e.g. silicon) and presence of complexing agents within the gastrointestinal tract (e.g. citrate). The urine is the most important route of aluminium excretion in humans (WHO, 1997; FAO/WHO, 2007).

4. EFFECTS ON EXPERIMENTAL ANIMALS AND IN VITRO TEST SYSTEMS

4.1 Acute exposure

The oral median lethal dose (LD_{50}) of aluminium nitrate, chloride and sulfate in mice and rats ranges from 200 to 1000 mg of aluminium per kilogram of body weight (WHO, 1997).

4.2 Short-term exposure

Groups of 25 male Sprague-Dawley rats were fed diets containing basic sodium aluminium phosphate or aluminium hydroxide at 0, 5, 67, 141 or 288/302 mg of aluminium per kilogram of body weight per day for 28 days. No treatment-related effects on organ and body weights, haematology, clinical chemistry parameters and histopathology were observed, and there was no evidence of deposition of aluminium in bones. The no-observed-effect levels (NOELs) were 288 and 302 mg of aluminium per kilogram of body weight per day for sodium aluminium phosphate and aluminium hydroxide, respectively (Hicks, Hackett & Sprague, 1987).

In a study in which a wide range of end-points was examined, groups of 10 female Sprague-Dawley rats received drinking-water containing aluminium nitrate for 28 days at 0, 1, 26, 52 or 104 mg of aluminium per kilogram of body weight per day. The only effects noted were mild histopathological changes in the spleen and liver of the high-dose group. Although tissue aluminium concentrations were generally higher in treated animals, the increases were significant only for spleen, heart and gastrointestinal tract of the high-dose group. The no-observed-adverse-effect level (NOAEL) was 52 mg of aluminium per kilogram of body weight per day (Gomez et al., 1986).

Groups of 10 female Sprague-Dawley rats received aluminium nitrate in their drinking-water at doses of 0, 26, 52 or 260 mg of aluminium per kilogram of body weight per day for 100 days. Organ and body weights, histopathology of the brain, heart, lungs, kidney, liver and spleen, haematology and plasma chemistry were examined. The only effect observed was a significant decrease in body weight gain associated with a decrease in food consumption at 260 mg of aluminium per kilogram of body weight per day. Aluminium did not accumulate in a dose-dependent manner in the organs and tissues examined. The NOAEL in this study was 52 mg of aluminium per kilogram of body weight per day (Domingo et al., 1987a).

Sodium aluminium phosphate, a leavening acid, was administered to groups of six male and six female Beagle dogs at dietary concentrations of 0%, 0.3%, 1.0% or 3.0% for 6 months. Statistically significant decreases in food consumption occurred sporadically in all treated groups of female dogs, but there was no associated decrease in body weight. No significant absolute or relative organ weight differences were found between any of the treated groups and controls. Haematological, blood chemistry and urinalysis data showed no toxicologically significant trend. The NOAEL was the highest dose tested, approximately 70 mg of aluminium per kilogram of body weight per day (Katz et al., 1984).

Beagle dogs (four per sex per dose) were fed diets containing basic sodium aluminium phosphate at 0, 10, 22–27 or 75–80 mg of aluminium per kilogram of body weight per day for 26 weeks. The only treatment-related effect was a sharp, transient decrease in food consumption and concomitant decrease in body weight in high-dose males. The lowest-observed-adverse-effect level (LOAEL) was 75–80 mg/kg of body weight per day (Pettersen, Hackett & Zwicker, 1990).

Wistar rats exposed to aluminium chloride in their drinking-water at reported aluminium doses of 5 and 20 mg/kg of body weight for 6 months showed reduced body weight and reduced erythrocyte counts and associated parameters, but there were no clear dose–response relationships (Somova & Khan, 1996). Results of histopathological examinations indicated spongiform changes and neurofibrillary degeneration in the hippocampus and atrophy and fibrosis in the kidney at 20 mg/kg of body weight (Somova, Missankov & Khan, 1997).

4.3 Long-term exposure

No adverse effects on body weight or longevity were observed in Charles River mice (54 males and 54 females per group) receiving 0 or 5 mg of aluminium (as potassium aluminium sulfate) per kilogram of diet during their lifetime (Schroeder & Mitchener, 1975a; WHO, 1989).

Two groups of Long-Evans rats (52 of each sex) received 0 or 5 mg of aluminium (as potassium aluminium sulfate) per litre of drinking-water during their lifetime. No effects were found on body weight; average heart weight; glucose, cholesterol and uric acid levels in serum; and protein and glucose content and pH of urine. The lifespan was not affected (Schroeder & Mitchener, 1975b; WHO, 1989).

4.4 Reproductive and developmental toxicity

Aluminium nitrate was administered by gavage to groups of pregnant Sprague-Dawley rats on day 14 of gestation through day 21 of lactation at doses of 0, 13, 26 or 52 mg of aluminium per kilogram of body weight per day. These doses did not produce overt fetotoxicity, but growth of offspring was significantly delayed (body weight, body length and tail length) from birth to weaning in aluminium-treated groups (Domingo et al., 1987b). In a similar study, aluminium nitrate was dosed to males for 60 days prior to mating and to virgin females for 14 days prior to mating and throughout mating, gestation, parturition and weaning of the litters. No reproductive effects on fertility (number of litters produced), litter size or intrauterine or postnatal offspring mortality were reported. There was a decrease in the numbers of corpora lutea in the high-dose group. A dose-dependent delay in the growth of the pups was observed in all treatment groups; female offspring were affected at 13 mg of aluminium per kilogram of body weight per day and males at 26 and 52 mg of aluminium per kilogram of body weight per day. Because of the study design, it is not clear whether the postnatal growth effects in offspring represented general toxicity to male or female parents or specific effects on reproduction or development (Domingo et al., 1987c).

Aluminium hydroxide did not produce either maternal or developmental toxicity when it was administered by gavage during embryogenesis to mice at doses up to 92 mg of aluminium per kilogram of body weight per day (Domingo et al., 1989) or to rats at doses up to 265 mg of aluminium per kilogram of body weight per day (Gomez et al., 1990). When aluminium hydroxide at a dose of 104 mg of aluminium per kilogram of body weight per day was administered with ascorbic acid to mice, no maternal or developmental toxicity was seen, in spite of elevated maternal placenta and kidney concentrations of aluminium (Colomina et al., 1994); on the other hand, aluminium hydroxide at a dose of 133 mg of aluminium per kilogram of body weight per day administered with citric acid produced maternal and fetal toxicity in rats (Gomez, Domingo & Llobet, 1991). Aluminium hydroxide (57 mg of aluminium per kilogram of body weight) given with lactic acid (570 mg/kg of body weight) to mice by gavage was not toxic, but aluminium lactate (57 mg of aluminium per kilogram of body weight) produced developmental toxicity, including poor ossification, skeletal variations and cleft palate (Colomina et al., 1992).

In studies on Swiss-Webster mice given 500 or 1000 mg of aluminium per kilogram of diet as aluminium lactate with a control of 7 mg of aluminium per kilogram of diet (reported to provide doses of <1, 50 or 100 mg of aluminium per kilogram of body weight in adult mice) from conception to weaning, grip strength was reduced in both treatment groups without showing a dose–response relationship. Elevated aluminium concentrations were reported in brain, spinal cord and liver without a dose–response relationship (Golub et al., 1995). These investigators also carried out a similar study with the same control diet and an additional treatment of 100 mg of aluminium per kilogram of diet (10 mg/kg of body weight per day) from conception to 35 days of age. There were no differences in reproductive indices, but, by weaning, both males and females in the two highest dose groups had lower body weights than other groups (Golub & Germann, 2001).

Guo, Lu & Hsu (2005) gave male CD-1 mice 0, 7 or 13 mg of aluminium per kilogram of body weight per day for 14 days, by subcutaneous injection, before mating. There was an initial reduction in mating frequency in treated groups that returned to control levels, but significantly higher numbers of post-implantation losses, fetal mortality and induced petechial haemorrhage, but not fetal abnormalities, were reported in treated groups. The weights of testes decreased as aluminium accumulation increased, and spermatogenic impairment was apparent, but these effects had disappeared by the end of the study.

Aluminium nitrate (nonahydrate) was given to female Sprague-Dawley rats in drinking-water at doses of 0, 50 and 100 mg of aluminium per kilogram of body weight per day for 15 days before mating and throughout gestation, lactation and post-weaning. The aluminium content of the feed was 42 mg/kg. In order to enhance gastrointestinal absorption, citric acid doses of 355 and 710 mg/kg of body weight per day were added to the drinking-water of the 50 and 100 mg of aluminium per kilogram of body weight per day groups, respectively. Controls received water supplemented with citric acid at 710 mg/kg of body weight per day. Doses were adjusted to maintain a constant uptake of aluminium. Body weight was decreased relative to controls on postnatal days 12–21 in pups treated with 100 mg of aluminium per kilogram of body weight per day. Sexual maturation was delayed in all aluminium-treated females and in aluminium-treated males at 100 mg/kg of body weight per day. Forelimb grip strength was reduced in males at 100 mg of aluminium per kilogram of body weight per day (Colomina et al., 2005).

Thirty-one time-mated Charles River CD dams were given aluminium lactate solution by gavage at a dose of 0, 5, 25, 50, 250, 500 or 1000 mg of aluminium per kilogram of body weight per day from days 5 to 15 of gestation. No information was provided on the dietary aluminium content, so the total dose of aluminium is uncertain. The 390 offspring were evaluated for morphological and physiological parameters of reproductive functioning, including birth weight, anogenital distance, timing of vaginal opening, regularity of estrous cycles, duration of pseudopregnancy, number of superovulated oocytes and gonadal weight. No consistent or reproducible findings were reported in these parameters, with the exception of the regularity of estrous cycles. A temporary increase in the proportion of aberrant estrous cycles was detected in the first four cycles after vaginal opening in the group at 250 mg/kg of body weight per day, with none by the fifth consecutive cycle. The authors suggested that aluminium does not have a toxic effect on reproductive functioning in offspring (Agarwal et al., 1996).

Swiss Webster mice were fed diets containing aluminium at 25 (control), 500 or 1000 mg/kg (as aluminium lactate) from conception through weaning. Reported maternal intakes were 5, 100 and 200 mg of aluminium per kilogram of body weight, respectively, at the beginning of pregnancy and 10, 210 and 420 mg of aluminium per kilogram of body weight, respectively, near the end of lactation. Pups were assessed for growth, neurobehavioural development and toxic signs before weaning, immediately after weaning and 2 weeks after weaning, during which time they were maintained on control (25 mg of aluminium per kilogram) diet. No maternal or reproductive toxicity was detected, and there were no group differences in pup mortality, growth, toxic signs or neurobehavioural development before weaning. In general, dietary aluminium was associated with dose-related greater foot splay, decreased sensitivity to heat and greater forelimb and hindlimb grip strength shortly after weaning and, to some extent, after a 2-week recovery period on control diet (Donald et al., 1989).

Male Swiss Webster mice were fed diets containing 7 (control, with and without citrate), 100, 500, 750 or 1000 mg of aluminium per kilogram diet as aluminium lactate (with 3.2% citrate to promote aluminium absorption) from the beginning of puberty (45 days of age) for either 4 or 8 weeks. There was no effect of aluminium content on food intake in any of the treatment groups or on liver, spleen and tibia weights. A decrease in brain weight was recorded in the animals that received 1000 mg of aluminium per kilogram of diet (which the authors considered to provide an aluminium dose of 100 mg/kg of body weight per day) for 4 weeks, but not in the same group treated for the longer duration. A dose-related effect of aluminium on forelimb grip strength was recorded in the groups exposed for 4 weeks (i.e. in pubertal mice), but this effect disappeared in young adulthood, despite continued administration of aluminium (Golub & Keen, 1999).

Groups of 18 male and female Swiss Webster mice were fed diets containing aluminium at a dose of 1000 mg/kg of diet in the form of aluminium lactate, from conception and throughout their lifespan. The authors considered this diet to provide a dose to adult mice of 100 mg of aluminium per kilogram of body weight per day; the control diet provided less than 1 mg of aluminium per kilogram of body weight per day. Animals in the control and treated groups had a similar mortality rate, and no evidence of gross neurodegeneration was seen. There were no consistent differences in neurobehavioural tests based on grip strength, temperature sensitivity or maze negotiation. The only toxic signs reported were red eyes, fur loss and circling (motor stereotypy), all with a low incidence (no group incidences reported) (Golub et al., 2000).

In the study described in section 4.4, Swiss Webster mice received diets containing 7 (control), 100, 500 or 1000 mg of aluminium per kilogram of diet as aluminium lactate throughout development (conception to age 35 days) and were subjected to behavioural tests as adults (aged more than 90 days). The authors considered these dietary doses to be equivalent to <1, 10, 50 and 100 mg of aluminium per kilogram of body weight per day in adult mice. By weaning, both males and females in the groups at 500 or 1000 mg of aluminium per kilogram of diet weighed significantly less than controls. One offspring from each litter was used for behavioural testing. Subtle deficits in several neurological parameters, including impaired learning in a maze, were observed in the animals that received diet containing 1000 mg of aluminium per kilogram, but not at the lower doses. A reduction in hindlimb grip strength was reported in approximately 15% of animals receiving the highest dose; this was no longer significant after adjustment for body weight (Golub & Germann, 2001).

4.5 Mutagenicity and related end-points

Aluminium can form complexes with deoxyribonucleic acid (DNA) and cross-link chromosomal proteins and DNA, but it has not been shown to be mutagenic in bacteria or induce mutation or transformation in mammalian cells in vitro. Chromosomal aberrations have been observed in bone marrow cells of exposed mice and rats (WHO, 1997).

4.6 Carcinogenicity

There is no indication that aluminium is carcinogenic. The Joint Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Expert Committee on Food Additives (JECFA) evaluated the limited studies of Schroeder & Mitchener (1975a,b; section 4.3) and concluded that there was no evidence of an increase in tumour incidence related to the administration of potassium aluminium sulfate in mice or rats (WHO, 1989).

4.7 Neurotoxicity

Behavioural impairment has been reported in laboratory animals exposed to soluble aluminium salts (e.g. lactate, chloride) in the diet or drinking-water in the absence of overt encephalopathy or neurohistopathology. Both rats (Commissaris et al., 1982; Thorne et al., 1987; Connor, Jope & Harrell, 1988) and mice (Yen-Koo, 1992) have demonstrated such impairments at doses exceeding 200 mg of aluminium per kilogram of body weight per day. Although significant alterations in acquisition and retention of learned behaviour were documented, the possible role of organ damage (kidney, liver, immunological) due to aluminium was incompletely evaluated in these studies (WHO, 1997).

In studies on brain development in mice and rats, grip strength was impaired in offspring of dams fed 100 mg of aluminium (as aluminium lactate) per kilogram of body weight per day in the diet, in the absence of maternal toxicity (WHO, 1997).

Additional studies on neurobehavioural development are discussed in section 4.4 above.

5. EFFECTS ON HUMANS

There is little indication that aluminium is acutely toxic by oral exposure despite its widespread occurrence in foods, drinking-water and many antacid preparations (WHO, 1997).

In 1988, a population of about 20 000 individuals in Camelford, England, was exposed for at least 5 days to unknown but increased levels of aluminium accidentally distributed to the population from a water supply facility using aluminium sulfate for treatment. Symptoms including nausea, vomiting, diarrhoea, mouth ulcers, skin ulcers, skin rashes and arthritic pain were noted. It was concluded that the symptoms were mostly mild and short-lived. No lasting effects on health could be attributed to the known exposures from aluminium in the drinking-water (Clayton, 1989).

Following the observation that high levels of aluminium in dialysis fluid could cause a form of dementia in dialysis patients, a number of studies were carried out to determine if aluminium could cause dementia or cognitive impairment as a consequence of environmental exposure over long periods. Aluminium was identified, along with other elements, in the amyloid plaques that are one of the diagnostic lesions in the brain for Alzheimer disease, a common form of senile and pre-senile dementia. Numerous epidemiological studies have been carried out to try to determine the validity of this hypothesis. These have been reviewed in detail by several authorities, including JECFA (FAO/WHO, 2007; WHO, 2007), the United Kingdom Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT, 2005), the United States Agency for Toxic Substances and Disease Registry (ATSDR, 2008) and Environment Canada & Health Canada (2010).

Investigators have identified a number of difficulties in carrying out such studies on conditions for which the causes are multifactorial. In addition, there are questions regarding the levels of exposure of aluminium from different sources and the relative bioavailability from these sources. Most of the studies have focused on aluminium in drinking-water—although this is a very minor source of exposure—and Alzheimer disease. Most of the studies do not consider the speciation of aluminium, and the assessment of exposure from both drinking-water and food is not usually well characterized. In particular, there are difficulties in determining recollected exposure when the subject has a degenerative neural condition affecting cognitive performance. The conclusion of the recent JECFA evaluation (FAO/WHO, 2007) was that "some of the epidemiology studies suggest the possibility of an association of Alzheimer disease with aluminium in water, but other studies do not confirm this association.... All studies lack information on ingestion of aluminium from food and how concentrations of aluminium in food affect the association between aluminium in water and Alzheimer disease." There are suggestions that some genetic variants may absorb more aluminium than others, but there is a need for more analytical research to determine whether aluminium from various sources has a significant causal association with Alzheimer disease and other neurodegenerative diseases.

6. PRACTICAL ASPECTS

6.1 Analytical methods and analytical achievability

Aluminium is reacted with pyrocatechol violet followed by spectrometric measurement of the resulting coloured complex. The method is restricted to the determination of the aquated cations and other forms of aluminium readily converted to that cationic form by acidification. The limit of detection is 2 µg/l (ISO, 1994). The limit of detection for the determination of aluminium by inductively coupled plasma atomic emission spectroscopy ranges from 40 to 100 µg/l (ISO, 1996).

Flame and graphite furnace atomic absorption spectrometric (AAS) methods are applicable for the determination of aluminium in water at concentrations of 5–100 mg/l and 0.01–0.1 mg/l, respectively. The working range of the graphite furnace AAS method can be shifted to higher concentrations either by dilution of the sample or by using a smaller sample volume (ISO, 1997).

6.2 Treatment and control methods and performance

A number of approaches are available for minimizing residual aluminium concentrations in treated water. These include use of optimum pH in the coagulation process, avoiding excessive aluminium dosage, sufficient mixing at the point of application of the coagulant, optimum mixing conditions for flocculation and efficient filtration of the aluminium floc (Letterman & Driscoll, 1988; WRc, 1997). Residual aluminium concentration is affected not only by obvious factors, such as operational conditions and raw water quality, but also by more obscure factors, such as water treatment plant capacity and the size of the water supplier (Ohno et al., 2009). Under good operating conditions, concentrations of aluminium of 0.1 mg/l or less are achievable in large water treatment facilities. Small facilities (e.g. those serving fewer than 10 000 people) might experience some difficulties in attaining this level, because the small size of the plant provides little buffering for fluctuation in operation, and small facilities often have limited resources and access to expertise to solve specific operational problems. For these small facilities, 0.2 mg/l or less is a practicable level for aluminium in finished water (WRc, 1997).

7. CONCLUSIONS

The Environmental Health Criteria document for aluminium (WHO, 1997) concluded that:

> On the whole, the positive relationship between aluminium in drinking-water and AD [Alzheimer disease], which was demonstrated in several epidemiological studies, cannot be totally dismissed. However, strong reservations about inferring a causal relationship are warranted in view of the failure of these studies to account for demonstrated confounding factors and for total aluminium intake from all sources.
>
> Taken together, the relative risks for AD from exposure to aluminium in drinking-water above 100 µg/litre, as determined in these studies, are low (less than 2.0). But, because the risk estimates are imprecise for a variety of methodological reasons, a population attributable risk cannot be calculated with precision. Such imprecise predictions may, however, be useful in making decisions about the need to control exposures to aluminium in the general population.

In 2007, JECFA developed a provisional tolerable weekly intake (PTWI) for aluminium from all sources of 1 mg/kg of body weight (FAO/WHO, 2007). The Committee concluded the following:

> ...the available studies have many limitations and are not adequate for defining the dose–response relationships. The Committee therefore based its evaluation on the combined evidence from several studies. The relevance of studies involving administration of aluminium compounds by gavage was unclear because the toxicokinetics after gavage were expected to differ from toxicokinetics after dietary administration, and the gavage studies generally did not report total aluminium exposure including basal levels in the feed. The studies conducted with dietary administration of aluminium compounds were considered most appropriate for the evaluation. The lowest LOELs for aluminium in a range of different dietary studies in mice, rats and dogs were in the region of 50–75 mg/kg bw [body weight] per day expressed as Al.
>
> The Committee applied an uncertainty factor of 100 to the lower end of this range of LOELs (50 mg/kg bw per day expressed as Al) to allow for inter- and intraspecies differences. There are deficiencies in the database, notably the absence of NOELs in the majority of the studies evaluated and the absence of long-term studies on the relevant toxicological end-points. The deficiencies are counterbalanced by the probable lower bioavailability of the less soluble aluminium species present in food. Overall, an additional uncertainty factor of three was considered to be appropriate. The Committee confirmed that the resulting health-based guidance value should be expressed as a PTWI, because of the potential for bioaccumulation. The Committee established a PTWI of 1 mg/kg bw for Al, which applies to all aluminium compounds in food, including additives.

A health-based value derived from the JECFA PTWI would be 0.9 mg/l (rounded value), based on an allocation of 20% of the PTWI to drinking-water and assuming a 60 kg adult drinking 2 litres of water per day. However, there remain uncertainties as to the extent of aluminium absorption from drinking-water, which depends on a number of parameters, such as the aluminium salt administered, pH (for aluminium speciation and solubility), bioavailability and dietary factors.

The beneficial effects of the use of aluminium as a coagulant in water treatment are recognized. Taking this into account and considering the potential health concerns (i.e. neurotoxicity) of aluminium, a practicable level is derived based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants, to minimize aluminium levels in finished water. For large, well-operated and well-controlled plants, a residual aluminium concentration in the final water of

0.1 mg/l should be achievable. For smaller facilities, a residual concentration of 0.2 mg/l is a more reasonable expectation.

