Alum Use in the Victorian Water Sector

Desktop Review

Wannon Water/DEECA

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→ The Power of Commitment

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The Power of Commitment

Executive Summary

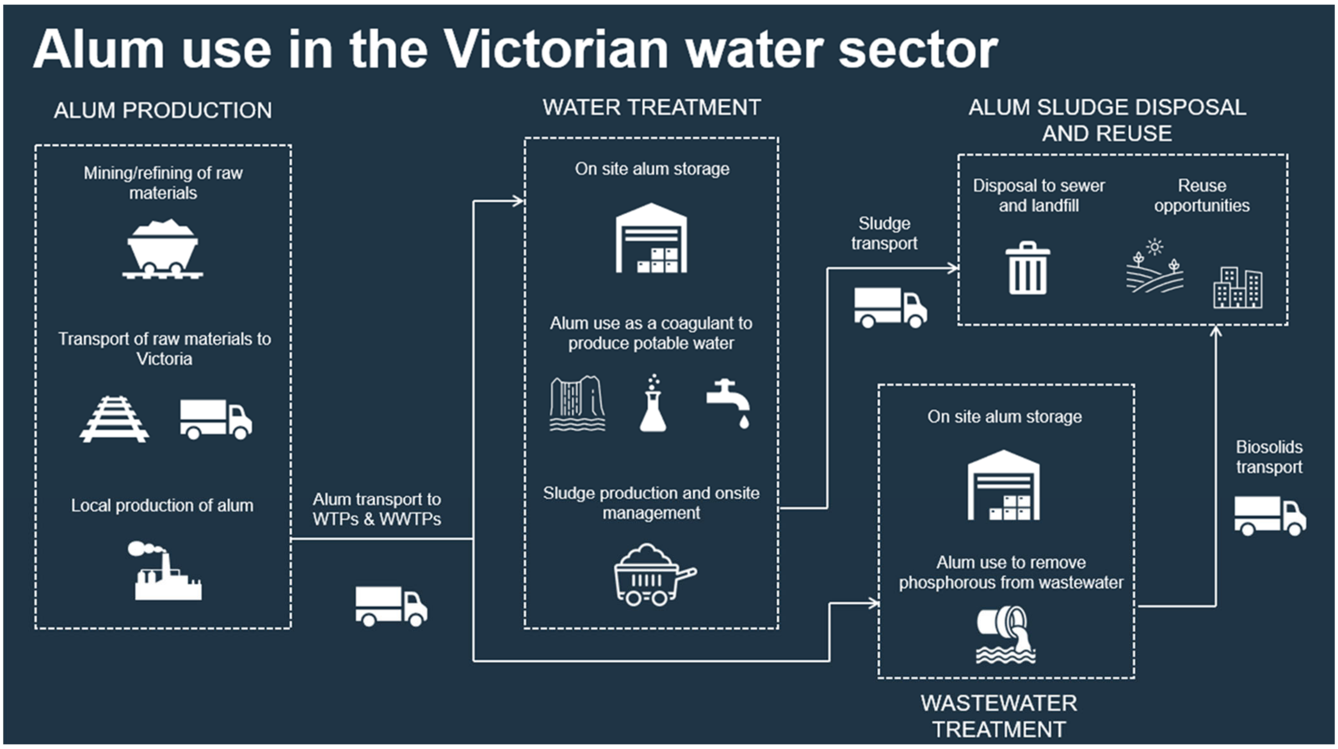
This report is subject to, and must be read in conjunction with, the limitations set out in section 1 and the assumptions and qualifications contained throughout the Report.

Summary of alum use in Victoria

This desktop study considers circular economy aspects of the use of aluminium sulphate (alum) in the Victorian water sector. Alum is a chemical commonly used for coagulation in water treatment, and used for the removal of phosphorus in wastewater treatment applications. The current state of alum uses in the Victorian water industry can be summarised as follows:

- To produce alum, chemical suppliers import raw materials to Victoria from other states, namely hydrated alumina and sulphuric acid
- Alum is prepared in batches by mixing the hydrated alumina and sulphuric acid, then transported to water treatment plants and wastewater treatment plants where it is stored prior to use
- At water treatment plants, alum is dosed into raw water as a coagulant to reduce turbidity and colour
- At wastewater treatment plants, alum can be dosed at various points throughout the treatment process to remove phosphorous
- Alum waste solids from water treatment are typically disposed to landfill, or to sewer where it is managed with biosolids
- Biosolids generated at wastewater treatment plants, which may contain alum waste solids from water treatment and/or solids precipitated for phosphorous removal, are typically applied to land or disposed to landfill

This process is shown diagrammatically below.



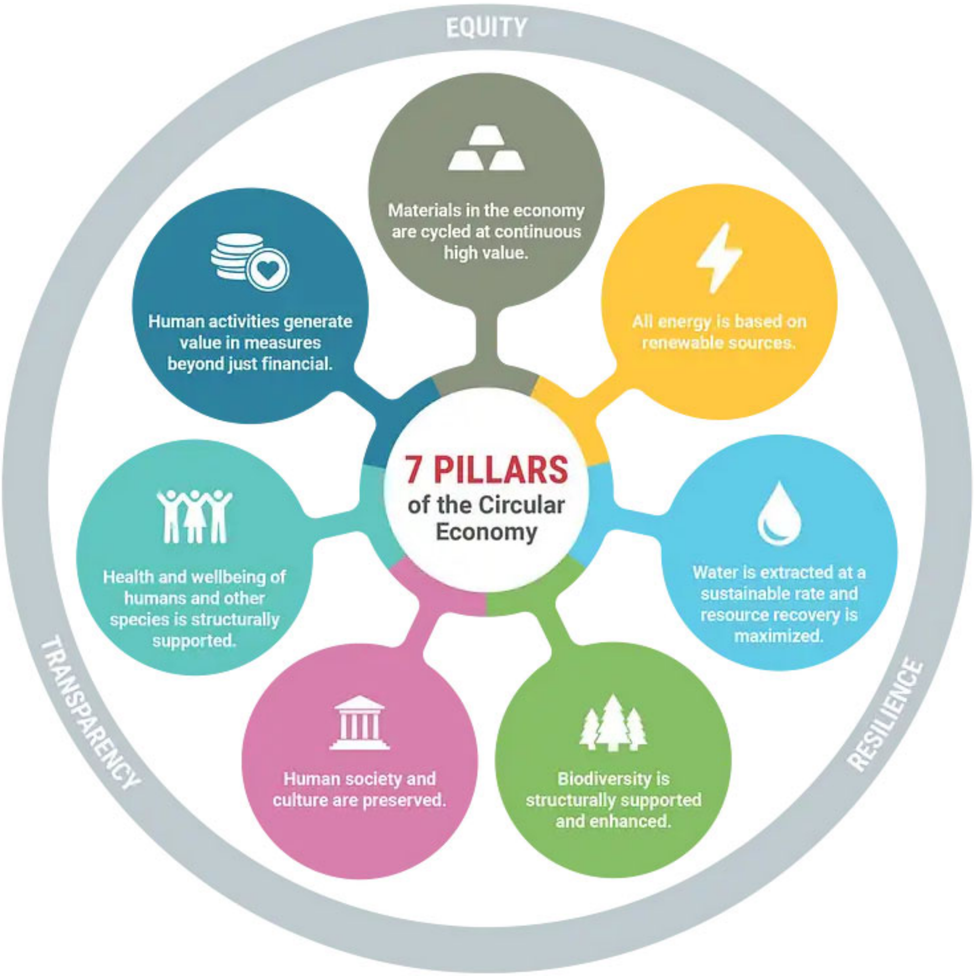
Not all water or wastewater treatment plants use alum. Some use alternative coagulant chemicals or an alternative treatment process is employed that do not require alum. However, alum is the most commonly used coagulant in Victoria. It is estimated that annual alum usage in Victoria is in the order of 13 to 20 kt/year, at an overall cost to water authorities of $3M to $5M/year. The use of this alum generates thousands of tonnes of sludge that is typically disposed to landfill, again costing millions of dollars to water authorities.

From a circular economy perspective, the preferred solution would be to eliminate both the use of alum and the waste that it produces. However, this is not a practicable solution, as the primary goal of a water treatment plant is to produce safe drinking water. This requires removing the colloidal matter and pathogens, which inevitable produces a residual waste product (regardless of the coagulant that is chosen). While some water in Victoria is safe to drink without a filtration process (i.e. no coagulation and sludge generation), the majority of raw water requires filtration and will produce a waste product (including the desalination of seawater at the Victorian Desalination Plant)

Circular economy framing

Circular economy can be considered in terms of seven pillars that serve as idealised features for an end state once a circular economy has been achieved. These pillars are shown in the figure below. While this end state may never be realised, the pillars are specific aspirational targets that can guide decision making to achieve a more circular economy. This project has specifically considered the following pillars:

- Materials are cycled at continuous high value
- The health and wellbeing of humans and other species are structurally supported
- Human society and culture are preserved
- All energy is based on renewable sources
- Biodiversity is supported and enhanced through human activity

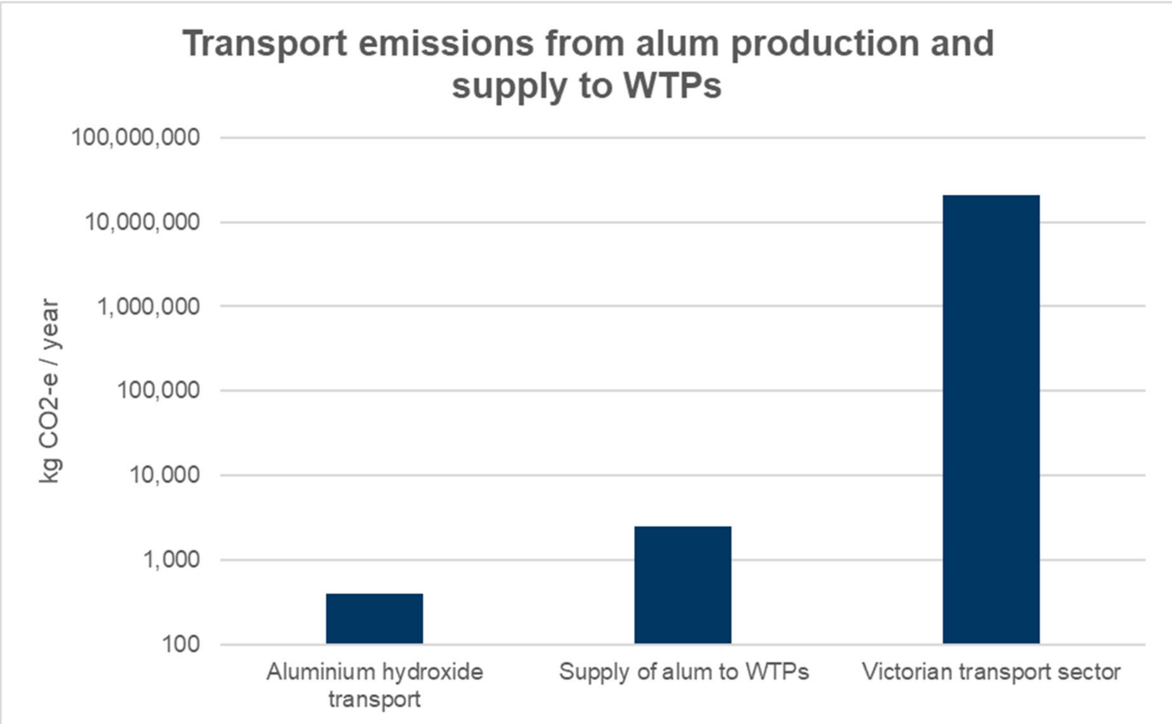


Alum production

The production of alum occurs in Victoria using raw materials imported from other states. Circular economy aspects of alum production include the review of the raw material supply chain, the biodiversity impacts of mining, the cost of supply, greenhouse gas emissions and human rights and modern slavery impacts. As alum production represents only a small fraction of the total worldwide demand for mined aluminium, water authorities are unlikely to have much power within the market to leverage producers to adopt better practices with respect to aforementioned areas. Nonetheless, the major refiners in Australia have net zero ambitions and commitments for their organisations. Furthermore, international organisations, such as the International Council for Metals and Mining (ICMM), have developed recognised best practice principles for the extractives industry, including for mining and biodiversity, ethical business, human rights, and indigenous people engagement. Many large mining companies are signatories to these principles and are being scrutinised through obligatory and voluntary reporting and auditing schemes.

Water authorities could consider implementing socially/environmentally conscious procurement practices that address some of these concerns. By requiring that their supply partners act in accordance with certain principles, upstream supply chain concerns may be avoided, and supply partners may be incentivised to improve practices (if not already doing so).

As part of this desktop review, transport carbon emissions for the supply of aluminium hydroxide and the supply of alum to WTPs in Victoria were estimated. Aluminium hydroxide transported by train from Perth to Melbourne is estimated to account for 0.39kt CO_2-e/yr, while the supply of alum from suppliers to WTPs is estimated to account for 2.84kt CO_2-e/yr. Overall, the Victorian transport sector accounts for approximately 20.8 Mt CO_2-e[1], which is four orders of magnitude greater than the supply of alum throughout Victoria. This is shown in the figure below.



Management of waste residuals generated from alum usage

From a circular economy perspective, the leverage that water authorities currently have to make impacts with regards to alum usage is related to the management of waste residuals that are produced at water treatment plants. In Victoria, waste residuals from water treatment plants are almost exclusively disposed of to either landfill or sewer. For disposal to sewer, the solids are then subsequently managed with the biosolids from the wastewater

[1] State and territory greenhouse gas inventories: annual emissions - DCCEEW. (2022). Dcceew.gov.au.

treatment plant. The 'disposal' route to either landfill or sewer is typically the least desirable from a waste management perspective. However, if a water authority is sending solids to a wastewater treatment plant through the sewer network, there may be some beneficial reuse of those solids depending on the ultimate fate of the biosolids. The net outcome in this instance is the avoidance of landfill, but due to the complexities of managing biosolids it must be considered on a case-by-case basis as to whether this is the best way to reduce landfill disposal.

This report has considered several scenarios where water authorities may have alternative levers to reduce the amount of water treatment plant solids than ends up in landfill. These include:

- Environmental reuse
- Use in construction materials
- Use of alternative coagulants
- Alum recovery from waste alum
- Reduced alum usage

The sections below outline the most promising of these alternatives.

Environmental reuse

Of these scenarios, the most promising is environmental reuse of alum sludge by applying it to land or other agricultural/environmental applications. This is in fact already practiced at by some water authorities throughout Australia. Key benefits of this practice include savings for water authorities for waste disposal, improved soil quality, crop yield or other environmental benefit from the end use, and overall community benefits from diverting waste that would otherwise end up in landfill. The major current limitation is the management of large waste volumes reliance by water authorities, and the subsequent reliance on a third party to accept this waste and beneficially reuse it in some way. As for all beneficial reuse options, there must be sufficient ongoing demand for the end product to make it economically viable.

Use in construction materials

Studies have shown that alum sludge has the potential to be used in construction materials such as road base or bricks, but there are no current examples of its use commercially in Australia. Key benefits of this practice include savings for water authorities for waste disposal, potentially improved physical properties of materials and lower material production costs, and overall community benefits from diverting waste that would otherwise end up in landfill. As noted above the major limitation is the management of large waste volumes and sufficient ongoing demand for an end product. Further trials and research are required to determine the most suitable construction materials that can be produced, considering both the sludge properties and the desired end use.

Alum recovery

Alum recovery requires the construction of new infrastructure at a water treatment plant or some nearby site. It is a feasible process that has been practiced worldwide, the technology is readily available, and has the potential to reduce the amount of virgin alum that is used.

Studies on a case by case basis are required to determine at what scale recovery becomes viable compared to raw alum. One could consider scaling up recovery by consolidating alum sludge in regional recovery hubs, which could potentially provide a revenue or cost reduction pathway. Transport, chemical and equipment requirements would need to be well understood in relation to the cost benefit and emissions that are produced from this process.

For water authorities, the major limitations to include the amount of alum that can be recovered feasibly and the cost (both capital and operational) and complexity of the alum recovery process. These costs and complexities have thus far driven the majority of water authorities to continue with existing disposal methods or pursue alternative beneficial reuse options (as outlined above).

Template for further circular economy studies

The process undertaken during this review may serve as a template for water authorities or other entities interested in exploring and pursuing circular economy opportunities relating to other chemicals or issues. When considering circular economy reviews of other chemicals, it must be noted that:

– All chemicals used in a water treatment plant are done so with a specific purpose and end goal, i.e. produce safe drinking water. These chemicals are often hard to substitute for anything other than another chemical (e.g. chlorine gas versus sodium hypochlorite for disinfection)
– The analysis of chemicals that do not have any waste product will be more limited than the analysis in this report, and will be more focused on production, transport and alternative chemicals or processes
– Some chemicals will have clear process alternatives that achieve a similar outcome, e.g. the use of powder activated carbon versus granular activated carbon filters to remove taste and odour compounds

As noted throughout this report, the best solution for a specific scenario must often be weighed up on a case-by-case basis, considering local factors that may influence the outcome of each scenario.

Conclusion

The use of alum in the water industry is primarily driven by its use in drinking water treatment. The usage is a function of raw water quality, and the need to produce high quality and safe drinking water. Alternative coagulant chemicals are available in the market; however these have similar supply chain and waste sludge considerations that would need to be addressed.

For individual water utilities, the footprint of their alum use is driven by geographical considerations. The demand for alum is related to raw water quality, over which there is limited influence. The carbon footprint is also driven by transport requirements, with utilities remote from Melbourne incurring additional transport costs and carbon impacts.

For reuse opportunities, the following general conclusions can be drawn:

– The pathway to agricultural reuse via application to land (as described in 7.3.4) is best led by regional water utilities. They are well placed to establish interest in reuse within their region, noting that this will require contact with individual farmers to understand their requirements and ability to reuse sludge wastes
– The pathway to industrial reuse is likely to sit better with larger urban based utilities, in part due to having a larger stream of alum waste to utilise. The process might be different to that for agricultural reuse, with an expression of interest type process or similar being used to “advertise” the resource and seek innovation from industry for its reuse
– Alum recovery at water treatment plants for reuse as coagulation requires further treatment processes and introduces additional plant and operational complexity, likely including additional chemicals. The benefit of such an approach will depend on its ability to preserve security of supply for this critical chemical and will be influenced by scale of the treatment plant with economies of scale making larger plants more likely to be viable
– Disposal to sewer to assist phosphorus removal at wastewater facilities provides an additional benefit for the alum, however the degree to which it provides circularity depends on the end use of the produced biosolids

Overall, a consolidated effort is required by water authorities to track and understand what opportunities exist to improve the circularity of their alum use. Some national body or register could be established, perhaps as an extension of existing circular economy interest groups within the water industry. There is an opportunity for the water sector, being highly regulated, to use its critical role for societal wellbeing to collect and share data that reflects their future ambitions to inform policy, with the ultimate goal of diverting what is considered as waste and sent to landfill, to more beneficial reuses.

As per circular economy principles this work is one ‘piece of a larger puzzle’ to progress the body of knowledge in transitioning Victoria and Australia towards a circular economy.

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1. Introduction

1.1 Purpose of this report

The purpose of this report is to provide a desktop review of the circular economy aspects of alum coagulant use in the Victorian water sector.

1.2 Scope and limitations

This report: has been prepared by GHD for Wannon Water/DEECA and may only be used and relied on by Wannon Water/DEECA for the purpose agreed between GHD and Wannon Water/DEECA as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Wannon Water/DEECA arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

Accessibility of documents

If this report is required to be accessible in any other format, this can be provided by GHD upon request and at an additional cost if necessary.

1.3 Abbreviations list

Table 1 Abbreviations list

Abbreviation	Definition
ACH	Aluminium Chlorohydrate
ADWG	Australian Drinking Water Guideline
BOD	Biological oxygen demand
CAPEX	Capital expenditure
CE	Circular economy
CO2-e	Carbon dioxide equivalent
COD	Chemical oxygen demand
DAF	Dissolved Air Flotation
DAFF	Dissolved Air Flotation Filtration
DEECA	Department of Energy, Environment and Climate Action
DNA	Deoxyribonucleic acid
DS	Dry solids
EMF	Ellen MacArthur Foundation
EOW	End of waste
EPA	Environmental Protection Authority
EVS	Envirosuite
GED	General Environmental Duty

Abbreviation	Definition
GHG	Greenhouse gas
GL	Gigalitres
ICMM	International Council for Metals and Mining
LRV	Log Reduction Value
ML	Megalitres
NEMP	National Environmental Management Plan
NHMRC	National Health and Medical Research Council
NPC	Net Present Cost
NTU	Nephelometric Turbidity unit
OHS	Occupational health and safety
OPEX	Operating Expenditure
PAC	Powder Activated Carbon
PAO	Phosphorus accumulating organisms
PASS	Polyaluminium silicate sulphate
PFAS	Per- and polyfluoroalkyl substances
PFS	Polymerised ferric sulfate
RMIC	Recommended Maximum Impurity Concentration
STP	Sewage treatment plant
UNGC	United Nations Global Compact
UV	Ultraviolet
WSAA	Water Services Association of Australia
WTP	Water treatment plant
WWTP	Wastewater treatment plant

2. Project background

2.1 Background

Aluminium sulfate (alum) is a critical input for the safe and effective treatment of potable water. It is widely used for coagulation and clarification of water mainly due to its relatively cheap cost of supply, ease of use and general effectiveness. However, the aluminium-rich solids by-product is a growing concern, with an increased focus on environmental impacts of disposal potentially having a significant impact on the sector. All this is counter to circular economy principles, providing an opportunity for new thinking.

Wannon Water has been awarded a grant by Department of Energy, Environment and Climate Action (DEECA) to undertake a review of the circular economy aspects of alum use for the Victorian water sector. As part of the funding agreement, GHD was nominated as a collaborator to assist in the delivery of the project.

The drivers for this project are to:

- Accelerate industry innovation and help build the evidence base required for investment certainty in circular economy opportunities within the water sector
- Create value for Wannon Water's customers and community, and help southwest region of Victoria explore and fulfil its potential
- Support Victorian State objectives:
  - The establishment of a new economy aligned with Recycling Victoria goals
  - Progress towards Climate smart businesses and communities, identified in Victoria's Climate Change Strategy
  - Environment Protection Authority (EPA) Victoria General Environmental Duty obligations, Victoria's biodiversity strategy and the Modern Slavery Act
- Improve the working knowledge of circular economy within both Wannon Water and GHD
- Share learnings across the water sector to collectively accelerate uptake of circular economy opportunities, while enhancing delivery of core business functions

The objective of this project is to produce a desktop-review of the circular economy aspects of Alum use for the Victorian Water sector and share the learnings across the Victorian and Australian water industry.

2.2 Victorian water industry

The Victorian water sector consists of 18 water corporations that oversee water and wastewater services, organised as:

- A wholesaler and three retailers in Melbourne
- Twelve regional urban water utilities, with four offering rural water services for irrigation, stock, and domestic use, as well as environmental and recreational purposes

The focus of this project is on the use and disposal of alum by the water corporations above.

Water in Victoria comes from both surface water and groundwater. Surface water includes water from storage reservoirs, streams, and rivers. Additionally, Melbourne's water supply is supplemented by seawater desalinated at the Victorian Desalination Plant.