As indicated above, a health-based value based on the JECFA PTWI would be 0.9 mg/l (rounded value). However, as also noted above, practicable levels based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants are 0.1 mg/l or less in large water treatment facilities and 0.2 mg/l or less in small facilities. In view of the importance of optimizing coagulation to prevent microbial contamination and the need to minimize deposition of aluminium floc in distribution systems, it is important to ensure that average residuals do not exceed these values.

8. REFERENCES

Agarwal SK et al. (1996) Evaluation of the developmental neuroendocrine and reproductive toxicology of aluminum. *Food and Chemical Toxicology*, 34(1):49–53.

Ainsworth RG, Oliphant R, Ridgway JW (1980) *The introduction of new water into old distribution systems*. Medmenham, Water Research Centre (TR 146).

ATSDR (2008) *Toxicological profile for aluminum.* Atlanta, GA, United States Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry (http://www.atsdr.cdc.gov/toxprofiles/tp22.pdf).

CCME (1988) *Canadian water quality guidelines.* Ottawa, Ontario, Canadian Council of Ministers of the Environment.

Clayton DB (1989) *Water pollution at Lowermoor, North Cornwall: report of the Lowermoor incident health advisory committee.* Truro, Cornwall District Health Authority, 22 pp.

Colomina MT et al. (1992) Concurrent ingestion of lactate and aluminum can result in developmental toxicity in mice. *Research Communications in Chemical Pathology and Pharmacology*, 77:95–106.

Colomina MT et al. (1994) Lack of maternal and developmental toxicity in mice given high doses of aluminium hydroxide and ascorbic acid during gestation. *Pharmacology and Toxicology*, 74:236–239.

Colomina MT et al. (2005) Concurrent exposure to aluminum and stress during pregnancy in rats: effects on postnatal development and behavior of the offspring. *Neurotoxicology and Teratology*, 27(4):565–574.

Commissaris RL et al. (1982) Behavioral changes in rats after chronic aluminum and parathyroid hormone administration. *Neurobehavioral Toxicology and Teratology*, 4:403–410.

Connor DJ, Jope RS, Harrell LE (1988) Chronic, oral aluminum administration to rats: cognition and cholinergic parameters. *Pharmacology, Biochemistry, and Behaviour*, 31:467–474.

COT (2005) Appendix 16: Review paper on aluminium prepared for the Lowermoor Subgroup by the Department of Health Toxicology Unit, Imperial College, London. In: *Subgroup report on the Lowermoor water pollution incident.* United Kingdom Food Standards Agency, Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (http://www.dh.gov.uk/prod_consum_dh/groups/dh_digitalassets/@dh/@en/documents/digitalasset/dh_4102168.pdf).

Domingo JL et al. (1987a) Nutritional and toxicological effects of short-term ingestion of aluminum by the rat. *Research Communications in Chemical Pathology and Pharmacology*, 56:409–419.

Domingo JL et al. (1987b) Effects of oral aluminum administration on perinatal and postnatal development in rats. *Research Communications in Chemical Pathology and Pharmacology*, 57:129–132.

Domingo JL et al. (1987c) The effects of aluminium ingestion on reproduction and postnatal survival in rats. *Life Sciences*, 41:1127–1131.

Domingo JL et al. (1989) Lack of teratogenicity of aluminum hydroxide in rats. *Life Sciences*, 45:243–247.

Donald JM et al. (1989) Neurobehavioral effects in offspring of mice given excess aluminum in diet during gestation and lactation. *Neurotoxicology and Teratology*, 11(4):345–351.

Environment Canada, Health Canada (2010) *Canadian Environmental Protection Act, 1999. Priority substances list assessment report. Follow-up to the state of science report 2000. Aluminium chloride, aluminium nitrate, aluminium sulphate.* Ottawa, Ontario, Environment Canada and Health Canada (http://www.ec.gc.ca/CEPARegistry/documents/subs_list/Aluminum_Salts/final/Al_salts_toc.cfm).

FAO/WHO (2007) In: Aluminium (from all sources, including food additives). In: *Evaluation of certain food additives and contaminants. Sixty-seventh report of the Joint FAO/WHO Expert Committee on Food Additives.* Geneva, World Health Organization, pp. 33–44 (WHO Technical Report Series, No. 940; http://whqlibdoc.who.int/trs/WHO_TRS_940_eng.pdf).

Golub MS, Germann SL (2001) Long-term consequences of developmental exposure to aluminum in a suboptimal diet for growth and behavior of Swiss Webster mice. *Neurotoxicology and Teratology*, 23(4):365–372.

Golub MS, Keen CL (1999) Effects of dietary aluminum on pubertal mice. *Neurotoxicology and Teratology*, 21(5):595–602.

Golub MS et al. (1995) Behavioral performance of Swiss Webster mice exposed to excess dietary aluminum during development or during development and as adults. *Toxicology and Applied Pharmacology*, 133(1):64–72.

Golub MS et al. (2000) Lifelong feeding of a high aluminum diet to mice. *Toxicology*, 150(1–3):107–117.

Gomez M et al. (1986) Short-term oral toxicity study of aluminium in rats. *Archives of Pharmacology and Toxicology*, 12:145–151.

Gomez M et al. (1990) Evaluation of the maternal and developmental toxicity of aluminum from high doses of aluminum hydroxide in rats. *Veterinary and Human Toxicology*, 32:545–548.

Gomez M, Domingo JL, Llobet JM (1991) Developmental toxicity evaluation of oral aluminum in rats: influence of citrate. *Neurotoxicology and Teratology*, 13:323–328.

Guo C-H, Lu Y-F, Hsu G-SW (2005) The influence of aluminum exposure on male reproduction and offspring in mice. *Environmental Toxicology and Pharmacology*, 20:135–141.

Health Canada (1993) *Guidelines for Canadian drinking water quality. Water treatment principles and applications: a manual for the production of drinking water.* Ottawa, Ontario, Health Canada, Environmental Health Directorate. Printed and distributed by Canadian Water and Wastewater Association, Ottawa, Ontario.

Hicks JS, Hackett DS, Sprague GL (1987) Toxicity and aluminium concentration in bone following dietary administration of two sodium aluminium phosphate formulations in rats. *Food and Chemical Toxicology*, 25(7):533–538.

ISO (1994) *Water quality—Determination of aluminium: spectrometric method using pyrocatechol violet.* Geneva, International Organization for Standardization (ISO 10566:1994 (E)).

ISO (1996) *Water quality—Determination of 33 elements by inductively coupled plasma atomic emission spectroscopy*. Geneva, International Organization for Standardization (ISO 11885:1996 (E)).

ISO (1997) *Water quality—Determination of aluminium—Atomic absorption spectrometric methods*. Geneva, International Organization for Standardization (ISO 12020:1997 (E)).

Katz AC et al. (1984) A 6-month dietary toxicity study of acidic sodium aluminium phosphate in Beagle dogs. *Food and Chemical Toxicology*, 22:7–9.

Letterman RD, Driscoll CT (1988) Survey of residual aluminum in filtered water. *Journal of the American Water Works Association*, 80:154–158.

Lide DR, ed. (1993) *CRC handbook of chemistry and physics*, 73rd ed. Boca Raton, FL, CRC Press.

MAFF (1993) *Aluminium in food—39th report of the Steering Group on Chemical Aspects of Food Surveillance*. London, United Kingdom Ministry of Agriculture, Fisheries and Food.

Miller RG et al. (1984) The occurrence of aluminum in drinking water. *Journal of the American Water Works Association*, 76:84–91.

Ohno K et al. (2009) Plant capacity affects some basic indices of treated water quality: multivariate statistical analysis of drinking water treatment plants in Japan. *Journal of Water Supply: Research and Technology – Aqua*, 58(7):476–487.

OMEE (1995) *Drinking water surveillance programme—Province of Ontario*. Toronto, Ontario, Ontario Ministry of Environment and Energy.

Pennington JA, Schoen SA (1995) Estimates of dietary exposure to aluminium. *Food Additives and Contaminants*, 12(1):119–128.

Pettersen JC, Hackett DS, Zwicker GM (1990) Twenty-six week toxicity study with KASAL (basic sodium aluminum phosphate) in Beagle dogs. *Environmental Geochemistry and Health*, 12:121–123.

Priest ND (2004) The biological behaviour and bioavailability of aluminium in man, with special reference to studies employing aluminium-26 as a tracer: review and study update. *Journal of Environmental Monitoring*, 6:375–403.

Priest ND et al. (1998) Uptake by man of aluminium in a public water supply. *Human and Experimental Toxicology*, 17(6):296–301.

Schroeder MA, Mitchener M (1975a) Life-term effects of mercury, methylmercury and nine other trace metals on mice. *Journal of Nutrition*, 105:452–458.

Schroeder MA, Mitchener M (1975b) Life-term studies in rats: effects of aluminum, barium, beryllium, and tungsten. *Journal of Nutrition*, 105:421–427.

Somova LI, Khan MS (1996) Aluminium intoxication in rats. II. Chronic toxicity: effects on aluminium balance, aluminium plasma and tissue levels and haematology. *South African Journal of Food Science and Nutrition*, 8:102–105.

Somova LI, Missankov A, Khan MS (1997) Chronic aluminum intoxication in rats: dose-dependent morphological changes. *Methods and Findings in Experimental and Clinical Pharmacology*, 19(9):599–604.

Stauber JL et al. (1998) *Bioavailability of aluminium in alum-treated drinking water and food*. Melbourne, Urban Water Research Association of Australia (UWRAA Research Report No. 203).

Thorne BM et al. (1987) Aluminum toxicity and behavior in the weanling Long-Evans rat. *Bulletin of the Psychonomic Society*, 25:129–132.

WHO (1989) Aluminium. In: *Toxicological evaluation of certain food additives and contaminants.* Geneva, World Health Organization, pp. 113–154 (WHO Food Additives Series, No. 24).

WHO (1997) *Aluminium.* Geneva, World Health Organization, International Programme on Chemical Safety (Environmental Health Criteria 194).

WHO (2007) Aluminium from all sources, including food additives. In: *Safety evaluation of certain food additives and contaminants.* Geneva, World Health Organization, pp. 110–208 (WHO Food Additives Series, No. 58; http://whqlibdoc.who.int/publications/2007/9789241660587_eng.pdf).

Wilhelm M, Idel H (1995) [Aluminium in drinking water: a risk factor for Alzheimer's disease?] *Forum, Städte, Hygiene*, 46:255–258 (in German).

WRc (1997) *Treatment technology for aluminium, boron and uranium.* Document prepared for WHO by the Water Research Centre, Medmenham, and reviewed by S. Clark, United States Environmental Protection Agency; A. van Dijk-Looijaard, KIWA, the Netherlands; and D. Green, Health Canada.

Yen-Koo HC (1992) The effect of aluminum on conditioned avoidance response (CAR) in mice. *Toxicology and Industrial Health*, 8:1–7.

Appendix D – Standard for the Supply of Polyaluminium Chloride for Use in Water Treatment

Standard for the Supply of Polyaluminium Chloride for Use in Water Treatment

Second Edition

2013

water
NEW ZEALAND
The New Zealand Water & Wastes Association Waiora Aotearoa

STANDARD FOR THE SUPPLY OF POLYALUMINIUM CHLORIDE FOR USE IN WATER TREATMENT

Second Edition

2013

The first edition of this standard was prepared for the Water Supply Managers' Group of the New Zealand Water & Wastes Association (now trading as Water New Zealand) and the Ministry of Health by Works Consultancy Services Ltd in 1994.

ISBN 1-877134-08-2

Published by:
Water New Zealand
PO Box 1316, Wellington 6140
Phone: 04 472 9825, Fax 04 472 8926
Email: enquiries@waternz.org.nz
Website: www.waternz.org.nz

Contents

1 General

1.1 Scope

This Standard covers polyaluminium chloride as used in the treatment of water supplies. This is abbreviated to PolyAC in this standard. It may be supplied in liquid or powdered form.

1.2 Purpose

The main purpose of this Standard is to provide purchasers, manufacturers and suppliers with the minimum requirements for polyaluminium chloride, including physical, chemical and testing requirements.

1.3 Application

This Standard can be referenced in specifications for purchasing and receiving polyaluminium chloride and can be used as a guide for testing the physical and chemical properties in samples of this product. The stipulations of this Standard apply when this document has been referenced and only for polyaluminium chloride intended for use in water treatment.

1.4 Uses in Water Treatment

Polyaluminium chloride is used in the water treatment industry for the coagulation of organic and mineral colloids prior to sedimentation and/or filtration. The aluminium destabilises fine colloidal suspensions and promotes the forming together of large conglomerations of this material bound in a chemical precipitate (called floc) which is able to be removed from the water by sedimentation, flotation and/or filtration. In general, polyaluminium chloride is preferred over aluminium sulphate if a larger, faster forming floc is desired, as this may remove the need for a flocculant to facilitate sedimentation.

1.5 Manufacture

Liquid polyaluminium chloride is prepared by combining aluminium hydroxide with hydrochloric acid and sulphuric acid at elevated temperatures, then treating the resultant product with calcium carbonate to raise its basicity. The resulting mixture is then put through a centrifuge to separate the liquid polyaluminium chloride from the solid product (gypsum). Powdered polyaluminium chloride is produced from the reaction of hot HCl gas with an aluminium substrate producing a dry material.

1.6 Description of Chemicals

Polyaluminium chloride is available in the following forms in New Zealand:

- powdered
- liquid

Powdered PolyAC is available as a white powder which comes in 20 or 25 kg bags.

Liquid PolyAC is usually sold as a 34% w/w solution, either via bulk tanker, or in smaller containers such as 20 L jerry cans, 200 L drums, or 1000 kg intermediate bulk containers (IBCs).

1.7 Methods of Dosing

Polyaluminium chloride is dosed as a liquid solution. It is usually dosed via diaphragm pumps into a zone of high water turbulence to facilitate rapid mixing of the solution with the water. It is normal to pump the solution with additional dilution water into the water being treated in order to facilitate good mixing and rapid coagulation.

1.8 Definitions

The following definitions shall apply in this Standard:

PolyAC	PolyAC refers to polyaluminium chloride.
Polyaluminium chloride	A compound with the formula $[Al(OH)_aCl_b(SO_4)_c]_n$, where $(a + b + 2c) = 3$, with $a > 1.05$. Some polyaluminium chlorides may not contain SO_4 and conform to the formula $[Al(OH)_aCl_b]_n$, where $(a + b) = 3$, with $a > 1.05$. Generally the basicity of these compounds used in the water treatment industry does not exceed 60% (see reference 1)
Manufacturer	The party that manufactures fabricates or produces materials or products.
MAV	Maximum acceptable values
Purchaser	The person, company or organisation that purchases any materials or work to be performed.
Reception Point	The point of physical transfer of materials from the supplier to the purchaser.
SIL	Specific impurity limit for a specified determinand identified by the purchaser
Supplier	The party who supplies material or services. A supplier may or may not be the manufacturer.
w/w	Weight for weight.

2 MATERIALS

2.1 Physical Properties

Solid PolyAC shall be clean and dry, and shall be in the powdered form.

Liquid PolyAC shall be a nearly saturated solution of polyaluminium chloride and it shall have not greater than 0.2% precipitated material present in the solution.

Some physical properties of the forms of PolyAC are listed in Table 1.

Property	Form of Polyaluminium chloride	
	Solid	Liquid*
pH of solution	N/A	2.6 ± 0.3
Specific gravity	N/A	1.2 (at 10.1% Al_2O_3, or 5.3% as Al)
Bulk density	0.77 tonne/m^3	N/A

*Figures are given for a 34% w/w solution of polyaluminium chloride.

Table 1: Some physical properties of the two forms of polyaluminium chloride

2.2 Chemical Requirements

The chemical requirements of both forms of polyaluminium chloride are given below.

Powdered PolyAC shall contain water-soluble aluminium of not less than 14 ± 0.3% w/w as Al, or 30% w/w as Al_2O_3.

Liquid PolyAC shall contain water-soluble aluminium of not less than 2.16% w/w as Al or 10% w/w as Al_2O_3. In liquid PolyAC, the water-insoluble matter shall not exceed 0.2% w/w.

2.3 Impurities

2.3.1 Specific Impurity Limits

2.3.1.1 The limits of specific impurities in the PolyAC shall be set by the purchaser. In setting impurity limits, the purchaser shall take into consideration the expected maximum dosage (MD) of inorganic coagulant, the maximum acceptable value (MAV) of a determinand taken from the Drinking-water Standards for New Zealand 2005 (revised 2008) and a safety factor which reflects the maximum percentage of a MAV that may be contributed by a specific impurity. The specific impurity limits shall be calculated using the following equation.

$$SIL\ (mg/kg) = \frac{MAV\ (\ mg\ /\ litre\ )\ x\ 10^6}{MD\ (\ mg\ /\ litre\ )\ x\ SF}$$

Where SIL = Specific Impurity Limit
MAV = Maximum Acceptable Value (see DWSNZ 2005 (Revised 2008))
MD = Maximum Dosage
SF = Safety Factor

2.3.1.2 Alternative MAVs to those in the Drinking-water Standards for New Zealand may be chosen by the purchaser to reflect their individual requirements (eg, fluoride). The purchaser may also vary the SF to suit.

2.3.1.3 The MD (maximum dosage) of the inorganic coagulant shall be based on the maximum dose used at the purchaser's treatment plant in the previous 12 month period. However, if the previous 12 months are not deemed to be representative of usual conditions, the purchaser may refer to other time periods deemed to have had usual conditions to find the maximum dose to be used in SIL calculations.

2.3.1.4 The SF (safety factor) to be used shall be less than or equal to 10, which reflects the view that no more than 10% of a MAV should be contributed by a given impurity in a water supply chemical.

2.3.1.5 Specific impurity limits shall be given as weight of impurity by weight of inorganic coagulant.

2.3.1.6 Specific impurities that may be of importance to test for are: antimony, arsenic, barium, boron, cadmium, chromium, copper, fluoride, iron, lead, manganese, mercury, molybdenum, nickel, selenium, and zinc.

2.3.2 General Impurities

In addition to the above specific impurities, the PolyAC may not contain any other impurities that may be deleterious to health or aesthetically objectionable as determined in the 2005 Drinking-water Standards for New Zealand (revised 2008). General impurity limits shall be based on the maximum dosage of inorganic coagulant as determined in section 2.3.1.3, the MAV of determinands in the DWSNZ 2005 (revised 2008), and a minimum SF of 10.

3 DELIVERY

3.1 Packaging and Shipping

3.1.1 Solid and liquid forms of the inorganic coagulant may be transported in the quantities described in their individual sections within Section 1.6.

3.1.2 Tanks for transporting PolyAC shall comply with all conditions as required under the Transport Act 1998 (see link below) and shall not contain any substances that might affect the quality of the liquid inorganic coagulant in treating water supplies.

http://www.legislation.govt.nz/act/public/1998/0110/latest/DLM433613.html

3.2 Labelling

Each shipment of material shall comply with the New Zealand Standard NZS 5433:1988, *Code of Practice for the Transport of Hazardous Substances on Land* and specifically must be clearly identifiable and be marked and/or accompanied by clear means of giving the following information:

Contents:	Proper Shipping Name for coagulant
Net weight	
Name of manufacturer:	
Hazardous Chemical Classification:	

Additionally, a date of manufacture and/or 'use by' date should be attached to the product to enable identification of expired product.

3.3 Unloading and Storage

3.3.1 The purchaser shall provide an appropriate receiving vessel for the bulk liquid coagulant, and the supplier shall provide an appropriate "camlock" or other type of coupling as agreed with the purchaser for connection to the storage tank inlets if required, in order to prevent discharge to incorrect tanks.

3.3.2 Empty bulk trucks shall not be washed out at the delivery site without the express approval of the purchaser's representative or operating personnel.

3.3.3 Bags or drums shall be unloaded with a forklift or by hand. Bags shall be stored in a designated dry storage area. PolyAC absorbs moisture from the air so the storage area should be covered and bags shall be stored on wooden pallets.

3.3.4 Bags damaged prior to delivery will be the responsibility of the supplier and bags damaged during unloading at the purchaser's premises will be the responsibility of the agent undertaking the unloading.

3.3.5 The condition on delivery of the paper outers of the bags shall not have deteriorated to any extent so as to impede handling or emptying of the bags. Bags with deteriorated paper outers on delivery shall be replaced by the supplier at no cost to the purchaser.

4 SAFETY

4.1 Health and Safety

4.1.1 Suppliers of PolyAC must comply with the requirements of the Health and Safety in Employment Amendment Act 2002 and take all practicable steps to protect the purchaser and others from hazards rising from the transportation, delivery and supply of the product.

4.1.2 Within two weeks of award of a contract to supply product and prior to delivery the supplier shall provide to the purchaser the following information:

(a) an updated copy of the Material Safety Data Sheet, which as a minimum, shall follow the Approved Code of Practice for Material Safety Data Sheets (see link)

Safety Data Sheets - Code of Practice for the Preparation of and

(b) Evidence that drivers have been adequately trained and have adequate knowledge and experience in the handling and delivery of the inorganic coagulant being delivered.

4.1.3 Prior to the commencement of the contract, a copy of the purchaser's Health and Safety Management Plan (H&SMP) shall be made available to the supplier of the inorganic coagulant, as will the supplier's H&SMP be made available to the purchaser. Any contradictions or conflicts, relevant to the supply of the named inorganic coagulants, between the two H&SMP's shall be modified to the satisfaction of both parties before the commencement of the contract. Each party shall otherwise comply with the H&SMP of the other party, and any practices by either party which do not comply with the Health and Safety Management Plans may be grounds for the termination of a supply contract. Health and Safety Management Plans are discussed in the National Guidelines for Occupational Health and Safety in the New Zealand Water Industry, second edition (2001).

http://www.waternz.org.nz/Category?Action=View&Category_id=199#waternzguidelines

4.2 Protective Equipment

The purchaser and the supplier will be responsible for providing their respective personnel or agents with any necessary safety and protective equipment identified in their Health and Safety Management Plans and ensuring it is used as required.

4.3 Spills

The supplier, their agent, or the authorised purchaser's representative responsible for unloading the inorganic coagulant, shall immediately attend to and report any spills within the grounds of the property in which the inorganic coagulant reception point is located. Clean-up and reporting procedures should be specified in Health and Safety Management Plans; they may also be specified in the water treatment plant consent issued by the regional council.

5 TESTING METHODS

5.1 General

5.1.1 The manufacturer or supplier shall test the materials at their own cost in order to provide a certificate of compliance as required in Section 6.1.

5.1.2 The purchaser may randomly take samples (see section 5.2) of the material and have these samples analysed for conformance with this Standard, at the cost of the purchaser. These samples may be taken at the place of manufacture and/or at the delivery point, as may be agreed upon by the manufacturer or supplier and the purchaser.

5.1.3 When inspection and sampling are to be conducted at the point of manufacture, the manufacturer shall afford the inspector representing the purchaser all reasonable facilities for inspection and sampling of finished material, which shall be so conducted as not to interfere unnecessarily with the operation of the plant. When on site, the purchaser must follow the manufacturing site's safety policies and procedures when taking the sample, or allow the manufacturer to take the sample itself while under supervision of the supplier's representative.

5.1.4 Analytical testing methods shall be as specified in this Standard in Section 5.3.

5.1.5 If the analysis of a sample taken at the place of manufacture shows the material does not comply with the requirements of this Standard, the purchaser may require that the manufacturer provide a certified analysis from a suitably accredited testing laboratory for successive deliveries.

5.1.6 If the analysis of a sample taken at the point of delivery shows the material does not comply with the requirements of this Standard, a notice of non-conformance must be provided by the purchaser to the supplier in accordance with Section 6.4.

5.2 Sampling

5.2.1 All samples taken for testing purposes must be stored in sealed containers and be appropriately labelled. A suitable sampling procedure is set out in Appendix B of this Standard, but shall be agreed upon by the purchaser and supplier, prior to the award of a contract to supply product, to provide a sample properly representative of the supplied material.

5.3 Standard Tests

5.3.1 For the standard test methods for the following properties of liquid PolyAC refer to ANSI/AWWA Standard B408-10, section 4, pp 3 – 16.

- specific gravity
- polyaluminium chloride content in liquid PolyAC as % by mass Al or Al_2O_3
- percent basicity
- turbidity.

5.3.2 A similar standard does not exist in ANSI/AWWA standards for solid PolyAC chemicals. Samples of solid material should be taken and a solution of the concentration used in processing prepared for analysis as described in section 5.3.1.

5.3.3 Test methods for specific impurities are found in *Standard Methods for the Examination of Water and Wastewater*, 22nd Edition, 2012 (by subscription online or hard copy). Methods for some parameters are given under the following codes at Standard Methods Online:

Antimony	3500-Sb
Arsenic	3500-As
Barium	3500-Ba
Boron	4500-B
Cadmium	3500-Cd
Chromium	3500-Cr
Copper	3500-Cu
Fluoride	4500-F^-
Iron	3500-Fe
Lead	3500-Pb
Manganese	3500-Mn
Mercury	3500-Hg
Molybdenum	3500-Mo
Nickel	3500-Ni
Selenium	3500-Se
Zinc	3500-Zn

Maximum acceptable values (MAV) for determinands of health significance and guideline values for aesthetic determinands (iron and zinc) can be found in Table 2.2 and Table 2.5 respectively of Drinking Water Standards for New Zealand 2005 (Revised 2008) using the link provided.

Drinking-water Standards for New Zealand 2005 (Revised 2008)

6 QUALITY ASSURANCE

6.1 Certificate of Compliance

6.1.1 The manufacturer or supplier shall provide the purchaser with a certificate of compliance that states that the material furnished in accordance with the purchaser's order complies with all applicable requirements of this Standard.

6.1.2 The purchaser may require that the supplier provide a certified analysis of the material, from a mutually agreed upon laboratory at the commencement of the contract and thereafter at three monthly intervals or as agreed between purchaser and supplier. The purchaser may also require that the supplier provide a certified analysis for insoluble matter or particular impurities, from a mutually agreed upon laboratory, for each delivery.

6.2 Method of Manufacture

6.2.1 The quality of a water treatment chemical is greatly influenced by the method of manufacture and quality of raw material used. If other than recognised methods of manufacture, or if unusual raw materials are used, the potential may exist for impurities to be present, or poor quality chemical to be produced, that may be inconsistent with good water treatment practice.

6.2.2 If the method of manufacture, source and/or quality of raw material used is changed during the period of the contract, then additional samples shall be analysed at the manufacturer's or supplier's cost, to demonstrate that the changes have not affected compliance with this Standard.

6.3 Weight Certificate

Delivered bulk product shall be weighed over certified weighbridges and the docket produced on delivery.

6.4 Rejection

6.4.1 Notice of Non-conformance

If the inorganic coagulant delivered does not meet the requirements of this Standard or the specific impurity limits notified by the purchaser, a notice of non-conformance must be provided by the purchaser to the supplier within 10 working days after receipt of the shipment at the point of destination. The results of the purchaser's tests shall prevail unless the supplier notifies the purchaser within five working days after receipt of the notice of complaint that a retest or inspection is desired. On receipt of the request for a retest, the purchaser shall forward to the supplier one of the sealed samples taken in accordance with Section 5. In the event that the results obtained by the supplier upon retesting do not agree with the results obtained by the purchaser, the other sealed sample shall be forwarded, unopened, for analysis to a referee laboratory agreed upon by both parties. The results of the referee analysis or inspection shall be accepted as final.

The cost of the referee analysis shall be paid by the supplier if the material does not meet the requirements of this Standard, and shall be paid by the purchaser if the material does meet the requirements of this Standard.

6.4.2 Material Removal

6.4.2.1 If the material does not meet the impurity limit requirements of this Standard, the supplier shall remove the material from the premises of the purchaser. Removal of material shall be at no cost to the purchaser.

6.4.2.2 If the material meets the impurity limits but not the water soluble aluminium or water insoluble matter content requirements of this Standard, a price adjustment may be agreed between the supplier and the purchaser. In the event that a price adjustment cannot be agreed, the supplier shall remove the material from the premises of the purchaser if required by and at no cost to the purchaser.

6.4.2.3 The material that shall be removed shall include the rejected material and any other material the rejected material may have contaminated, for example contents of a tank into which a bulk delivery has been unloaded, if required by the purchaser.

6.4.2.4 All material removed shall be concurrently replaced with material conforming to this Standard with an appropriate compliance certificate at no cost to the purchaser.

Appendix A: Conversion Factors for Coagulant Concentrations

A1 Conversion factor table between weight of Al and the coagulant compound

	$Al_2(OH)_5Cl_{2.6}$ (ie. PolyAC[1])	$Al_2(OH)_3Cl_4(SO_4)_{1.5}$ (ie. PolyAC sulphate[2])	Al_2O_3
Molecular weight (g/mol)	231.18	391.07	101.96
Al to *PolyAC* conversion factor	4.28	7.25	1.89

---

[1] Polyaluminium chloride has a variable chemical formula, the formula cited being an example of the empirical formula $Al(OH)_aCl_b$ where (a + b) = 3, with a >1.05

[2] Polyaluminium chloride sulphate has a variable chemical formula, the formula cited being an example of the empirical formula $Al(OH)_aCl_b(SO_4)_c$ where (a + b + 2c) = 3, with a >1.05

Appendix B: Sampling Procedure

B1 Sampling Method

B1.1 General

B1.1.1 Sampling and preparation shall be conducted as expeditiously as possible in order to avoid undue exposure of the material to the air, thus avoiding contamination and evaporation.

B1.1.2 The sampling method must give a gross sample that is representative of the material, and which may be divided to provide representative samples for analysis. The quantity of sample required by the testing laboratory to carry out the desired tests must be known prior to the sample being taken.

B1.1.3 Samples for analysis shall be provided in triplicate. One sample is for the immediate use of the purchaser for testing of the shipment. The other two samples shall be retained until it is known from the results of the laboratory examination that the shipment meets the requirements of this Standard. The second sample shall be delivered to the supplier if requested within five days of notification of the examination results of the first sample. The third sample is for the use of a referee laboratory if there is a controversy over the analyses.

B1.1.4 Samples shall be sealed in airtight, moisture-proof containers which are of a material known not to interfere with, or be degraded by, the product to be stored in it.

B1.1.5 Each sample shall be labelled with the minimum information as follows: the material name, the name of the purchaser, the name of the sampler, package number, date sampled, and date received.

B1.2 Solid Inorganic Coagulant

B1.2.1 If the coagulant is packaged, 5% of the number of the packages shall be sampled. No sample shall be taken from a broken package.

B1.2.2 Care shall be taken to include a proportional amount of lumps and fines, to obtain representative material.

B1.2.3 Ground coagulant shall be sampled using a sampling tube or other effective device that measures at least 2 cm in diameter.

B1.2.4 The gross sample, of at least 8 kg or as agreed, shall be mixed thoroughly and quartered and quartered again to provide eight 0.5 kg samples. Six of these samples shall be sealed in containers as in Section B1.1.4. Two samples (a duplicate) shall be for use by the purchaser. The other four, representing two duplicate samples, shall be retained to be used for retesting as provided for in Section B1.1.3.

To quarter the sample, tip it on to a clean surface so that it forms a conical or hemispherical pile. With a clean knife, cut the pile vertically, dividing the pile into four equal parts. Make up a new pile with one of these four parts, and repeat the quartering process.

B1.3 Liquid Coagulant

B1.3.1 Equal portions shall be taken at four equally spaced time intervals during the unloading of the tank truck. The total sample volume shall equal 2 litres, or as agreed. Special sampling arrangements may be necessary at unmanned water treatment plants, particularly if a new load is pumped into a tank that still has some coagulant in it.

B1.3.2 The gross sample (2 litres) should be thoroughly mixed, and three 0.5 litres samples retained.

BIBLIOGRAPHY

ANSI/AWWA Standard for Polyaluminium chloride. ANSI/AWWA B408-10, 2010.

Drinking-water Standards for New Zealand 2005 (revised 2008). Ministry of Health, Wellington.

National Guidelines for Health and Safety in the New Zealand Water Industry. New Zealand Water and Wastes Association, Auckland, 1997.

Standard Methods for the Examination of Water and Wastewater. 22nd Ed. APHA, AWWA, WEF, 2012.

REFERENCES

1 Helmboldt et al. Aluminium Compounds, Inorganic. In Ullmanns Encyclopedia of Industrial Chemistry. 2007.

Appendix E – Treatment Processes, Coagulation

Chapter 13: Treatment processes, coagulation

Contents

List of figures

13.1 Introduction

This chapter covers the water treatment process of chemical coagulation, with or without sedimentation. It also covers the situation where sedimentation is not followed by rapid granular media filtration. The discussion on coagulation includes details of chemical coagulants and polyelectrolytes used in the process. The separate stages of coagulation: flocculation and conventional sedimentation (also called clarification) are included. In current terminology sedimentation is one of a number of processes that are grouped as clarification. New high-rate clarification processes, (lamella plates, tube settlers, buoyant media clarifiers, dissolved air flotation (DAF) and Actiflo®) are also covered in this chapter.

The discussion on filtration in this chapter covers only rapid gravity granular media filtration (pressure filters are used sometimes too). This is the most common filtration method following coagulation in use in New Zealand. Other filtration methods that do not normally involve coagulation, eg, diatomaceous earth, cartridge, slow sand and membrane filtration, are discussed separately in Chapter 14. Although coagulation is commonly practised with membrane filtration to remove colour, membrane filtration does not rely on coagulation for removal of protozoa and is therefore classified separately as filtration without coagulation, in terms of the *Drinking-water Standards for New Zealand 2005, revised 2008* (DWSNZ).

The combined process of coagulation and filtration is used commonly throughout New Zealand and is effective at removing dissolved and colloidal colour (natural organic matter), turbidity (suspended solids), algae (phytoplankton), bacteria, viruses and protozoa (eg, *Giardia* and *Cryptosporidium*). This treatment combination is often referred to as 'conventional treatment'.

The DWSNZ outline turbidity criteria and turbidity monitoring requirements that must be met by water treatment plants to ensure compliance with the protozoa criteria. Guidance on compliance with respect to coagulation and filtration is discussed in Chapter 8: Protozoa Compliance, section 8.3.2 of these Guidelines; this chapter concentrates more on operational aspects.

This chapter includes a section (section 13.6) that discusses lime softening. This usually operates at a pH that is high enough for calcium and magnesium salts to form a floc, so as well as softening the water, organic matter, turbidity and (oo)cysts can be removed. Therefore the process can earn protozoal log credits, see Chapter 8: Protozoal Compliance, section 8.4.2.1. Water softening (and other benefits) by using ion exchange is included in section 13.6 for completeness, although the process does not include coagulation and does not earn log credits. Softening is also discussed briefly in Chapter 18: Aesthetic Considerations, section 18.3, and in Chapter 19: Small, Individual and Roof Supplies, section 19.3.4.

The 2008 DWSNZ include a new section, section 5.17: Alternative processes: treatment compliance criteria, whereby water suppliers may apply to the Ministry of Health to have other treatment processes assessed for a log credit rating. This approach, which is explained more fully in section 8.4.5 of the Guidelines, allows water suppliers to apply for a log credit rating (or a variation to the prescribed log credits) for a treatment plant or process:

a) not covered in sections 5.1–5.16 of the DWSNZ

b) that performs demonstrably better than its compliance criteria

c) that performs to a lesser, but reliable, level than specified in its compliance criteria.

Some process variation is normal and expected; however, too much variability can result in treatment failures, leading to waterborne disease outbreaks. An objective of the DWSNZ, therefore, is to keep process variability within acceptable limits. Understanding the causes of process variations should prevent recurrences. Problems may be able to be avoided and the time spent problem solving can be reduced by implementing an effective water safety plan (WSP – formerly known as public health risk management plans, PHRMPs).

Rapidly increasing plant production rates can cause sludge blanket disturbance and filter breakthrough. The main reason for this could be due to inadequate clear water storage at or near the water treatment plant (ideally at least 24-hour storage is recommended), or there is a need for more storage in the distribution system. The more consistent the treatment rate, the easier it is to maintain a good quality end product.

AWWA (2000) produced a series of manuals covering control of coagulation, filtration, softening, and the chemicals used for these, see full list at **http://www.awwa.org/files/Resources/Standards/StandardsSpreadsheet.xls**.

Risk management issues related to the treatment processes in this chapter are discussed in the:

- MoH Public Health Risk Management Plan Guide PHRMP Ref. P5.1: Treatment Processes – Coagulation/Flocculation/Sedimentation
- MoH Public Health Risk Management Plan Guide PHRMP Ref. P5.2: Treatment Processes – Dissolved Air Flotation
- MoH Public Health Risk Management Plan Guide PHRMP Ref. P5.3: Treatment Processes – Direct Filtration

- MoH Public Health Risk Management Plan Guide PHRMP Ref. P6.1: Treatment Processes – Rapid Sand Filtration
- MoH Public Health Risk Management Plan Guide PHRMP Ref. P8.1: Treatment Processes – pH Adjustment
- MoH Public Health Risk Management Plan Guide PHRMP Ref. P11: Treatment Processes – Plant Construction and Operation.

Records should be kept of all chemicals used in treatment processes. These should include the supplier, certification of the specification and grade of the chemical and datasheets, routine monitoring of the quality and standard of chemicals used, conditions of its supply and subsequent storage. Records of actual dosing of the chemical should show the chemical name, rates and quantity of the chemical dosed, the type and calibration of the equipment used. A method statement should give standard procedures in case of failure or breakdown of the system, with associated safety data sheets and Hazchem labelling for all chemicals used.

The Water Supply Managers' Committee of the New Zealand Water and Wastes Association (NZWWA) has been developing standards for chemicals used in water treatment. These cover aluminium sulphate, hydrated lime, three fluoride chemicals and three polyelectrolytes.

DWI (2011) has a list of chemicals that have been approved for use in water supply in the UK.

Documentation of the quality and quantity of chemicals used in the treatment process is important for the appraisal of the efficiency of the processes being used, and may affect which Priority 2 determinands are assigned to a supply and the frequency of sampling required for them.

The Hazardous Substances and New Organisms (HSNO) Act 1996 now controls the use of the following chemicals:

- chlorine gas
- calcium hypochlorite
- sulphuric acid
- hydrochloric acid
- sodium hydroxide
- aqua ammonia
- hydrogen peroxide
- potassium permanganate.

Since 1 October 2004 users may need a Location Test Certificate and/or an Approved Handler Test Certificate. Details are available by using the Step-by-Step Guide to Finding Controls and Other Useful Links at **www.ermanz.govt.nz**.

DWI (2013) investigated the incidence of impurities in chemicals used in the UK for water treatment. Chemicals used in the UK must be permitted under regulation 31 and normally this means the chemicals conform to a European or national standard, such as a BS EN, or the introduction or application of the chemical has been specifically approved by the Secretary of State. Unexpected contaminants can occur in chemicals even though they are compliant with the regulatory requirements. For example, a 2008 study found evidence of N-nitrosodimethylamine (NDMA) contamination of ferric coagulants (which otherwise conformed to the relevant BS EN standard). The use of this chemical gave rise to small but detectable concentrations of NDMA in drinking water. There were few reported concerns in the US about specific trace contaminants. The most frequent complaints were associated with gross contaminants, such as sediment or floating debris in liquid chemicals. While the source of the contamination was sometimes traced to a deficiency in the manufacturing or refining process, the most frequently reported incidents occurred during transport, primarily associated with improperly cleaned or maintained delivery containers or transfer hoses. DWI (2013) includes contaminant specs for several BS EN standards.

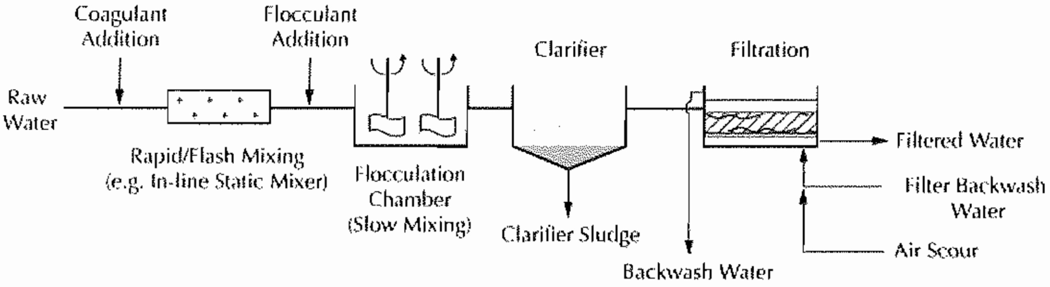
13.2 Coagulation process

Coagulation, flocculation and clarification, followed by rapid granular media filtration, are the key steps in conventional water treatment systems. This is a well-proven technology for the significant removal of colour and particulate matter including protozoa (eg, *Cryptosporidium* oocysts and *Giardia* cysts), viruses, bacteria, and other micro-organisms. Iron, manganese, tastes and odours may also be removed from the water by these processes.

If not removed, natural organic matter can react with chlorine to reduce disinfection efficiency and form chlorinated organic species, eg, disinfection by-products (DBPs), some of which are chemical determinands of health significance, see Chapter 10: Chemical Compliance and Chapter 15: Treatment Processes, Disinfection. Micro-organisms remaining in treated water may also pose risks to public health.

Conventional treatment (coagulation, sedimentation and sand filtration), as illustrated in Figure 13.1, has several distinct stages. A coagulant is added to neutralise the natural electrical charges on the colloidal particles that prevent them from agglomerating, and is rapidly mixed into the water to be treated. This process is referred to as the coagulation stage; it is sometimes referred to as the colloid destabilisation phase. The process water will then enter a flocculation chamber, where further chemicals may be added depending upon the raw water characteristics and the level and rate of treatment to be achieved. Gentle mixing during this stage allows particles to agglomerate and form settleable flocs.

Figure 13.1: Conventional coagulation, sedimentation and filtration

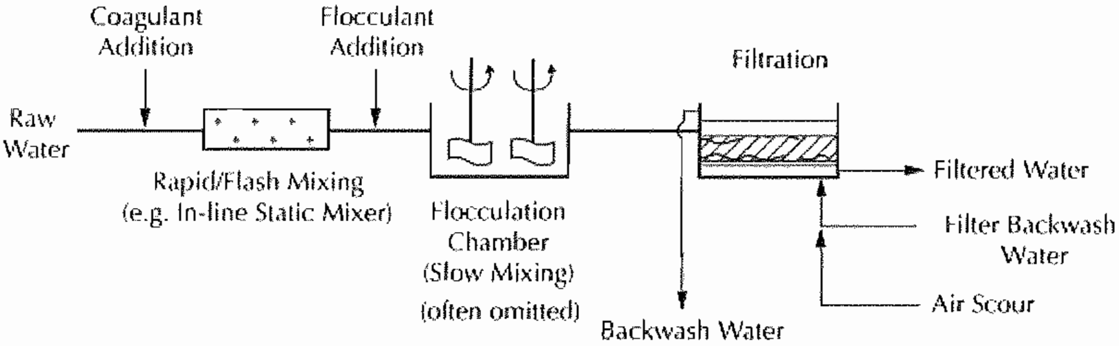


Clarification usually follows the flocculation process. Typically in New Zealand this involves sedimentation or settling, which allows the formed flocs to be separated for subsequent removal as sludge. Clarification is then followed by filtration which provides a second, polishing step for particulates that were not removed during the clarification step. The DWSNZ also cover the situation where rapid granular media filtration does not follow the sedimentation stage.

Some membrane filtration (MF) plants incorporate a coagulation and sedimentation step upstream of the MF step. The coagulation process may be continuous, or intermittent depending on the raw water quality.

For raw waters with consistently low colour (eg, less than 40 TCU) and low turbidity (eg, less than 10 NTU), direct filtration can be adopted, as illustrated in Figure 13.2. There is no clarification step in this case, and the coagulated water flows directly to the filtration process, providing the only particulate removal step. If the solids loading is too high, the filters will require frequent washing, which may lead to supply problems.

Figure 13.2: Direct filtration



As new clarification processes are emerging and becoming increasingly common, further variances from the conventional coagulation/filtration process may become more common. Lamella plates can be installed in place of traditional sedimentation tanks, and tube settlers can be placed in the tanks. These do not alter the basic principles of the process, but they may improve the efficiency, reliability, and allow higher throughputs for the same footprint to be achieved.