The water quality from the different sources varies greatly throughout Victoria, and this directly impacts the treatment processes that are required to make the water safe to drink:

- Surface water from closed catchments used to supply Melbourne (and surrounding areas) typically requires disinfection only (i.e., no filtration processes required to remove solids from the water)
- Surface water from rivers, streams and reservoirs in regional areas varies in quality depending on the source, however clarification and/or filtration is almost always required
- Groundwater in regional areas typically requires disinfection only

– The Victorian Desalination Plant uses a reverse osmosis process to remove salt from seawater, with a number of other processes

Melbourne's supply of largely unfiltered water is relatively unique, with most large cities around the world typically relying on some type of clarification or filtration process. As a result, approximately half of the drinking water supplied to Victoria does not rely on the use of alum (or any other coagulant) to meet safe drinking water standards.

2.3 Waste management in Victoria

One of the key drivers for this project is to support Victorian State objectives with regards to Recycling Victoria's aim of increasing the reliability and transparency of the waste and recycling sector, and to maximise the ongoing use of products and materials that would otherwise be waste. In particular, there is a focus on deriving value from products that would otherwise be waste, in order to reduce landfill, greenhouse gas emissions and other pollution.

In Victoria, 15.7Mt of waste was generated in 2019/20[2]. Of this, 10.9Mt was recovered while 4.8Mt was sent to landfill. The Victoria water sector, while contributing only a small fraction of this total waste, represents a state funded sector that has the potential to lead the way in terms of resource recovery. Solids from water treatment plants and wastewater treatment plants accounts for the vast majority of waste generated in the Victorian water industry and represents a key area to focus efforts for resource recovery.

2.4 Data used in this report

Survey of Victorian water authorities

To understand the use of alum in the Victorian water industry, GHD and Wannon Water undertook a survey of water authorities to collect information on their use of alum. The information from this survey is referred to throughout this report. The survey received a total of ten responses, including seven from Victorian water authorities. A summary of the collated survey results is included in Appendix A.

Annual reports and water quality data reports

To supplement the information provided in the survey, data was gathered from publicly available annual reports and water quality reports from all Victorian water authorities. These reports provide information on the volume of water produced, treatment processes, and chemicals added through treatment processes (including alum).

2.5 Project methodology/template

The process undertaken during this investigation and some further steps that may be taken are outlined in Figure 1. This process may serve as a template for water authorities or other entities interested in exploring and pursuing circular economy opportunities relating to other chemicals or issues.

[2] Recycling Victoria (2023, June). Victorian waste projection model

Step 1: Establish Context

In this step, seek to answer the following questions:

- What is the purpose of the chemical? What factors influence its use? Raw water quality? Other things?
- How much is used? If possible, get this information statewide, or derive it from typical dose rates
- Are there unique Victorian circumstances around the choice or dose of chemical that need consideration?
- What proportion of statewide use of chemical, or production of waste is this particular chemical responsible for?
- Where is the chemical mined/manufactured?
- Where are the key impacts? On CO_2, land, water, etc.?

Step 2: What are possible ways to reduce impacts?

In this step consider the following possibilities:

- Can the dose of the chemical be reduced?
- Are there alternative chemicals, and if so, what are their impacts and other factors?
- Are there alternative treatment processes which avoid the use of the chemical completely?
- Can the characteristics of the sludge be altered?
- Where does the sludge go now, and where else could it go?
- Are any of the alternatives beneficial in some way? If so, by how much?
- Can the chemical be extracted from a waste stream and recycled?
- Is there an alternative source with fewer impacts?
- Are there other approaches used elsewhere? Why not here? What is different?
- Are there any key economic factors which would drive a different outcome (triggers)?

Step 3: Analyse the most promising options

- Compare the option against key circular economy factors/criteria
- Consider core requirements like drinking water quality, environmental outcomes and safety - are they compromised in any way?
- What are the barriers to implementing the option? Costs/timing?
- For any promising options, what are some ‘tests’ that could be done to see if they have merit: market sounding, EOIs, etc.
- Conduct detailed feasibility studies for preferred/shortlisted options

Figure 1 ***Project methodology template for circular economy studies on chemicals***

3. Circular economy framing

The Water Services Association of Australia (WSAA) refers to an established and common definition of circular economy by the Ellen Macarthur Foundation in the UK[3]:

Looking beyond the current take-make-dispose extractive industrial model, a circular economy aims to redefine growth, focusing on positive society-wide benefits. It entails gradually decoupling economic activity from the consumption of finite resources and designing waste out of the system. Underpinned by a transition to renewable energy sources, the circular economy builds economic, natural, and social capital. It is based on three principles:

– Design out waste and pollution
– Keep products and materials in use
– Regenerate natural systems

A circular economy is described as closely aligned with the Sustainable Development Goals[4], where WSAA specifically highlights interrelationships with the following goals (amongst others):

– Goal 6: Clean Water
– Goal 7: Affordable and clean energy
– Goal 8: Decent work and economic growth
– Goal 11: Sustainable cities and communities
– Goal 12: Responsible consumption and production

Furthermore, circular economy can be considered in terms of seven pillars that serve as idealised features for an end state once a circular economy has been achieved[5]. These pillars are shown in Figure 2. While this end state may never be realised, the pillars are specific aspirational targets that can guide decision making to achieve a more circular economy. Table 2 describes the pillars that are being considered as part of this project.

Table 2 Pillars of circular economy targeted in this project

Focus area	Circular economy pillar	How this project addresses the pillars and focus areas
Review of recycling options	**Materials** are cycled at continuous high value	Expanding and updating previous work, novel and effective methods for recycling alum will be examined. Comparison of alum recycling to the existing supply chain and production cycle to identify the value that can be derived from alum recovery.
Review of alternatives	The **health and wellbeing** of humans and other species are structurally supported	While alum is generally considered to be cheap and effective, alternatives do exist, and these will be examined.
Review of production cycle	Human **society and culture** are preserved All **energy** is based on renewable sources **Biodiversity** is supported and enhanced through human activity	Project will examine the human-rights, and modern-slavery implications from the production of alum materials. The emissions from the production of alum will be examined. Potential biodiversity impacts from mining and refining will be considered.

To engage with and transition to a circular economy it is required to acknowledge the complexity and interdependencies of systems, apply a system of systems thinking lens. This means we cannot only approach the circular economy with singular changes and solutions without considering consequences and interactions with technical, economic, political and social aspects, including those of solutions considered or implemented in

[3] Ellen Macarthur Foundation. (2023). What is a circular economy? Ellen MacArthur Foundation.
[4] United Nations. (2015). The 17 sustainable development goals. United Nations.
[5] The Seven Pillars of the Circular Economy. (2020, July 16). Metabolic.

parallel. This implies that embracing the circular economy necessitates a comprehensive approach, accounting for consequences and interactions with technical, economic, political, and social aspects, including those stemming from concurrently considered or enacted solutions. The transition of a circular economy is achieved through continuous improvement of interacting systems in cities, regions, and economies at different scale.

Circular economy thrives by converting waste into resources or reducing the use of raw materials, while also focusing on regenerating natural systems. This approach poses key challenges that span across different sectors globally. The handling of chemicals, tight and slow responding regulatory frameworks, market demand and maturity, work force responsibilities and requirements across regional, national and international markets are just some challenges to mention. Drawing systems boundaries to enable breaking down complexities and providing conceptual frameworks that can be approached by and communicated to multi-disciplinary and multi-stakeholder audiences is also a key challenge.

Circular economy considerations need to be carefully examined to understand issues such as trade-offs, cost-benefits and in particular unintended consequences by changing sourcing, use, and reuse patterns across respective value chains of alum or when replacing alum with alternative materials.

The study on alum use in the Victorian water sector aims to collate foundational information to initiative thinking about alum in context of a circular economy and to develop approaches, opportunities and challenges. We have considered the frameworks established for the water sector by WSAA, derived from the globally accepted principles set out by the Ellen MacArthur Foundation as well as additional frameworks as describe in Table 2.

Scenarios that differ from business as usual are then developed, discussed and assessed taking into account framework themes and considerations. The scenarios then undergo a high-level assessment in relation to:

– Impact potential (scale required, emission reduction, social and environmental benefits)
– Implementation (complexity, cost time frame for value creation
– Market readiness (market potential/maturity/accessibility and revenue potential, policy, and legal compliance)

Assessment categories and themes are based on water professionals' insights from across water sector organisations reflecting current thinking.

It is an opportunity for the water sector, being highly regulated, to further strengthen their relationship with government and using their critical role for societal wellbeing to collect and provide high quality data from their operations and reflecting their future ambitions to inform policy and e.g., enable productisation of what is currently considered as waste to divert these form landfill.

As per circular economy principles this work is one 'piece of a larger puzzle' to progress the body of knowledge in transitioning Victoria and Australia towards a circular economy.

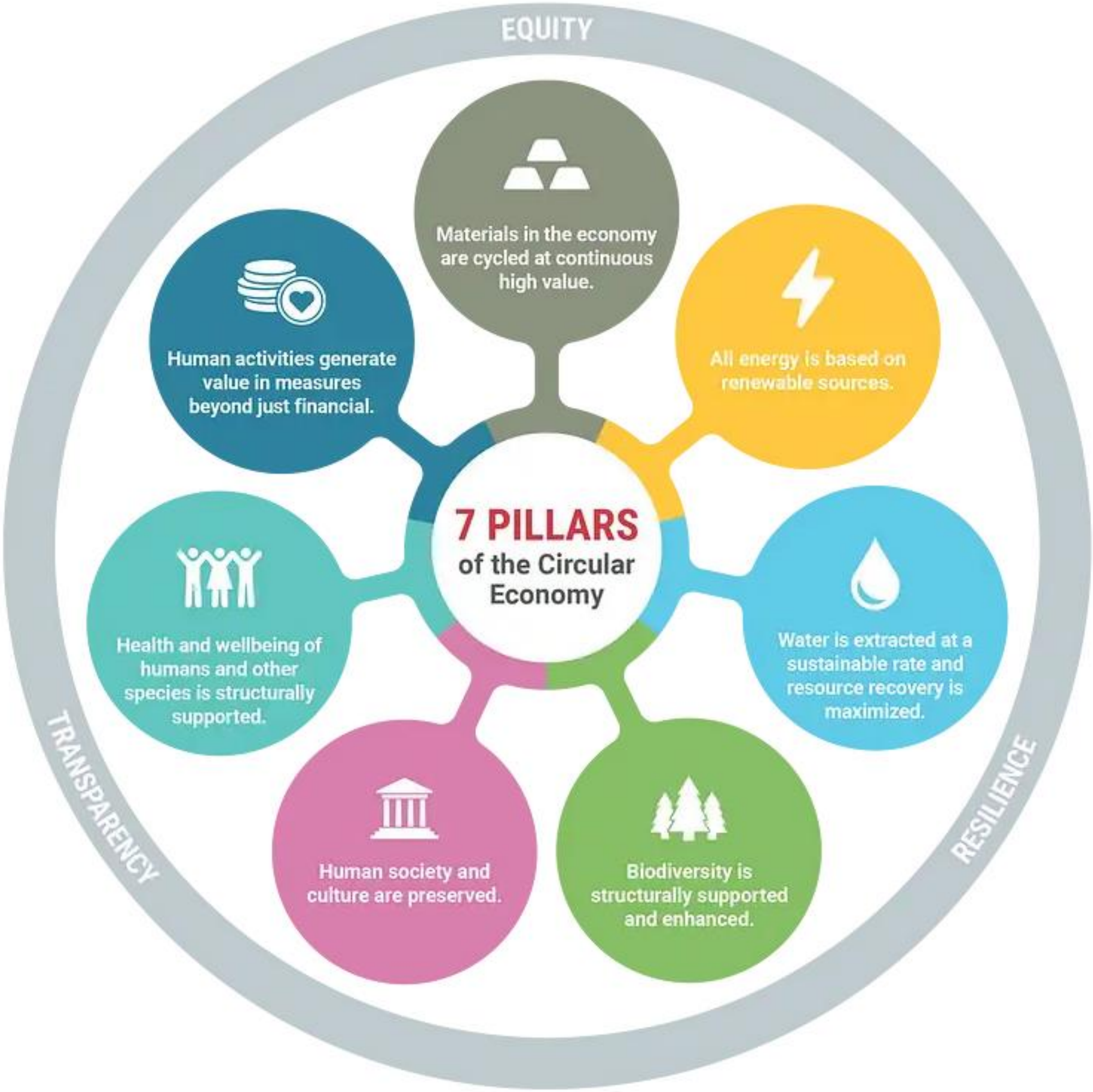


Figure 2 ***Seven pillars of the circular economy*** [6]

[6] The Seven Pillars of the Circular Economy (metabolic.nl)

4. An overview of the alum lifecycle in Victoria

Alum is a commonly used coagulant for coagulation in water treatment. Additionally, it is also used for the removal of phosphorus in wastewater applications. The current state of alum uses in the Victorian water industry can be summarised as follows:

- To produce alum, chemical suppliers import raw materials to Victoria from other states:
  - Hydrated alumina is typically imported from Western Australia
  - Sulphuric acid is typically imported from Tasmania
- Alum is prepared in batches by mixing the hydrated alumina and sulphuric acid, then stored until ready for transport
- Alum is transported to site in liquid form where it is stored prior to use
- At water treatment plants alum is dosed into raw water as a coagulant to reduce turbidity and colour
- At wastewater treatment plants alum can be dosed at various points throughout the treatment process to remove phosphorous
- Alum water treatment solids are typically disposed to landfill, or to sewer where it is managed with biosolids
- Biosolids generated at wastewater treatment plants, which may contain alum water treatment solids and/or solids precipitated for phosphorous removal, are typically applied to land or disposed to landfill

A high-level overview of this process is represented graphically in Figure 3.

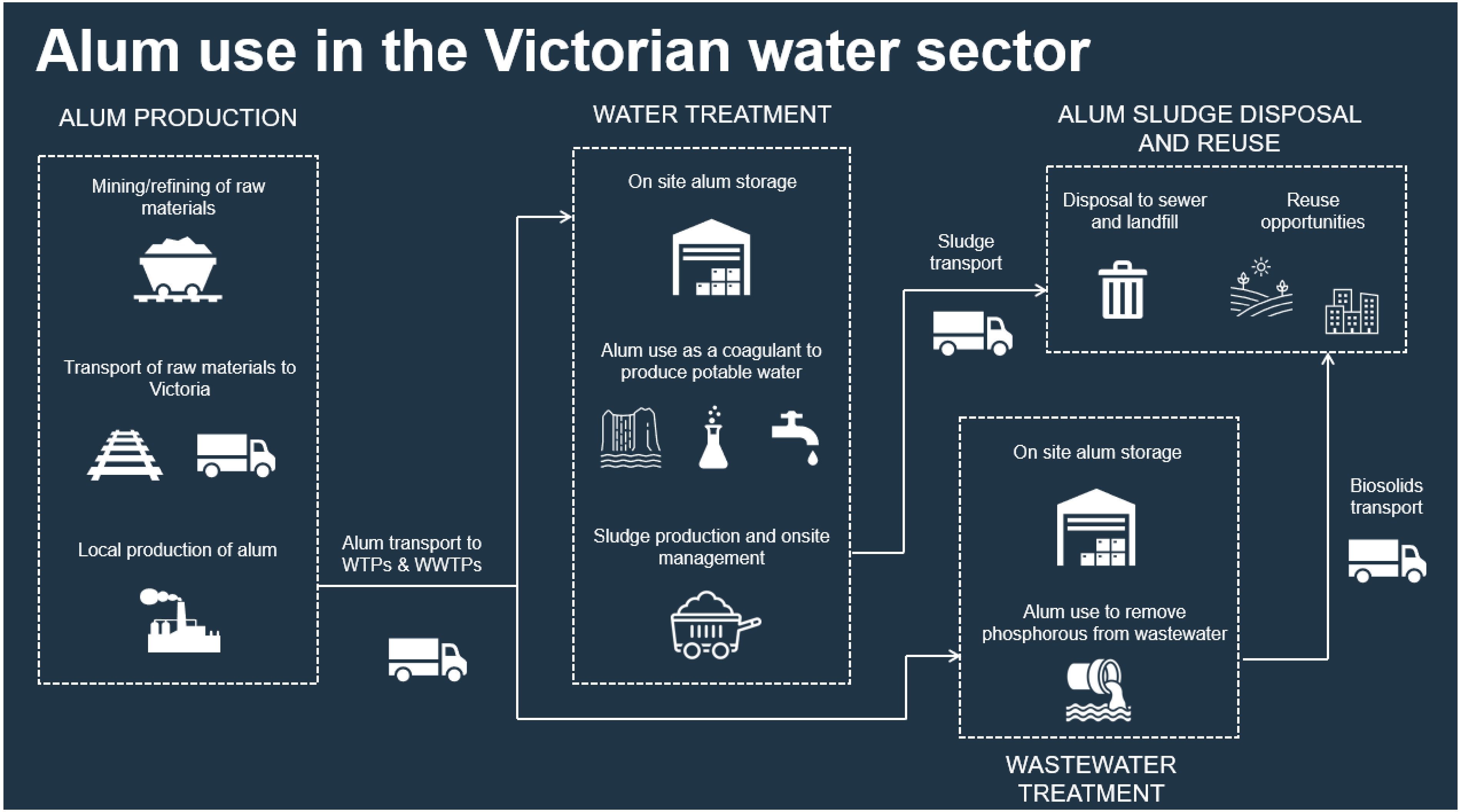


Figure 3 Overview of the typical alum lifecycle in Victoria

5. Alum production and supply

5.1 Alum production

5.1.1 Production

Alum can be made from various raw materials containing aluminium, including metal aluminium, bauxite and aluminium hydroxide (also referred to as alumina trihydrate, hydrated alumina $Al(OH)_3$). The normal commercial batch process uses acid and heat to pull aluminium from aluminium hydroxide. The acid used in this process is usually sulfuric acid, due to cost considerations. Batch sizes in commercial manufacturing tend to be ~10 to 20 tonnes. As the reaction between aluminium hydroxide and sulfuric acid is exothermic, no additional energy beyond mixing is typically required during alum production.

Although alum can be produced in powdered form, it is generally used in liquid form – currently all alum supplied to the Victorian water industry is in liquid form. The hydration of the alum is variable between sources, but most are commonly around $Al_2(SO_4)_3.10H_2O$. to $Al_2(SO_4)_3.20H_2O$.

The two main producers of alum on the east coast of Australia are Ixom and Omega Chemicals. All alum used in the Victoria water industry comes from one of these two suppliers, both of whom produce alum locally in Victoria. Other key alum suppliers in Australia include Nowra Chemicals in NSW, Hardman Chemicals in Western Australia and Cleveland Bay Chemical Co in Queensland.

Powdered alum is produced by dehydrating liquid alum. As Victorian water authorities have transitioned away from the used of powdered alum, there are currently no sites in Victoria that produce powdered alum.

5.1.2 Strength, quality and impurities

The solution strength of alum is shown as % w/w of water-soluble aluminium, as is expressed in terms of Al_2O_3. The aluminium content in the solution is determined using very precise specific gravity measurement. Alum supplied to water authorities typically has a strength of 7.5 to 8% Al_2O_3. This translates to approximately 50% w/w of $Al_2(SO_4)_3.18H_2O$ (noting that the hydration of the alum ranges from around $10H_2O$ to $20H_2O$).

Chapter 8 of the Australian Drinking Water Guidelines (ADWG) (NHMRC 2011), provide guidance for the use and quality control of drinking water treatment chemicals, including those used for coagulation and flocculation. Alum is listed as one of the chemicals recommended for use in the treatment of drinking water for the purpose of coagulation. The assessment and management of risks associated with chemicals include those intrinsic to the chemical toxicology, dosage, and treatment process, but also include the consideration of contaminants or impurities from manufacturing or handling.

To understand the potential impurities present in the potable water treatment chemicals, it is common to require composition testing of each batch of alum. This is typically conducted by an independent analytical laboratory and provided to the water business by the chemical supplier prior to use. The acceptance criteria for treatment chemicals are based on functional properties (i.e., aluminium content, clarity, pH, suspended solids) and specific impurity limits (i.e. heavy metal concentrations). The chemical testing conducted by chemical manufacturers to meet water businesses acceptance criteria thus provides some information on the source of potential contaminants in alum-containing WTP solids.

The ADWG provides a recommended process for determination of maximum impurity concentration. These follow a Recommended Maximum Impurity Concentration (RMIC) approach, which proposes that no contaminant should add more than 10% of that allowable by the ADWG health guideline value (NHMRC 2011). These include consideration of the concentration of impurity in the chemical, the drinking water health guideline in treated water, the expected dosage, and the chemical strength.

5.2 Raw materials

As noted above, alum is produced in Victoria by Omega Chemicals and Ixom. Both companies import aluminium hydroxide and sulfuric acid into Victoria for this process.

5.2.1 Aluminium hydroxide

For the production of alum in Victoria, aluminium hydroxide is currently imported as a powder from Alcoa in Western Australia, where it is mined. The purity of alum depends on the source of raw materials, and the impurities are not predictable without knowledge of the sources. Alum produced from different raw materials results in different quality product. The impurities in bauxite are mostly predictable according to the geological origin.

An alternative supply of aluminium hydroxide may be sourced from Queensland, however recent supply chain issues have highlighted that this may not be a viable option to meet the current alum demand in Victoria (at least as a short-term option, refer section 5.3 for further details).

Alum production from bauxite tends to include more impurities, particularly iron, than that produced from aluminium hydroxide. This has resulted in Nowchem, which supplies alum to NSW and the ACT, in using aluminium trihydrate (refined bauxite) in the manufacturing process. This is done to reduce the iron content in the alum and sludge levels in storage tanks.

The product specification provided by the chemical supplier generally contains the best available data on the quality of the alum, including the impurities present. However, this data may not necessarily reflect any specific batch of alum, but rather be generalised for a particular manufacturing process.

The production of aluminium hydroxide is a precursor step to the production of alumina. The historical price of alumina is shown in Figure 4. Despite a number of fluctuations in price from 2016 to 2019, and again around 2022, the price of alumina has been approximately USD$300-400 per tonne over the past 13 years. Local changes to the cost of alum supply in Victoria are more likely to be related to local market factors, e.g., cost of labour and transport.