Dissolved air flotation (DAF) can be installed in place of the conventional sedimentation tank (or clarifier) and this process floats, rather than settles, the flocs. Widely used in Europe and now becoming more common in North America, DAF can be used for treating moderate turbidity and high colour waters. It is especially effective at removing algae, which can be difficult to remove by sedimentation and would otherwise clog downstream filters, and for raw waters that produce flocs with poor settling characteristics. The DAF process can be a good choice for very cold water temperatures because it is more effective at removing the weak flocs that are commonly produced in such waters.

A further development, the Actiflo® process, is a ballasted flocculation process, which adds microsand to the flocculation chamber. Coagulation, flocculation and clarification are provided as a single unit.

A further variation is the buoyant media clarifier (also called the adsorption clarifier). This process combines the flocculation and clarifier into one stage, and effectively acts more like a filtration process, rather than a settling clarifier. This process is best suited for raw waters of lower turbidity.

See WHO (2004a) for a description of coagulation systems, some operational aspects, and a discussion on their ability to remove various organisms. Refer also to Chapter 5 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to sedimentation.

The USEPA talks of 'enhanced coagulation' as though this were a new type of water treatment process. USEPA (2007) states that enhanced coagulation can include one or more of the following operational changes:

- increasing the coagulant dose
- changing the coagulant
- adjusting the pH (eg, using acid to lower the pH to as low as 5.5)
- improving mixing conditions or applying a moderate dosage of an oxidant
- adding a polymer.

Some advantages of enhanced coagulation are said to include:

- improving disinfection effectiveness
- reducing DBP formation
- reducing bromate formation
- enhancing arsenic and radionuclide removal.

Based on the above, 'enhanced coagulation' would seem to be little more than optimising the conventional process.

13.3 Coagulants and flocculants

13.3.1 Definitions

The addition of certain chemicals into the raw water causes particles to destabilise and allows agglomeration and floc formation to occur. The general terms for chemicals used for this purpose are:

- coagulants, which assist the destabilisation of particles (particularly colloidal sizes)
- flocculants (also known as flocculant aids or coagulant aids), which assist in the joining and enmeshing of the particles together. Most flocculants used today are polyelectrolytes.

13.3.2 Coagulants

Most New Zealand water treatment plants use aluminium-based coagulants (eg, aluminium sulphate (alum) or polyaluminium chloride (PACl – PACl is the preferred acronym because PAC can also mean powdered activated carbon). Aluminium chlorohydrate (ACH) has limited usage, mainly in membrane filtration. A very small number of plants use iron-based coagulants (ferric chloride or ferric sulphate). Although alum and PACl are most commonly used, other coagulants may have benefits in particular applications, such as low turbidity waters. NZWWA (1997, revised 2012) published the second edition of a standard that covered aluminium-based coagulants.

PACl and ACH are two of a number of pre-hydrolysed metal salt coagulant solutions that have been developed in recent years. The key characteristic of this class of coagulants is that they consume less alkalinity when added to the raw water, and are less affected by low water temperatures than alum.

In addition to aluminium and iron-based (inorganic) coagulants, organic chemicals known as polyelectrolytes may also be used as coagulants or flocculant aids, to assist in producing low turbidity levels in treated water. This is particularly necessary for high rate clarification and high rate filtration processes.

Polyelectrolyte coagulants such as polyamines, polyacrylamides, and polyDADMACs are used occasionally in New Zealand as the primary coagulant, especially on low turbidity, low colour waters, where treatment is by direct filtration. They can also be used in conjunction with inorganic coagulants, in which case they are referred to as coagulant aids or flocculants.

13.3.3 Flocculants

Polyelectrolytes are now commonly used as flocculants in the majority of water treatment plants in New Zealand. Used as a flocculant aid the polyelectrolyte is added following coagulant dosing to increase the size, strength and settleability of flocs. Polyacrylamide-based polyelectrolytes are the most commonly used flocculants in New Zealand. These may be cationic, anionic, or non-ionic. They are produced with varying degrees of ionicity and in a range of molecular weights. Generally, the higher the MW, the more effective the polyelectrolyte. Cationic polyelectrolytes usually perform better in New Zealand waters.

To achieve their full effectiveness, polyelectrolytes are added after the primary coagulant (eg, alum). A contact time of at least three minutes is not uncommon. Contact time in this context is the time the water takes to flow between the two dosage points.

13.3.4 Health effects

For some time concerns have been raised in the international technical literature and by interest groups about whether there are adverse health effects on consumers from residuals of chemicals in drinking-water following treatment. As an example, some communities have opted not to use aluminium-based coagulants because of unsubstantiated reports that claim that the aluminium in drinking-water poses a risk to public health, despite scientific evidence (eg, Srinivasan et al 1999) that adverse effects have not been demonstrated. Because there is no evidence of health risk, based on WHO (2004), the DWSNZ do not have a Maximum Acceptable Value (MAV) for aluminium. WHO (2012) does not change this point of view. These Guidelines include a datasheet for aluminium. Alternatives to aluminium coagulants exist, eg, iron-based coagulants such as ferric chloride, but there may be performance and cost penalties associated with their use.

Proven concerns do exist for kidney dialysis patients if the water that is used by the patient as the dialysate liquid contains high concentrations of residual aluminium. Users of dialysis machines should be advised to provide specific pre-dialysis treatment to ensure that residual concentrations of aluminium and some other contaminants potentially introduced by treatment chemicals and distribution materials are kept to acceptably low levels. This is absolutely critical if aluminium is being used in the treatment of a supply for the first time, even though DWSNZ are (strictly speaking) only applicable to water intended for drinking (refer section 1.3 of DWSNZ).

If water treatment chemicals are used in such a way that their residual concentration in the drinking-water does not exceed the MAV, available research indicates there will be no significant risk to health from drinking the water for a lifetime. However, industry practice is to operate treatment plants significantly below these levels.

Only flocculants that are specifically manufactured for potable water use should be used in drinking-water treatment. Many of the monomers used in the manufacture of polyelectrolytes, and their impurities and resultant degradation products, are toxic, and the manufacturing process needs to be controlled properly to limit the quantity of unreacted monomer in the manufactured polyelectrolyte. For example acrylamide (a monomer residual of the manufacture of polyacrylamides) has proven toxicity and carcinogenicity (its MAV is 0.0005 mg/L). Epichlorohydrin (present in dimethylamine/epichlorohydrin cationic polyelectrolytes) also has a MAV listed in the DWSNZ (0.0005 mg/L). The NZWWA Standards (1999, being revised 2012/13) for the supply of three types of polyelectrolytes for use in drinking-water treatment outline minimum requirements to ensure that high quality and low impurity products are used in drinking-water treatment applications.

Part 3.4 of the index section of the datasheets lists the chemical determinands with health (or possible health) concerns that can be found in water treated with coagulants and flocculants.

The total dose of polyelectrolytes applied in the water treatment process should be controlled to limit the residuals in the treated water, see Chapter 10: Chemical Compliance. In particular, the doses applied in sludge dewatering need to be taken into account if the supernatant water is recycled into the treatment process.

13.4 Coagulation and flocculation

13.4.1 Overview

Coagulation and flocculation processes are intended to form particles that are large enough to be separated and removed by subsequent sedimentation, or alternative clarification processes.

The coagulation stage occurs when a coagulant, such as alum, is added to the water to neutralise the charges on the colloidal particles in the raw water, thus bringing the particles closer together to allow a floc to begin to form. The coagulant solution should be applied at a concentration of around 0.5 percent, and certainly less than 1 percent (WHO 2001). Rapid, high-energy mixing (eg, mechanical mixers, in-line blenders, jet sparge mixing) is necessary to ensure the coagulant is fully mixed into the process flow to maximise its effectiveness. The coagulation process occurs very quickly, in a matter of fractions of a second. Poor mixing can result in a poorly developed floc.

The flocculation process which follows coagulation, allows smaller particles formed during the rapid coagulation stage to agglomerate into larger particles to form settleable and/or filterable floc particles. After coagulant addition, the process water is mixed slowly for a defined flocculation period, commonly 10–30 minutes, however the optimum flocculation time will vary depending on the raw water quality and downstream clarification process. Gentle mixing during this stage provides maximum particle contact for floc formation, whilst minimising turbulence and shear which may damage the flocs. Effectiveness of flocculation depends on the delay time (or contact time) and mixing conditions prior to any flocculants being added, the rate of treatment, water temperature and the mixing conditions within the flocculation chamber.

Contact flocculation is a variation from conventional flocculation in which the flocculation takes place within the clarification process. The coagulation step remains the same, however the flocculation chamber contains a contact medium. This medium traps the flocculating particles, which will then attach to other particles, thereby continually increasing the size of the flocs until the build-up of particles clogs the media. Backwashing is then required to remove the flocculated particles. Refer to Figure 13.4 (upflow adsorption clarifier).

13.4.2 Jar testing

The best approach for determining the treatability of a water source and determining the optimum parameters (most effective coagulant, required dose rates, pH, flocculation times, most effective flocculant aids) is by use of a jar tester.

As optimum pH and coagulant dose vary significantly with raw water characteristics, an initial thorough investigation into the variations in raw water quality from the source should help in the selection of the appropriate type of coagulation system to be used and its design. Unexpected variations in raw water quality can cause the coagulation process to be compromised, causing consequent problems with treated water quality.

The normal procedure when conducting a jar test is initially to find the best performing coagulant and dose rate, and then to determine the optimum pH for the chosen coagulant and dose rate. Performance is usually judged on turbidity, and then on colour (or UV absorbance) removal. Jar tests can also be used to compare the usefulness of different flocculant polyelectrolytes, but not their optimum dose rates; this must be done on the plant itself.

Standard aluminium and iron salt coagulants are acidic and therefore neutralise the alkalinity present in the raw water. Excess alkalinity (after the addition of coagulant) is needed to allow good floc formation. The optimum coagulant dose added at the wrong pH could result in almost no floc formation. In New Zealand's soft surface waters the optimum pH for coagulation is often only achieved by adding an alkali such as soda ash (sodium carbonate) or hydrated lime, perhaps in the range of 5–20 mg/L, see section 13.4.3.

A raw water with a high pH and a low coagulant demand may not reach the optimal pH without adding acid. However, unless the acid requirement is quite high, the optimum pH is usually achieved simply by adding excess coagulant. This should not be done if it unduly increases the concentration of aluminium in the finished water.

Smaller water treatment plants often choose to use PACl to avoid the need to dose alkali or acid, as PACl is much less acidic than alum and is usually effective over a broader range of pH values.

To assist in maintaining good control of the coagulation process, jar tests should be carried out routinely as part of the plant process control. The procedure should be conducted frequently, whenever changes in the characteristics of the raw water occur, eg, after rain, intake changes, etc, or when the water treatment plant is performing poorly.

Depending on the experience of the operator and the extent to which the raw water characteristics have changed since the current dose rates were chosen, the first set of jar tests usually trials a range of coagulant doses. Examination of the results should indicate which coagulant dose is closer to that required for removal of the colour and turbidity.

Many water supplies need a second set of jar tests at different pH values, to give an indication of where the optimum pH is likely to be. Subsequent jar tests fine up on the dosage selection. Generally, the more turbidity and colour there is, the higher the optimum coagulant dose. Experienced operators will know, usually from the turbidity, how much coagulant is needed to remove the solids (or colour) load. Alum or iron salts are usually dosed at about 15–50 mg/L (solid weight equivalent).

The individual jars are assessed for a variety of factors, including which developed a floc first, which jar's floc grew the fastest and became the largest, which settled fastest and which gave a supernatant with the lowest colour, turbidity and coagulant residual. Normally, the same jar scores best on each count. In some difficult waters the optimum dosage conditions are different for colour and turbidity removal, or the optimum dose for colour and turbidity removal results in excessive residual concentrations of coagulant entering the distribution system. These waters require extensive jar testing to determine the best compromise. The number of jar tests needed to determine optimum parameters is learned from experience.

Refer to AWWA (2000) for further information on the jar testing procedure.

Additional laboratory equipment useful for managing coagulation and subsequent treatment includes a bench turbidimeter, colour comparator, pH meter, alkalinity titration equipment and a spectrophotometer for measuring aluminium and possibly iron and manganese residual concentrations following treatment. Colour measurement is a fairly subjective test, and readings made by a group of people can have a wide spread. If the laboratory intends to use a spectrophotometer, it may be wise to purchase a UV/visible model, because for a particular water a correlation can be established between the true colour (Hazen units) and the UV absorbance measured in a 1 cm cell at 254 or 270 nm after filtration. UV absorbance is able to be measured quickly and reliably.

13.4.3 Performance and control

The performance of coagulation and flocculation is dependent on a large number of factors, many of which are inter-related, making optimisation difficult. Source water characteristics, chemical dose rates, mixing conditions, flocculation times, the selection of chemicals and their order of addition, treatment rates, water temperature, can all affect performance. Control of pH and alkalinity is also essential to maintain performance.

Clarifier and filter performance will also be directly affected by the overall performance of these stages of the process. It is therefore critical to maintain good performance and control of coagulation and flocculation for overall treatment plant performance.

Depending on the pH of the source water, pH adjustment prior to coagulant addition may be required to achieve the optimum pH levels. Subsequent readjustment will almost certainly be required to ensure acceptable pH levels in the distribution system.

The optimum pH for the coagulation process varies with the choice of coagulant. For aluminium sulphate it is usually 5.5 to 7.5, for ferric salts it may be within the range 5 to 8.5. The optimum pH will vary with changing raw water characteristics.

Many surface waters in New Zealand have an alkalinity of less than 20 mg/L as $CaCO_3$. 1 mg/L of alum (measured as solid weight equivalent)[1] will consume 0.5 mg/L of alkalinity (as $CaCO_3$). If all the alkalinity is neutralised, no more floc will form. Often the alum dose that is required to coagulate all the turbidity and colour present requires soda ash, caustic soda or hydrated lime to be dosed to provide the additional alkalinity and maintain control of the pH. This commonly occurs after heavy rain, and if the alkalinity and pH are not controlled, process failure can result, with turbid water and dissolved aluminium entering the distribution system.

Being a sensitive, physico-chemical process, coagulation/flocculation is most reliable when raw water quality is consistent, when changes occur slowly, or when adequate automation is used to respond to changes in raw water quality. Unfortunately, this is not true of many of our streams and rivers. See Chapter 12: Pretreatment Processes, section 12.3.2 for a discussion on the benefits of off-river storage.

As raw water conditions change, optimal coagulation dose rates also change and careful control is required to prevent overdosing and underdosing.

Overdosing can lead to excessive concentrations of coagulant entering the distribution system, and waste money. This can occur if the pH and alkalinity are not controlled at optimum levels too. The guideline value for aluminium (an aesthetic determinand) is 0.1 mg/L as Al, which is approximately equivalent to 1.1 mg/L as solid weight equivalent alum.

---

[1] Solid weight equivalent alum refers to $Al_2(SO_4)_3.14H_2O$ (molecular weight of 594). New Zealand liquid alum is delivered as 47% w/w (equivalent to 62% w/v). Sometimes alum doses are reported as Al_2O_3 (molecular weight of 102, 8.2% w/w of as-delivered liquid alum) or as Al (molecular weight of 54, 4.3% w/w of as-delivered liquid alum).

Underdosing can cause poor removal of colour, turbidity and micro-organisms.

Online monitoring of raw water quality determinands, such as pH and turbidity will aid treatment plant performance and assist in selecting optimum coagulation dose rates. It may be helpful to measure UV absorbance online if the raw water has high colour.

Severe rainstorms can seriously affect the quality of lake water, causing stress to the water treatment plant. With luck, the problem can be exacerbated by valve selection.

Water from the main tributary and side streams flowing into a lake or reservoir tends to find its way to water of the same specific gravity, which usually means water of the same temperature.

Rain falling during a cold southerly during the summer may be less than 10°C while the lake water may be about 20°C at the surface and 10°C at the bottom. This run-off will find its way to the bottom. Sometimes this can be observed visibly with the dirty flood water colouring the clean lake water – at the point where the flood water sinks there can be a distinctive plunge line. Until the lake water mixes, water from the upper valves remains relatively clean.

Flood water resulting from warm rain will remain on the surface, and until the particulate matter settles, water from lower valves may remain relatively clean for quite some time.

If the reservoir or lake is being aerated or circulated for manganese control the temperature will be much the same at all depths so the dirty run-off will tend to "blend" with the lake water, obviously assisted by the artificial mixing process.

Control of the coagulation process can be automated. Two control methods used in New Zealand for coagulation are the streaming current monitor (very common) and feed forward control (less common).

- Streaming current monitors measure the zeta potential (a measure of the electrical charge on the particles in the water) of the raw water following chemical addition and this can be used to adjust the coagulant dose rate accordingly as the raw water characteristics vary. This process was described by Ogilvie (1998).
- Feed forward control systems monitor natural organic matter (using UV light) and pH in the raw water prior to coagulant addition and predict the required coagulant dose rates to be applied.

13.5 Clarification and sedimentation

13.5.1 Overview

The term clarification, or sedimentation, is normally used to describe the settling of the flocs produced by the coagulation and flocculation process. This is distinct from presettling of highly turbid waters in detention ponds, which is discussed in Chapter 12: Pretreatment Processes, section 12.3.3.

Historically, clarification involved the simple principle of particle settling to separate the floc particles. New technologies such as dissolved air flotation (DAF), and high rate clarification processes, such as lamella plates, tube settlers, Actiflo®, and buoyant media clarification, have been developed and are being used increasingly. These clarification processes are illustrated in Figures 13.3 to 13.6 and are described below. The majority of the clarifiers in New Zealand are of the upflow, sludge blanket, hopper bottomed configuration. However, there are small numbers of most other designs including horizontal flow, DAF, buoyant media clarifiers and lamella settlers.

The surface loading rate is a key parameter in clarifier design, irrespective of the clarifier type. This is usually expressed in $m^3/m^2/h$ (more correctly $m^3/m^2.h$ or m/h). This is the flow (m^3/h) that occurs over the horizontal area (m^2) of the settling zone of the tank. Acceptable surface loading rates vary significantly for the different clarification types from 2 m/h for a hopper bottomed upflow clarifier, to 12 m/h for a DAF process, to 40 m/h for the Actiflo® process.

Chapter 5 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) discusses various types of sedimentation basins.

13.5.2 Clarifier types

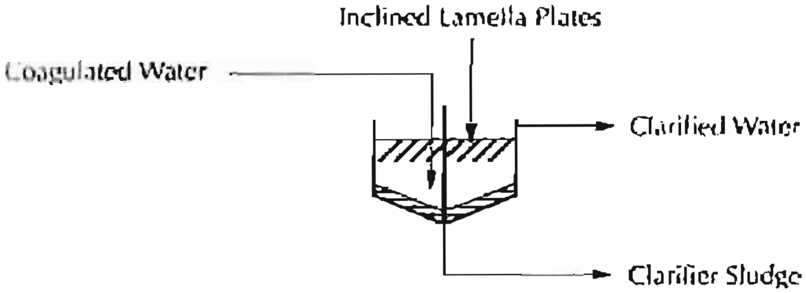
Conventional clarifiers

Conventional clarifiers (or sedimentation tanks) may be classified on the basis of flow direction (horizontal, radial, or upflow), the presence or absence of a sludge blanket, and shape (circular, rectangular, or hopper/wedge bottomed). A few earlier plants recycled a fraction of the sludge in an effort to enhance flocculation. Upflow clarifiers are suitable for a large range of raw water turbidities, however they are sensitive to flow changes. Flocculation times of 3–6 minutes are typical (further flocculation will continue to occur in the clarifier itself) whereas horizontal clarifiers require approximately 20–30 minutes flocculation time. Typical surface loading rates for conventional clarifiers are 2 m/h. This can be increased to up to 5 m/h if polyelectrolytes are used.

Lamella settlers

Lamella settlers, Figure 13.3, make use of inclined plates or tubes to increase the effective surface area for settling (and hence are also known as plate or tube settlers), thereby increasing the efficiency of the clarification process. For a given throughput the footprint of a lamella settler will be considerably less than a conventional clarifier. Typical surface loading rates are 5–15 m/h. Lamella settlers are less vulnerable to flow fluctuations than conventional clarifiers.

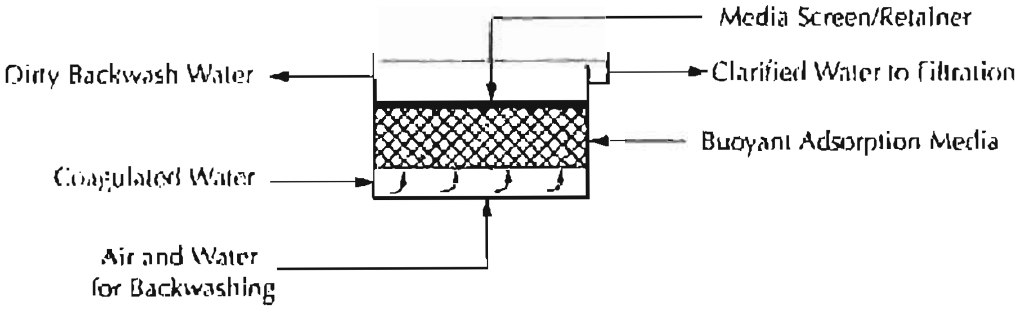
Figure 13.3: Lamella plates



Buoyant media clarifiers

Buoyant media clarifiers, or adsorption clarifiers, Figure 13.4, are a variant on the conventional clarification stage and combine flocculation and clarification into one step. The coagulated water passes through a medium of buoyant adsorption material (normally a plastic), kept in place by a screen. This allows contact flocculation to take place as flocs attach to the media and are thereby removed from the water. Solids will continually build up until the media clogs. Backwashing is then required to expand the media and remove the solids.

Figure 13.4: Adsorption clarifier



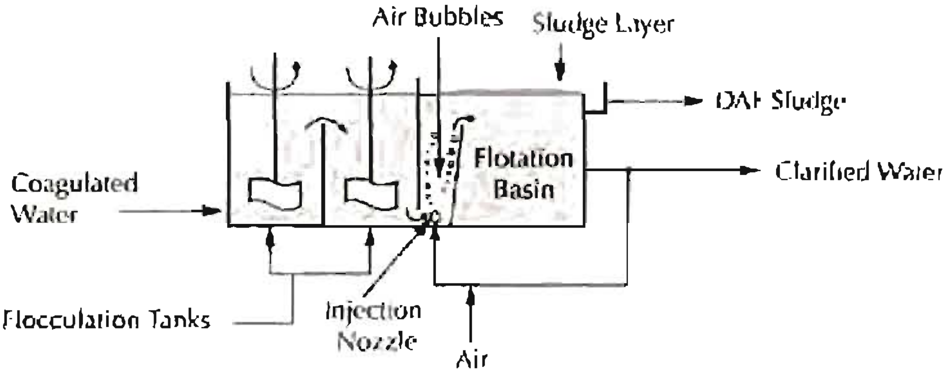
This process often requires a larger polyelectrolyte dose and is better suited to raw water sources with low turbidity and colour. High turbidities will very quickly clog the media and result in excessive backwashing. Typical surface loading rates of 19–25 m/h can be applied.

Dissolved air flotation

Dissolved air flotation (DAF), as illustrated in Figure 13.5, is a clarification process particularly effective for removal of colour, and algae cells that are difficult to settle. It is suited to moderate levels of turbidity, and only small doses of polyelectrolyte are typically required. Surface loading rates of 10–12 m/h are common.

The process works by injecting very small air bubbles near the inlet of the flotation tank, which attach to flocs (usually aluminium based) formed in a separate flocculation tank, and floats them to the surface. Flocculation times of 15–20 minutes are typically required. Clarified water is then collected from near the tank bottom. A portion of the flow (approximately 5–10 percent) is recycled and saturated with air. The recycled water re-enters the flotation tank through a series of nozzles, causing a pressure reduction that releases small air bubbles from the saturated water.

Figure 13.5: Dissolved air flotation (DAF)



Floated flocs collect as a sludge layer on the water surface. Periodic desludging occurs either by hydraulic flooding of the flotation tank, the sludge layer spilling over a collection weir, or by mechanical skimming, which will form a thicker sludge.

The in-filter DAF (sometimes referred to as DAFF) is a variation of the typical DAF process in which the base of the DAF tank is made into a rapid granular media filter, thus incorporating clarification and filtration into one step.

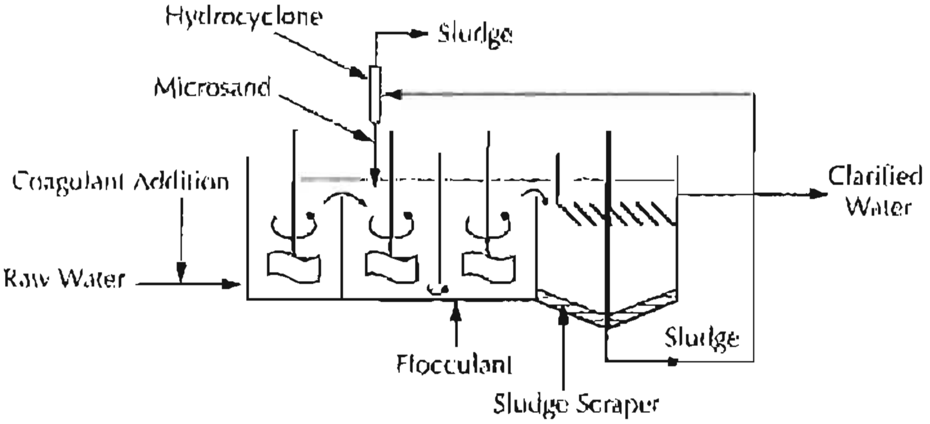
Pulsed blanket clarifiers

Pulsed blanket clarifiers use a vacuum system to create pulsations to hold the sludge blanket in suspension and aid flocculation, allowing for higher surface loading rates (up to 3 m/h). In the Superpulsator® system (installed at the Waikato Water Treatment Plant), clarification is enhanced by inclined plates, allowing surface loading rates of up to about 6 m/h.

Actiflo

The Actiflo® process is a package plant, microsand ballasted clarification process, as illustrated in Figure 13.6. The process reduces flocculation times to approximately 5–10 minutes, and allows very high surface loading rates of 30–40 m/h (up to 100 m/h). There are no Actiflo® units operating in New Zealand as at 2005.

Figure 13.6: Actiflo process



Coagulant addition and mixing occurs in the first chamber. Polyelectrolytes and microsand are added in a second chamber, and flocculation occurs in the third chamber. The flocculated water is then passed through a lamella settler. Settled sludge is collected and passed through a hydrocyclone, in which the microsand and floc particles are separated. The microsand is recycled back through the process and the sludge is separated for disposal.

The use of microsand as a seed for floc formation improves performance in two ways. The high specific area assists floc formation, whilst the high specific density improves the settleability characteristics of the flocs.

The Actiflo® process is similar in some respects to the Sirofloc process that was developed in Australia in the 1980s, except that the Sirofloc process uses 1–10 µm magnetite that behaves similarly to a coagulant when added (with acid) to the raw water. The resulting suspension is then subject to a magnetic field to form settleable flocs. The magnetite is recovered and reused.

13.5.3 Optimisation and performance issues

Most clarifiers will provide a reasonable level of treatment provided the upstream chemical dosing is optimised, and a reasonable surface loading rate suitable for the clarification type, is not exceeded. For example, studies on the removal of protozoal cysts in conventional treatment have shown that the clarifier is usually responsible for over 90 percent (1 log) of the (oo)cyst removal (USEPA 2003).

High effluent turbidities in water leaving a clarifier are indicative of poor performance. Flocs, which should have been removed in the clarifier, pass out and on to the filters. This will result in reduced filter run times and poorer filtered water quality. A well-operating clarifier should be able to produce an effluent of turbidity 2 NTU or less. Conventional clarifiers are sensitive to changes in flowrate, however, high rate clarification processes are less susceptible to such changes.

There is limited guidance for clarifier performance. The US Partnership for Safe Water Guidelines for Phase IV *Excellence in Water Treatment* sets performance goals as part of overall plant performance to achieve less than 0.10 NTU filtered water. This includes clarified water turbidity:

- less than 1.0 NTU 95 percent of the time when raw water is less than or equal to 10 NTU
- less than 2.0 NTU 95 percent of the time when raw water turbidity is >10 NTU.

Despite this, it has often been found that the sedimentation process is more effective when the raw water is turbid; some earlier plants with low turbidity raw water took advantage of this by dosing bentonite into the raw water.

The rate at which particles settle is dependent on water temperature, or more accurately, water viscosity. In summer when the water temperature is perhaps 20°C, particles may settle up to 50% faster than in winter, when the water temperature is perhaps 10°C, however, most water treatment plants operate at a lower rate during winter.

A key aspect of consistently achieving <0.10 NTU filtered water turbidity is that changes in raw water turbidity should have minimal effect on clarified water turbidity, and negligible effect on individual filter turbidity. This requires optimisation of coagulation.

A common operational problem in clarifiers of the hopper-bottomed upflow type in New Zealand is for short-circuiting currents to occur, usually in summer and around the middle of the afternoon. This can be attributed to a temperature differential between the incoming water and the water in the tank. The result is a billowing of the floc blanket and subsequent carry-over of floc on to the filters. The same effect can be caused by algae in the sludge blanket becoming buoyant due to increased production of oxygen due to photosynthesis. High algal populations are needed for this effect to become a nuisance. Clarifiers with good inflow mixing do not seem to experience the same degree of problem. The only satisfactory solution to this problem, (apart from fitting tube settlers to the tank), appears to be to reduce the flow and hence the surface loading rate during the problem period.

Another common problem is excessive floc carry-over caused by uneven flows occurring over the clarifier surface. Inspecting and levelling the outlet weirs to ensure that all receive equal flows can correct this. If the flows are still uneven, the inlet flows to each clarifier must be checked, and adjusted so that they are even. For non-hopper bottomed clarifiers it is also important to ensure that the distribution of the flow within the clarifier is even.

Multiple tanks in larger plants often experience a high frequency wave in the outlet weirs that may disrupt the floc blanket. However, this generally does not cause a significant problem.

For clarifiers using a floc blanket, good control of the blanket surface and regular removal of floc from both the top and body of the blanket and base of the tank is important. In conventional clarifiers, the use of sludge (or gravilectric) cones gives better results than the earlier system of constructed corner pockets. Bottom sludge scours should be operated regularly (based on experience) to keep sludge fresh and to prevent excessive sludge build up. Bottom sludge has been known to go anaerobic at plants with a high level of organic matter or algae in the raw water.

Regular sludge removal is important for all clarifier types. For DAF units, desludging should also occur regularly to prevent sludge re-settling. The sludge in this process is exposed, so it is important that the tanks are covered to prevent the rain and wind affecting performance.

Buoyant media clarifiers need to be backwashed when the media becomes clogged, again to prevent excessive floc carry-over to the downstream filtration step.

Growth of algae and slimes on the walls of sedimentation tanks and other channels should be discouraged. Regular cleaning is recommended, because such material can increase the levels of dissolved organic matter that the plant must contend with, and can contribute to taste and odour problems.

13.6 Lime softening and ion exchange

Water containing significant concentrations of calcium and magnesium is referred to as hard water. Hard water can cause scaling of pipes and household appliances and reduces the solubility of soaps and detergents in the water.

Lime softening and ion exchange processes can be used to soften water, however both are currently of limited use in New Zealand for drinking-water, mainly because, on average, New Zealand waters are softer than those found in many other parts of the world.

13.6.1 Lime softening

The lime softening process removes hardness by chemical precipitation, followed by sedimentation and filtration, therefore showing similarities to the conventional chemical clarification process. Lime, caustic soda (sodium hydroxide) or soda ash is added to the water, increasing the pH, which causes the metal ions to flocculate and precipitate. The metal precipitates are removed during the sedimentation stage, prior to filtration. Other contaminants may also combine with the precipitates and be removed by this process.

Calcium concentrations can be reduced at pH 9.5 to 10.5 in lime softening processes, although magnesium requires pH 10.5 to 11.5. Several organisms are inactivated at the latter pH; see WHO (2004a) for further information. The microbial treatment mechanism of this process is a combination of inactivation due to elevated pH levels, and removal by sedimentation. However, *Cryptosporidium* and *Giardia* are not inactivated by high pH levels. Removal of protozoa through this process is solely due to the sedimentation and subsequent filtration. Section 5.4 of the DWSNZ specifies the compliance criteria that need to be satisfied in order to qualify for 3 log credits.

A single stage lime softening plant consists of a primary clarifier and filtration step. An additional clarifier is required between the primary clarifier and the filtration step for two-stage lime softening. A coagulant is added to both stages of clarification. Two-stage lime softening can provide additional *Cryptosporidium* removal due to the additional sedimentation stage within the process. Refer also to Chapter 6 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to lime softening.

13.6.2 Ion exchange

Ion exchange is discussed in this section because it is used frequently to soften water; it is not a coagulation process, and does not earn protozoal log credits. Many aspects of ion exchange are covered in NSF/ANSI 44-2004.

Ion exchange treatment units can be cationic, anionic, weakly or strongly ionic, or mixed bed, depending on the reason for its use.

Mixed bed units are employed for producing deionised water, usually for laboratories and industry. WHO (2005) also discusses some negative aspects of drinking deionised, distilled or reverse osmosis water, due to their tastelessness, and loss of essential minerals, mainly calcium and magnesium. This is discussed briefly in Chapter 10: Chemical Compliance, section 10.2.2.

Cationic beds can be used to remove calcium from the water, usually replacing it with sodium; if iron and manganese exist in the water in the soluble state (ie, ionic) their concentrations can be reduced as well. The process needs to be monitored to determine when the resin needs recharging. Some smaller units use a colour indicator for this purpose.

Strong-base anion exchange can be used to reduce the concentration of arsenic in the form of soluble arsenite or arsenate. This process replaces most anions in the water, usually with chloride ions, which can make the water corrosive.

There are currently two approaches to nitrate removal. One is as described in the previous paragraph, where all anions are replaced with chloride. Since anion exchange resins are generally more selective for sulphate over nitrate, the capacity of a resin for nitrate removal will be limited by the concentration of sulphate. The other approach is to use a nitrate selective resin, usually reducing nitrate to less than 2 mg/L as N.

WHO (2004a) describes ion exchange as follows:

> Ion exchange is a treatment process in which a solid phase presaturant ion is exchanged for an unwanted ion in the untreated water. The process is used for water softening (removal of calcium and magnesium), removal of some radionuclides (eg, radium and barium) and removal of various other contaminants (eg, nitrate, arsenate, chromate, selenate and dissolved organic carbon). The effectiveness of the process depends on the background water quality, and the levels of other competing ions and total dissolved solids. Although some ion exchange systems can be effective for adsorbing viruses and bacteria, such systems are not generally considered a microbial treatment barrier, because the organisms can be released from the resin by competing ions and flow changes. Also, ion exchange resins may become colonised by bacteria, which can then contaminate treated effluents. Backflushing and other rinsing procedures, even regeneration, will not remove all of the attached microbes. Impregnation of the resin with silver suppresses bacterial growth initially, but eventually a silver-tolerant population develops. Disinfection of ion exchange resins using 0.01 percent peracetic acid (one-hour contact time) has been suggested.

As explained in the previous paragraph, ion exchange cannot be relied upon to consistently remove (oo)cysts from water, hence does not qualify for protozoal log credits. Ion exchange resins have been developed that can reduce the concentration of natural organic matter, eg, as used in Orica's (now IXOM's) MIEX (magnetised anion exchange resin) process. The MIEX® Process uses a fluidised bed ion exchange reactor to remove dissolved organic carbon. This process can be used upstream of a conventional chemical coagulation plant that has difficulty in complying with the criteria in section 5.4 of the DWSNZ. Although this ion exchange process does not qualify for log credits on its own, it may well be possible for the whole process to earn 3 log credits (section 5.4), or 3.5 (section 5.4 plus 5.7), or even 4 log credits (section 5.4 plus 5.8). The use of ion exchange resins that reduce the concentration of natural organic matter may offer the additional advantage of reducing the concentration of disinfection by-product precursors sufficiently to avoid monitoring for, or removing, DBPs. MIEX may also reduce the natural organic matter sufficiently from water with a low UVT (high UV absorbance) to render UV disinfection economic.

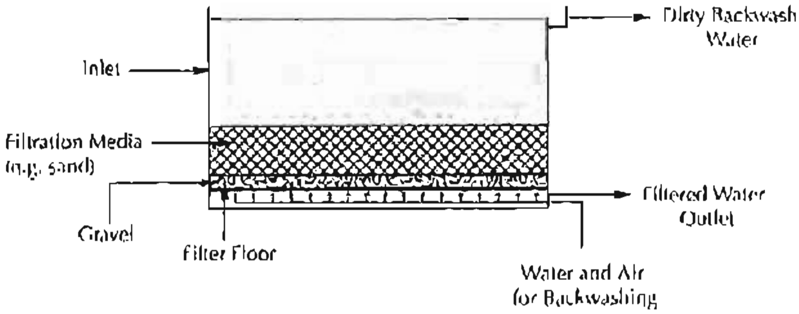
Ion exchange is discussed in Chapter 9 of AWWA (1990).

13.7 Rapid granular media filtration

13.7.1 Overview

Rapid granular media filtration, as illustrated in Figure 13.7, provides the conventional polishing step following coagulation and sedimentation, and is the only floc removal/polishing step in direct filtration plants. It is the most common type of filtration used in New Zealand water treatment plants. The filter may operate by gravity or pressure. Other filtration processes not generally used in conjunction with coagulation are discussed separately in Chapter 14: Treatment Processes, Filtration. WHO (2004a) discusses some design, operation and performance aspects of granular media filtration. Refer also to Chapter 7 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to filtration, including enhanced individual and combined filtration.

Figure 13.7: Rapid granular media filter



Like clarifiers, filters can be described by their treatment rate. This is usually expressed as m^3/m^2/h (more correctly m^3/m^2.h or m/h) and is the flowrate (m^3/h) that occurs over the surface area (m^2) of the filter bed. Filtration rates are also measured as mm/s.

Older filters were designed to operate at around 5 m/h (1.4 mm/s). However, many modern filters and dual media filters will operate at higher filtration rates of 10–15 m/h (2.8–4.2 mm/s), especially if the coagulant is assisted with polyelectrolyte.

As water passes through a filter bed of media, particulate matter (including micro-organisms) is trapped within the media primarily by a two-step process in which particles are moved to the surfaces of media grains or previously captured floc, and then become attached (adsorbed) to these surfaces. Physical straining is only a minor factor in rapid granular filtration.

The particles that build up in the bed are subsequently removed by backwashing at regular intervals. Traditionally, single medium sand filters of shallow depth (typically between 600 and 750 mm excluding the support gravel) were the most common. However, newer plants often contain dual media, either anthracite or thermally modified pumice (silicon sponge) over sand, or coarse medium deep bed with typical total media depths of between 1.2 and 1.5 m. For further information on these newer media refer to Kawamura (2000), and for pumice (or porous ceramic dual media) filters refer to Hill and Langdon (1991).

The concept of dual or multimedia filters is to include a relatively coarse medium (eg, anthracite) on the top, followed by finer media beneath. This causes deeper penetration of the particles being removed, allowing longer filter runs. Some multimedia filters use a very fine medium at the bottom of the bed (eg, garnet); this allows finer particles to be trapped but increases the headloss. The effectiveness of multimedia filters depends on the media remaining separate even after multiple backwashes. This is achieved by a balance between the relative densities of each filter medium and the backwashing conditions. Depending on the nature of the particles being removed, multimedia filters may be effective without using coagulation.

By using a polyelectrolyte as a coagulant aid or filter aid, the strength or 'stickiness' of the attachment between the floc particles and the media grains is increased, allowing higher filtration rates and coarser media gradings to be used thereby reducing the rate that headloss increases. It also means the filter is less likely to let go of these particles following flow increases or surges.

If too much polyelectrolyte is dosed, the particles will adsorb to sand grains at the top of the filter, causing the headloss to increase too quickly; excessive polyelectrolyte dosage may also cause backwash problems. At a more appropriate polyelectrolyte dose, the particles penetrate further into the bed, making more use of the full depth of the media, and allowing much longer filter runs. If the polyelectrolyte dose is too low, many of the particles may pass through the bed if the filter grains are coarse or the filtration rate too high. Bed penetration can be assessed by measuring the headloss at various depths through the filter.

Before the introduction of polyelectrolytes, filter sand was usually in the 0.6 to 1.2 mm diameter range, that is, in the 14/25 sieve range. Using such fine sand was considered necessary to strain out the particles. Using polyelectrolytes enables use of coarser sand, such as in the 2 to 4 mm range. The advantages include less headloss, and deeper penetration thereby using more of the bed leading to longer filter runs.

Rapid granular filters can be operated at either a constant rate of flow (constant rate filtration) or at a flow rate that declines as headloss builds up during a filter run (declining rate filtration). Constant rate filtration is the more common method and is normally achieved by the control valve on the filter outlet opening progressively during a filter run to compensate for the build-up of headloss though the bed.

Water treatment plants may not be able to remove all the soluble manganese. One technique that is used to enhance manganese removal is to use greensand filters; apparently with varying degrees of success. ANSI/AWWA Standard B102-10 is titled Manganese Greensand for Filters.

Backwashing is the term used to describe the cleaning of the filter by passing water (often preceded by, and/or in combination with, air) in the reverse flow direction to when the filter is in normal operation. Similarly to the term filtration rate, the term backwash rate in m/h (or mm/s) is used to describe the intensity of the backwash operation. Traditionally in New Zealand, backwash rates were low (typically 20–25 m/h), preceded by an air scour at a similar rate. There are a variety of systems in use including air scour followed by water backwash, water only, and combined air/water followed by water backwash. Modern best practice is a combined air scour/low rate water backwash (the optimal regime is known as collapse pulsing), followed by a high rate water backwash (as high as 55 m/h). A bed expansion of 20 percent is the objective during the high-rate backwash to ensure full bed fluidisation and adequate cleaning. Note that to achieve the same degree of bed expansion will require higher flow rates in summer compared with winter, as warmer water has a lower viscosity than cold, and the effects of this should be considered in backwash design.

13.7.2 Turbidity monitoring

Turbidity measurement is used to assess the efficiency of the filter in achieving protozoa removal for compliance with DWSNZ. Sampling must be made on water directly from the filtration process. The DWSNZ require turbidity monitoring of each filter (unless the population served is below a threshold value – see Table 5.3 of DWSNZ). Particle counters can also be used to measure and optimise filter performance, but these are not required for compliance purposes.

Although turbidimeters are not required on individual filters at smaller plants, their use is strongly encouraged. This is because when measuring a combined effluent from multiple filters, one filter may be producing poor quality water that is then diluted by good quality water from the other filters and the sub-standard filter's performance would not be noticed. Continuously monitoring each filter will indicate whether any slow start mechanism, filter-to-waste, the headloss control, filter run length, filtration rate control, and filter cleaning are operating or selected correctly.

To earn 3 log credits under DWSNZ for protozoa removal using the coagulation, sedimentation, filtration process, or 2.5 log credits for direct filtration, one of the requirements is that the filtrate from each filter must be less than 0.30 NTU for at least 95 percent of the time (DWSNZ, sections 5.4 and 5.5).

Additional log credits are available for enhanced filtration, ie, individual filter effluent (IFE) monitoring and combined filter effluent (CFE) monitoring, see Chapter 8: Protozoa Compliance. These will usually be the standard rapid granular media filters, but producing a lower turbidity filtrate. The standard tungsten lamp type nephelometer may not be sensitive enough at such low NTUs; a laser turbidimeter may be required. Turbidity measurement and calibration is discussed in Chapter 8: Protozoa Compliance, section 8.6.2.

13.7.3 Filter operation

As solids build up through the bed, headloss across the bed will increase and at some stage filtrate turbidity will also increase. Backwashing frequency can therefore be triggered by headloss, turbidity or filter run times (based on operational experience). The filter goes through a ripening period when it is brought back online, during which time the filtrate quality will be substandard. For this reason slow-start, delayed starts, and filter-to-waste are becoming common practice.

13.7.4 Optimisation of the filtration process

Increased filtrate turbidity (or residual coagulant, eg, aluminium or iron) is the primary indication of problems with a filter, however reduced run times (caused by turbidity or headloss reaching the set point earlier than usual) can also highlight problems.