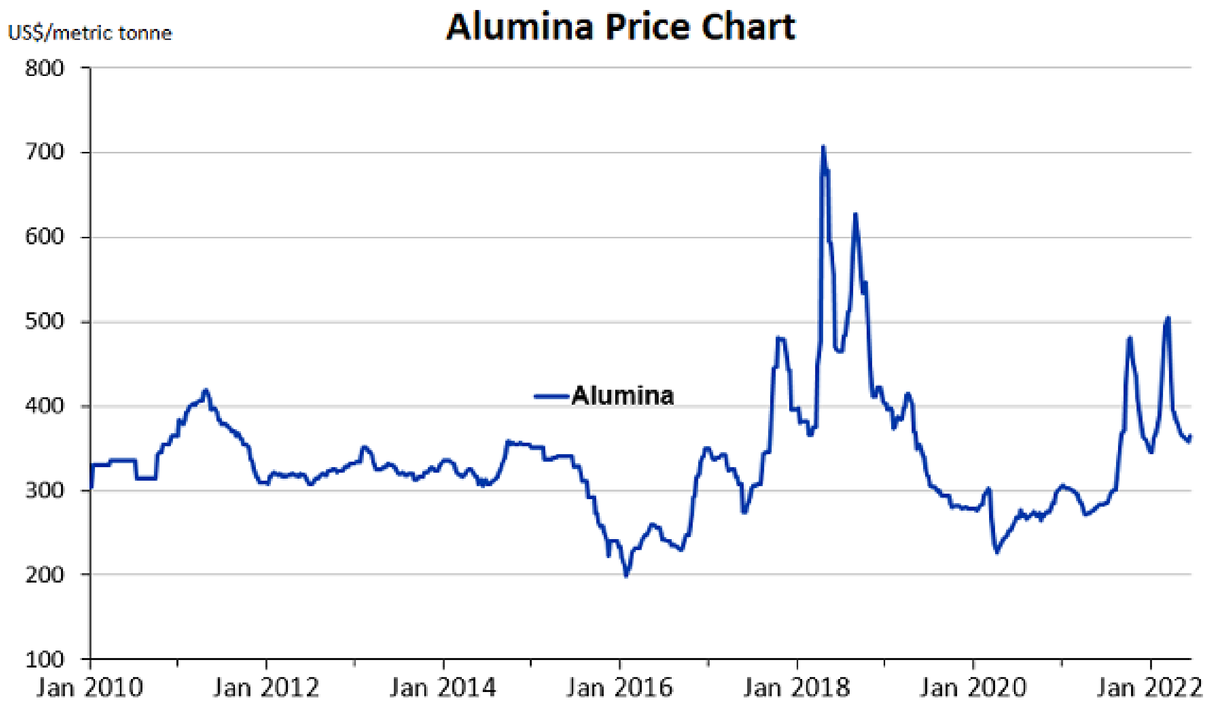


Figure 4 Alumina price chart[7]

[7] Consensus Economics. Alumina Price Forecasts - Energy & Metals Consensus Forecasts. (n.d.).

5.2.2 Sulfuric acid

Sulfuric acid is generally sourced as a by-product from various zinc, copper and nickel production processes. The production levels of sulfuric acid are thus affected by demand and production levels for these metals. Sulfuric acid used for the production of alum in Victoria is currently imported from Tasmania where it is produced as a by-product of nickel production.

The purity of acids can be less predictable, mainly due to the tendency to obtain materials through intermediaries, who stabilise the supply chain by sourcing materials from a multitude of global manufacturers. There is broad industrial demand for industrial acids, and strength of demand is highly variable.

Sulfuric acid is among the highest volume industrial chemical used globally, and the vast majority is used for the production of phosphate fertilisers and other agricultural chemicals. Other industrial uses include ore leaching, petroleum refining, pigment, plastic, paper, and chemical manufacturing. Because sulfuric acid is used to create many common products, demand is a major factor affecting price. The price and availability of sulphur also affects the price and production of sulfuric acid. The production of some metals (e.g., zinc and copper) and petroleum processes influence the availability of sulfuric acid, and thus the availability and price of sulfuric acid is affected by the production levels of these commodities. Although it is possible to manufacture sulfuric acid from raw sulphur, the price of mined sulphur is much greater than when sourced as a by-product from other industries.

Summary

Two suppliers currently provide alum to the Victorian water sector. The quality of the alum supplied is controlled by the ultimate need for water authorities to demonstrate that the treated water complies with guidelines/regulations. This means that the introduction of impurities into the treatment process needs to be managed. ADWG provide guidance for use and quality control of drinking water treatment chemicals, including those used for coagulation and flocculation, such as alum. Accordingly, alum manufacturers are effectively regulated in terms of the quality of the chemical to ensure the alum meets the water authorities’ quality

5.3 Alum and raw material supply chain

Water authorities surveyed as part of this project from Victoria, ACT, South Australia and Queensland all reported a number of supply chain disruptions to their alum supplies over the last several years:

– Some short-term delays were experienced due to covid related disruptions
– The supply of aluminium hydroxide from Alcoa in Perth was disrupted in early 2022 for approximately one month due to flooding of the Indian-Pacific railway. This supply was further disrupted in late 2022 due to a train derailment
– Changing demand for alum (or other coagulants) due to wet weather events. During wet weather events, a reduction in water quality drives an increase in coagulant use (refer section 6.1.2). When these events are isolated or short in nature, on site storage volumes of alum (or other coagulants) are typically sufficient to allow an increase in dose rate without affecting the overall supply chain. However, when these events are prolonged and widespread, increased coagulant dose rates across multiple WTPs can place pressure on supply chains

No Victorian water authority reported any major disruption to the volume or quality of water that was able to be produced during the above supply chain disruptions. One survey respondent also noted that in response to the disruption of aluminium hydroxide from Alcoa in 2022, alternative suppliers of this raw material in Queensland struggled to meet the demand from Victoria. It was also noted that during this period, due to the reduced supply available from Victoria, some alum customers located in regional NSW shifted their source of alum from Melbourne to Queensland. This in turn placed pressure on the local supply of alum to Queensland water authorities, which was also responding to increases in alum demand due to ongoing wet weather events along the east coast of Australia. One survey respondent noted that the alum demand from one supplier in southeast Queensland almost doubled during this time.

Based on the typical volumes of chemicals stored on site (refer section 5.5), as well as the limited readily available supply of aluminium hydroxide from alternative suppliers, supply chain issues that last for more than one month may start to impact on the quality and production of water in Victoria.

Summary

Supply chain disruptions in recent years have demonstrated that there are some vulnerabilities within the alum supply chain. Therefore, any circular economy interventions which assist in reducing exposure to the supply chain vulnerabilities may have merit.

5.4 Biodiversity impacts of raw material mining

As described in section 3, one of circular economy pillars to be considered in this project is that biodiversity is supported and enhanced through human activity. As one of the core principles of acting within a circular economy is to preserve complexity, preserving biodiversity is a top priority. Habitats, especially rare habitats, are not encroached upon or structurally damaged through human activities. Preservation of ecological diversity is one of the core sources of resilience for the biosphere. Material and energetic losses are tolerated for the sake of preservation of biodiversity; it is a much higher priority.

Raw materials for alum in Victoria are mined, refined or are by-products of the Australian extractives sector further described in 4.2 and 4.3. The greatest impact of mining on biodiversity in Australia occurs through cumulative effects of multiple projects in one region and impacts are best managed by assessing impacts in the regional context[8]. Nevertheless, individual sites and their support activities such as transportation, processing and mine waste storage (e.g., tailings storage facilities) impact biodiversity in relation to changes in landscape, impact on water quality and availability, soil and air quality to some extent. In Australia, federal and state government processes are in place to safeguard acceptable (by legislation) impacts, their management and mitigation (e.g., off sets).

In addition, international organisations, such as the United Nation Global Compact and specifically the International Council for Metals and Mining (ICMM) have developed recognised best practice principles for the extractives industry, including on mining and biodiversity (as well as ethical business, human rights, and indigenous people engagement). Many large mining companies, such as bauxite mining and alum refining Alcoa of Australia, are signatories to these principles and are being scrutinised through obligatory and voluntary reporting and auditing schemes specifically on but not limited to their biodiversity impacts.

The assessment of biodiversity impact of mining across direct, indirect and supply chain factors is complex, even more so when comparing to Scope 1, 2 and 3 emissions reporting. It is recognised that further research is required to gain a better understanding in measuring biodiversity impacts and continuous improvement of practices and principles in applicable standards need to take place. ICMM has recently released report on research findings on reducing mining waste in tailings, starting out with precision mining reducing actual impact and disturbance on the ground, and by extension waste materials to be generated.

It is noted that alum production represents only a small fraction of the demand for mined aluminium. Thus, Water Authorities are unlikely to have much power within the market to leverage producers to adopt better practices. The larger consumers are better positioned to drive change within the sector if needed.

5.5 Cost and supply of alum to water authorities

From the survey responses provided, the cost of alum in Victoria ranges from approximately $250 to $350 per tonne. This cost was consistent with the cost of alum in other states. The cost varies based on the amount of alum that is supplied, the volume per delivery, and the distance from the supplier to the point of use. Considering the overall consumption of alum in Victoria (refer section 6.1.4), it is estimated that the overall cost of alum supply in Victoria is in the order of $3M to $5M/yr.

Alum is currently supplied throughout Victoria from one of two locations: either the western suburbs of Melbourne, or Morwell location in the state’s east. The chemical is transported by suppliers using their own fleets of trucks, ranging from bulk 18kL and 10 kL tankers down to tray trucks that can be used for ‘milk runs’ to sites that required small volumes of chemical. Based on the size of the trucks available and the available storage volume, operators from water authorities are able to coordinate bulk deliveries. While bulk chemical deliveries from one tanker across

[8] Alan Andersen, Garry Cook and Nicholas Bax (July, 2014). CSIRO Biodiversity chapter 11, Mining and biodiversity

multiple sites are possible, this is not a common practice due to the volume requirements in tankers; each compartment in the tanker (i.e., 3 x 6 kL compartments in an 18 kL tanker) must be greater than 80% or less than 20% full. This is to prevent tank sloshing that can destabilise a tanker and lead to loss of control by the driver.

A key factor in the amount of alum that can be delivered is the amount of chemical storage on site. The survey results indicated that chemical storage varies between water authorities. Typical requirements are based on providing a minimum chemical storage volume to meet periods of both average and peak demand. Chemicals storage rules spanned the following periods:

– 14 to 40 days average demand
– 14 to 30 days at peak demands

In addition to these rules, the following approaches are commonly adopted for sizing chemical storage systems:

– Chemical storage tanks must align with available tank sizes provided by suppliers
– Dead volume in the bottom of a tank must be considered
– If possible, chemical storage volume should align with a typical delivery volume to allow a tanker to empty its entire contents per delivery. For sites with only one storage tank, allowance must be also made for a minimum working volume and trigger points for delivery

The optimisation of storage volumes with respect to chemical delivery sizes is an opportunity to reduce delivery costs and scope 3 carbon emissions associated with these deliveries. For brownfield sites, this must be weighed up against a number of factors, including suitability to augment existing storage systems, and the capital investment required for any augmentation.

Opportunity

Adding additional chemical storage capacity at sites may permit larger truck deliveries/less frequent deliveries. This would result in a lower cost and less and carbon emissions per tonne of alum delivered.

5.6 GHG emissions and industry carbon footprint

Mining and Refining

A 2022 report[9] by Deloitte for the Australian Renewable Energy Agency, in consultation with Alcoa, Rio Tinto and South 32, looks at the emissions for mining, refining, and smelting for the Australian Aluminium industry. For Alum especially the mining of bauxite and the refining of alumina are relevant.

It is reported that approximately 1 ton of mined bauxite contributes 3.92 kg carbon dioxide equivalent (CO_2-e) of emissions.

For aluminium refining it is approximated that 1 t of refined alumina has 713 kgCO_2-e of combined Scope 1 and 2 emission, 95% percent of the emissions are in scope 1.

Alcoa[10], the source of alumina used in Victoria, promotes low carbon alumina with a reported average emission intensity of no more than 600 kg CO2-e of with direct and indirect emission of bauxite mining and alumina, less than half of global industry average. For this study we assume this value as the baseline for calculations.

Alumina refining is considered hard to abate as the process is usually heavily relying on combustion of fossil fuels, and technology maturity and feasibility is lacking at this stage. Australian alumina production emissions are lower due to the fact that majority of fossil fuels use in the refining process in coming is natural gas rather than coal.

The major refiners in Australia have net zero ambitions and commitments for their organisations, in line with Australia’s net-zero commitment by 2050.

[9] A Roadmap for Decarbonising Australian Alumina Refining. (n.d.). Australian Renewable Energy Agency.
[10] Alcoa -- Sustana. (n.d.). Www.alcoa.com.

Transport

Estimated transport carbon emissions for the supply of alumina to Victoria and the supply of alum to WTPs is shown in Figure 5. To estimate carbon emission an emission calculator[11] was used obtain train and truck transport per ton:

– Aluminium hydroxide transported by train from Perth to Melbourne for processing is estimated to account for 0.39kt CO_2-e.
– The Victorian water sector currently uses an estimated 13 to 20 kt of alum each year which represents an estimated transport emission from suppliers to respective treatment plants of 2.84kt CO_2-e (Well-to-Wheel) [12] per year.

It can be seen that the distribution of alum by truck throughout Victoria is an order of magnitude larger than the transport of aluminium hydroxide to Victoria and is a potential area of focus to reduce carbon emissions associated with the production of drinking water.

Overall, the Victorian transport sector accounts for approximately 20.8 Mt CO_2-e[14], which is four orders of magnitude greater than the supply of alum throughout Victoria.

The coming decades are expected to show significant decarbonisation of the transport sector and respective vehicle fleets by replacing fossil fuels with green energy and may reduce these emissions. Nonetheless, the emissions and impacts of the alum supply chains (scope 3) should be considered by water authorities, despite being difficult to fully account for.

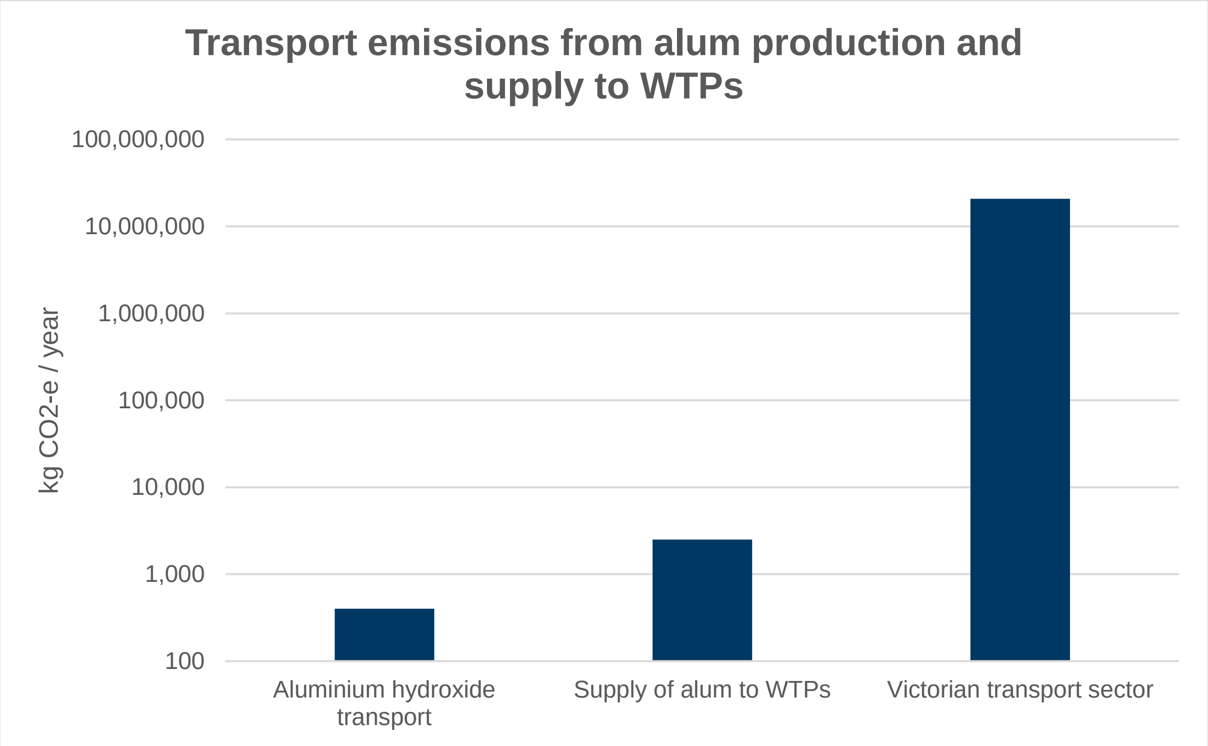


Figure 5 ***Carbon emissions from the supply and transportation of Alum in Victoria***

Treatment process

Limited studies exist that describe the emissions of coagulants where the raw material alumina holds and estimated 61% of the alum footprint[15]. While transport is the second most intensive component and therefore very variable depending on distribution regions.

[11] CO2 calculator of greenhouse effects for transport and logistics. (n.d.).
[12] CO2 calculator of greenhouse effects for transport and logistics. (n.d.).
[14] State and territory greenhouse gas inventories: annual emissions - DCCEEW. (2022). Dcceew.gov.au.
[15] Dr.-Ing. Justyna Homa and Prof. h.c. Dipl.-Ing. Erhard Hoff mann (2014). INCOPA LCA Executive Summary d04 ds.indd

Within the treatment process itself[16] the emission generation in the coagulation process is not significant in comparison to other emission sources, e.g., the electricity usage for the overall treatment process.

5.7 Human rights and modern-slavery implications

As described in section 3, another circular economy pillar to be considered is that human cultures and social cohesion are extremely important to maintain. In a circular economy, processes and organisations make use of appropriate governance and management models, and ensure they reflect the needs of affected stakeholders. Activities that structurally undermine the well-being or existence of unique human cultures are avoided even at high cost.

Mining activities are considered high risk in relation to human rights and modern-slavery implications across their operations, support services and supply chains[17].

In Australia the extractives industry is under close observation and scrutiny by government and civil society in relation to their practices founded in organisational culture, obligatory compliance, pledges of adherences to best practices in relation to human-rights, highlighting indigenous rights, as well as modern slavery considerations.

As in 4.4, international organisations, such as the UNGC and ICMM, as well as national organisations, such as Aluminium Stewardship Initiative[18] and the Minerals Council for Australia[19], have developed industry-recognised best practice principles for the extractives industry, in relation to ethical business incl. labour standards, human rights, and indigenous people engagement. Many large mining companies, such as bauxite mining and alum refining Alcoa of Australia, are signatories to these principles and are being scrutinised through obligatory and voluntary reporting and auditing schemes specifically on, but not limited to, their human-rights and modern-slavery compliance and continuous improvement thereof, both in Australia and overseas supply chains.

The assessment of human-rights and modern slavery implications in mining across direct, indirect and supply chain factors is complex. Extractives operation and support services in Australia are highly regulated and compliance is enforced. While relevant procurement policies are often in place a company has limited control and insights of their international supply chain, as Alcoa of Australia[20] reports in their Sustainability report. It is recognised that further research is required to gain better understanding in measuring human-rights and modern slavery implications and continuous improvement of practices, principles in applicable standards need to be an ongoing requirement.

Opportunity

It is suggested that water authorities could implement socially/environmentally conscious procurement practices that address some of these concerns. By requiring that their supply partners act in accordance with certain principles, upstream supply chain concerns may be avoided, and supply partners may be incentivised to improve practices.

It is noted that some procurement practices may already be in place, however, these could be extended to incorporate chemical procurement as well, if this is not already the case. While the key sources of alum supplied to the Victorian water sector come from Australia, future investigations may uncover that this is not true for other chemicals. As such, there may be social or environmental concerns associated with possible international sources that could be addressed by implementing procurement practices.

[16] Magnus Rahmberg, Sofia Lovisa Andersson, Erik U Lindblom and Kristin Johansson (2020, November). LCA analysis of different WWTP processes (ivl.se)
[17] Resources, energy and modern slavery: Practical responses to managing risks to people (2021) | Australian Human Rights Commission. (n.d.). Humanrights.gov.au.
[18] ASI Home. (n.d.). Aluminium Stewardship Initiative.
[19] Minerals Council of Australia (2020, October). Respecting human rights
[20] Alcoa of Australia Statement #2022-859. (n.d.). Modernslaveryregister.gov.au. (accessed May 2023)

6. Alum use by water authorities

6.1 Alum use in water treatment plants

6.1.1 Alum as a coagulant

In water treatment plants, alum is used as a coagulant for the removal of suspended and colloidal solids. This is particularly important when treating surface waters, but not as common for the treatment of groundwater.

When water is dosed with alum, a hydrolysis reaction occurs to form aluminium hydroxide flocs and hydrogen ions. The characteristics of the flocs that are formed (i.e., size and strength) can be modified or controlled through various mixing techniques. To further assist in the coagulation of particles, some treatment processes utilise a flocculant (e.g., the non-ionic polymer LT20) after the coagulation process. Conventional coagulation occurs at pH 7.5 to 5.8, and colour and colloidal matter is removed by adsorption to aluminium hydroxides. This is primarily practiced for optimal turbidity control.

After the coagulation/flocculation step, there is usually a clarification and/or filtration stage; agglomerated particles can be removed via sedimentation in a clarifier, forced to the surface and skimmed off (i.e., dissolved air floatation), and/or filtered through filtration media. The sludge that is collected from these processes must then be managed separately.

6.1.2 Alum dose rates

The required dose rate is driven by several key raw water characteristics which are outlined below. It should be noted that in any water treatment plant, the required dosage of coagulant cannot be determined with sufficient accuracy by calculation along due to the wide variance in the concentration and the nature of substances in the raw water. Jar testing is therefore essential in setting the dosage.

Turbidity and colour

Alum dose rates are primarily driven by the raw water turbidity and colour, with higher turbidity and colour yielding higher dose rates. The general effect of alum dosage on turbidity removal is shown in Figure 6, with increasing dosage resulting in lower turbidity once a minimum dose rate is achieved. For some WTPs, increasing the dose of alum has been reported to increase the turbidity after some minimum turbidity has been achieved. Table 3 below outlines typical expected alum dose ranges based on raw water turbidity and colour.

Table 3 Approximate alum dose rates based on turbidity and colour

Turbidity	Colour	Expected alum dose range, mg/L (100% $Al_2(SO_4)_3.18H_20$)
Low to high	Low	10 to 50
Low	High	40 to 120
High	High	100 to 300

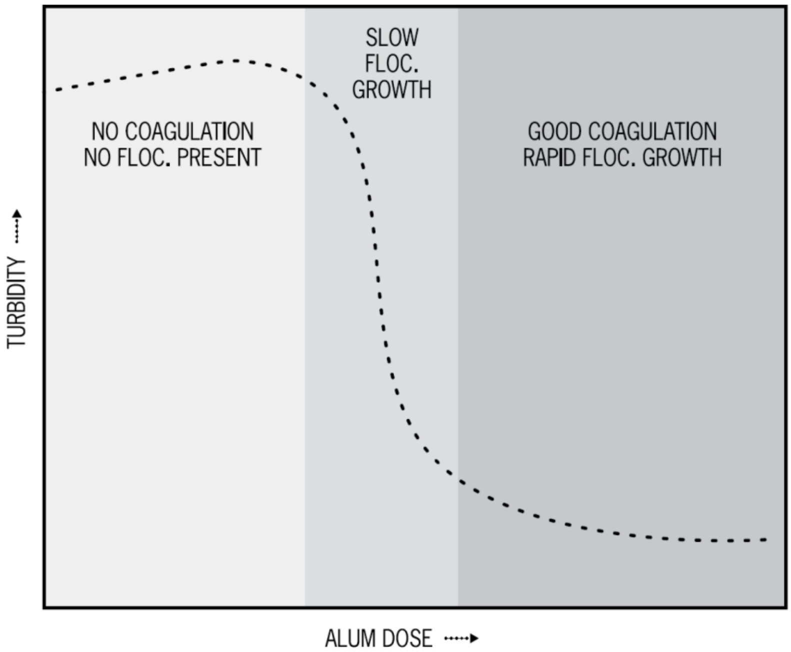


Figure 6 Alum dose rate as a function of turbidity

Ongoing operational experience may also be tapped into to optimise alum dose rates. This is essential to ensuring treated water quality targets are met.

Temperature

The temperature of clay colloids is affected by temperature; an increase in temperature lowers the required coagulant dose and broadens the pH range for effective coagulation (while also slightly shifting this pH range to lower values)

pH

The pH range in which coagulation process occurs is extremely important. Coagulant chemicals have their own characteristic optimum pH range and rate of floc formation. Like most other operating parameters, this can only be accurately determined by jar testing.