Raw water that has high colour and low turbidity (and typically with low alkalinity) can be very difficult to treat, particularly when the water is less than say 10°C. The floc often only forms in a narrow range of alum dose and pH conditions. It is usually small, slow to form, and light, so that it is very susceptible to shear due to flow changes. It can even be difficult to see. Removal of protozoa in these conditions will be sub-optimal. These waters can also result in elevated aluminium levels in the filtered water, and hence additional attention should be paid to monitoring filtered water aluminium.

If filtrate turbidity increases are observed across all the filters, there is likely to be a common problem upstream of the filters. The following are some possible causes of high turbidity in the filtered water:

- non-optimal coagulant dosing may cause poor floc formation, which can overload and/or pass through the filters; this can be caused by selection of an inappropriate alum dose, raw water alkalinity too low for the alum dose rate being used, or coagulation occurring at the wrong pH
- operational problems such as the alum solution being the wrong strength (or even run out!), or the automatic adjustment to flow rate being faulty, or inadequate sludge removal from the settling tanks
- dose pumps not performing to specification; a good practice is to check the pump discharge against the dose setting (sometimes called the stroke), for example, by using dose timers, or calculating from the weight used while a measured flow has been treated
- flowrates may have been increased too rapidly, causing sludge blanket instability
- floc carry-over from a poor clarification process will increase the solids loading on to the filters, reducing run times and causing excessive backwashing
- insufficient polyelectrolyte for the conditions, causing sludge blanket instability
- excessive polyelectrolyte dosing, which can quickly blind the filter and reduce filter runs, thereby causing the filtered water turbidity to increase earlier than expected
- flow increasing excessively through the remaining filters when one is being washed
- direct filtration, being a one-step process, is particularly susceptible to sudden changes in raw water quality and flowrate.

If filtered water turbidity is high on a single filter, the problem is likely to reside only with that filter. Some problems, their consequences, and potential indicators are listed below:

- backwash/air scour flowrates too low resulting in a partially washed filter being put back into service
- backwash/air scour flowrates too high resulting in loss of sand, allowing particles to pass through the shallower bed

- insufficient duration of washing, also resulting in a partially washed filter being put back into service; an elevated clean bed headloss (above normal values) on start-up immediately after a backwash is a good indication that insufficient backwashing has occurred
- failed or blocked backwash nozzles or underdrain system. This situation results in excessive filtration rates and backwash flows through that part of the filter bed that is still in operation. Observing a filter during a wash can assist in detecting individual failed nozzles: the overall water or air distribution pattern during the wash will be uneven
- filter flow meter, controller, or filtration rate indicator may be out of calibration
- uneven flow split to each filter may cause reduced filter run times for some filters and excessive flows to others. Inlet pipe or channel configurations should be checked.

If filter runs are longer than expected, they may not be due to improved quality of the water feeding the filters. They can result from:

- backwash/air scour flow rates being too high or the duration too long. Over-washing may lead to media loss (thus reducing media depth in the filter), or impairment of the media's ability to adsorb particles. Checking and recording the media depth at regular intervals can highlight if media is being lost due to over washing
- if the alum dose is incorrect, or raw water alkalinity too low for the alum dose rate being used, minimal floc may be forming, reducing the solids loading on the filter, thereby increasing filter run times. Protozoa removal will be sub-optimal
- polyelectrolyte dosage is important, particularly in high rate or coarse-grained filters. As mentioned above, too much polyelectrolyte can blind the filter, but too little polyelectrolyte can result in some floc passing through the bed
- plants treating raw water with a low turbidity and average to high natural organic matter, often using direct filtration, may produce filtered water with a low turbidity despite very little of the aluminium being removed. A slower than usual increase in headloss indicates a low removal rate of particulate matter. Plants treating raw water like that should test for aluminium in the final water to check that the process is operating satisfactorily.

Sudden flow changes can cause problems with filtrate quality, eg, when:

- filters are taken out of service, as there will be a corresponding flow increase to the other filters. Allowing only gradual flow changes during this operation, rather than a sudden change, will minimise these effects
- poor flow control at the outlet from the filter typically caused by incorrect valve and/or actuator selection
- inadequate storage of treated water can require sudden increases in flow through the plant which will challenge the whole treatment process.

Monitoring the raw water quality, optimisation of the coagulation and clarification processes, and good operating procedures can minimise these effects.

Other common problems with granular media filters include bed cracking, shrinkage of the media away from the walls, mudballing, and the media in multimedia beds intermixing. These are generally caused by excessive clarifier effluent turbidity, dosing polyelectrolyte too high, poor filter backwash/air scour capability, or excessive filtration rates for the filter type, and can usually be checked by visually assessing or sampling the media.

Mudballing problems (ie, sand particles sticking together) can be alleviated by using high pressure sparge cleaning and/or acid, chlorine or caustic soda washing to break up the mud balls. Often there is a more fundamental problem that needs to be addressed to solve the problem long term, such as inadequate filter backwashing that may require significant upgrading of the filters.

A quick checklist that can be used if the turbidity of a filter effluent exceeds the required or normal level is as follows; determine whether:

- the raw water quality changed
- the solids loading on the filters increased
- the coagulant dose was selected correctly
- the coagulant is being dosed correctly
- the coagulation pH is optimum
- all the alkalinity has been neutralised
- polyelectrolyte is needed or is being dosed correctly
- the turbidity excursions occur at the same time of day or season (eg, algal problems)
- one or more of the filters is responsible
- the filter-to-waste period should be extended
- the filters are receiving unequal flows
- the backwash and air scour flows and pressures are correct
- parts of the bed are mudballed (blocked), causing uneven filtration rates
- the filter beds are cracked or shrinking away from the walls
- excessive sand loss has reduced the media depth
- the filter rate is excessive for the type of filter
- the problem only occurs when 'a certain' operator is on duty.

If the filtered water turbidity readings tend to produce spikes, check whether:

- all filters are responsible
- the filters are returning to service too soon after a wash
- the slow start mechanism is operating correctly
- a filter run was excessive
- the state of the filter bed and underdrainage system cause poor backwashing
- the headloss instruments or flow controllers are inaccurate
- the treatment plant output increased too much or too rapidly

- the flow balancing system is operating correctly (eg, when a filter is taken out of service for washing)
- the filter outlet valve is modulating smoothly enough
- more polyelectrolyte is needed to cope with short periods of high flow
- it happens at the same time as something else (eg, when pump settings or valves are altered or when the washwater is returned).

For further reading, try USEPA (1999). Section 4.2 deals with system evaluation and plant optimisation, section 5 deals with individual filter self-assessment, and section 6 with comprehensive performance evaluation.

WHO (2001) covers a lot of ground too.

13.8 Second stage filtration

Secondary filtration is a process whereby an entirely separate rapid granular filter box or vessel is used as a second filtration stage following a first stage filter (ie, two separate filters used in series).

To qualify for additional log credits, coagulation must have taken place before the first stage filter, which may contain a coarse medium, followed by the secondary filtration stage that is typically a conventional dual or multimedia filter. Additional coagulants (or more commonly) filter aids (polyelectrolytes), or oxidants can be added between the first and second stages.

Some reasons for using two-stage filtration include:

- following direct filtration if the raw water quality is variable and the option is cheaper than building sedimentation tanks
- where the treatment plant occasionally experiences periods of stress, eg:
  - when very cold winter water causes aluminium flocs to form slowly
  - or during high summer flows
- to remove iron and manganese after an oxidation stage, eg, after chlorination
- to remove grit from poor quality lime. At this elevated pH, more iron and manganese may be removed too
- to remove further organic matter, including any disinfection by-products, by using granular activated carbon (GAC) filters or biologically activated carbon (BAC) filters.

Complying with section 5.4: Coagulation, sedimentation and filtration processes earns 3 log credits. Complying with section 5.5: Coagulation, direct filtration: treatment earns 2.5 log credits. Secondary filtration may earn an additional 0.5 log credit for protozoal compliance, refer DWSNZ, section 5.6.

The secondary stage filters must involve the use of a rapid sand, dual media, granular activated carbon (GAC or BAC), or other fine grain media unit process applied in a separate stage following rapid granular or dual media filtration. To qualify, a continuous chemical coagulation process must be in operation upstream of the first filters. One of the monitoring requirements is that the turbidity of the water leaving the secondary filters must not exceed 0.15 NTU for more than 5 percent of the time, see section 5.6.1 of the DWSNZ. See also USEPA (2003), and Chapter 9 of the review draft LT2ESWTR Toolbox Guidance Manual (USEPA 2009) which discusses issues related to second stage filtration.

Sometimes the coagulation process is followed by membrane filtration. In this situation, a second stage filter cannot earn additional log credits. The main reason is that water that has passed through a very fine filter should not earn any more log credits for passing through a much coarser filter. A compliant membrane filter will already be producing water with a turbidity less than 0.10 NTU, so it is not logical to earn more log credits for producing water that could have a higher turbidity!

References

ANSI/AWWA B100-09. *AWWA Standard for Granular Filter Material* (2/6/2009).

ANSI/AWWA B102-10. *AWWA Standard for Manganese Greensand for Filters.*

AWWA. 1990. *Water Quality and Treatment* (4th edition). McGraw-Hill Inc.

AWWA. 2000. *Operational Control of Coagulation and Filtration Processes.* Manual M37 (2nd edition). Denver CO: American Water Works Association.

Dugan N, Fox K, Owens J, et al. 2001. Controlling *Cryptosporidium* oocysts using conventional treatment. *J AWWA* 93(12): 64–76.

Drinking Water Inspectorate (DWI). 2011. *List of Approved Products for Use in Public Water Supply in the United Kingdom.* London: Department for Environment, Food and Rural Affairs. See **www.dwi.gov.uk or http://dwi.defra.gov.uk/drinking-water-products/approved-products/soslistcurrent.pdf**.

DWI. 2013. *Potential Contaminants in Drinking Water Treatment Chemicals: Final Report.* WRc Ref: Defra9033.03. 129 pp. http://dwi.defra.gov.uk/research/completed-research/reports/DWI70-2-272.pdf or **http://dwi.defra.gov.uk/**.

Hill T, Langdon A. 1991. Porous ceramic dual media filtration. *Water & Wastes in New Zealand* 66(July): 19–20, 22.

Kawamura S. 2000. *Integrated Design and Operation of Water Treatment Facilities* (2nd edition). New York: John Wiley & Sons.

The New Zealand Ministry of Health's Guides for drinking-water supplies can be accessed as Word documents on the Ministry of Health website: **http://www.health.govt.nz/water** then select publications and Water Safety Plans.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref. P5.1. Treatment Processes – Coagulation/Flocculation/Sedimentation.* Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref. P5.2. Treatment Processes – Dissolved Air Flotation.* Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref. P5.3. Treatment Processes – Direct Filtration.* Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref. P6.1. Treatment Processes – Rapid Sand Filtration.* Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref. P8.1. Treatment Processes – pH Adjustment.* Wellington: Ministry of Health.

Ministry of Health. *Public Health Risk Management Plan Guide PHRMP Ref. P11. Treatment Processes – Plant Construction and Operation.* Wellington: Ministry of Health.

Ministry of Health. 2005. *Drinking-water Standards for New Zealand 2005, revised 2008.* Wellington: Ministry of Health.

NSF/ANSI 44-2004. Updated 2007. *Residential Cation Exchange Water Softeners.* Ann Arbor, Michigan: NSF International.

NZWWA. 1997. *Standard for the Supply of Aluminium Sulphate for Use in Water Treatment* (2nd edition). New Zealand Water and Wastes Association. Revised 2012.

NZWWA. 1999. *Standard for the Supply of Polyacrylamides for Use in Drinking-water Treatment,* ISBN 1-877134-24-4. New Zealand Water and Wastes Association.

NZWWA. 1999. *Standard for the Supply of Polydadmac for Use in Drinking-water Treatment,* ISBN 1-877134-25-2. New Zealand Water and Wastes Association.

NZWWA. 1999. *Standard for the Supply of Epi-DMA Polyamines for Use in Drinking-water Treatment,* ISBN 1-877134-26-0. New Zealand Water and Wastes Association.

NZWWA. 2013. *Standard for the Supply of Polyaluminium Chloride for Use in Water Treatment* (2nd edition). ISBN 1-877134-08-2. **www.waternz.org.nz**.

Ogilvie D. 1998. Streaming current detection. *Water & Wastes in NZ* 101 (July): 32, 34–35.

Srinivasan PT, Viraraghavan T, Subramanian KS. 1999. Aluminium in drinking water: an overview. *Water SA* 25(1, January): 47–55.

USEPA. 1999. *Guidance Manual for Compliance with the Interim Enhanced Surface Water Treatment Rule: Turbidity provisions.* Report EPA 815-R-99-010. **http://water.epa.gov/lawsregs/rulesregs/sdwa/mdbp/mdbptg.cfm**.

US Partnership for Safe Water Guidelines for Phase IV. *Excellence in Water Treatment.* See information on this subject at: **http://www.docstoc.com/docs/132750163/Partnership-for-Safe-Water-American-Water-Works-Association**.

USEPA. 2007. *Simultaneous Compliance Guidance Manual for the Long Term 2 and Stage 2 DBP Rules*. EPA 815-R-07-017. 462 pp. **http://water.epa.gov/lawsregs/rulesregs/sdwa/stage2/compliance.cfm** or **http://water.epa.gov/lawsregs/rulesregs/sdwa/lcr/upload/2007_5_10_disinfection_stage2_guide_st2_pws_simultaneous-compliance.pdf**.

USEPA. 2009. *Long Term 2 Enhanced Surface Water Treatment Rule, Toolbox Guidance Manual Review Draft*. Go into **http://www.epa.gov/safewater/disinfection/lt2/** and then enter: toolbox guidance manual review draft in the 'search' box. See USEPA (2010) for Final.

USEPA. 2010. *Long Term 2 Enhanced Surface Water Treatment Rule, Toolbox Guidance Manual*. EPA-815-R-09-016. 375 pp. **http://www.epa.gov/safewater/disinfection/lt2/pdfs/guide_lt2_toolboxguidancemanual.pdf**.

WHO. 2001. *Upgrading Water Treatment Plants*. ISBN 0 419 26050 1. Published on behalf of WHO by Spon Press, London. Available on the internet at: **http://www.who.int/water_sanitation_health/hygiene/om/treatplants/en/index.html**.

WHO. 2004. *Guidelines for Drinking-water Quality 2004* (3rd edition). Geneva: World Health Organization. Available at: **www.who.int/water_sanitation_health/dwq/gdwq3/en/print.html** see also the addenda.

WHO. 2004a. *Water Treatment and Pathogen Control: Process efficiency in achieving safe drinking water*. MW LeChevallier, K-K Au. IWA Publishing. 136 pp. Available at: **www.who.int/water_sanitation_health/publications/en/index.html**.

WHO. 2011. *Guidelines for Drinking-water Quality* 2011 (4th edition). Geneva: World Health Organization. Available at: **http://www.who.int/water_sanitation_health/publications/2011/dwq_guidelines/en/index.html**.

WHO. 2017. *Guidelines for Drinking-water Quality: Fourth edition incorporating the first Addendum*. Geneva: World Health Organization. 631 pp. **http://www.who.int/water_sanitation_health/publications/drinking-water-quality-guidelines-4-including-1st-addendum/en/**.

TE MATO VAI

Appendix 4

Memorandum

31 October 2019 CKT

To	Lloyd Miles		
Copy to	TMV PMU, MFEM		
From	David Sloan, Scott Cairney, Peter Free	Tel	+64 27 216 1783
Subject	MISC No's. 41/2016 to 50/2016 - Follow-up Actions Table for Concerns of Selected Landowners' items 3, 4 and 5	Job no.	51/33141/

Introduction

1. The purpose of this memorandum is to provide further information relevant to the use of Poly Aluminium Chloride (PACl) as a coagulant chemical as part of the water treatment process in Rarotonga.
2. This memorandum responds to 'Follow-up Actions Table for Concerns of Selected Landowners' items 3, 4 and 5
    a. Residual aluminium (Al) content in sludge and potential effects
        i. High level assessment of residual Al in sludge
        ii. Comparison with international standards etc.
        iii. Description of risk of Al leaching / discharge into environment (groundwater, stream)
        iv. Description of potential environmental effects
    b. Provide independent information on PACl safety, environmental effects and standard monitoring/ management procedures
    c. Sludge ponds design
        i. Adequacy of the design
        ii. Short term storage of sludge in ponds
        iii. Effects of rainfall, flooding, overflow/failure of ponds
3. My affidavit sworn on 1 August 2019 NZT for the High Court Application MISC. No.s 41/2016 to 50/2016 describes the settling tank and the coagulation requirement. The affidavit summarises how the coagulant chemical is added to the water at the settling tank.
4. The process of coagulation is described in a paper prepared by To Tatou Vai (TTV) *'Memorandum for landowners on coagulation and flocculation'* dated 26 August 2019, which I understand has been presented to Tai Nicholas. The memo discussed what coagulation is and summarises how it is used and what happens to the sludge created by the process.

5. This memorandum also serves to build on the content of my affidavit and Brent Manning's paper by also discussing:
    a. how PACl is dosed
    b. how the settling tank is emptied and it's sludge is managed
    c. how the AVG filter backwashes and it's sludge is managed
    d. the design of the scour and backwash ponds on site
    e. potential effects of Aluminium in the environment
    f. Effects of aluminium on the animals, agriculture and human health
    g. potential monitoring regime (including frequency and locations of sampling)

New Zealand and Cook Islands Drinking Water Standards

6. PACL, or residual Aluminium (Al) concentrations, in drinking water is not deemed to be a health risk. New Zealand Drinking Water Standards 2005 (revised 2018) (NZDWS) has a Guideline Value (GV) for Aluminium in drinking water, and this is due to the potential aesthetic characteristics of aluminium in water, rather than a health risk. There is no Maximum Allowable Value (MAV) for Aluminium because it is not deemed to have health effects associated with it. The GV for Aluminium in drinking water in the NZDWS is 0.1mg/L.

7. The (Draft) Cook Island Drinking Water Standards has also adopted a GV of 0.1mg/L for Aluminium.

8. The following is a quote from *Guideline for Drinking Water Quality Management For New Zealand*, May 2019 published by the New Zealand Governments Ministry of Health:

    "For some time concerns have been raised in the international technical literature and by interest groups about whether there are adverse health effects on consumers from residuals of chemicals in drinking-water following treatment. As an example, some communities have opted not to use aluminium-based coagulants because of unsubstantiated reports that claim that the aluminium in drinking-water poses a risk to public health, despite scientific evidence (eg, Srinivasan et al 1999) that adverse effects have not been demonstrated. Because there is no evidence of health risk, based on WHO Guidelines for Drinking – Water Quality (2004), the DWSNZ do not have a Maximum Acceptable Value (MAV) for aluminium. WHO Guidelines for Drinking – water Quality (2011) does not change this point of view."

Effects of Aluminium on the Animals, agriculture and human health

9. The following is taken from *Aluminium in Drinking-water*, WHO 2003 (WHO/SDE/WSH/03.04.5):

    "There is little indication that aluminium is acutely toxic by oral exposure despite its widespread occurrence in foods, drinking-water, and many antacid preparations (WHO, 1997)."

    "The beneficial effects of the use of aluminium as a coagulant in water treatment are recognized. Taking this into account and considering the potential health concerns (i.e. neurotoxicity) of aluminium, a practicable level is derived based on optimization of the coagulation process in drinking-water plants using aluminium-based coagulants, to minimize aluminium levels in finished water.

    A number of approaches are available for minimizing residual aluminium concentrations in treated water. These include use of optimum pH in the coagulation process, avoiding excessive aluminium dosage, good mixing at the point of application of the coagulant, optimum paddle speeds for flocculation, and efficient filtration of the aluminium floc (Letterman & Driscoll, 1988; WRc, 1997). Under good operating conditions, concentrations of aluminium of 0.1 mg/litre or less are achievable in large water treatment facilities. Small facilities (e.g.

> *those serving fewer than 10 000 people) might experience some difficulties in attaining this level, because the small size of the plant provides little buffering for fluctuation in operation, and small facilities often have limited resources and access to expertise to solve specific operational problems. For these small facilities, 0.2 mg/litre or less is a practicable level for aluminium in finished water (WRc, 1997)."*

10. In Australia Aluminium based sludge is normally sent to landfill, however in some areas it is used in soil applications. An example of its use is in Ballarat, Victoria, Australia where it is used as a filler in soils by a landscape gardening company. The use of this sort of sludge to help plant growth has also been studied by SEQ Water (Queensland Government Bulk Water Supply Authority) in Queensland, Australia. In that case it was shown to increase plant growth as the particular sludge also contained phosphorus and trace mineral nutrients which acted like a fertiliser for certain plants.

11. Some well documented studies have shown that the effects of ingestion of alum sludge on sheep and cattle is minor and in particular found that there were no adverse impacts at the loading rates applied (78 tons/ha pasture for the cattle study and 8 g AL/kg feed for the sheep study). In terms of human health, the paper suggested that at rates less than 25 t/A (approx. 60 t/h) there was no risk to endangering human health and at a surface-loading rate of 10 t/A there was no impact on the dissolved Al concentrations on groundwater.

Effects of Aluminium on the Aquatic environment

12. According to Auckland Regional Council TP227, *"it is generally accepted that dissolved aluminium at a concentration between 0.050 and 0.100 mg/L with a pH between 6.5 –and 8.0 presents little threat of toxicity. However, at lower pH, the toxicity increases with an effect of possible major concern being the coagulation of mucus on the gills of fish."*

13. The actual dissolved aluminium concentration in the proposed release of "near clear water" from the settling tank or supernatant from the sludge pond cannot be reliably predicted. In theory, if this water has a low organics content, a turbidity <1 NTU and the pH is in the range 6 to 7.5, it is possible that the soluble aluminium will be <0.1 mg/L (as Al). The extent of toxicity risk for fish would therefore be expected to be low, but it is recommended that a suitable ecological study for the actual fish populations of interest be completed if concentration are determined to be higher than 0.1mg/L. The monitoring regime during initial operation will confirm this.

14. It is important to note that in the instance of elevated Al concentrations (i.e. above 0.2mg/L) that this does not necessarily result in toxicity. There are a few water chemistry parameters that can affect the bioavailability of Al in water, including pH, total hardness and dissolved organic carbon. These items will change and be different depending on the raw water characteristics at each site.