Alum acts as coagulant by effecting charge neutralisation of negatively charged particles through two possible pH dependent reactions. The pH of water dosed with alum decreases, due to hydrolysis to form aluminium hydroxide floc and hydrogen ions. The decrease in pH from alum treatment is considerably greater than from alternate polyaluminium coagulants due to the pre-hydrolysed form of these coagulants (for further details on alternative coagulants, refer to section 6.1.6).

The vast majority of coagulation problems can be attributed to improper pH levels. Whenever possible, coagulation should by conducted in the optimum pH zone. When this is not done, lower coagulation efficiency occurs, generally resulting in chemical waste and lowered water quality. For removal of clay colloidal turbidity, the range of pH is about 6.5 to 7.5. As described above, the usual working pH range for alum is from 5.6 to 7.5.

As alum is effective in a small pH range, pH correction is often practiced, typically using hydrated lime, soda ash or caustic soda. When these chemicals are not otherwise used on site, pH correction therefore introduces an additional chemical on site. However, in many cases, rather than complicate a treatment plant with the addition of acid, the pH can be lowered by simply increasing the coagulant dose, given that alum is weakly acidic. The lowered pH from the use of alum can also drive the requirement for post-treatment pH and alkalinity correction. This can be exacerbated for soft raw water with low alkalinity, where small variations in chemical dosing can result in relatively large changes in pH.

Enhanced coagulation occurs at lower pH (<5.0), in which aluminium ions directly neutralise the negative charged colloidal and organic particles. The primary purpose of enhanced coagulation is removal of dissolved organic matter, including disinfection by-product precursors and harmful organic micropollutants (e.g. pesticides, taste and odour compounds, algal toxins) (Freese 2001; Eikebrokk, Juhna et al. 2006). Other aluminium based coagulants may not be as effective in achieving enhanced coagulation to remove dissolved organic matter and disinfection by-product precursors. The implication of increased coagulant dosages required for this process is strict pH control and elevated sludge productions rates.

6.1.3 Raw water quality variability

There are many factors that affect the raw water quality, and for any given raw water source the variability in these factors drives changes in the alum dose rates within each WTP. It is good practice for WTP operators to constantly review changes in raw water quality and adjust alum dose rates accordingly to meet the desired treated water quality targets. Key factors that affect raw water quality are described below.

Source water category and catchment characteristics

Source water in Australian can be classified as Category 1 through to Category 4. These categories are determined by assessing the vulnerability classification of each catchment with the results of microbial monitoring data. Category 1 source water is considered fully protected and has the lowest treatment requirements, while category 4 source water is unprotected and has the highest treatment requirements. The key factors that will affect a catchments classification as Category 1 to 4 are:

– Human habitation
– Public access to water
– Stock access

The geographic characteristics of a catchment and the bathymetry of reservoirs also significantly affect raw water quality at WTPs, as these factors affects how easily and quickly contaminants can enter a water source and make their way to the inlet of a WTP following rainfall.

Wet weather events

Storms and other wet weather events often result in short term raw water turbidity spikes due to dirt and other particulate matter being flushed from catchments into streams, creeks, and reservoirs. The severity of the spikes will vary based on the size and characteristics of each catchment. These spikes are often managed by short term increases to coagulant dosing rates and reducing plant throughput so as to maintain treated water turbidity targets. Very large or prolonged events may significantly alter the water quality in a reservoir, resulting in long term changes (this has recently been observed for one treatment plant in NSW, which has had experienced ongoing poor raw water quality since 2020.

6.1.4 Alum dose rates and consumption throughout Victoria

Actual dose rates of alum vary across the state based on the quality of the water that is being produced. For example:

– Water sourced from the Otway System in the southwest of Victoria typical requires a dose rate of 18 to 35 mg/L
– Treatment of surface water from other reservoirs, rivers and creeks typically range from 20 mg/L to 80 mg/L. The highest known dose rates are in the order of 100 mg/L for some WTPs that treat water from the Murray River

Based on data these assumptions, as well as publicly available annual reports and water quality reports published by Victorian water authorities, estimated alum consumption rates throughout Victoria have been prepared. This is shown in Table 4, along with other information on the state of the Victorian water industry. Some key findings of this study pertinent to this review are outlined below:

– Alum is by far the most common coagulant for water treatment used throughout Victoria:
  - 43% of all WTPs use alum as a coagulant
  - All water authorities across Victoria use alum in at least one treatment plant, except for East Gippsland Water which only doses ACH at its WTPs
  - Approximately one third of all water produced in Victoria is dosed with alum

- Melbourne Water produces the largest volume of potable water in the state. However, due to the quality of the water from a number of its closed catchments, most of the water produced by Melbourne Water only undergoes chemical treatment (i.e., disinfection, fluoridation, and where required stabilisation with lime). This is a unique feature of Melbourne's water supply system, with most major cities around the world relying more heavily on coagulation for clarification and filtration
- Melbourne Water's only WTP that uses alum is the Winneke WTP, which treats water from Sugarloaf reservoir. Water in this reservoir can come from Maroondah reservoir (closed catchment) or the Yarra River (open catchment). This WTP is the single largest user of alum in Victoria by a considerable margin

Table 4 Water production and alum use in Victoria

Parameter	Unit	Value
Victorian WTPs (including disinfection plants and the Victorian Desalination Plant)	No.	208
Potable water produced in Victoria (2020/21)	GL/y	670
Victorian WTPs dosing alum	No.	88
Estimated volume of water dosed with alum	GL/y	230
Estimated annual Victorian alum usage	kt/y	13 to 20

Opportunity

It is noted that if Melbourne Water were to start treating and dosing alum to the Silvan water supply, this would result in roughly a doubling of the usage of alum by the Victoria water industry. Thus, ongoing catchment management is essential to reducing the likelihood of a deterioration in the water quality feeding Silvan and a future need for coagulant dosing.

Optimisation of alum dose rate

Alum dose rates are typically flow paced, with a dose rate set by the operator and the speed of the dosing pumps automatically adjusted to meet the dose date based on the flow rate through the plant. This method relies on operators routinely monitoring raw and treated water quality and adjusting the dose rate accordingly. One survey respondent indicated an ongoing trial of feed forward control for alum dosing, whereby the raw water quality is continuously monitored upstream of the dosing point, and the alum dose rate is automatically adjusted to meet the raw water quality. This has the potential to reduce the amount of alum that is used by only dosing what is actually required at any point in time based on the incoming raw water quality. This trial is ongoing, with further work required around the accuracy and reliability of the online monitors.

6.1.5 Impacts of alum use on water quality

6.1.5.1 Achieve health based targets

As described in the Australia Drinking Water Guidelines (ADWG), the supply of safe drinking water involves the use of multiple barriers to prevent the entry and transmission of pathogens. These barriers include the clarification and filtration treatment processes that rely on alum to for coagulation.

Dose rates of alum are set based on the factors described above to assist in achieving specific treated water turbidity (critical limits) downstream of treatment process units (e.g., clarification, filtration, membranes, dissolved air floatation). Turbidity is a widely used surrogate for the performance of these treatment processes and the pathogen removal that is achieved.

Changing specific treated water quality limits for turbidity could be considered to reduce alum dose rates and therefore the amount of chemical that is consumed. However, this may create a risk to public health; the clarification and filtration processes would not achieve the validated pathogen log reduction values (LRVs) as described in chapter 5 of the ADWG. Furthermore, disinfection processes downstream of clarification and filtration (e.g., chlorination and UV) rely on sufficiently low turbidity to achieve validated LRVs. Considering that sufficient LRVs are required (based on raw water quality) to meet the ADWG's health-based targets, a targeted approach to reduce treated water quality limits for turbidity would increase the risk to public health through a reduction in pathogen removal.

6.1.5.2 Residual chemical concentrations

The dosing of alum into raw water has the potential to increase the concentration of residual aluminium and sulfate in treated water. Table 10.6 of the ADWG provides guideline values for chemical characteristics in treated water. The table provides values for health and/or aesthetics; for both aluminium and sulfate no guideline value for health considerations has been set due to insufficient data. The following aesthetic based guidelines have been set:

Aluminium (acid-soluble): 0.2 mg/L

Guideline value based on post-flocculation problems; < 0.1 mg/L desirable. Lower levels needed for renal dialysis.

The ADWG describe negative post-flocculation effects if the concentration of soluble aluminium is greater than 0.2 mg/L, with potential to form an aluminium hydroxide precipitate in the distribution system. However, achieving this concentration target is readily achievable for a well operated filtration plant, even those that use alum for coagulation.

Sulfate: 250 mg/L

Natural component of water and may be added via treatment chemicals. Guideline value is taste threshold. Concentrations greater than 500 mg/L can have purgative effects.

It has been reported that on average, dosing with sulfate containing coagulants (e.g., alum) increase the sulfate concentration in the drinking water by four times the source water sulfate concentration[21]. Furthermore, for areas with drinking water dosed with alum, elevated concentrations of sulfate have been observed in sewage, with approximately half of this sulfate concentration attributed to coagulant dosing. This alum derived sulfate load therefore becomes the primary source of sulfide in these sewer networks. Considering the costs associated with sewer corrosion due to sulfide, a reduction in sulfate-based coagulants like alum presents an opportunity for significant savings in sewer repair costs.

Summary

Coagulation is often needed in water treatment trains where processes such as filtration and clarification are included. Alum is the most common and proven coagulant and required alum dose rates are driven by raw water quality.

6.1.6 Alternative coagulants

In Victoria, the second most commonly used coagulant is aluminium chlorohydrate (ACH). A range of other coagulants are also used across a small number of WTPs. Coagulants used in Victoria other than alum include:

- ACH
- Ferric chloride
- Ferric sulfate
- Polymerised ferric sulfate (PFS)
- Polyaluminium silicate sulphate (PASS)
- Polyaluminium chlorohydrate (PACl)
- Ultrion

The majority of alternative coagulants used in Victoria are other aluminium compounds which have been developed for improved performance compared to traditional inorganic coagulants of alum, ferric chloride and ferric sulfate. These alternate compounds are generally more expensive, mainly due to production using more expensive raw materials (metal aluminium and hydrochloric acid). However, these polymer-based coagulants can

[21] “Reducing sewer corrosion through integrated urban water management”, *Science 345,* No. 6198, 812-814

be more effective for potable water clarification for particular source waters, notably in cold temperatures and low alkalinity raw waters (ADWG 2011).

Some surveyed water authorities noted previous concerns with the use of ferric chloride as a coagulant due to issues with corrosivity or the introduction of iron residuals on pipes that can negatively affect water quality. Additionally, due to trace manganese present in ferric chloride, caution must be exercised when using higher doses so as not to affect the treated water.

Summary

The use of alternative coagulants may avoid the production of alum sludge. However, other aluminum-based or iron-based sludges are produced in place of alum sludge, representing a trade-off.

6.1.7 Alternatives to coagulation

The success of the conventional water treatment processes of filtration and coagulation rely on the use of a coagulant to remove colloidal matter from raw water and produce safe drinking water. However, based on the raw water quality, alternative processes that do not use coagulants may also be adopted to produce safe drinking water. In Victoria this is widely practiced with disinfection treatment plants treating:

- Surface water from a number of closed catchments surrounding Melbourne
- Groundwater from various aquifers throughout regional Victoria, in particular in the west and southwest of the state

Avoiding the use of coagulation in water treatment while ensuring the treated water remains complaint with regulations is thus only possible with certain raw water sources.

6.2 Alum use in wastewater treatment

6.2.1 Alum use as coagulant for nutrient removal

Similar to water treatment, chemicals can be added to wastewater for coagulation and precipitation processes. These chemicals aid in removing organic compounds and nutrients contained in wastewater. Alum is one of the most common chemicals added to wastewater primarily due to its ability to remove phosphorus. It has been used historically due to its ability to be incorporated in the treatment process easily and is typically highly effective.

Phosphorus is used by biological organisms for plant growth in the formation of DNA, cellular energy, and cell membranes. However, too much phosphorus in surface water can lead to increased growth of algae and aquatic plants which can decrease levels of dissolved oxygen and affect other aquatic life. In addition, algae blooms can produce algae toxins (such as cyanobacteria) that can be harmful to human and animal health.

Increasingly, water quality based effluent standards and limitations for total phosphorus discharged to surface waters from wastewater treatment plants are being implemented into wastewater treatment plant effluent discharge permits. Permit effluent limits have typical ranges between 0.1 to 1.0 mg/L of phosphorus, however, some areas with impaired waters are seeing limits below 0.1 mg/L. Acceptable levels of nutrients (such as phosphorus) vary and are usually assessed on a case-by-case basis to avoid excessive nutrient levels in the receiving water body.

The principal chemicals used for the removal of phosphorus from wastewater include:

- Aluminium sulphate (alum)
- Ferric chloride (ferric)

Chemicals are used to precipitate phosphorus into a solid form which in combination with tertiary filtration can reduce effluent phosphorus levels. Chemicals can also be dosed into secondary treatment processes, with removal of phosphorous in the biosolids wasted from the plant.

The high generation of sludge from chemical precipitation is one of the disadvantages of this method of phosphorus removal.

Generally, the dosage rate for ferric is less than alum but ferric is a corrosive acid and iron compound which makes it more difficult to handle for operators. In addition, in some areas, alum is more readily available.

6.2.2 Factors affecting alum dose

pH

The effectiveness of alum at low dosages is impacted in wastewater with high pH values, and pH control may therefore be needed to utilise low alum dosage.

Alkalinity

When using alum for phosphorus removal, sufficient calcium and magnesium bicarbonate alkalinity is required based on the alum dosage in order for a precipitate of aluminium hydroxide to form. If alkalinity is lacking in the wastewater, additional alkalinity will need to be added to provide phosphorus removal with alum.

6.2.3 Typical alum dose rates

The dose rate of alum is dependent on the amount of dissolved phosphorus present in the wastewater, the target phosphorus dose, and the stage of the process into which the alum is dosed (e.g., raw sewerage, secondary treated effluent, etc.). Theoretically, a stoichiometric dose of approximately 9.6 mg alum per 1.0 mg of phosphorus is required to precipitate phosphorus. Typical chemical treatment is assumed to require an alum dose considerably greater than the dosage suggested by stoichiometry based on all the other reactions that can occur with alum in wastewater. This is highlighted in Table 5 which shows typical molar ratios of aluminium in alum that are required to meet various effluent phosphorus concentrations. The lower the final effluent phosphorus concentration, the more alum that is required.

Table 5 Typical Al:P ratios required to achieve various effluent phosphorus concentrations

Effluent phosphorous concentration (mg/L)	Aluminium to phosphorus ratio
2	1.5
1	1.6
0.75	2.5
0.5	3
0.2	4

6.2.4 Alternatives to coagulation (other treatment processes)

In addition to chemical treatment, phosphorus can also be removed biologically. Biological removal involves creating a suitable environment for phosphorus accumulating organisms (PAOs) to uptake large amounts of phosphorus within their cells. Typically, this requires putting the wastewater through an anaerobic phase and then an aerobic phase. These organisms are settled or filtered out later in the treatment process. The volume of sludge production from the biological process is less than from chemical treatment.

Historically, wastewater treatment plants did not have appropriate reactor sizing and infrastructure to convert to a biological nutrient removal process. For brownfield sites, the retrofitting of additional reactors into an existing process usually adds more cost and complexity compared to the installation of chemical storage, chemical dosing and additional solids handling infrastructure. However, as chemical and sludge processing costs have risen, these enhancements are occurring more frequently at wastewater treatment plant upgrades to satisfy increasingly stringent effluent permit limits while reducing reliance on chemical dosing.

Summary

Coagulants such as alum and ferric are commonly used in wastewater treatment for coagulation and precipitation of organic compounds and nutrients. The efficacy of alum dosing is affected by pH and alkalinity and thus these parameters may need to be controlled to limit required alum dose rates.

Alum dose rates also depend on phosphorus levels in the wastewater and the desired effluent phosphorus concentration. Phosphorus may also be removed via biological treatment. Biological phosphorus removal generates less sludge compared to chemical (coagulant) removal.

7. Alum WTP solids disposal and reuse

7.1 Solids generation

7.1.1 Solids mass

As described in section 6.1.1, water that is dosed with a coagulant forms' flocs to remove colour and colloidal matter. These agglomerated particles are removed as sludge either via sedimentation in a clarifier, forced to the surface and skimmed off (i.e., dissolved air floatation), and/or filtered through filtration media. As a rule of thumb, for every mg/L of alum that is dosed, approximately 0.23 to 0.26 mg/L of aluminium hydroxide is produced. This is in addition to the solids that are generated from other chemicals or constituents in the raw water. Some general guidelines for solids production are outlined in Table 6. The estimated solids generation in Victoria due to aluminium hydroxide precipitation (as a direct result of alum dosing) is in the order of 2000 t/y.

From Table 6 it can be seen that alum (or other coagulants) only form part of the total solids that are generated; the raw water also contribute to the total mass of solids that are produced. That is to say, regardless of the coagulant that is selected, some minimum amount of solids will be generated based on the raw water quality. The total mass of sludge will then depend on the selection of coagulant, the dose rate of that chemical, and if any other chemicals are dosed (e.g. powdered activated carbon for taste and odour removal). It is important to note that while say ACH yields a higher sludge mass per litre, often lower dose rates of this coagulant are required to say alum, typically yielding a lower overall sludge mass.

Table 6 Guidelines for sludge mass production rates for various chemicals and raw water characteristics.

Parameter	Sludge mass production rate (mg/L per unit)
Chemicals	
Alum (as $Al_2(SO_4)_3.18H_2O$)	0.23 mg/L per mg/L
Alum (as $Al_2(SO_4)_3.14H_2O$)	0.26 mg/L per mg/L
ACH	0.89 mg/L per mg/L
Ferric sulfate (as $FeSO_4.7H_2O$)	0.38 mg/L per mg/L
Raw water characteristics	
Turbidity	1.5 to 2 mg/L per NTU
True colour	0.1 to 0.2 mg/L per Hu
Polymer	1 mg/L per mg/L

7.1.2 Water treatment plant solids quality

The quality of the solids is highly dependent on the quality of the source water, the quantity and purity of the alum, as well as other treatment chemicals used such as powdered activated carbon for taste and odour control, and polymer as a flocculation aid. Depending on the nature of the source water catchment, along with variations in seasons and weather conditions, the water quality parameters may be variable and susceptible to changes, both slow or sudden. These parameters include but are not limited to colour, turbidity, alkalinity, natural organic material, nutrients, iron, manganese and algae. Water authorities have identified heavy rainfall, algal blooms and the fluctuation in water demand as some of the key seasonal issues affecting sludge quality and quantity. WTPs that dose high levels of PAC will have vastly different solids quantities and characteristics to plants that do not. As the dosing of PAC is also seasonal, the quality and quantity of solids might fluctuate over the course of a year. This could result in an irregular feedstock for potential third-party beneficial reuse.

Water treatment plants will usually have an EPA licence with attached conditions that govern solids management and disposal. As such, issues relating to quality of the sludge and contaminants are considered alongside the licencing conditions. In cases where the alum containing WTP solids are sent to the wastewater treatment plant it may be managed under the wastewater treatment plant's licence conditions.

Contaminants of concern - PFAS

In recent years, increasing attention has been placed on potential contamination of water with per- and poly fluoro-alkyl substances (PFAS), with water authorities now undertaking some sampling for these substances. Raw water for drinking water has the potential to collect PFAS existing within the environment, and where PFAS is detected in high enough concentrations, specific treatment processes would be required to remove these to meet the ADWG (<0.07 µg/L) for the treated water quality. However, there are no water treatment plants in Victoria that currently have a dedicated PFAS removal treatment process. If a specific PFAS removal process was required, the sludge generated from this process would require dedicated disposal. Ideally, it would be managed separately from other sludge generated at a WTP to minimise overall sludge disposal cost and maximise potential beneficial reuse of sludge that is not contaminated with PFAS.

7.2 Solids management at WTPs

The sludge that is collected from clarification and filtration processes must be managed and disposed of. A typical sludge concentration is in the order of 0.1% w/v. There are a range of management processes that water authorities employ to manage this sludge, including:

- Disposal directly to sewer
- Settling and thickening in sludge thickeners or lagoons. Settled/thickened sludge is either disposed of to sewer or undergoes dewatering
  - The solids content of thickened sludge is typically 2-4% solids
- Dewatering of settled/thickened sludge using processes such as centrifuges, sludge drying bed and geobags. The solids content of dewater sludge is highly variable based on the method of dewatering:
  - Mechanically dewatered sludge (e.g. via a centrifuge) is typical between 17 to 23% solids. This dewatering occurs on a regular basis to continually manage sludge. Sludge that has been dewatered requires constant management and removal from site. WTPs that manage high solids loads may have several truck movements per day, while others may only require solids to be removed on a weekly basis
  - Sludge in lagoons or drying beds is estimated at 50-70% solids
  - Stockpiled sludge is estimated at >75% solids

Sludge from geobags, sludge lagoons, drying beds, or stockpiles is removed periodically, ranging from monthly for smaller volumes, to more than several years for lagoons and stockpiled solids.

7.3 Overview of disposal and reuse options

7.3.1 Water treatment plant solids management in Victoria

In Victoria, the surveyed water authorities indicated that sludge is typically disposed of to landfill or to sewer. There is insufficient data available to provide a breakdown of the amount of sludge that is disposed to sewer compared to landfill. However, based on the survey results it is evident that the majority of WTP sludge in Victoria is sent to landfill, regardless of the coagulant that is used.

While the overall volume of sludge generated in Victorian WTPs is unknown, based on the approximate alum consumption in Victoria it is estimated that the amount of sludge generated from alum only (i.e., precipitated aluminium hydroxide) is in the order of 2000 tonnes per annum.

Water treatment plant solids management in other states

Of the several survey respondents from outside of Victoria, disposal to landfill was the predominant disposal method. However, there are notable cases of beneficial reuse or in Queensland and NSW, where some sludge is diverted for land application as a soil ameliorant, soil conditioner, additive in compost, landscaping and gardening.

Further to this, water authorities are actively pursuing investigations in the following reuse areas:

- Compost additive in green waste
- Brick manufacturing

– Wetland construction
– Road base
– Alum recovery from sludge

These reuses are detailed in the following sections.

7.3.2 Disposal options

The sections below describe a range of options that can be considered for the disposal of WTP solids. While many of these options are also applicable to water treatment plant solids produced with different coagulants, the focus of this report is the management of solids generated from alum.

Disposal to landfill

From a circular economy and waste management hierarchy perspective, disposal to landfill is the least desirable option for sludge management. Despite this, disposal to landfill is widely practiced in Victoria.

The total amount of sludge that is sent to landfill depends on two key factors:

– The sludge mass that is generated, which is variable based on the factors described in section 7.1.1
– The dry solids content that is achieved, which is variable based on the onsite sludge management processes in place at each WTP (refer section 7.2). While a higher dry solids content is desirable to reduce the overall volume of sludge that is sent to landfill (and hence transport/disposal costs), this requires greater capital investment and ongoing costs

Survey respondents indicated sludge transport distances to landfill in Victoria from < 20km, ranging up to 200 km (this is the equivalent of transporting sludge from Melbourne to Sale, Shepparton, Ararat, or Camperdown).

While not practiced in Victoria, water authorities also have the option of stockpiling sludge in a self-managed landfill. This is a more complex solution than disposal to landfill, as it requires additional capital investment and ongoing operating costs. This option is more likely to be attractive to water authorities with smaller volumes of sludge and those that are able to purchase sufficient cheap land relatively close to the WTP.