15. Additional to the water chemistry characteristics, duration of exposure also plays a role in the toxicity of Al in aquatic environments. This means that exposure to short durations of 'high' concentrations can be withstood by the environment without causing detrimental outcomes. This means that if during testing for Al, 'high' concentrations are found, operations can be stopped until the concentrations can be lowered, thereby allow concentrations to dissipate while operations are adjusted to reduce any impact. This is an example of how the dynamic nature of the source water catchments in Rarotonga can be managed and accommodated by the treatment plants.

How PACl Works

16. This is covered in the To Tatou Vai (TTV) document *'Memorandum for landowners on coagulation and flocculation'* dated 26 August 2019.

General Raw Water Characteristics on Rarotonga

17. Water quality testing undertaken on the streams at each site indicate that all streams typically generate relatively 'clear' water (when compared to other raw water sources at other water treatment plants internationally due to limited human activity in the source water catchment). This does not mean that the water is clean e.g. current testing also show *E.Coli* contamination exists at all sites. The generally clear nature of the water changes rapidly in wet weather and the water changes to very dirty and turbid water, where it will be critical that PACl is used to ensure the system continues to provide clear water. This will be particularly important when long term disinfection is implemented, giving disinfection the best chance of success. However, it does mean that less PACl will likely be needed to produce acceptable results.

18. Jar testing already undertaken across the raw water sources (streams) indicates that dosing rates for PACl on the Te Mato Vai sites will be much lower than typical dosing rates used at other treatment plants internationally. Typical dosing rates for PACl are generally 14-24mg/L, however, the proposed dosing rate for Te Mato Vai sites are significantly lower at approximately 4-6mg/L.

19. The reason for the reduced dosing rate on Te Mato Vai relates to the clarity of the dry weather flows, but also due to the settling tank configuration. The settling tank configuration selected provides a very robust approach to the coagulation, flocculation and sedimentation process and provides a large buffering capacity to deal with changes in raw water characteristics, without having to change the dosing rates.

20. Quote from *Using Polyaluminium Coagulants in Water Treatment*, Peter Gebbie, September 2001:

    "The coagulant was found to be very effective and since changing over to PACl one of the most noticeable (and unexpected!) advantages noted has been the increased "robustness" of the water treatment process. Previously when using alum, plant performance was adversely affected after heavy rain. PACl has shown an ability to much better deal with these changes. The chemical's ability to coagulate over a wider pH range is of enormous benefit in this instance."

Settling Tank Operations

21. The operational purpose of the settling tank is to remove the bulk of the suspended solids and organic material from the raw water before the water is filtered through the AVG.

22. The settling tank is essentially acting as a coarse 'filter' by removing the bulk of sediment prior to the water being put through a fine filter (the AVG).

23. Sediments and organic material can be very fine, negatively charged and in some cases dissolved in the water, these attributes mean that achieving a cleanliness of water (suitable for filtration and ultimately consumption through the network) is essentially impossible by gravity alone i.e. there is no sensible sized settling tank large enough that will achieve the required outcomes without the use of a coagulant

24. To aid the process of removing sediment in the raw water, and also increase the efficiency of the settling tank, PACl has been selected as the most appropriate coagulant for use in the coagulation, flocculation and sedimentation process for the Te Mato Vai treatment Plants.

How is PACl dosed?

25. The type of PACl selected is delivered in 20 or 25kg bags of powder, with the bulk of the PACl being stored in a central secure location. A small amount of powdered PACl may be stored from time to time at each site in the dosing shed (each shed is gated and locked).

26. The PACl is typically mixed with water to produce a 30% w/w solution. The PACl solution is then stored in a large dosing tank from where it enters a constant head tank for feeding by gravity through a metering valve to the 'sparge' pipes in the inlet of the settling tank(s).

27. Water for making the solution is taken from the outlet chamber of the settling tank by using a portable generator powered pump. The water is pumped into mixing tanks in the PACl building, and then the PACl powder is added. Mixing is done by using the same portable pump to recirculate the mixing tank contents.

28. When the PACl is dissolved, the solution is then transferred to the large PACl dosing tank for storage.

29. The same portable pump is used for transferring the PACl solution to the storage tank.

30. The PACl solution preparation procedure can be provided if required.

31. PACl from the dosing tank is dosed by gravity to the inlet chamber of the settling tanks. Dosing flow control is done manually by the operator using a metering valve and there is no automatic adjustment of flow.

32. Though flow adjustment is done manually (by an experienced operator), the system is configured to shut off PACl dosing if the storage tanks is full, which then stops the flow through the treatment system and / or the plant is no longer treating water.

33. The metering valve is calibrated.

34. The dose rate is determined by jar tests on a regular basis and the dose rate adjusted accordingly. The dose rate has to be manually adjusted when inlet flows change.

35. The dose rate will be typically set at a 'low' level i.e. consistent with dry weather flows where there is low turbidity.

36. Due to the general design of the settling tanks, even relatively low levels of PACl dosing will produce 'good' results for a broad range of raw water turbidity conditions. This is due to the large volume of water held in the settling tanks, which creates a large 'buffering' capacity within the tanks that can manage rapid and large changes in turbidity with relatively low PACl dosing rates, without having to adjust the dosing rates to respond to a change in conditions.

37. Therefore the operator is not required to be on site to change the dosing rate if a rainfall event occurs, and the raw water quality suddenly and drastically changes.

38. The typical PACl dosing rates will be specific to each site and will result from the particular conditions found at each site. It cannot be absolutely determined prior to putting the settling tanks into operation, however, jar testing provides a very good indication.

39. Water quality tests have indicated very low turbidity in the raw water during dry weather flows at all sites.

40. The dosing rate may also be changed to suit seasonal variations, and the regularity of turbid water flows.

Sludge

41. The TTV memo notes *'The small particles of impurities have a negative charge. For this reason they repel each other. It is only by these small particles sticking together that they reach a weight greater than that of the water they are in and then sink slowly to the bottom. The* ***coagulant*** *does this. It causes those particles to stick together in a process known as* ***flocculation*** *which create* ***flocs*** *which fall to the bottom of the* ***clarifier.***

    The product of ***flocculation*** *is* ***sedimentation.*** *At the bottom of the* ***clarifier*** *is* ***sludge*** *and there is near clear water above it.'*

Settling Tank Discharge

42. There are three types of discharge from the settling tank.

43. Process Water – the 'clear' water from the coagulation / flocculation process is taken from the top of the settling tank water level and flows to the AVG for filtration.

44. Near Clear Water – This is drained from the top half of the settling tank to the stream as part of a regular, but periodic (estimated to be every 3-6 months), maintenance process. The 'near clear water' would only be removed from the top part of the tank any floc had dropped below the draw off point.

45. Sludge and Water mixture – Also produced as part of the regular, but periodic maintenance process. After the 'near clear water' has been drained to the stream, the remaining sludge and water mixture is drained the scour / backwash ponds. At the scour / backwash ponds, the sludge and water mixture settles and is separated into 'supernatant' (near clear water that has been separated from the sludge / water mixture) and 'sludge'. The 'supernatant' is discharged to the stream leaving the 'sludge' in the scour / backwash pond.

Emptying the 'Sludge' from the Settling Tank

46. Each settling tank will require periodic emptying to remove the residual sludge content. To permit this, each settling tank has a 'mid-level' drain. The mid level drain allows the removal of the 'near clear water' above the sludge. The mid level drain discharges the 'near clear water' to the stream.

47. Depending on the operation of the tanks and recent turbidity levels of the raw water, it may be necessary for the settling tank to be left for a period of time, while not operating, prior to the mid-level drains being opened. This will allow any sediment (or floc) still suspended in the water above the mid-level drain height, to settle below the mid-level drain, thereby allowing the 'near clear water' to be as clear as practically possible.

48. Once the settling tank has been emptied to the level of the 'mid-level drain', the remaining water and sludge can be removed. A scour drain at the bottom of the tank is opened to drain the tank to the scour pond.

49. Refer to Figure 1 which shows the drains used to empty the settling tank.

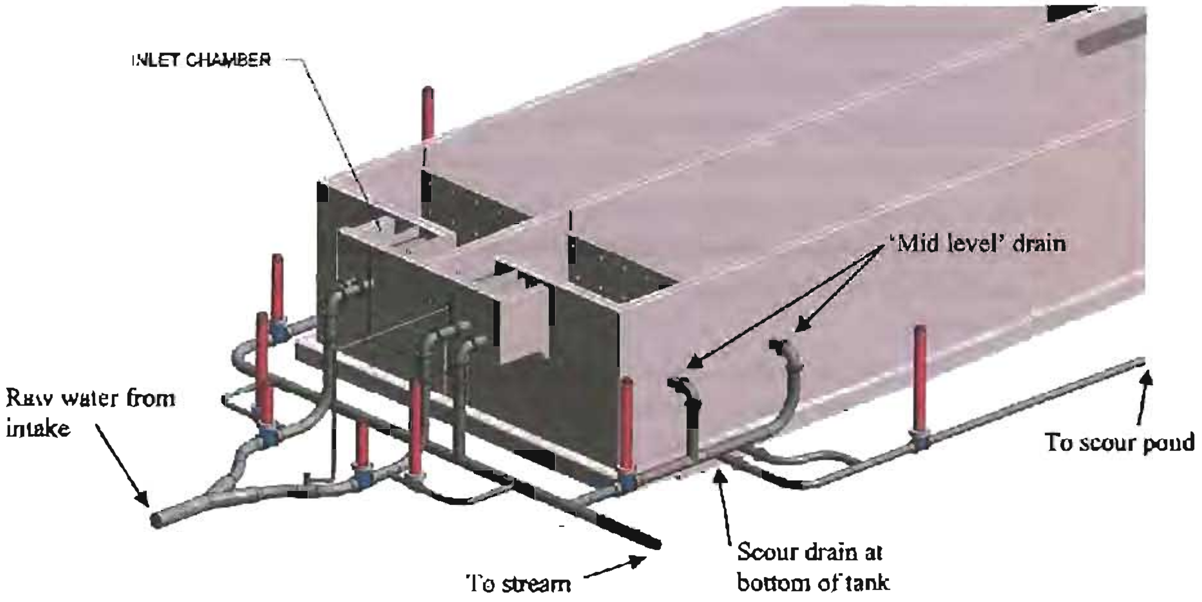


Figure 1: Emptying the settling tank

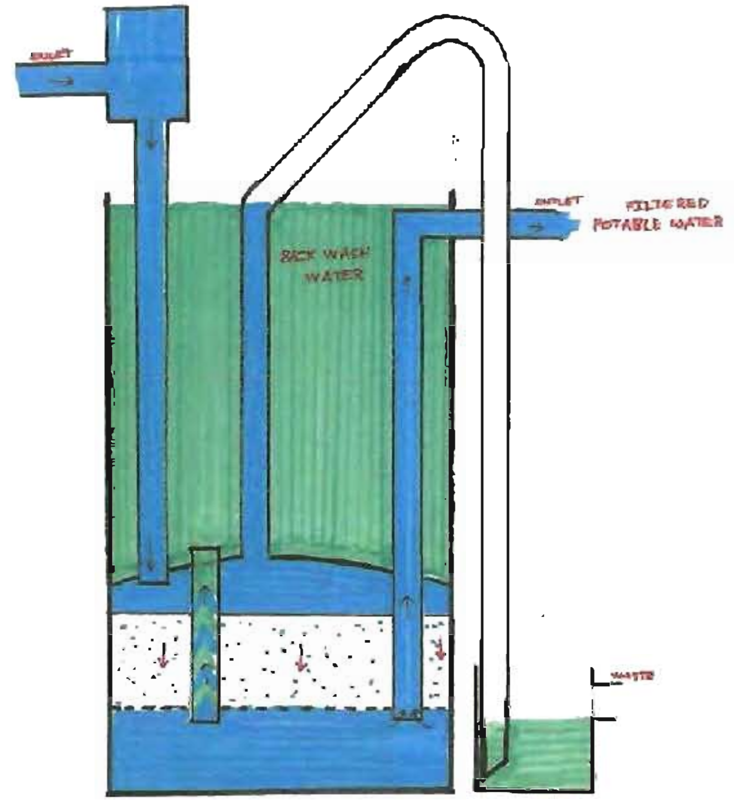
AVG Filter Operations

50. The AVG filtration process is required to remove floc that is too small to have settled out through gravity in the settling tank.

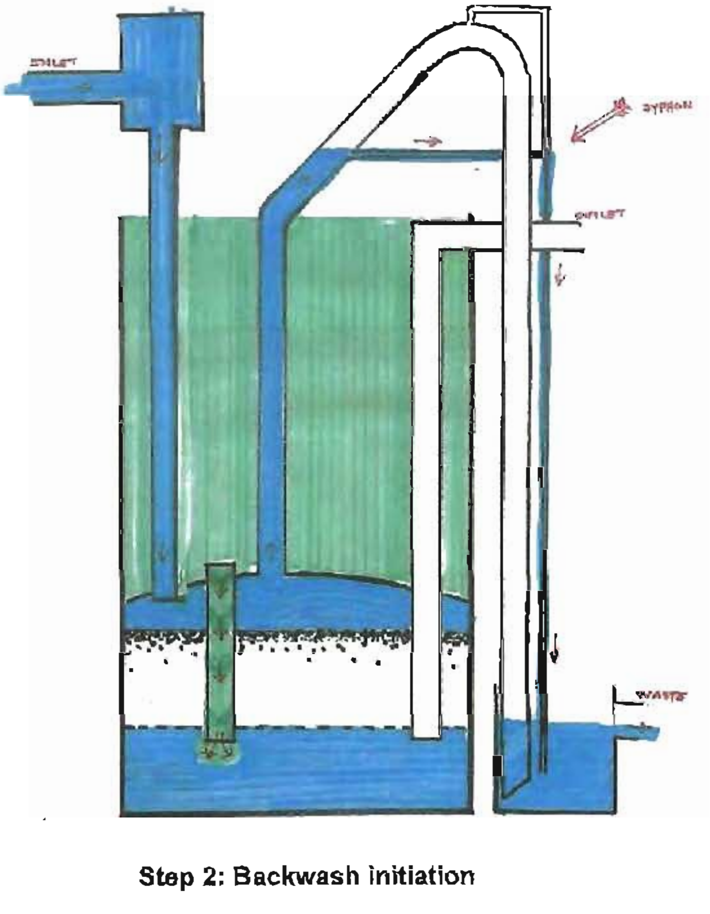
51. When the "process" water flows through the filter, the majority of any remaining floc is trapped in the sand in the filter.

52. As more floc is trapped it starts the clog the sand and inhibit the efficiency of the filter. When this happens, the AVG will automatically backwash to remove the floc from the sand. The water from the backwash is drained to the scour / backwash ponds. Backwashes are estimated to occur every 1-7 days, and are dependent on the flow of water through the filter.

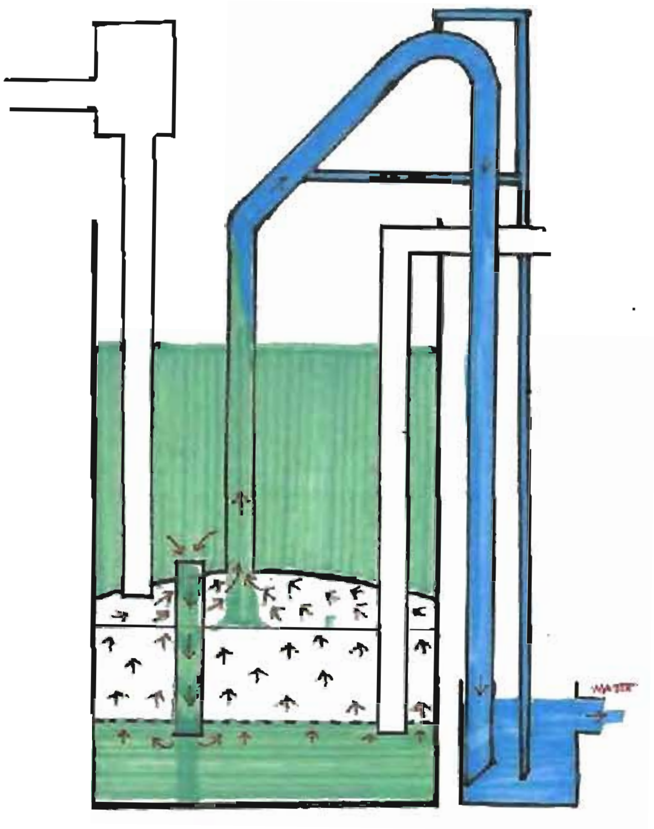
53. The following are simplified drawings showing the typical operational stages of an AVG filter:



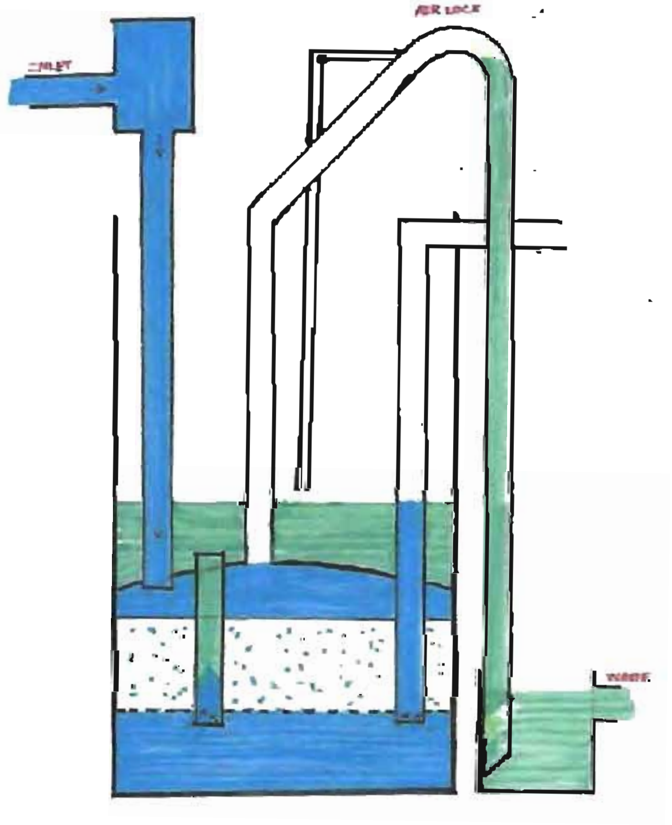
Step 1: Normal Operation



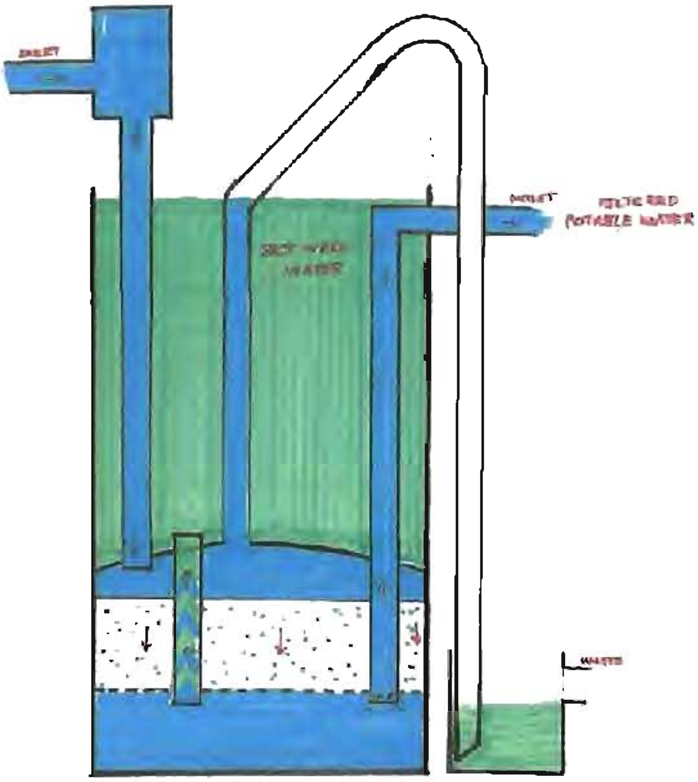
Step 2: Backwash initiation



Step 3: Backwash



Step 4: End of backwash



Step 5: Return to normal operation

AVG Filter Discharge

54. There are two types of discharge from the settling tank.

55. Process Water - After going through the AVG filter, the 'process' water is (typically) disinfected, and then released to the network for consumption.

56. Backwash Water – the sludge / water mixture resulting from the backwash process is sent to the scour / backwash ponds. Like the sludge / water mixture from the settling tank, the backwash water settles in the ponds and is separated into 'supernatant' (near clear water that has been separated from the sludge / water mixture) and 'sludge'. The 'supernatant' is discharged to the stream leaving the 'sludge' in the scour / backwash pond.

57. Because most of the organic material and suspended particles have been removed from the "process" water in the settling tank, the volumes of sludge that are produced by the AVG are relatively low (when compared to the settling tank), but backwashing happens on a much more frequent basis. Though the sludge is produced in lower volumes, it is still essentially the same sludge product that is produced in the settling tank.

Scour and Backwash Ponds

58. Below is an extract from the project's Detailed Design Report:

"The design of the ponds have been governed by the tender specification and clarifications. Ponds are typically designed to be 2.0m deep, unless local ground conditions dictate otherwise.

Generally, two types of pond are provided unless site constraints limit this to a combined pond. The ponds are:

***Scour pond** – to receive scour drain waste from the sedimentation tank(s). The pond is sized to receive 50% of the volume of the sedimentation tank, since the initial 50% of top water will be drained off via the mid-level drain in the sedimentation tank.*

***Backwash pond** – to receive backwash waste from the filter(s). The pond will be split into two cells, each sized for two backwash volumes from the filter(s). The dividing wall between the two ponds shall be a shorter wall to allow high level overflow between the ponds. Flow to the two cells can be manually changed over by operators.*

***Combined scour and backwash pond** – to receive both backwash waste from filter(s) as well as scour drain from sedimentation tank. The pond is split into two cells similar to the dedicated backwash pond described above. The total pond volume shall be sized based on the larger requirement of the two pond criteria mentioned above – this works out to be the sedimentation tank scour drain volume in all cases. This volume is then split between the cells.*

Sludge removal shall be carried out by an excavator from the top ground level.