Disposal to sewer

Many WTPs in Victoria dispose sludge directly to sewer after some initial settling/thickening process. This allows for the return of supernatant from this process to the head of the WTP for reprocessing (increasing overall water yield) and reducing the volume of water that is sent to the wastewater treatment plant. However, there are instances of sludge treatment processes being disposed of directly to sewer.

While disposal to sewer reduces the complexity of sludge management at the WTP, the management of the additional solids and water is transferred to the WWTP. Some WWTPs are more suited than others to manage the additional volume and solids from a WTP, however this is not a suitable option for all WWTPs. In recent years there have been several instances of WTPs undergoing works to improve their onsite sludge management to reduce the hydraulic and solids load at the WWTP and throughout their sewer network.

Despite the additional flow and solids load to WWTPs, disposal of alum containing WTP solids to sewer can have several benefits:

– Phosphorous uptake in the sludge, potentially reducing the phosphorous concentration in the effluent at the WWTP and therefore reducing reliance on other phosphorous removal processes. A study published in 2020 showed that the dosing alum containing WTP solids was effective in removing phosphate at a ratio of 0.29 mg P/mg Al[22]. Note that this is lower than phosphorous removal using alum, which is in the order of 0.77 mg P/mg Al when removing phosphorous in effluent down to concentrations of approximately 2 mg/L
– If there is insufficient space at the WTP to effectively manage sludge, disposal to sewer also presents a simple and inexpensive method of transporting alum containing WTP solids to a WWTP that may be better suited to manage the sludge

[22] Chemical Engineering Journal 387, (May, 2020) "Effects of dosing iron- and alum-containing waterworks sludge on sulfide and phosphate removal in a pilot sewer "

Section 7.4 describes the management of biosolids, which incorporates alum containing WTP solids disposed to sewer.

Reuse at WWTPs

Similar to sewer disposal, directly importing alum containing WTP solids to wastewater treatment plants can be considered for the removal of phosphorous. The benefit of direct reuse at WWTPs is that the sludge can be directed to the specific process where it is required to maximise the potential phosphorous removal, hence reducing the reliance on other phosphorous removal processes. However, the additional solids load on the WWTP will also increase, increasing the volume of biosolids produced.

Kang et al. investigated the potential of re-using alum containing WTP solids as a substitute for traditional coagulant-flocculant agent in an animal farm wastewater treatment facility[23]. The process was reported to be effective at the laboratory-scale. At a dosing rate of 1200mg/L alum containing WTP solids, the removal of phosphate was 96.9%.

7.3.3 Recovery of alum

A previous study by GHD considered the reuse of alum, and in particular alum recovery from WTP solids. Acid digestion of sludge was evaluated as being potentially cost-effective, particularly where CAPEX for new treatment plants could be reduced through cost avoidance, and where local restrictions or cost increases for sludge disposal were envisaged. Further examination of this process at a pilot-scale at an applicable plant could be performed, which could lead to a more accurate and specific estimation of financial feasibility that incorporates local factors.

The alum recovery using acid digestion would comprise:

– Acid digestion reactors and antifoam water spray systems
– Sulphuric acid dosing system
– Residuals thickener
– Neutralisation tank and lime dosing system
– Polishing filter and recovered liquid alum storage
– Hydrogen peroxide dosing system

Alternatively, a hydrothermal process for recovery of alum is possible, however it is complex, experimental and may not increase alum recovery significantly beyond what can be accomplished via acid extraction.

7.3.4 Environmental reuse

Land application/agricultural reuse

Land application of alum containing WTP solids is a commonly practiced beneficial reuse method in Australia which has benefits of improving soil structure and pH, supplementing trace elements and increasing moisture holding capacity and soil aeration. In a review by Zhao et al. (2018), it was found that out of 35 case studies conducted on land application, 21 reported positive results while 14 reported negative results.

– Research has shown that alum containing WTP solids can be reused as a suitable plant growth medium, in particular due to its moisture retaining capacity[24]
– Alum containing WTP solids that have some alkalinity (e.g., as a result of lime dosing in the WTP) may be useful in providing buffering capacity to prevent acidic soil. As aluminium is known to inhibit plant growth in acidic soils, this buffering assist in hindering the aluminium in the sludge from inhibiting plant growth
– A study by Kluczka et al.[25] reported despite alum containing WTP solids containing significant quantities of aluminium, it was still suitable for agricultural applications as only approximately 10% of the total aluminium were in bioavailable form in soil pH not lower than 5.6

[23] Journal of Water Process Engineering 46 (April, 2020) “Use of aluminium-based water treatment sludge as coagulant for animal farm wastewater treatment”,
[24] News. (n.d.). CQUniversity Australia.
[25] Environmental Monitoring and Assessment 189, (July 2017). “Assessment of aluminium bioavailability in alum sludge for agricultural utilization.”

Alum containing WTP solids may be applied directly to land or blended with other organic material. A number of companies throughout Australia accept WTP solids for land application.

Land remediation and pollutant removal agent

Chemical immobilisation is an in-situ remediation approach that can make use of inexpensive waste material such as alum containing WTP solids. It can be applied to solids contaminated with heavy metals to reduce their solubility and bioavailability, converting them from labile forms to more stable forms. A study by Elkhatib, E.A and Moharem, M.L[26] (2015) reported that using an application rate of 8% alum containing WTP solids by weight of sandy soil, extractable copper, lead, and nickel were reduced by 68%, 85% and 87%, respectively.

In industrial wastewater treatment processes, heavy metals such as zinc, copper, lead, chromium, mercury, cadmium and arsenic are of major concerns. A review by Nguyen et al.[27] has shown the potential for alum containing WTP solids to be used as a low-cost adsorbent to remove heavy metal pollution from soil and water bodies. It demonstrated good adsorption capacity towards heavy metals, with the highest for mercury (79mg/g), followed by cadmium (25 mg/g) and lead (21.75 mg/g). Zhou and Haynes[28] also reported the use of alum sludge to be effective in the removal of chromium and lead in a batch-testing solution. Similarly, Castaldi et al[29] investigated the sorption capacity of alum containing WTP solids towards lead and copper.

Several processes have also been reported in the recent scientific literature for processing alum sludge as a primary or secondary product that can be used as a landfill cover material. Rosli et al.[30] (2020) reported the use of sewage sludge and red gypsum as a temporary landfill cover, with an optimum mix of sludge and red gypsum in a 1:1 ratio.

Use in constructed wetlands and control of phosphorous runoff

Alum containing WTP solids can be incorporated into the substrata of constructed wetlands, utilising its adsorptive capacity to remove nutrients from wastewater streams such as phosphorous. Hernandez-Crespo et al.[31] described its use in pilot constructed wetlands in two wastewater treatment plants in Valencia, Spain. The results found that under continuous flow, the constructed wetland yielded a reduction of 62%, 8%, 23% and 40% in total phosphorous, total nitrogen, COD and BOD, respectively. The potential release of aluminium was also negligible.

Further to this, in a study by Ippolito[32], the use of alum containing WTP solids in a study investigating urban phosphorous runoff found a 60% reduction in the amount of phosphorous leached.

[26] "Immobilization of copper, lead, and nickel in two arid soils amended with biosolids: effect of drinking water treatment residuals", Journal of Soils and Sediments (April 2015), 1937-1946
[27] "Beneficial reuse of water treatment sludge in the context of circular economy" *Environmental Technology & Innovation* (November 2022)
[28] "Removal of Pb(II), Cr(III) and Cr(VI) from Aqueous Solutions Using Alum-Derived Water Treatment Sludge", *Water, Air & Soil Pollution* (June 2010)
[29] "Copper(II) and lead(II) removal from aqueous solution by water treatment residues", *Journal of Hazardous Materials 283 (*November 2015)
[30] "A mixture of sewage sludge and red gypsum as an alternative material for temporary landfill cover" *Journal of Environmental Management 263* (June 2020)
[31] "Valorisation of drinking water treatment sludge as substrate in subsurface flow constructed wetlands for upgrading treated wastewater" *Process Safety and Environmental Protection 158* (February 2022), 486-494
[32] "Aluminium-Based Water Treatment Residual Use in a Constructed Wetland for Capturing Urban Runoff Phosphorus: Column Study" *Water, Air & Soil Pollution 226* (September 2015)

Summary

Environmental reuse options include:

Land application/agricultural reuse

This is the most practised beneficial reuse method in Australia. It enhances soil properties and promotes plant growth. Various companies throughout Australia accept WTP sludge for land application.

Land remediation and pollutant removal agent

Alum sludge can be used to adsorb heavy metal contaminants in soil, thus reducing their solubility and bioavailability.

Use in constructed wetlands and control of phosphorous runoff

Alum sludge's adsorptive capacity to remove nutrients means it can be incorporated into the substrata of constructed wetlands for wastewater treatment or used as a phosphorus adsorbent to control runoff.

7.3.5 Manufacturing and construction

Cement manufacturing

During cement production, materials such as limestone, shale and clay are supplemented as a source of calcium, silica, aluminium, and iron. Alum containing WTP solids typically contains some or all these supplementary elements and can be added during the manufacturing process. The use of alum containing WTP solids can reduce the manufacturing cost by reducing the volume of other supplementary materials which would be required. Various studies have reported on the benefits of adding these solid to the cement manufacturing process. Liu et al.[33] investigated the use of a combination of alum containing WTP solids and limestone as 30% cement replacement in a ratio of 1:1 and 2:1, respectively. The study found an improvement in the mechanical performance of the cement-based mortar in terms of compressive strength, flexural strength, and water absorptivity.

Brick manufacturing

In brick making, there is potential for partial substitution of conventional raw materials with coagulant residues due to the similarities in their physical and chemical properties. The residues can be optimally introduced into the brick making process during the stage where other raw materials are crushed and blended, after which the remainder of the process remains unchanged.

Areias et al.[34] conducted a case study on the potential for alum containing WTP solids to be directly added to clay bricks from 6 WWTPs located in the city of Campos dos Goytacazes, Brazil. The study found that a 15% addition by weight of these solids and a firing temperature between 850 to 950°C was the maximum found to still produce clay bricks that attend to the Brazilian standards for linear shrinkage, water absorption and mechanical strength. Moreover, the high firing temperature was sufficient to burn organic matter and eliminate potential pathogens, as well as release heat that contributed to 40% saving in firing energy. The overall process was reported to produce inexpensive clay bricks with a price of 16% of a concrete brick or 20% of a common clay brick fired at higher temperature.

In Europe, an initiative by the Public Buyers Group (comprising of AquaMinerals, De Watergroep and Scottish Water) has resulting in the recent awarding of a contract to Netics B.V. to develop bricks from alum containing WTP solids. The process trialled by Netics BV requires no kiln or furnace, reducing the overall energy requirements in the manufacturing process[35].

[33] "Modification of microstructure and physical properties of cement-based mortar made with limestone and alum sludge" *Journal of Building Engineering 58* (October 2022)
[34] "Could city sewage sludge be directly used into clay bricks for building construction? A comprehensive case study from Brazil", *Journal of Building Engineering 31* (September 2020)
[35] Alu Circles: Pan-European innovation partnership procedure boosting the circular economy. (n.d.). Allied Waters.

Soil stabilisation

Soil stabilisation is a fundamental requirement prior to the development and construction of road infrastructure. Alum containing WTP solids can be used as an inexpensive soil stabiliser to help increase soil strength, replacing other stabilisers such as cement, as well as offers a sustainable waste management solution that can establish circular economies. In a study by Aamir M et al.[36], an application dose of 8% of dry soil by weight produced a 10% improvement in the soil bearing ratio. In addition, maximum dry density, optimum moisture content and plasticity index were also at maximum levels.

Summary

Alum containing WTP solids may be incorporated alongside conventional materials into cement and bricks as it has similar physical and chemical properties. The is advantageous to manufacturers as it not only reduces production costs by reducing the volume of supplementary materials required, but can also improve the mechanical performance of the materials. It may also be used as an inexpensive soil stabiliser prior to the development and construction of road infrastructure.

Opportunity

Water authorities could release an "Expression of Interest" to the market offering their alum sludge to other parties free of charge/accompanied by a small payment. This may help to draw out potential parties in the area who are able and willing to receive the sludge for various reuse applications.

7.3.6 Waste management hierarchy considerations

Some of the solids management strategies considered in this report are analysed with respect to the waste management hierarchy, which gives the preference of the different waste management approaches. This is presented as Figure 7.

The waste hierarchy is one of eleven principles of environment protection contained in the *Environment Protection Amendment Act 2018*. EPA Victoria's program to control wastes is based on the hierarchy in order of preference as shown in . In essence, the hierarchy describes that the best way to manage waste of all types is to stop its generation in the first place, with treatment and disposal the least preferred approach.

Further to the waste management hierarchy, EPA Victoria sets out laws about managing industrial waste in the *Environment Protection (Industrial Waste Resource) Regulations 2009*. These regulations outline requirements for industrial waste producers:

- Assess whether there is an opportunity to avoid the production of waste, or if that is not possible reduce the production of waste
- Where avoidance or reduction opportunities are not available, assess prescribed industrial waste for the potential for reuse or recycling
- Where potential for reuse or recycling (or technology and facilities necessary to realise this potential) are not practicably accessible, assess prescribed industrial waste for potential for treatment or reprocessing

When considering solids generated by water treatment plants, these regulations are applicable for wastes with any contaminant concentrations or leachable concentrations resulting in categorisation as category A, B or C waste, as specified in EPA Victoria's *Solid Industrial Waste Thresholds.* Biosolids from wastewater treatment plants are considered as a prescribed industrial waste.

The circular economy review in this project is complemented by the waste management hierarchy, which can be used to highlight intervention points in the alum value and use cycle and to apply circular economy thinking.

[36] Aamir M et al. (June, 2019). "Performance Evaluation of Sustainable Soil Stabilization Process Using Waste Materials", *Processes 7*

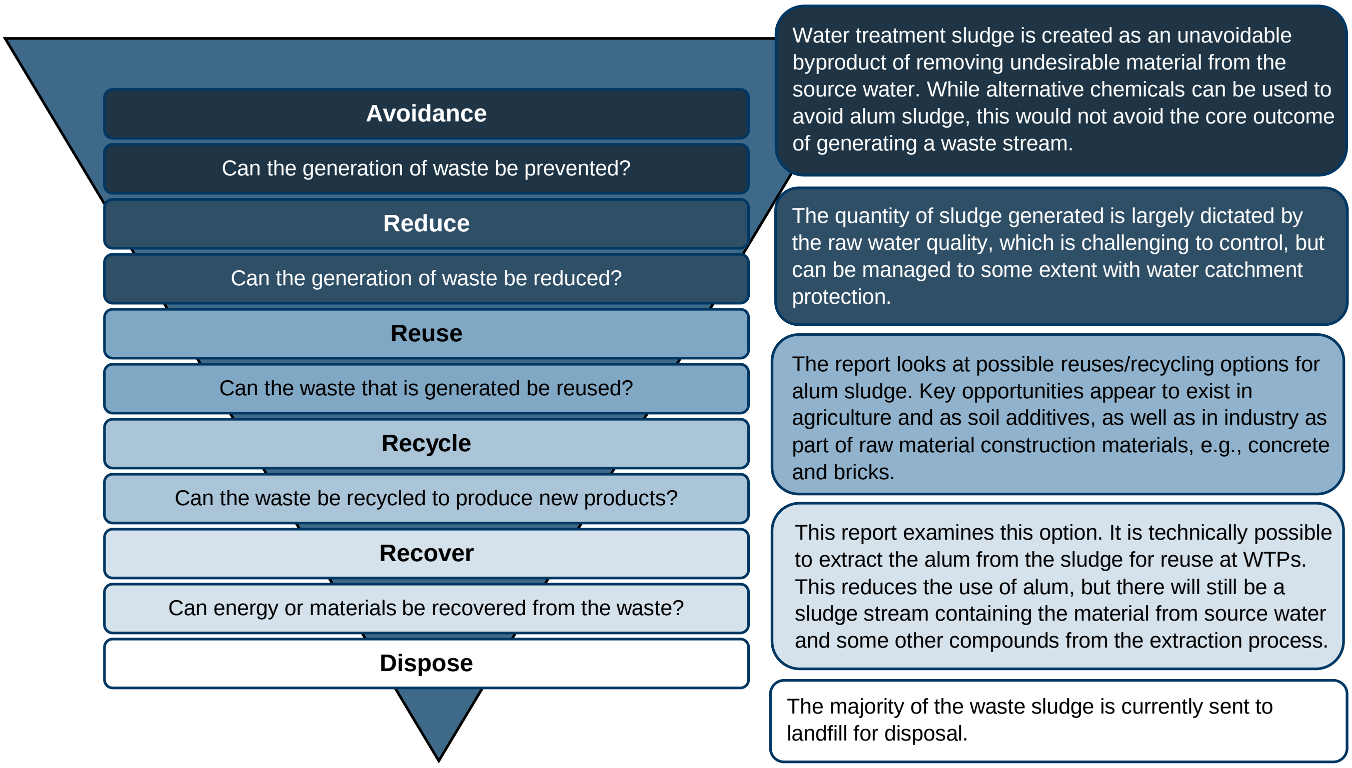


Figure 7 Waste management hierarchy considerations

7.3.7 Consideration of drivers for disposal and reuse

When determining how to manage solids generated at a WTP, there are a range of factors that must be considered. As noted in section 7.3.2, when considering disposal to sewer or landfill there is a trade-off between the % dry solids that can be achieved, and the cost required to reach the % dry solids. However, a number of other potential reuse options existing and there are a range of factors that must be considered when determining how sludge can be reused or disposed.

Cost

Cost is one of the primary factors in determining the preferred disposal route solids disposal. Options must be cost effective for water authorities. Costs that must be considered include:

- Capital cost of infrastructure to manage solids, e.g., mechanical equipment, holding lagoons or drying beds, land purchase, etc.
- Operating cost of solids management, including (where applicable):
  - Labour for operation of processes
  - Chemicals, e.g., polymers that are used to assist in thickening
  - Electricity, e.g., for operation of mechanical thickening equipment
  - Desludging of holding lagoons and drying beds
  - Transport of solids and gate fees for accepting sludge. These fees are often a function of the distance from each WTP to the disposal site, the volume of sludge and the constituents of the sludge (i.e., is the sludge prescribed industrial waste)
  - Revenue earned from the sale of solids for beneficial reuse

Existing WTP solids management processes

For existing water treatment plants, the ability to change to a different reuse or disposal option may be constrained by the existing solids management processes, and the ability of that site to expand these processes. When augmenting existing water treatment processes, emphasis is usually placed on ensuring the water treatment plant has or will have sufficient capacity to meet the required water demand over time, and that this water is safe to drink. The management of solids, while a key part of the overall treatment process, is more easily neglected as the optimisation of this system does not necessarily directly affect the volume and quality of the drinking water that is produced. Nonetheless, capacity constraints in the solids management system can affect the ability of a treatment plant to operate at its nameplate capacity, and poor performance can lead to additional operating costs.

Sludge volume and reuse demand

The volume of sludge produced at each WTP, or by individual water authorities, can have a large significance on the ability to dispose or reuse that sludge. Considering beneficial reuse, the challenge for water authorities is finding opportunities that are able to accept variable sludge loads over time due to:

– Variable WTP production levels to meet seasonal water demands (e.g., high water volumes in summer)
– Changing water quality throughout the year
– Changing water quality over time in response to long term weather patterns (e.g., periods of long drought followed by heavy rainfalls may cause long term worsening of water quality)
– Suitable stockpiling of sludge may be beneficial to allow balancing as solids loads change

General environmental duty

Water authorities have obligations under the recently introduced Victorian Environmental Protection Act (2017) as part of the General Environmental Duty (GED) to understand and minimise the risk of harm to the environment and human health. This is more pertinent for the management of biosolids rather than WTP solids, however this should be considered for contaminants in the solids that may drive classification of the solids as prescribed industrial waste.

Supernatant management

As the dry solids contents increases, additional water that is removed=, known as supernatant, must be managed. Supernatant from water treatment plants requires careful consideration, as if the supernatant is recycled back into the treatment plant any pathogens that end up in the supernatant are also recycled back into the plant.

7.4 Management of biosolids

Alum containing WTP solids that are disposed to sewer must eventually be managed with biosolids from a WWTP. The management of biosolids is more complex than WTP solids due to pathogen loads in the biosolids, and is subject to several Acts, including the *Environment Protection Amendment Act 2018*. Guidance for the application of biosolids to land in Victoria is provided in EPA *Victoria's Guidelines for environmental management: Biosolids land application.*

There is also growing concern about PFAS contamination in biosolids. The latest draft National Environmental Management Plan on PFAS (NEMP 3.0) includes limitations to the application rate of biosolids contaminated with PFAS. Further to this, water authorities have obligations under the recently introduced Environmental Protection Act (2017) as part of the GED to understand and minimise the risk of harm to the environment and human health. These two factors have the potential to affect the disposal options for biosolids contaminated with PFAS.

Due to the complexity of managing biosolids, to derive the most value from alum containing, typically the most preferred solution is to segregate alum sludge from biosolids. i.e., manage alum sludge at the WTP. The management of alum sludge that is incorporated into biosolids (i.e., disposal to sewer) may increase the infrastructure requirements at a WWTP due to higher flows and loads, and a greater volume of biosolids that must be appropriately managed or stockpiled.

8. Recycling Victoria goals

The Victorian State government has a number of policy goals related to recycling and the circular economy. The following table summarises the concepts explored in this report against some of these goals.

Table 7 Responses to Recycling Victoria goals

Goal	Report response
1. Design to last, repair and recycle. Generate less waste in businesses through innovation and design; use recycled materials in products and consider impacts across product life cycles; and support business to explore new circular economy business models.	The production of waste sludge (for any chemical used as a coagulant including alum) is largely driven by the water quality from the source, and the drinking water guidelines and regulations. Therefore, there is limited opportunity to reduce the amount produced. The report explores two issues in this area: 1. A large volume of water is not currently filtered in Melbourne due to the protected catchments, and that if this changed, the volume of sludge produced would increase significantly 2. Alternative chemicals and treatment processes would change some characteristics of the sludge, but not significantly alter the quantity Note also that increasing population and increasing use of water will also lead to increased sludge production. (If this demand were to be met via seawater desalination a similar sludge would be produced, which is salty, and is not addressed in this report as alum is not used.) One possible effect of climate change is accessing poorer water sources, which could lead to a relative increase in sludge production.
2. Use products to create more value. Help people make smart purchasing decisions and extend the life of products and support the reuse economy; repair goods where possible.	This is not explored as the provision of safe drinking water is a core service needed by society. There are initiatives more generally to explore if there are ways to reduce water consumption while maintaining the value it provides, and these (if successful) would have the flow on effect of reducing alum sludge quantities.
3. Recycle more resources. Reform kerbside collections to generate more value from waste; improve the separation of recyclable materials; develop markets for recovered materials; plan for and boost investment in recycling infrastructure; embed the waste hierarchy in the management of materials; support the development of appropriate waste to energy facilities.	The potential to recycle/reuse/find benefits for alum sludge is the key topic explored in this report. In very brief summary, opportunities do exist, but they are location specific and subject to wider economic factors.
4. Reduce harm from waste and pollution. Protect communities and the environment from high-risk and hazardous wastes.	This is explored to some degree. Note that the presence of problematic substances in the sludge reflects their origin in catchments, and that better land management overall would have positives impacts in this area. However, water authorities have limited control over this, and therefore the sludge composition is hard for them to control. Management of the sludge is managed through the EPA and therefore GED best practices must be followed.

9. Circular economy review

9.1 Overview

The purpose of this section is to summarise the conceptual interventions available, and to outline some of the opportunities and constraints which arise when considering them. This section tries to use a jargon free approach to explanation to illustrate the key points.

This section should be read together with the more detailed discussions in the report, as it simplifies many issues.

9.1.1 Objectives of considering Circular Economy interventions

Different circular economy systems have different metrics. Broadly, they commonly adhere to the following principles as established by the Ellen MacArthur Foundation (EMF) and promoted by the Water Services Association of Australia (WSAA):

1. Can we reduce the use of resources or designing out waste?
2. Can we keep resources in use and reduce carbon footprints?
3. Can we regenerate natural systems?

A 'circular' system can achieve all of these. Also note the word 'economics' - for interventions to be successful, it is helpful if they are economically viable.

In this report we have also considered the question of immediate practicality: i.e., is there an opportunity to execute the intervention at the scale needed?

9.1.2 Interventions/scenarios to change status quo

There is unlikely to be a universally applicable single best way to reuse sludge, with local factors heavily influencing any reuse option. The scenarios will therefore look different for each water authority based on their location, sludge volume, chemical consumption, etc…

Can multiple interventions be done at once?

It is useful to consider this point, as there may be cases where interventions are synergistic, and others where they are not.

To illustrate:

– Changing supply of alum from liquid to solid could be matched to changing the final use of the sludge, as the sludge composition will not change in this case.
– Re-using alum around the plant (covered in the report) will lead to a different sludge composition and therefore different final disposal considerations.

Are there 'Trigger Points' which would lead to particular interventions?

In broad terms there are different kinds of trigger points which might arise:

– A policy change which in itself (or indirectly through pricing) makes current practices impractical. For example, any change which constrained (or made much more expensive) landfill disposal would lead to consideration of many different interventions
– A change in broader economics elsewhere. For example, it could be that sustainably sourced bricks start to command a much higher price, and that alum sludge became an attractive feedstock
– A technology innovation. New water treatment processes could arise which need much less coagulant

Part of moving toward a circular economy approach will involve tracking trends in all these areas, rather than accepting the current approach as the ongoing approach for the future.

9.1.3 Circular economy criteria

A circular economy assessment of various scenarios is presented in the following sections. For each scenario (excluding business as usual), a qualitative assessment has been completed against the following criteria:

- **Impact potential**, include scale required, emission reduction, social and environmental benefits
- **Implementation,** including complexity, cost and time frame for value creation
- **Market Readiness**, including market potential, maturity and accessibility of technology, revenue potential, policy, and legal compliance

A traffic light assessment has been used to qualitatively score the performance of each option against the circular economy criteria. Below defines the scoring system

Table 8 Traffic light assessment legend

Colour	Definition
	Good
	Moderate
	Poor

9.2 Scenario 1: Business as usual

9.2.1 Scenario description

The current scenario in Victoria with regards to alum is described in the sections above. Further context is provided here considering the circular economy aspects of this scenario.

9.2.2 Supply

Figure shows a breakdown of estimated alum supply for WTPs by water authority. There are only two alum suppliers in the state. As noted in section 5.3, a disruption to either one of these suppliers for more than approximately month may start to impact on the quality and production of water in Victoria. The Sankey-Diagram in Figure 8 highlight the scale of alum supply originating from these two suppliers in Victoria, their distribution across water authorities and then on to their respective water treatment plants. The Sankey Diagram, read from left to write and bottom up, shows the largest alum supplier and water authority on the bottom, with decreasing quantities going up.

It can be seen that across the five largest water authority users of alum, the alum usage is dominated by one or two treatment plants, with the overall Victorian usage concentrated across less than ten sites.

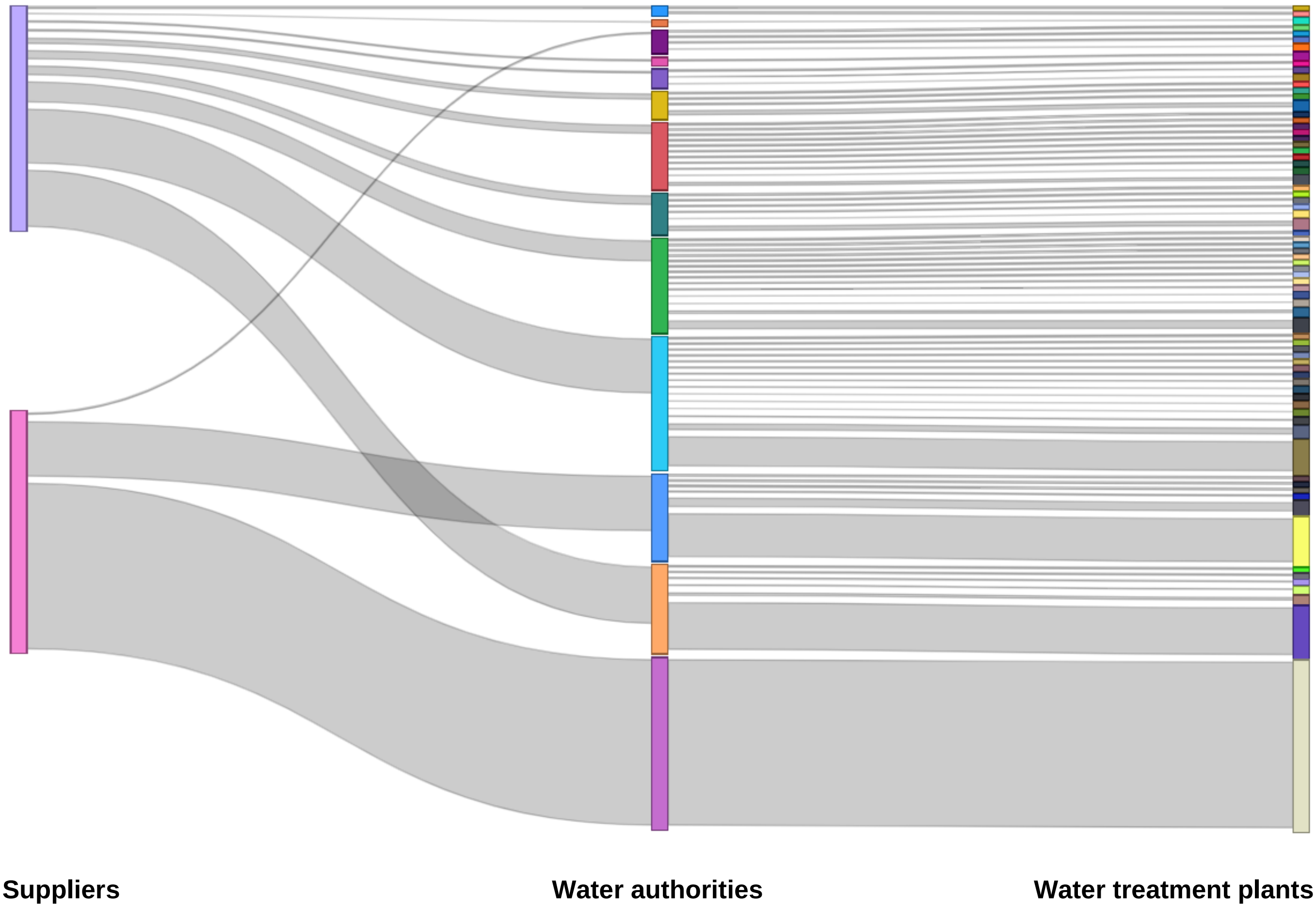


Figure 8 Estimated alum supply and use in Victoria by supplier and water authority

The estimated carbon footprint for the supply of alum to Victorian WTPs is presented in Figure 9. This estimate has been prepared based on the transport by truck from the alum supplier in Victoria to each WTP. The proximity from each WTP to the supplier has shown to be a large contributing factor to carbon emissions; Melbourne Water is the largest user of alum in Victoria due to its usage at the Winneke WTP, however the carbon emissions associated with supply to site are equivalent to Lower Murray Water who uses approximately one third of the alum.

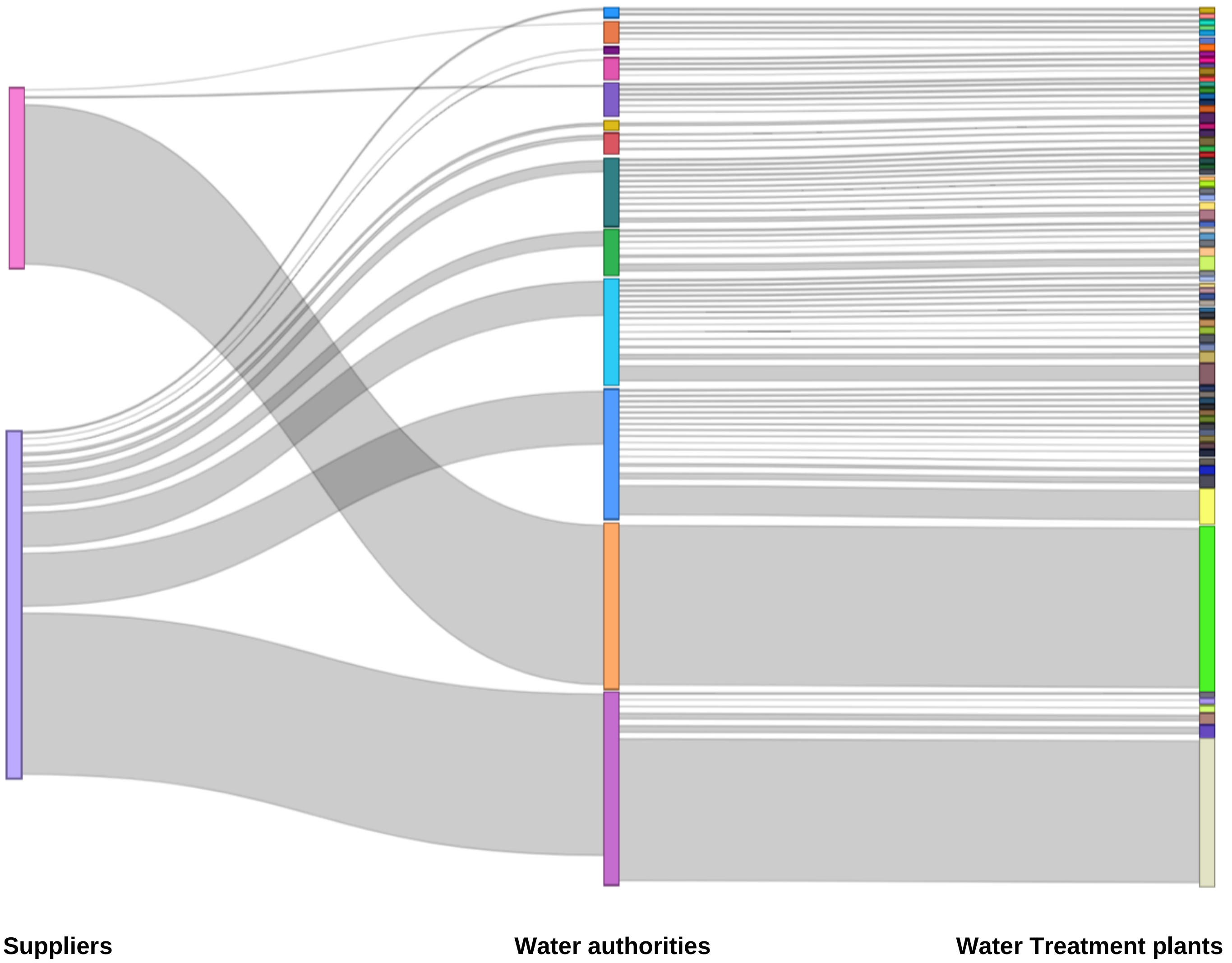


Figure 9 *Estimated carbon footprint associated with the supply of alum to Victorian WTPs (delivery transport by truck only)*

Figure 10 provides a summary of the estimated alum use and carbon footprint distribution for Victorian Water Authorities. In relation to different scenarios mapped out in the subsequent chapters, this illustrates how other factors impact must be considered in recovery and redistribution for recycling, remanufacturing and reuse itself. Where circular opportunities are identified, these may fall short on the basis of carbon footprint due to the geographic location of each WTP and the end use markets. Crucially, detailed studies are required to fully understand the circular impacts of any change, including transport emissions to current land-fill sites and ongoing costs through handling, processing, transport and landfill levies. Section 10 outlines a case study for Wannon Water with regard to some of these considerations.

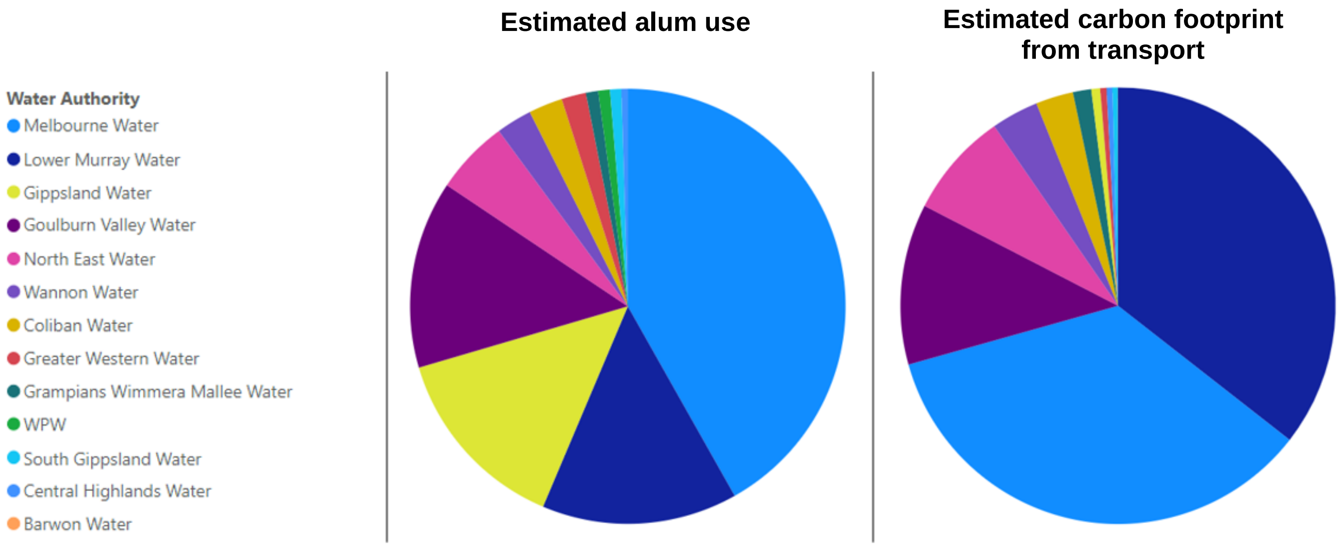


Figure 10 ***Estimated alum use distribution in Victoria by water authority (left) and estimated carbon footprint associated with the supply of alum to Victorian WTPs by Water Authority (delivery transport form local supplier only) (right)***

9.2.3 Use in WTPs

A summary of alum in WTPs in Victoria is provided below.

– Alum is the most common coagulant for water treatment used in Victoria. East Gippsland Water is the only water authority that does not use alum in any of its WTPs, instead using ACH as a coagulant.
– Approximately one third of all water produced in Victoria is dosed with alum. This is dosed at an estimated 88 WTPs (43% of all WTPs)
  - The median alum use per WTP is in the order of 25 kL/y
  - Approximately 80% of alum use in Victoria spread across a handful of major WTPs that supply the urban areas of Melbourne, Euroa, Shepparton, Morwell/Traralgon, Moe, Mildura, Wodonga, Warrnambool and parts of the Macedon Ranges. The remainder of alum use is spread across a large number of smaller WTPs
  - Melbourne Water's only WTP that uses alum is the Winneke WTP, which treats water from Sugarloaf reservoir. Water in this reservoir can come from Maroondah reservoir (closed catchment) or the Yarra River (open catchment). This WTP is the single largest user of alum in Victoria by a considerable margin
  - Melbourne Water produces the largest volume of potable water in the state. However, due to the quality of the water from a number of its closed catchments, most of the water produced by Melbourne Water only undergoes chemical treatment (i.e., disinfection, fluoridation, and where required stabilisation with lime). This is a unique feature of Melbourne's water supply system, with most major cities around the world relying more heavily on coagulation for clarification and filtration
– The amount of alum used in a function of the volume of water produced and the water quality. Actual dose rates of alum vary across the state based on the quality of the water that is being produced. For example:
  - Water sourced from the Otway System in the southwest of Victoria typical requires a dose rate of 18 to 35 mg/L
  - Treatment of surface water from other reservoirs, rivers and creeks typically range from 20 mg/L to 80 mg/L. The highest known dose rates are in the order of 100 mg/L for some WTPs that treat water from the Murray River
– As described in section 6.1.5.2, dosing with alum (or other sulfate containing coagulants) increase the sulfate concentration in the drinking water. While this meets drinking water requirements as part of the ADWG, this has been shown to increase concentrations of sulfate in sewage compared to areas that do not use sulfate containing coagulants. The alum derived sulfate load may become the primary source of sulfide in these sewer networks, which may have considerable effects on sewer corrosion

Figure 12 shows the approximate location and order of magnitude of annual alum consumption for WTPs in Victoria.

9.2.4 Disposal

WTP sludge in Victoria is almost exclusively disposed to landfill or sewer. For disposal to sewer, the sludge is then managed with the biosolids.

- There are no regulations or legislation that drive beneficial reuse of alum sludge
  - In Queensland, an end of waste (EOW) code exists for water treatment residuals. EOWs specify outcomes that need to be achieved for a waste to be deemed a resource and are issued in accordance with the Queensland *Waste Reduction and Recycling Act 2011*
- When alum sludge is disposed to sewer and ultimately managed with biosolids, the management of the biosolids becomes bound up with issues pertaining to biosolids management. This then becomes a complicated problem bound up in the issue of biosolid management
  - When considering the management of biosolids, presently the most challenging contaminant of concern is PFAS, with PFAS becoming a limiting factor in the disposal of biosolids. NEMP guidelines describe how much can be applied to land, and there is now growing interest in the water industry for the pyrolysis of biosolids to managing this emerging risk
- Disposal of alum sludge to sewer may have benefit in the removal of phosphorous from the sewer network, however this is difficult to quantify
- Water authorities may elect to dispose of solids to a self-managed landfill to minimise ongoing levies for landfill disposal. Depending on the location, this may also reduce greenhouse gas emissions associated with transport. This requires additional capital investment and ongoing operational costs. Seqwater in Queensland currently disposes of some of its WTP solids at a self-managed landfill

As described in section 7.4, due to the complexity of managing biosolids, to derive the most value from alum sludge, typically the most preferred solution is to segregate alum sludge from biosolids. i.e., manage alum sludge at the WTP rather than disposal to a WWTP. However, there may be some instances where a WTP is unable to manage sludge and sewer disposal is a preferred option. This must be considered on a case-by-case basis.

There is a significant cost associated with the disposal of WTP solids to landfill. The current Victorian landfill levy rates for industrial waste are $129.27/tonne for metro areas and $113.69 for rural areas. As shown in Figure 11 these costs have almost doubled since 2021/22, and almost tripled since 2011/12.

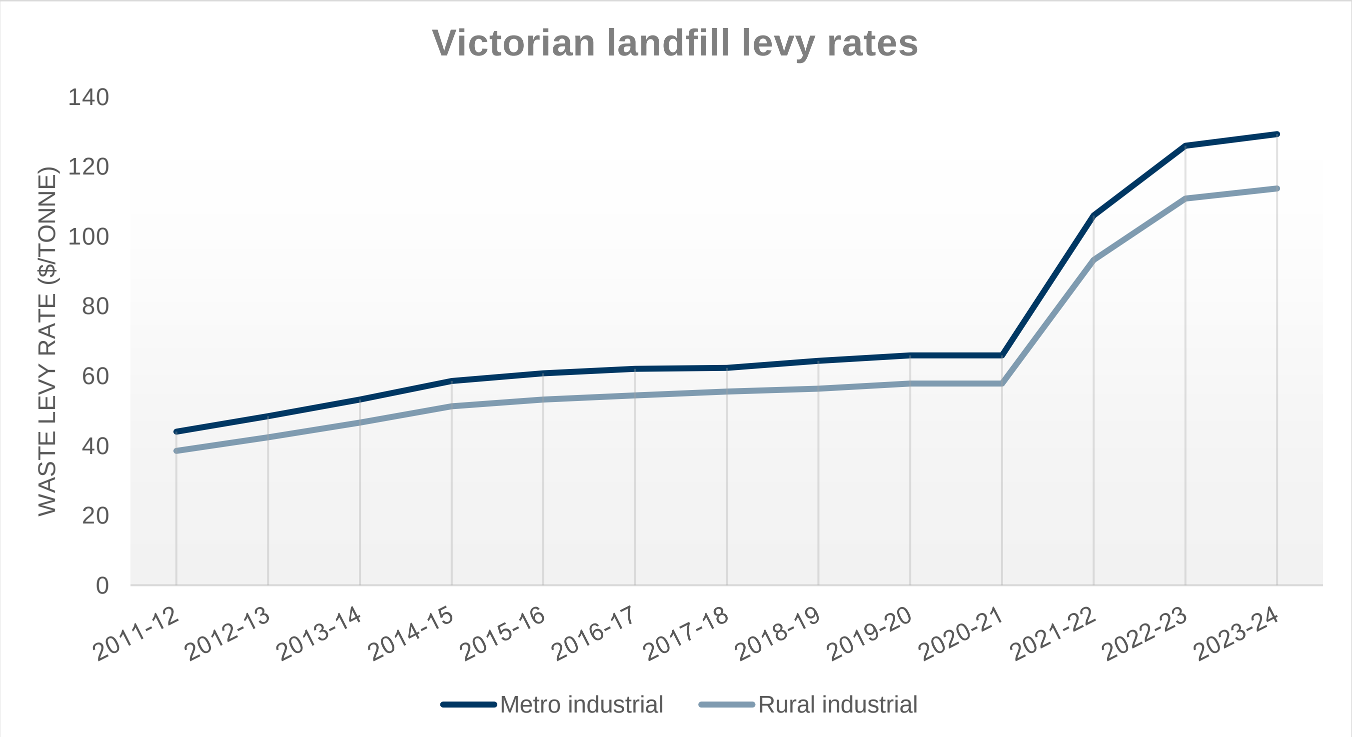
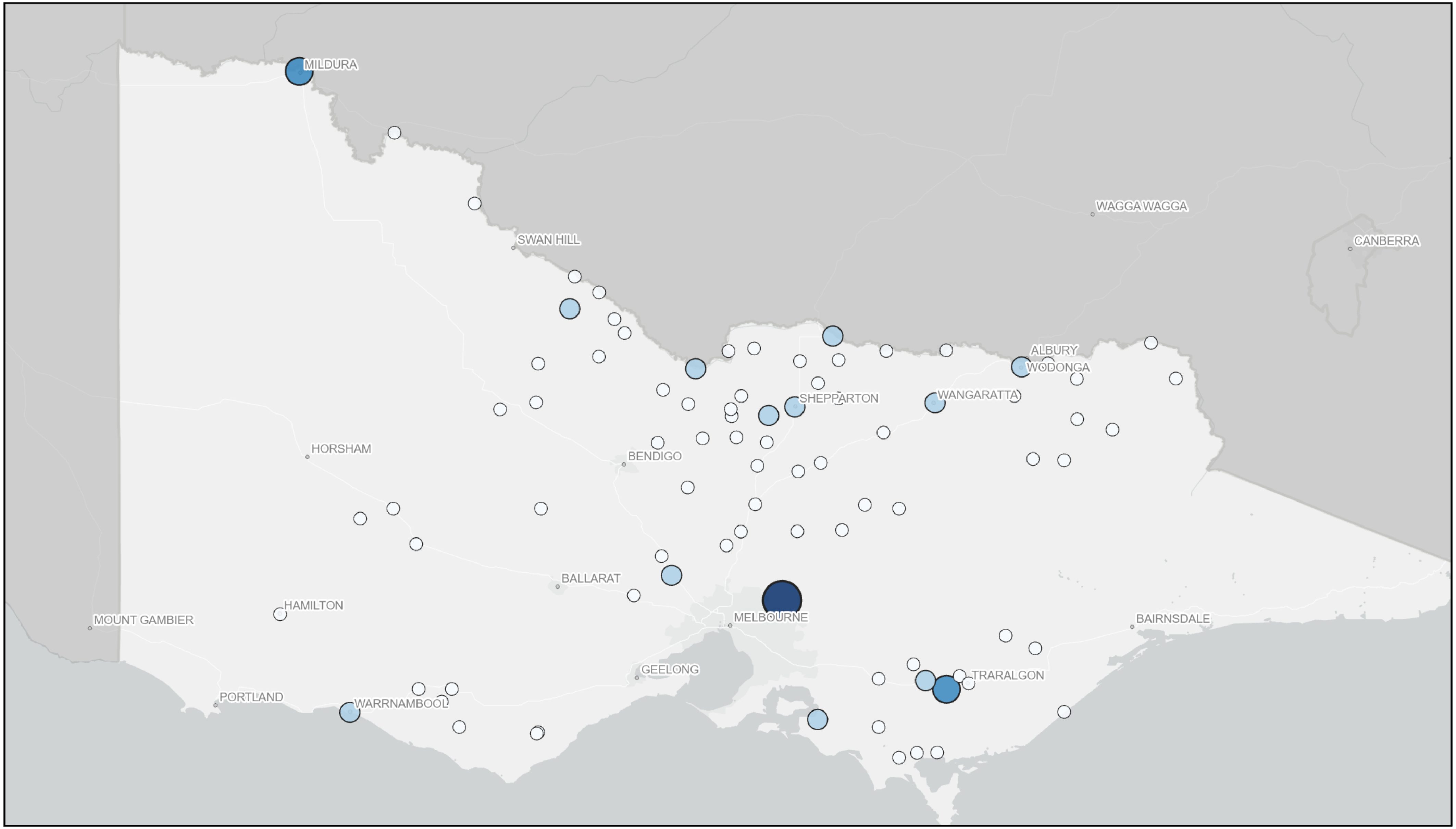