An adjustable decanting solution is proposed for all ponds at all sites. This is the T-bar Pond Decant System. This pond decanter system provides the required adjustable decanting with a simple construction.

The installation of the T-bar Decant system shall be undertaken as per the manufacturer's recommendations.

The T-bar Decant operates using a floating perforated pipe with adjustable height (through Y- posts and pully systems) in each pond or cell. Where multiple T-bars are used, these T-bars are connected to a common pipe via flexi couplers at a fixed penetration point in the embankment. By adjusting the level of the perforated T-bar using the pulley system the level of decanting can be adjusted."

4.11.1 Scour Pond

The scour ponds have been designed to provide sufficient volume for 50% of the Sedimentation Tank's volume (sedimentation tank scour volume).

Flow from the settling tank scour line enter a rip-rap lined channel for velocity dissipation and erosion protection. After the dissipation channel, the flow enters the pond. Velocity dissipating rip rap shall also be placed at the channel discharge point into each pond.

Within the pond a single perforated pipe T-bar will be provided for decanting into the stream at the same fixed level.

4.11.2 Backwash Pond

The backwash pond is split into two cells that operate as duty/assist and the ponds have been designed to provide sufficient volumes for two backwashes of each AVG Filter.

The cells are linked via a central dividing wall. The top of this dividing wall is 300mm below the ground level providing a hydraulic linking between the two cells. To minimise erosion, during overflow conditions, the dividing wall shall be rock-lined.

Flows from the AVG filter backwash enter a rip-rap lined channel for velocity dissipation and erosion protection. After the dissipation channel, the flow enters a common chamber containing separate channels feeding into each cell. A removable stoplog panel shall be used to isolate one cells at any one time, deferring flows to the other cell. The details of the stop log are outlined within the drawings. Velocity dissipating rip rap shall also be placed at the channel discharge point into each cell.

Within the backwash ponds a single perforated pipe T-bar will be used within each cell, decanting into piped outlet discharge to the stream, the details of this outlet pipe will vary depending on the site.

The proposed invert of the perforated T-bar at each site is shown in Table 20. This invert has been calculated to provide sufficient volume between the T-bar invert and the central dividing wall/overflow for 1.5x backwash volumes from a single AVG. Hence, as these pond cells operate as duty/assist, the pond system shall be able to cope with up to three backwash volumes within the time required to decant one AVG backwash worth of volume as shown in Table 20.

4.11.3 Combined Scour and Backwash Pond

The combined scour and backwash ponds shall operate as duty/assist and have been designed to provide sufficient volumes for 50% of the Sedimentation Tank's volume (sedimentation tank scour volume). The sedimentation tank scour volume has governed the volumetric design of the ponds as this volume is larger than that of the AVG Filter backwash requirements.

The design of the combined pond is similar to that of the backwash ponds described in the previous section. The decanting system and the decanting sizing are also similar and the details are provided in Table 20 below.'

Table 20: Site-wide Scour and Backwash Pond Design Criteria

Location	Avana	Avatiu	Matavera	Ngatoe	Papua	Taipara	Takuvaine	Totokoitu	Tupapa	Turangi
Drawing Set	01	02	03	04	06	08	09	10	11	12
Storage Tank Scour Pond (no standby)										
Applicable	N	Y	N	Y	N	N	Y	N	N	N
Minimum Pond Volume per Duty Pond (m^3) $^{(B)}$	-	120	-	120	-	-	180	-	-	-
Pond Depth (m) $^{(A)}$	-	2.0	-	2.0	-	-	2.0	-	-	-
Approximate Decanting time (hrs)	-	22.2	-	22.2	-	-	33.3	-	-	-
AVG Filter Backwash Pond (Duty/Standby)										
Applicable	N	Y	N	Y	N	N	Y	N	N	N
Minimum Pond Volume per Duty Pond (m^3) $^{(B)}$	-	41.6	-	41.6	-	-	62.4	-	-	-
Pond Depth (m) $^{(A)}$	-	1.7	-	2.0	-	-	2.0	-	-	-
Approximate Decanting time (hrs) $^{(C)}$	-	5.9	-	5.9	-	-	8.9	-	-	-
Combined Scour/Backwash Pond (Duty/Standby)										
Applicable	Y	N	Y	N	Y	Y	N	Y	Y	Y
Minimum Pond Volume per Duty Pond (m^3) $^{(D)}$	83	-	72	-	120	72	-	96	72	102
Pond Depth (m) $^{(A)}$	2.0	-	1.5	-	2.0	2.0	-	2.0	2.0	2.0
Maximum Approximate Decanting time $^{(C)}$	15.4	-	13.3	-	22.2	13.3	-	17.8	13.3	18.9
Approximate decanting time for 1x AVG Backwash (hrs)	4.4	-	3.0	-	5.9	3.0	-	5.9	3.0	4.4

Notes: (A) including 300mm freeboard

(B) Backwash volume = 2x backwash volume + 30%. For sites with 2x AVGs the backwash volume accounts for both backwashing simultaneously

(C) For sites with 2x AVGs the backwash volume accounts for both backwashing simultaneously

(D) Settlement tank scour volumes larger than backwash volume hence govern the Combined pond requirements

59. The above information is provided to demonstrate that the ponds required as part of the TMV treatment process are engineered designs, and are not just 'holes in the ground'. They are sized based on expected flow conditions.

60. The ponds take into account the following key design parameters

    a. Size

        i. Each pond has a minimum freeboard of 300 mm. This is a contingency, and allows for some uncertainties and other effects over and above a calculated water level. The ponds are designed for maximum volume, plus an additional 300mm height above the calculated top water level.

        ii. Each pond shall have a maximum usable depth of 1.7 m, excluding freeboard. This was considered a reasonable pond depth from practical operation and maintenance perspective, as well as taking into account health and safety.

        iii. The scour ponds are sized to contain the standing volume of the settlement tank, plus a reasonable margin for solids settlement resulting from treatment plant operations.

    b. Decant of supernatant (liquid which lies above a sediment or precipitate, or in this case the sludge)

        i. A decant system is being installed at each pond that draws supernatant from the top of the standing water in the ponds and discharges it to the stream. Therefore the sludge and sediment laden water are retained in the ponds. Further detail on the decant system can be provided is required.

    c. Robust design

        i. Geotechnical design is a 1:1 batter slope for the ponds. This is based on geotechnical investigation based on actual soil conditions encountered on site. The geotechnical investigation undertaken at the start of the project informed this design parameters.

        ii. Rip-rap lined channels are proposed for dissipation of the velocity of flow being discharged from the settling tank. This is via rock lining of the flow channels. This mitigates the risk of erosion at the flow channels and in the ponds. Geotextile is placed below the rip-rap to protect the rock rip rap from displacement or settling.

        iii. The central embankment between the pond cells has a rock lined top for erosion protection.

        iv. The treatment plant site layouts take into account stormwater management and runoff control. The ponds are protected from receiving and potentially being overwhelmed by stormwater runoff. Bunding and contouring of final ground levels directs stormwater runoff away or around pond locations.

        v. The pond embankments and embankment heights take into account fluctuating stream flow and associated water levels. This is discussed further below.

Sludge Removal

61. Sludge removal

    a. The ponds are designed such that removal of the sludge is anticipated to be required no more than annually, however, it is noted that this is dependent on water quality received by the treatment plant, which has an impact on the volume of material being captured within the settling tanks. The actual volume and need for sludge removal will change from year to year, and cannot be established until the actual operation has commenced.

b. Sludge removal shall be carried out by an excavator from the top ground level.

c. It is currently proposed by TTV to dispose of the sludge to landfill, likely via a sealed truck (the sealed nature of the deck-well means that wet material will not seep onto the roads).

Typical WTP Arrangements using PACl (outside of the Cook Islands)

62. In New Zealand and Australia, sludge supernatant is in most cases recycled back to the inlet of the water treatment plant. This is achieved by pumping the supernatant back up to the head of the works prior to the dosing point. In this way, it is only the sludge that becomes waste product as the supernatant is recycled back into the "process" water and is ultimately consumed.

63. Without a permanent power supply at each site, this is not possible at the Te Mato Vai sites, and so the supernatant is proposed to be discharged to the adjacent streams.

Exception to WTP arrangements using PACl (outside of the Cook Islands)

64. We have identified one example of where sludge pond supernatant is discharged back into the environment and provides guidance on how a monitoring process may be arranged for the treatment plants on Rarotonga. This is at the Wairoa Water Treatment Plant (WTP) located in Frasertown, Wairoa District on the east coast of the North Island of New Zealand.

65. The control conditions for the Wairoa WTP that are set by the Hawkes Bay Regional Council are:

1. *The maximum discharge rate shall not exceed 28 L/s and the maximum volume discharged in any 24 hour period shall not exceed 600 m3.*
2. *Sampling conducted once every three months in 4 locations:*
    - a) *In the tributary of the stream 20 m upstream from the point of discharge*
    - b) *In the tributary of the stream 50 m downstream from the point of discharge*
    - c) *In the stream 50 m downstream from the confluence with the tributary*
    - d) *In the stream 20 m upstream from the confluence with the tributary*
3. *The samples are tested for dissolved aluminium, turbidity and pH*
4. *The dissolved aluminium results for sample (c) are compared to the ANZECC (2000) trigger value for dissolved aluminium of 0.055 mg/L in the receiving water.*
5. *If any result for samples taken at location (c) exceed the trigger, then the dissolved aluminium results from the other 3 locations are compared to determine if the discharge is the likely principal cause, or a likely significant contributor to the exceedance.*
6. *If it is determined that the discharge is the likely principal cause, or a likely significant contributor to the ANZECC trigger value exceedance, then the sampling required will be increased to once every month until 4 consecutive samples at location (c) are compliant.*
7. *The treatment plant produces a bi-annual report summarising the monitoring and sampling undertaken, critical analysis of compliance and potential adverse environmental effects and any recommendations.*
8. *The council can review and change the conditions of the consent annually.*

Discharge of Supernatant and 'Near Clear Water' to Stream (Te Mato Vai)

66. The concentration of Aluminium discharged to the streams will depend on the concentration of aluminium in the 'near clear water' and the 'supernatant' and the amount of flow in the stream during the discharge period. For both the near clear water and the supernatant, the concentration of aluminium will change depending on the amount of PACl being used, which is then influenced by:

    i. The raw water characteristics at each site i.e. pH level, the relative level 'dirtiness' of wet weather flows, turbidity, suspended solids
    ii. The volume of water treated at each site
    iii. Seasonal weather variations

67. The amount of PACl dosed will be changed regularly at each site and therefore concentration of aluminium discharged to the streams cannot be predicted with confidence (for both the 'near clear water' and the 'supernatant'), and therefore, depending on how operations are carried out the residual aluminium level could be in the range 0.05 to 5 mg/L (as Al).

68. Measurements of the aluminium concentrations over time will increase confidence in what the levels are being discharged.

69. The actual aluminium levels in the supernatant and / or the 'near clear water' and the amount that is dissolved can only be accurately determined by direct measurement of aluminium levels in the water to be sent to the stream at the time just prior to its release.

Possible Stream Monitoring Proposal for Te Mato Vai

70. Based on the monitoring process adopted at the Wairoa WTP, the following monitoring approach could be taken at each site in the Te Mato Vai Project:

    1. *Sampling conducted once every week for 4 months of operation in 4 locations:*
        - *(a) At the Intake structure*
        - *(b) In settled water in the scour / backwash ponds*
        - *(c) In the stream approximately 50m downstream of the discharge point from the scour / backwash pond*
        - *(d) In the stream approximately 100m upstream of the discharge point into the lagoon*
        - *(e) In the stream approximately half way between the treatment plant and the lagoon discharge point*
    2. *The samples are tested for dissolved aluminium, turbidity and pH*
    3. *The dissolved aluminium results for sample (c) are compared to the ANZECC (2000) trigger value for dissolved aluminium of 0.055 mg/L in the receiving water.*
    4. *If any result for samples taken at location (c) exceed the trigger, then the dissolved aluminium results from the other locations are compared to determine if the discharge is the likely principal cause, or a likely significant contributor to the exceedance.*
    5. *If it is determined that the discharge is the likely principal cause, or a likely significant contributor to the ANZECC trigger value exceedance, then alternative coagulants, or operational approaches will need to be developed to reduce the concentrations.*
    6. *If after the 4 months of operation, results show Al concentrations are stable and below the ANZECC threshold, the sampling required will be decreased to once every month*

until 4 consecutive samples at location (c) are compliant. Then reduced to once every 6 months for perpetuity.

7. *If an exceedance occurs in any test, then the testing regularity will revert to the next highest level of testing regularity until the issue is resolved.*
8. *The treatment plant produces a bi-annual report summarising the monitoring and sampling undertaken, critical analysis of compliance and potential adverse environmental effects and any recommendations.*
9. *The NES can review and change the conditions of the consent annually.*

Discharges to the Ground

71. The sludge that is drained from the bottom of the settling tank, and from the AVG, to the scour / backwash ponds is transported through a closed pipe by gravity to the scour ponds so contamination of the groundwater, or surrounding area, can only occur if there is a leak in the pipeline or the settling tank. The likelihood of this is expected to be very low. All pipework installed has been tested as part of the Contractor's commissioning requirements prior to putting into service.
72. The sludge is a concentrated mixture of the suspended clays and organic materials found in the raw water plus aluminium hydroxide precipitate. Sludge is expected to be removed from the scour / backwash ponds every 6 to 12 months however, it will depend on the quality of the raw water, with poorer quality water producing more sludge.
73. Sludge produced in water treatment that use an aluminium salt coagulant is commonly termed alum sludge. The aluminium content in the sludge is expected to be high. However, the majority of this aluminium will be in a stable aluminium hydroxide precipitate. When dried out to a "spadable" moisture content solid (i.e. moist soil consistency) it is not expected to leach aluminium when re-wetted. The following comment applies;
74. *"International research conducted on the toxicity and leaching characteristics of Alum sludge has indicated that most pollutants are tightly bound to the aluminium matrix with little or no affinity for release from either dried or wet sludges."* – Auckland Regional Council 2004, TP227.
75. Ponds are typically lined to prevent leaching of water from the ponds into the ground water. However, this is more important where the pH of water is low and the leachate can present higher levels of dissolved aluminium, which could potentially get into groundwater. If the ponds are adequately clay lined or plastic membrane lined to low permeability limits then the risk of significant flow into groundwater is avoided.
76. The pH of the water in Te Mato Vai is typically high (i.e. >7.0). So high concentrations of dissolved Al in the supernatant is less likely. Potential transfer of Al into the ground water is therefore reduced, at least at high concentrations.
77. The alum sludge typically has a low permeability and does not let a lot of water through into the ground water because the sludge effectively 'seals' the surrounding ground and prevents water migration through at high rates.
78. Any dissolved aluminium that does come through the sludge and enter the surrounding ground typically very quickly binds with the soil in the surrounding area i.e. it does just flow with the water. As a result, Al levels would only be expected to be elevated in close proximity to the ponds i.e. within a few meters of the ground surface exposed to the sludge / supernatant.
79. Where ponds are unlined it is recommended that nearby groundwater sources are tested for dissolved aluminium to monitor/manage associated risks. The soil immediately surrounding an unlined pond is likely to have a higher aluminium residual than the rest of the area, however

aluminium is naturally present in soils and the additional aluminium content is not expected to increase the risk of soil toxicity (in particular the further away you get from the ponds).

80. The way the sludge releases into the environment will be as a fluid unless the sludge has a % Dry Solids content (DS) of about >10 %DS. At this % dry solids content the sludge has a "jelly-like appearance". It is noted that the sludge from a settling tank that is filling the pond can often be only about 0.5 to 1% DS. In a sludge pond that is kept full of water, the sludge at the bottom is usually at <10% DS. Only when the pond is allowed to dry out, so the sludge can be excavated, and sent to landfill, will the sludge become more solid. Usually when it reaches about 18 to 25% DS (spadable to quite dry looking) will it be removed.

Uncontrolled Discharges from the Ponds

81. Pond embankment failures could potentially occur, however this is extremely unlikely. Embankment failure would typically be caused from either poor embankment construction or erosion of the embankment to the point of failure. The majority of the ponds have been constructed in 'in-situ' ground i.e. the walls have not been constructed so the risk of poor construction causing a failure is very low. Construction has also been undertaken by a competent Contractor under supervision and monitoring throughout the Contract Works.

82. Though in many cases across the 10 sites the ponds are constructed in close proximity to the streams, they are constructed entirely outside the normal flow path of the streams. This means that erosion of the stream banks to the point of failure wouldn't be typically predicted to occur because the existing stream embankments have not been altered during the construction. As part of the operation and maintenance requirements of the treatment plants, TTV will undertake routine monitoring of the stream banks and can install erosion protection if areas are being eroded, or undermined. It should be noted that some areas, where they may be prone to erosion, have already had erosion protection or stream bank reinforcing installed as part of the construction.

83. As most of the streams do not have any current flow monitoring in place, it is not possible accurately predict what the actual potential flood levels of the streams are, so the design has relied on empirical levels. Below is a quote from the Design and Build Construction Contractor concerning the design of the ponds:

"Physically, the ponds were located in areas suitable in size and away from flood zones, over the course of the construction period flooding damage from previous and recent floods were evident on site, and taken into account when constructed. From observations, the main sites that were affected by high stream/flooding scenarios were Avana and Takuvaine."

84. The ponds have been built in locations where there is no evidence that the ponds are in the 'normal' flood plain for the streams. This is not to say that the stream will never reach a level where they may inundate the ponds, but where this has been identified as a potential risk, ground levels have been modified during the construction to minimise the chance of this happening. An example of this is at Avana where the stream side embankment of the ponds has been constructed higher than the other pond embankments to protect from potential flood water levels. Another example of pond protection at Avana is where the access road has been locally raised at the stream crossing above the pond, to assist in keeping high water levels within the stream extent and mitigate the risk of water flowing down the access road.

85. In the low chance that ponds are inundated with flood flows, the sludge in the bottom of the ponds is not very mobile i.e. it is not easily resuspended by the flowing water over the top of it. This is due to its consistency, and also that it has a specific gravity of 1.2 (meaning that it is heavier than water). This is especially the case as the water will flow over the top of the ponds at

the surface level and at the bottom of the ponds, where the sludge sits, the water velocities are very low and will not mix with the majority of the sludge.

86. The pond's detailed design is based on avoiding excessive surface rainfall runoff entering the pond and that the pond's embankments are well constructed and located away from areas close to the stream where embankment damage could occur due to a large stream flow event.

87. The effects of rainfall within the pond extents will be negligible and will serve only to offer a small amount of dilution to any residual supernatant, and reference to the available minimum freeboard of 300mm incorporated in the pond design described above is made.

Conclusions

88. PACl is a common chemical used in the coagulation of drinking water.

89. This memorandum provides further information relevant to the use of PACl as a coagulant chemical as part of the water treatment process in Rarotonga. There is no information provided in this memorandum that demonstrates PACl is not suitable to be used in the coagulation of drinking water in Rarotonga.

90. There are no human health issues identified with Aluminium in Drinking water, but there are Guideline Values for aesthetics in the NZDWS (0.1mg/L).

91. Concentrations of PACl dosing in the operation of the treatment plants is expected to be far lower than equivalent water treatment plants internationally – Typical dosing rates for PACl are generally 14-24mg/L, however, the proposed dosing rate for Te Mato Vai sites are significantly lower at approximately 4-6mg/L.. This reduces the likelihood that concentration of Al will be in excess of 0.1mg/L, but does not eliminate it.

92. It is accepted that Aluminium can be toxic in aquatic environments depending on concentration and water chemistry parameters, and this is why ongoing monitoring will be undertaken. NZ literature shows that concentrations below 0.1mg/L are generally acceptable. Where AL concentration exceed this value, that does not necessarily result in toxicity and is dependent on site specific water characteristics – where concentration exceeds this value, specific testing can be done to assess the actual environmental effect, if any. Operations can be stopped while methods to reduce the operational concentrations are established, or assessments undertaken on the actual impact to the environment at those concentrations where no cause of long term impact is demonstrated.

93. Al discharges to ground will be local and heavily reduced by the Sludge itself, due to the self-sealing nature of the walls of the ponds.

94. The scour / backwash ponds required as part of the TMV treatment process are engineered designs, and not just 'holes in the ground'. They are sized based on expected flow conditions, and informed by the geotechnical investigations undertaken at the start of the project.

95. Any Al escaping from the ponds will typically attach to soil and ground in the immediate vicinity of the ponds and is not particularly mobile in ground water.

96. Pond design has mitigated the likelihood of potential uncontrolled discharges. The majority of the ponds have been constructed in 'in-situ' ground. Erosion of the stream banks to the point of failure wouldn't be typically predicted to occur because the existing stream embankments have generally not been altered during the construction. Construction has also been undertaken by a competent Contractor under supervision and monitoring throughout the Contract Works.

97. There is an example of supernatant from sludge ponds being discharged to the environment at the Wairoa Water Treatment plant in New Zealand.

98. The discharge conditions (as developed for the Wairoa Water Treatment Plant in New Zealand) could be modified to make it appropriate for the environment in the Cook Islands.

References

99. Auckland Regional Council TP226 'Overview of the Effects of Residual Flocculants on Aquatic Receiving Environments' 2004 Technical Publication 226

100. Auckland Regional Council TP227 'The Use of Flocculants and Coagulants to Aid the Settlement of Suspended Sediment in Earthworks Runoff : Trials, Methodology and Design' [draft] June 2004 Technical Publication 227

101. Australian and New Zealand Environment and Conservation Council (ANZECC) & Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) 'Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1: The Guidelines', 2000

102. P. Gebbie, Fisher Stewart Pty Ltd, 64th Annual Water Industry Engineers and Operators' Conference 'Using Polyaluminium Coagulants in Water Treatment' September 2001

103. S. Agyin-Birikorang, G. O'connor & T. Obreza, University of Florida IFAS Extension SL 299 'Are Alum-Based Drinking Water Treatment Residuals Safe for Land Application?', July 2009

104. New Zealand Drinking Water Standards 2005 (revised 2018)

105. Guidelines for Drinking Water Treatment 2017

Regards

David Sloan
Engineer's Representative - TMV Stage 2

Co-written with:

Scott Cairney
Engineer to Contract – TMV Stage 2 / Project Director

Peter Free
Water Treatment Technical Director