Figure 11 Historical Victorian landfill levy rates



Legend

- Township

Approximate Annual Alum Consumption (kL)

- <100
- 100 - 1000
- 1000 - 5000
- >5000

Paper Size ISO A4

0 50 100

Kilometers

Horizontal Datum: WGS 1984
Grid: GCS WGS 1984

N

GHD

Wannon Water
Alum Use in the Victorian Water Sector

Approximate Annual Alum Consumption in WTPs

Project No. **12587588**
Revision No. **0**
Date **18/08/2023**

FIGURE 11

Data source: Light Gray Base: Vicmap, Esri, HERE, Garmin, FAO, NOAA, USGS,VicMap, DEECA;Wannon Water,2023; GHD,2023. Created by: cjauniau

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Print date: 18 Aug 2023 - 14:51

9.3 Scenario 2: Alum sludge for environmental reuse

9.3.1 Description

This scenario considers the continued use of alum as a coagulant, with a focus on avoiding landfill and instead maximising potential environmental reuse opportunities (which are described in section 7). Due to a wide range of factors, e.g., location and sludge volume, the beneficial reuse options under this scenario will vary for each water authority.

Much of the alum sludge currently produced is sent to landfill, either directly, or as part of biosolids disposal. In principle, it could be sent to use on agricultural land, either directly or post processing to form part of a soil conditioning material. Environmental reuse of WTP sludge is practiced throughout Australia, with examples of partial or almost full reuse in NSW and Queensland. However, there is little reuse in Victoria. An opportunity exists for water authorities, particularly those in regional areas, to work with local soil suppliers to allow beneficial reuse of WTP sludge. As described in section 7.3.4, this includes opportunities for the following:

Land application

This includes the application of WTP sludge for agricultural purposes. The key benefits can include improved soil structure and pH, supplementing trace elements and increasing moisture holding capacity and soil aeration. Sludge is often blended with other soil materials, but also has potential to be applied directly to land. For this reuse option, water authorities would need to supply sludge to specialist soil and land remediation companies for further processing.

Use in constructed wetlands

This considers the incorporation of alum sludge into the substrata of constructed wetlands. This has greatest potential in large growth areas such as Melbourne and Geelong where urban expansion is increasing the volume of stormwater that is generated and must be managed. Melbourne Water, as both a producer of alum sludge and a manager of stormwater, is in a unique position to consider further investigations for this beneficial reuse option.

9.3.2 Key risks and limitations

There are number of key risks and limitations for environmental reuse:

Sludge quality

There are some benefits from adding the material to land, but there are also some limitations depending on the acidity of the soil and the amount of lime in the sludge. This creates additional management requirements for the farmer or end user, which may not match the perceived benefits.

Sludge volume

Each beneficial reuse requires a water authority to find a third party that can accept the volume of sludge that it is trying to manage. Reuse options therefore become more limited as sludge volumes increase at larger WTPs. The end use may also not be continuous and potentially will be seasonal, and therefore some form of storage will be needed to create a balance. Water authorities may need to consider multiple options for sludge management, which increases operational complexity for water authorities.

Variable sludge volumes throughout the year, as well as over time with changes in water quality, must also be considered. This may be mitigated by stockpiling of sludge during times of increased sludge volume or having multiple sludge management options.

Third party reliance

There is an inherent risk in water authorities relying on a third party to accept a waste product, as the viability of the sludge management options relies on the viability of the third party’s business, and their capacity to accept variable sludge loads. The quality of the sludge produced may also inhibit reuse by certain end users.

The primary mitigation measure against third party reliance is having multiple and diverse options for sludge management and reuse, even if only one is practiced at any one time.

One alternative mitigation measure is for water authorities to manage their own beneficial reuse by developing a separate part of their business dedicated to sludge reuse. This is not dissimilar to the development of organic processing facilities by some Victorian water authorities, which produce energy from biosolids and other organic material. This option is likely to be attractive for larger authorities that both manage larger volumes of alum sludge and are able to provide dedicated resources.

Location

The location of the end use is a limiting factor in that increased trucking distance for sludge will increase costs. Notwithstanding future advancements in trucking and associated emissions, greater transport distances also increase the carbon footprint of this solution. The total distance of trucking to send the material for reuse may exceed existing distances of going to landfill. If the trucking has a carbon footprint, this may mean agricultural use has a higher carbon footprint and greater costs.

WTPs in regional areas that located closer to soil suppliers and potential end users (e.g., farmers) are more likely to find land application favourable. Conversely, it may be found that for WTPs located in expanding urban areas, the reuse of alum sludge for constructed wetlands is a preferred solution. However, in all circumstances the rigorous analysis of reused options is required to determine a preferred solution for each WTP or each water authority.

Summary

The benefits and costs for environmental reuse for land application are summarized below in Table 9.

Table 9 Summary of benefits and risks of land application of alum sludge for various entities

Entity	Benefits	Costs/risks
Water Authority	Potential cost savings or profits depending on arrangement	A gate fee could be required, the ability of the third party to accept the sludge may change
Land remediation company/farmer	Improved soil quality, improved crop yields	Variable sludge quality may affect usability which leads to additional management requirements/testing
Community	Sludge is diverted from landfill meaning more landfill space is available	Contaminant levels in soils need to be managed to protect the local community

9.3.3 Trigger points

Environmental reuse of alum sludge currently occurs in Australia, indicating that there is no single trigger point that must be met to make this a viable option. As highlighted in the case study below, reuse of WTP sludge is already proven to be a preferred option for some applications, however detailed studies are required to identify and realise these opportunities.

The rising cost of landfill shown in Figure 11 is likely to be a key trigger point for water authorities, with the current total cost of WTP solids disposal to landfill for Victorian water authorities estimated to be in excess of $1M.

These opportunities may be further aided through regulations or legislation (such as the Queensland End of Waste Codes) to encourage further beneficial reuse.

9.3.4 Circular economy criteria

From a circular economy perspective, this scenario prolongs use of alum through beneficial reuse on land instead of non-beneficial end-of-life solutions, i.e., landfill. The quantification and balancing of benefits in relation to emission reduction, valorisation through agricultural products and other environmental benefits is highly dependent on location and purpose.

Impact potential

- Under this scenario the upstream value chain is not impacted. In relation to the waste management hierarchy there is a potential to reuse sludge with minimal input of energy, with the exception of processing and transport
- Potentially all sludges can be used for suitable land management purposes such as land application and use in constructed wetlands. The avoidance potential to landfill is not yet quantified
- The number of truck movements for solids reuse is not likely to be greatly impacted, as WTP disposal volumes remain similar (unless additional drying is undertaken prior to transport)
- Based on the location of the reuse option, the total distance may increase to distribute products. Overall the carbon footprint is unknown with the downstream value chain of distributions, but ideally this should be better than existing. The carbon footprint may change in the future based on the extent of decarbonisation withing the transport industry. The location of the alternative reuse option is likely to be a key factor in determining impact potential
- While there is evidence of beneficial use for farmers and other land managers, the impact potential is highly dependent on location and for what purpose sludge is being reused. Where sludge can be applied with no negative environmental impact and supported by enabling policy and community acceptance, there is opportunity to reduce pressure on landfill (which serves as a 'last resort' end-of-life solution)

Implementation

- Where products are deemed suitable, sludge (and products derived from sludge) could be easily distributed and supplied through third party providers and business partners in the resource management sector. Cost is likely to be the most significant factor when providing consistent or tailored products for specific applications, and logistical requirements related to their distribution
- Depending on enabling policy, regulations, and acceptance, which are often the biggest impediments in the productisation of 'waste' resources, implementation may require medium-term time frames

Market readiness

- While it is not clear if revenue can be generated, even the reduction of cost to pay to a third party to accept materials versus the cost for landfill is worth consideration and may yield a net cost benefit
- Research and pilot projects are progressing with proven market potential and accessibility, especially when the sludge source is located in regional areas close to the potential destination. The maturity is still developing with uncertainties in relation to the regulation around productisation of waste and the scalability of managing large volumes of material on an ongoing basis

The traffic light assessment for the circular economy criteria for environmental reuse is shown in Table 10.

Table 10 Circular economy criteria for environmental reuse

Circular Transition Category	Criteria	Traffic light assessment
Impact potential	Scale, emissions reduction potential, social and environmental benefits	Moderate
Implementation	Complexity, cost, timeframe to value delivery	Moderate/Good
Market readiness	Revenue opportunity, market potential, maturity and accessibility, policies and legal compliance	Good

9.3.5 Case study

As part of the development of a new WTP in Australia, a multi-criteria assessment for WTP sludge management was undertaken to determine a preferred option. An overview of the considered options and the key drivers and outcomes is presented below.

Sludge management options overview

There were ten shortlisted options for sludge management considered in the assessment. They were as follows:

1. Self-managed landfill
2. External nearby landfill
3. Quarry – pipeline
4. Quarry – trucking
5. Agricultural reuse
6. Turf growing
7. General farmland – client purchases farm
8. General farmland – farmer takes sludge
9. Mine
10. Co-disposal with other nearby WTP

Note that details have been omitted due to project confidentiality.

Drivers and outcomes

The three highest ranking options from the assessment were:

– Option 5: Agricultural reuse
– Option 8: General farmland – farmer takes sludge
– Option 7: General farmland – client purchases farm

All of these options represent a form of recycling or beneficial reuse of the sludge. The preferred option was seen to be transporting the sludge to a local soil regeneration company for conversion to a composting product. This company focuses on recycling and revegetation and would use the sludge as an input into their production process. Options 7 and 8 involve application of the sludge to soil as a conditioner/ameliorant.

The key driving factors underpinning the outcome of the assessment are the OPEX and risks of losing the disposal location or insufficient capacity of the location to receive the sludge. Hence, not only do these reuse options present benefits in terms of ongoing sludge management costs, but they also provide more secure and robust sludge receival into the future.

It is also noteworthy that with respect to Net Present Cost (NPC), all three reuse options ranked highly, while options 1 and 2 (sending the sludge to landfills) were the two lowest ranking options. Accordingly, in this case financial benefits were able to be realised while simultaneously moving up the waste hierarchy to avoid disposal in favour of reusing.

Key takeaway

While the sludge management options assessment for this particular site highlighted that various reuse options are preferred to the alternative possible disposal methods, this may not always be the case. Detailed studies like the one above are required to identify and realise these opportunities. In this case, the proximity of the sludge source to the reuse facility and to general farmland is key in supporting the feasibility and favourability of these options.

9.3.6 Other Australian examples

In addition to the case study above, a number of recent projects have been undertaken throughout Australia by various water authorities investigating the potential for environment reuse of water treatment plant sludge:

- As part of a study on the phytotoxicity effects of alum sludge on plant growth, a research project was undertaken by Simon Clements at Seqwater's North Pine Water Treatment Plant to understand whether alum sludge could be used as an effective plant growth medium. The trial found that alum sludge was able to assist in plant growth for certain species
- Icon Water has conducted a successfully trial of composting water treatment solids with garden waste, with various ratios of solids and garden waste trialled. With certain ratios of garden waste and sludge, the blends were able to reach suitable temperatures for composting, with the composted material having good moisture retaining properties. With further processing, there is potential for this product to be made available commercially
- SAWater is conducting a number of trials with water treatment plant solids, with the aim of reuse for land rehabilitation

9.4 Scenario 3: Reuse for construction materials

9.4.1 Description

This scenario considers greater beneficial reuse of alum sludge through incorporation into construction materials. As described in section 7.3.5, this includes opportunities for the following:

Cement and brick manufacturing

During cement production, materials such as limestone, shale and clay are supplemented as a source of calcium, silica, aluminium, and iron. Alum sludge typically contain some or all these supplementary elements and can be added during the manufacturing process to reduce the manufacturing cost by reducing the volume of other supplementary materials required.

In brick making, there is potential for partial substitution of conventional raw materials with coagulant residues due to the similarities in their physical and chemical properties. The residues can be optimally introduced into the brick making process during the stage where other raw materials are crushed and blended, after which the remainder of the process remains unchanged.

Road infrastructure

Soil stabilisation is a fundamental requirement prior to the development and construction of road infrastructure. Alum sludge can be used as an inexpensive soil stabiliser to help increase soil strength, replacing other stabilisers such as cement, as well as offers a sustainable waste management solution that can establish circular economies.

For these scenarios, dried WTP sludge would be supplied to a dedicated manufacturer to develop materials for construction.

9.4.2 Key risks and limitations

There are number of key risks and limitations for environmental reuse:

– **Sludge volume**
– **Third party reliance**
– **Location**

As described in section 9.3.2, the variable volume of sludge that is produced, reliance on a third party to accept sludge, and the location of the WTP are key limiting factors. In particular, the proximity of a WTP to areas undergoing urban expansion, or close to existing materials manufacturers, may limit sludge reuse in manufacturing as a preferred solution for a WTP or water authority.

Construction material properties

While research has shown potential for alum sludge to be reused as a construction material, further research and development is required to produce materials with suitable properties for specific end uses (e.g., strength, corrosivity, hardness, density, etc.).

Summary

The benefits and costs for reuse for construction materials are summarised below in Table 9.

Table 11 Summary of benefits and risks of alum sludge reuse in construction materials for various entities

Entity	Benefits	Costs/risks
Water Authority	Potential cost savings or profits depending on arrangement	A gate fee could be required, the ability of the third party to accept the sludge may change
Construction material producer	Improve physical properties of materials, lower production costs	Additional testing may be required to ensure sludge properties are suitable for incorporation into materials and that material properties are adequate
Community	Sludge is diverted from landfill meaning more landfill space is available	The product quality and performance must be validated to ensure the materials are not compromised and pose risks to the community

9.4.3 Circular economy criteria

From a circular economy perspective, this scenario repurposed/recycles alum through incorporation into a new long-life product via recycling opportunities at the end of product life. The quantification and balancing of benefits in relation to emission reduction, and the reduction of the raw material value chain for building and infrastructure materials is highly dependent on the location of where the end products will be used. This will also depend on the total and material amount that can be viably recycled.

Impact potential

– Under this scenario the upstream value chain is not impacted. In relation to the waste management hierarchy there is a potential to recycle by incorporating sludge into a new long-life product. Energy requirements for processing and transport would have to be further investigated
– All sludge could potentially be used for productisation, assuming there are no health and environmental concerns arising from new products containing alum sludge. However the avoidance potential to landfill is not yet quantified, as this depends on the suitability and material use of alum sludge for building and infrastructure materials
– The number of truck movements for solids reuse is not likely to be greatly impacted, as WTP disposal volumes remain similar (unless additional drying is undertaken prior to transport)
– Based on the location of the reuse option, the total distance may increase to distribute products. Overall the carbon footprint is unknown with the downstream value chain of distributions, but ideally this should be better than existing. The carbon footprint may change in the future based on the extent of decarbonisation withing the transport industry. The location of the alternative reuse option is likely to be a key factor in determining impact potential
– While there is evidence of viable use for use in building materials, the impact potential is highly dependent on location and for what purpose sludge is being reused. Where sludge can be applied with no negative environmental impact and supported by enabling policy and community acceptance, there is opportunity to reduce pressure on landfill (which serves as a 'last resort' end-of-life solution). This may also offset impacts and emission from traditional building materials

Implementation

– Where products are deemed suitable, sludge (and products derived from sludge) could be easily distributed and supplied through third party providers and business partners in the resource management sector. Cost is likely to be the most significant factor when providing consistent or tailored products for specific applications, and logistical requirements related to their distribution
– Depending on enabling policy, regulations, and acceptance, which are often the biggest impediments in the productisation of 'waste' resources, implementation of this solution may require medium to long-term time frames
– A demand analysis would be required to better understand fraction of alum sludge suitable and required for recycling and incorporation into a new product. This is one of the largest barriers for this scenario, as there must be sufficient demand for the new product, and this demand must be ongoing to be a reliable method to manage the sludge

Market readiness

– Research and pilot projects are progressing with proven market potential and accessibility. The maturity is still developing with uncertainties in relation to the regulation around productisation of waste
– Demand analysis is required to understand the potential to reduce overall volume of alum sludge and keeping it out of landfill

Table 12 Circular economy criteria for reuse in construction materials

Circular Transition Category	Criteria	Traffic light assessment
Impact potential	Scale, emissions reduction potential, social and environmental benefits	Good
Implementation	Complexity, cost, timeframe to value delivery	Moderate
Market Readiness	Revenue opportunity, market potential, maturity and accessibility, policies, and legal compliance	Poor

9.5 Scenario 4: Alternative coagulants

9.5.1 Description

This scenario considers the use of alternative coagulants instead of alum. These may include:

- ACH
- Ferric chloride
- Ferric sulfate
- Polymerised ferric sulfate (PFS)
- Polyaluminium silicate sulphate (PASS)
- Polyaluminium chlorohydrate (PACl)
- Ultrion

Some of these coagulants (such as PACl) lead to a similar sludge in terms of containing aluminium but may have different pH, which may or may not be an advantage for management of the waste. Some (such as Ferric compounds) lead to sludge containing iron, which may in some cases be easier to use. In other cases, a sludge end use would 'prefer' aluminium to iron.

In Victoria, alternative aluminium based coagulants that have been developed for improved performance compared to traditional inorganic coagulants (e.g., alum) are in use. These alternate compounds are generally more expensive, mainly due to production using more expensive raw materials (metal aluminium and hydrochloric acid). However, these polymer-based coagulants can be more effective for potable water clarification for particular source waters, notably in cold temperatures and low alkalinity raw water (ADWG 2011).

As described in section 6.1.5.2, dosing with alum or other sulfate containing coagulants has been shown to increase the sulfate concentration in drinking water by up to four times the source water sulfate concentration. This leads to elevated concentrations of sulfate in the sewer network, which can increase the rate of sulfide-based sewer corrosion. Detailed studies are required to understand the potential cost savings for water authorities associated with switching from a sulfate containing coagulant. Of the non-sulfate containing coagulants, ACH and PACl may be more attractive to water authorities due to the relatively simple changeover from alum compared to the introduction of say ferric chloride which requires additional infrastructure.

9.5.2 Key risks and limitations

Protection of water quality and optimisation of water treatment process

Drinking water treatment plants hold the crucial responsibility of safeguarding public health during the production of water. Hence explorations of alternative coagulants require a meticulous testing procedure to guarantee that the plant's operational efficacy remains unharmed. Historically, these investigations have been carried out in past plants during the design and optimisation stage, hence it is probable the existing coagulant chemical is already optimal.

Pursing alternative chemicals would involve:

- Determining which alternative would lead to better outcomes for sludge disposal
- Testing and potentially piloting the chemical on the plant to determine if it will treat properly and at what dose
- Evaluating the whole outcome using CE principles

These analyses are likely to be site specific and therefore need to be undertaken at each plant.

Introduction of additional chemicals and infrastructure

Depending on the coagulant that is selected, infrastructure requirements may be required at the WTP for dosing of the new chemical, as well as dosing other chemicals for pH correction or aiding flocculation.

Corrosiveness

The use of ferric chloride as a coagulant may cause issues with corrosivity or the introduction of iron residual on pipes that can negatively affect water quality.

9.5.3 Circular economy criteria

The ability to further analyse this scenario is limited by lack of comparable knowledge and understanding of the alternative coagulants.

Alternative coagulants should be considered on a case by case basis. Further detailed work is required to enable a useful comparison to alum, particularly with respect to the impact potential. The most likely driver will be cost savings rather than carbon footprint

Table 13 Circular economy criteria for alternative coagulants

Circular Transition Category	Criteria	Traffic light assessment
Impact potential	Scale, emissions reduction potential, social and environmental benefits	Poor
Implementation	Complexity, cost, timeframe to value delivery	Moderate
Market Readiness	Revenue opportunity, market potential, maturity and accessibility, policies and legal compliance	Good

9.6 Scenario 5: Alum recovery from WTP sludge

9.6.1 Description

As described in Section 7.3.3, alum sludge from a WTP can be further treated to recover a usable alum product for reuse in the WTP process. A number of potential processes can be used, however the most commonly considered is acid digestion using sulfuric acid, and there are a number of case studies of this being employed at WTPs in north America and Japan, as well as previously in Brisbane.

Aluminium recovery is related to the pH of the acid digestion process, and with a pH of <3 recoveries in the order of 90% are feasible. There is significant opportunity for cost optimisation of any process, and by targeting a lower recovery there are significant reductions in the amount of acid requirement. For example, to achieve 80% recovery the acid requirement may be halved compared to 90% recovery.

A further consideration to provide a high-quality recovered alum product is to remove impurities that are simultaneously leached with the aluminium, including organics and metals. Oxidation, say with hydrogen peroxide, and a polishing filter may be required for metals removal.

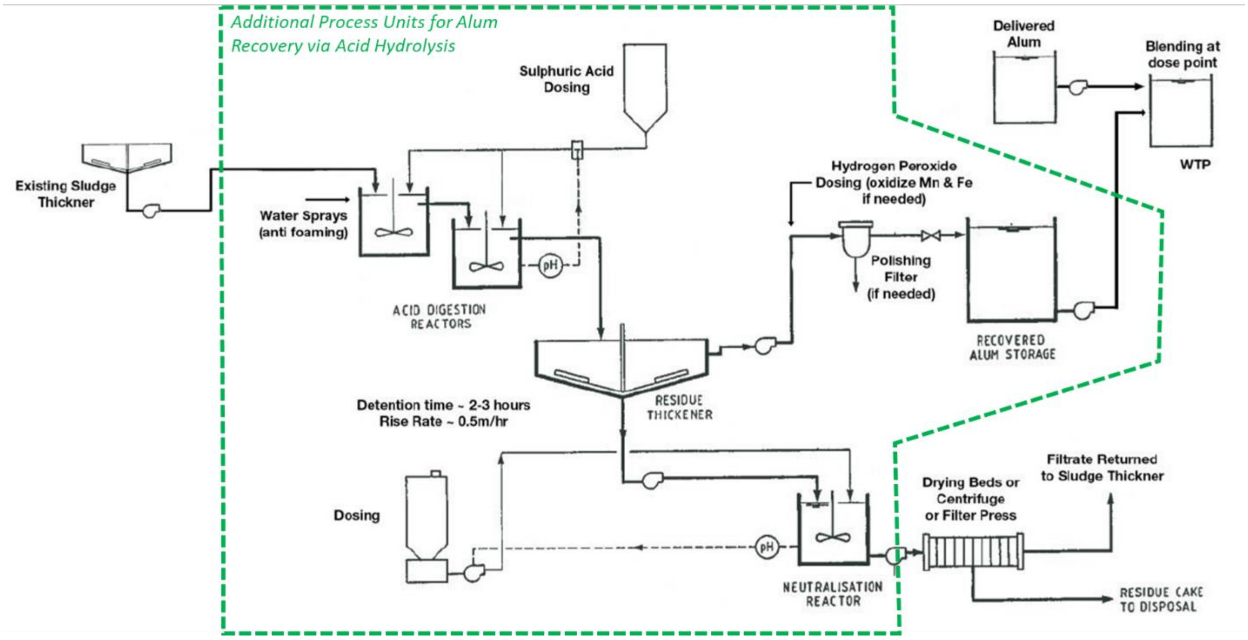

Figure 13 Example Alum Recovery Process for WTP Sludge (GHD 2015)

9.6.2 Key risks and limitations

Recovery of alum from WTP sludges introduces a number of new process steps at a WTP, and requires the use of sulfuric acid, which is not in widespread use in water treatment processes. Depending on the specifics of the recovery process, other chemicals are likely to be needed to provide for neutralisation of residual waste,

The benefits of recovering the alum need to be weighed against the costs related to additional plant complexity, (potentially) additional chemicals used and managed onsite, the associated safety concerns that will need to be addressed plus the direct costs.

Without further conditioning, the recovered alum includes a number of impurities including organics and metals, which may impact treated water quality. This consideration is secondary if recovered alum is to be used in a wastewater treatment process, although this will introduce a transport step and additional handling costs.

The economic viability of alum recovery improves with increasing scale due to economies of scale, as well as with higher quality sludge since recovery tends to be more efficient (and thus lower cost) when a lower concentration of contaminants is present. These factors potentially limit the feasibility of recovery to larger scale operations with high quality alum sludge inputs available.

9.6.3 Trigger points

Detailed economic analysis is required to determine the point at which the additional effort and complexity of recovering alum from waste WTP sludges is preferable to purchasing alum from a chemical supplier.

In general,

- WTPs that produce higher solids loads are more favourable to alum recovery
- Sludge handling including thickening and dewatering may still be required
- Optimisation of alum recovery is required in light of the cost of input acid
- Care is needed to not adversely affect treated water quality

9.6.4 Circular economy criteria

From a circular economy perspective, this scenario reduces the need for virgin alum and by recycling and prolongs the lifetime of the material prior to eventual disposal or reuse (as described in other scenarios). However, with the related process requirements, such as need for dangerous chemicals (e.g., sulfuric acid), capital investment for new infrastructure and ongoing operating costs for energy, labour and chemicals, alum recovery requirements need to be carefully mapped to understand the net benefits.

The quantification and balancing of benefits in relation to emission reduction, and the reduction and exchange of raw material value chains, is highly dependent on:

- The location of alum supplier, alum use, and the quantity of the chemical required
- The accessibility of materials/chemicals to extract the alum from the sludge

Impact potential

- Recovering alum sludge would have direct impact on the upstream value stream by reducing virgin alum use. But it has to be recognised that other chemical supply needs and associated socio-economic, environmental and governance factors will be impacted
- At this stage there are many unknows of the related systems and values chains that are impacted by focussing on recovery
- As indicated, there may be trade-offs in recovery rate reduction with significantly lowering sulfuric acid demand and related value chain considerations

Implementation

- Provided that the alum recovery process is constructed at the WTP, the recovered alum would be able to be reused at the point of regeneration, with a constant and reliable demand from the WTP
- As noted above, the recovery process comes with significant capital and operational costs and requires sufficient space at or near an existing WTP

Market readiness

- The technology is readily available to recover alum from sludge and ensure purity and contamination free products for reuse. As discussed in above, the economic viability of the process varies with the scale of the operation and the overall alum recovery target
- Further research is required to determine at what scale recovery becomes viable compared to raw alum. One could consider scaling up recovery by consolidating alum sludge in regional recovery hubs, which could potentially provide a revenue or cost reduction pathway. But as discussed previously, transport, chemical and equipment requirements would need to be well understood in relation to cost benefit, and emissions across scope 1-3

Table 14 Circular economy criteria for alum recovery from WTP sludge

Circular Transition Category	Criteria	Traffic light assessment
Impact potential	Scale, emissions reduction potential, social and environmental benefits	Moderate
Implementation	Complexity, cost, timeframe to value delivery	Moderate
Market Readiness	Revenue opportunity, market potential, maturity and accessibility, policies and legal compliance	Moderate

9.7 Scenario 6: Reduced alum usage

There are several potential scenarios that would result in reduce alum usage for WTPs and WWTPs. These are discussed in the sections below.

9.7.1 WTP: Improving raw water quality

Description

Water quality management interventions could be implemented in drinking water catchments, that improve water quality by reducing erosion and organics entering the waterways, particularly from runoff during large wet weather events. Interventions such as restoration of riparian vegetation, reduced stock access to water and land use changes can have other beneficial outcomes including reducing water quality risks associated with pathogens and other contaminants. Reduced turbidity and organic loads in the raw water will reduce the required chemical dosing rates for coagulation, hence reducing overall alum consumption and sludge volumes (refer section 6.1).

These approaches apply equally to selecting better quality sources where there are opportunities to selectively abstract water, and avoiding any reduction in raw water quality that drives the need for further treatment (refer section 9.7.7).

Key risks and limitations

Interventions to improve catchments through revegetation and selective land use changes are promoted by catchment mangers and water utilities. Depending on the catchment and existing land use, there may be many stakeholders in play and limited ability on behalf of the catchment manager to mandate an outcome. Furthermore, the lead time to realise benefits of some of these interventions, coupled with difficulty in objectively measuring the benefits provided is a challenge in demonstrating their benefit.

As outlined above, these interventions are typically driven by a desire to reduce water quality risks in source waters. Reducing risk includes avoiding treatment process upgrades. Consequential operating cost savings and reducing chemical use in treatment plants is likely a tertiary consideration.

9.7.2 Process Optimisation

Description

Optimisation of the water treatment process and coagulation chemistry can enable reductions in alum dose rates. This may be the only way to reduce coagulant usage in places where filtration is required. Substitution of alum for other coagulants requires consideration of the circular economy implications of those alternatives as described in Scenario 3 (section 9.5). Activities that support this may include:

– Use of additional instrumentation (for example streaming current analysers) and increased frequency of jar testing by operators
– Use of dedicated pH adjustments chemicals to control coagulation pH (e.g., acid dosing) where alum itself is used to reach the desired coagulation pH range
– Digital tools are increasingly available to leverage machine learning coupled with models rooted in the fundamental chemistry and physics. These tools include development of “digital twin” process models that can look at water quality data in real time and provide guidance to operators about how to optimise coagulation chemistry and dose rates. An example of such a tool is EVS:Water Optimiser

Process optimisation activities are typically driven by desire to reduce operating costs for facilities. Optimisation can enable reduction in chemical use (including alum) with flow on reduction in waste volumes. Maximising energy efficiency is also a key focus of these optimisation activities. Based on the cost driver, process optimisation is typically a focus for larger plants where economies of scale provide greater scope for saving. As digital tools and instrumentation become more widely used and trusted in the industry, these opportunities will be more accessible to smaller plants also.

Key risks and limitations

In general, water utilities are already incentivised to optimise processes to achieve operational cost savings.

A limitation of this approach may involve a lack of trust in relying on instrumentation or a model to control alum dosing, rather than providing advice to operators. This may limit the savings that can be achieved.

9.7.3 Substitute for alternative water sources

Description

Additional reliance on alternative water sources such as seawater desalination to supplement water supplies reduces the reliance on surface waters that currently require alum coagulation.

Key risks and limitations

The substitution for an alternative water source will typically introduce the use of an alternative coagulant (e.g. ferric based coagulants for desalination). However, above all there are a number of other social, economic, and environmental impacts to consider when investigating an alternative water source that lie beyond the consideration of coagulant use.

9.7.4 WWTP: Use of biological processes in-lieu of chemical precipitation

Description

Where phosphorous removal is required at a WWTP, processes can be designed to include biological phosphorous removal rather than using chemical precipitation with alum (or other coagulants). As chemical and sludge processing costs have risen, these enhancements are occurring more frequently at wastewater treatment plant upgrades to satisfy increasingly stringent effluent permit limits while reducing reliance on chemical dosing.

Key risks and limitations

The implementation of biological phosphorous removal may prove to be more beneficial at greenfield WWTPs where there is sufficient space to for additional reactors to assist with phosphorous removal. However for brownfield sites, the retrofitting of additional reactors into an existing process usually adds more cost and complexity compared to the installation of chemical storage, chemical dosing and additional solids handling infrastructure.

9.7.5 WWTP: Reduce the need for phosphorus removal

Description

By working with trade waste customers and the community, water utilities are able to influence the some of the behaviours that give rise to phosphorus. In particular, encouraging the use of cleaning and similar products that are low/no phosphorus can reduce the amount that needs to be removed at the WWTP, and in turn reduce (or even eliminate) the need for alum dosing.

Key risks and limitations

Reduce usage of phosphorous based cleaning chemicals is becoming a widespread practice, and there are ever reducing limited opportunities to reduce phosphorous usage. Water authorities have several levers that they may pull with trade waste customers to reduce the amount of phosphorous that is discharged to sewer, primarily through trade waste tariffs. However, a water authority may find that it has limited influence over some trade waste customers (based on the nature of their operations), and limited influence in local communities to reduce each community’s phosphorous usage.

Furthermore, WWTP effluent discharge licences (as governed by the EPA) are typically demanding lower phosphorous concentrations over time, driving increased efforts to removal phosphorous by biological or chemical means. In these instances, the limitations of biological phosphorous removal may drive increased chemical use. This is compounded by the increases alum dose rates required to achieve low phosphorus concentrations (refer section 6.2.3)

9.7.6 WWTP: Reuse WTP sludge at a WWTP

Description

Direct reuse of alum sludge from a WTP in a WWTP process can be used to assist in removing phosphorous, essentially providing for a "reuse" of the alum sludge.

Key risks and limitations

The reuse of alum sludge at a WWTP will increase the volume of biosolids that must be managed at the WWTP. There is limited data to provide analysis of the impact potential of this option, and direct should be considered on a case-by-case basis.

9.7.7 Case study – Avoiding the need for new filtration plants

As described in section 6.1.4 the Victorian water industry is in the unique position whereby almost 50% of the total water supplied for drinking water and urban use is unfiltered. Melbourne's protected catchments have been carefully managed over generations to exclude permanent and itinerant human populations, and proactively managing feral animal populations and fuel loads to minimise risk.

Changes to these catchments that might require filtration include:

– Additional human access, as a result of policy change or increased population living in proximity (increased unauthorised recreation), resulting in an increased water quality risk requiring filtration
– Increased feral animal populations (esp. deer) coupled with changes in the types of pathogenic microbes they carry, and/or changes in scientific understanding of the human infectivity of pathogenic microbes carried by animal populations, resulting in an increased water quality risk requiring filtration
– Changes in fire risk as a result of landscape and vegetation changes due the impacts of changing climatic conditions and/or impacts from feral animal populations. Increasing risk may drive a view to implement filtration to protect water supplies from potential post-fire impacts such as ash laden run off and erosion pollution reservoirs and raw water.

If filtration is required, this will likely see a very large and permanent increase in the use of alum (or another coagulant chemical), in the order of double current amounts.

9.7.8 Circular economy criteria

From a circular economy perspective, this scenario reduces the need for virgin alum as coagulant, which could be considered as the ultimate goal from a circularity perspective. From above, the major pathways that are available to achieve this are:

– Enhanced catchment management

Improving source water requires addressing complexities in catchment management. Catchment improvements alter systems significantly across spatial and temporal scales, and changes to coagulant usage would be difficult to link to specific catchment management activities, however an alternative key outcome for circular economy in regenerating nature may be realised.

– Optimisation of chemical dose rates

While process optimisation may be the easiest to realise (if not already achieved/considered), however related implications across each WTP have to be fully considered.

– Biological phosphorous removal at WWTPs

Biological phosphorous removal is a well understood process that is implemented where feasible. However many smaller WWTPs and brownfield sites will favour chemical phosphorous removal to due the process complexities associated with introducing a new biological process.

Impact potential

- Treatment plants with high treated water demands and high alum dosage requirements (indicative of lower water quality) would benefit from process optimisation if not already undertaken. However these optimisation processes have often already been undertaken in these instances in order to drive down chemical costs. Where dosage is low and processes are optimised, efforts would be far higher to achieve additional improvements
- Catchment management has to be carefully planned and their reach goes far beyond the alum use systems consideration and value chain. It brings into play again multiple interconnected systems and trade-offs that need to be made that again reach beyond catchment boundaries
- Depending on the scale of alum use reduction, and over which timeframe, may also influence market dynamics in the water chemicals sector due to demand changes
- Overall, the quantification and balancing of benefits in relation to emission reduction, and the reduction and exchange of raw material value chains is highly dependent on location and the scale of each treatment plant

Implementation

- Technical solutions within each treatment plant may be less costly than catchment improvements, and implementation success may be achieved on a short time frame. However the dependency on other process chemicals should also be considered
- Depending on the catchment, measures to improve water quality can be implemented over the medium to long term. However these are often costly and require significant effort to plan, implement and then measure the benefits

Market readiness

- Optimisation techniques are well established, and new technology is developing and becoming more readily available
- Catchment improvement interventions have been studied and successfully applied to improve water quality in catchments. While these solutions are desirable, they are complex to implement and may not be feasible depending on the location of the catchment

Table 15 Circular economy criteria for reduced alum usage

Circular Transition Category	Criteria	Traffic light assessment
Impact potential	Scale, emissions reduction potential, social and environmental benefits	Good
Implementation	Complexity, cost, timeframe to value delivery	Poor/moderate
Market Readiness	Revenue opportunity, market potential, maturity and accessibility, policies and legal compliance	Moderate

9.8 Scenario 7: Supply of powdered alum instead of liquid alum

9.8.1 Scenario description

Under this option, some powdered alum would be supplied to water authorities instead of liquid alum.

For chemical suppliers, this involves production of liquid alum (as described in 5.1), followed by an additional dehydration process to convert the liquid alum to powder. No chemical supplier in Victoria currently supplies powdered alum, so suppliers would need to invest in additional infrastructure if a powdered supply was to come from Victoria. Different trucks would also be required for the transport of powder.

WTPs that dose alum in Victoria are currently setup for the receival and dosing of liquid alum. Under this option, new infrastructure would be required to received powdered alum deliveries, then batch and dose liquid alum.

An alternative to this option would see water authorities or chemical suppliers develop a regional alum facility, whereby powdered alum could be delivered, batched, and then further distributed to nearby sites. This would reduce transport costs to a lesser extent than powder delivery to a plant but would reduce the required capital investment at each WTP to allow for the receival of alum powder. The location of such a facility would be important so as to minimise the distance required to transport the liquid alum once batched.

This scenario does not change the amount of sludge that is be produced. However considering the strength of alum solution is approximately 50% (as $Al_2(SO_4)_3.18.H_2O$), the conversion to powder could more than half the mass of chemical that is transported as water. This in turn would reduce carbon emissions associated with transport and reduce the cost of transport.

9.8.2 Key risks and limitations

– Safety risks associated with powder handling created for both suppliers and water authorities
– There is currently no current alum powder supplier in Victoria. There are additional costs required for suppliers in developing infrastructure to manufacture large volumes of alum powder. Furthermore, additional energy is required to prepare the powdered alum
– For water authorities, new infrastructure is required. In addition to cost, there may be limitations at sites that prevent the installation of this new equipment (e.g. space constraints)
– Additional labour costs at WTPs associated with the operation and maintenance of powder handling systems compared to liquid dosing systems

Summary

Alum is generally produced in a liquid form. Powdered alum is produced by an additional dehydration step of liquid alum. The conversion to powder could more than half the mass of chemical transported, thereby drastically reducing the carbon emissions associated with transport. However, the net emissions are impacted by the emissions generated during the dehydration process to produce the powder, as this requires some energy input. As such, the overall carbon impact needs to be investigated further.

9.8.3 Circular economy criteria

From a circular economy perspective, this scenario does not reduce the need for alum as coagulant, rather the primary impact is the reduction of carbon footprint from chemical transport. However, handling powdered alum would require changes in processing for both supplier and user. As described above the supplier would have to produce liquid alum that needs to be dehydrated prior to transport. The energy requirements for this process would be greater than the existing alum production energy requirements and may potentially outweigh carbon emissions offsets from reduced liquid alum transport.

The quantification and balancing of benefits in relation to emission reduction would be a key consideration for this scenario, In addition to investment requirements to make powdered alum both available on the market and usable within WTPs. Different sub-scenarios could be considered in relation to the locations powdered alum production and locations for reprocessing into liquid alum (e.g. at a WTP or at some regional hub), considering each scenarios environmental, social and economic footprints.

Impact potential

– Powdered alum, especially as part of process optimisation in larger WTP, would reduce required transport footprints when located further away from producers. One has to carefully assess associated impacts of the upstream production of powdered alum (i.e., dehydrated liquid alum) compared to the transport of liquid alum. Further, this solution would have to consider producing alum on site, or in other suitable locations closer to several alum using WTPs

Implementation

– Implementation requires significant investment from both water authorities and chemical suppliers, and is subject to space constraints at existing site
– The cost of transport would be reduced, however the chemical cost is likely to increase due to the additional processes required by suppliers
– There are additional safety considerations for the handling of a powdered chemical which may override potential reductions in emissions from reduced transport

Market readiness

– Technology to produce powdered alum is mature but not currently implemented in Victoria
– A sufficiently large quantity of alum would need to be delivered as a powder to make this option attractive both to water authorities and suppliers

Table 16 Circular economy criteria for powdered alum

Circular Transition Category	Criteria	Traffic light assessment
Impact potential	Scale, emissions reduction potential, social and environmental benefits	Moderate
Implementation	Complexity, cost, timeframe to value delivery	Poor
Market Readiness	Revenue opportunity, market potential, maturity and accessibility, policies and legal compliance	Moderate

9.9 Summary of scenarios

Table 17 provides a summary of the above scenarios. Our assessment has shown that increased environmental reuse, reuse for construction material amd alum recovery have the most potential of all scenarios.

Table 17 Summary of considered scenarios

Scenario	Impact potential	Implementation	Market Readiness	Waste management hierarchy	Summary
Scenario 1: Business as usual	N/A	N/A	N/A	Dispose	Majority of WTP solids end up in landfill.
Scenario 2: Increased environmental reuse	Moderate	Moderate/Good	Good	Reuse	Detailed reviews are required to identify and realise opportunities. The proximity of the sludge source to the reuse facility and to general farmland is key in supporting this option's feasibility and favourability. However, there are some examples of this occurring in Australia.
Scenario 3: Reuse for construction materials	Good	Moderate	Poor	Recycle	Detailed reviews are required to identify and realise opportunities, including detailed work on developing materials with suitable properties for the intended use. The proximity of the sludge source to the reuse location is key in supporting this option's feasibility.
Scenario 4: Alternative coagulants	Poor	Moderate	Good	Avoidance	Should be considered on a case by case basis. Further detailed work is required to enable a useful comparison to alum, particularly with respect to the impact potential. The most likely driver will be cost savings rather than carbon footprint
Scenario 5: Alum recovery	Moderate	Moderate	Moderate	Recover	Potential to reduce the amount of virgin alum used. Further studies are needed to be conducted in relation to scale and trade off in recover rate. Key limitations are the cost and complexity of additional infrastructure, as well as OHS requirements.
Scenario 6: Reduced alum usage	Moderate	Moderate/Poor	Poor	Reduce	There are multiple options that have the potential to reduce the amount of alum, including improving raw water quality and processes optimisation. Improving raw water quality at a catchment level is a complex task that is likely to involve costly interventions with slowly changing benefits that are difficult to measure. Process optimisation may only have moderate impact potential compared to other scenarios

Scenario	Impact potential	Implementation	Market Readiness	Waste management hierarchy	Summary
Scenario 7: Supply of powdered alum instead of liquid alum	Moderate	Poor	Moderate	Reduce	Detailed reviews are required to understand this solution. While less product needs to be transported, both, suppliers and users would require changing their processes as this powdered alum is not produced and use in the Victorian water sector currently. Also, this solution would have to be compared to solutions of distributed alum production, including on site and related benefits and challenges.

10. Wannon Water case study

The following section outlines a summary of Wannon Water's alum use at its WTPs and WWTPs, and a potential approach that could be taken by this water authority taking a circular economy approach to its alum use.

10.1 Wannon Water WTP overview

Wannon Water is a water authority in the southwest of Victoria, operating within a service area that extends from the Otway Ranges to the South Australian border. It supplies water services to nearly 45,000 customers and sewerage services to more than 38,000 customers. This includes residential, commercial, industrial and rural customers.

A summary of Wannon Water's main WTPs and disinfection plants is plants is included in Table 18. Of these plants, six use alum, two use ACH and two use ferric chloride as coagulants. There are also a number of disinfection plants, with the largest being Heywood, Port Campbell, Port Fairy and Portland. These plants treat groundwater and have no clarification or filtration process; therefore they do not use any coagulant.

Table 18 Summary of Wannon Water's major WTPs and disinfection plants

Plant	Treatment process	Coagulant used	Typical annual water production (ML/y)	Sludge disposal method
Balmoral WTP	DAFF	ACH/PACl	< 50	Geobags
Glenthompson WTP	Clarification/filtration	ACH	< 50	Drying beds
Camperdown WTP	DAFF	Alum	500 to 1000	Sewer
Cobden WTP	Clarification/filtration	Alum	500 to 1000	Sewer
Hamilton WTP	DAFF	Alum	> 1000	Drying beds
Simpson WTP	DAFF	Alum	< 50	Sewer
Terang WTP	Clarification/filtration	Alum	100 to 500	Sewer
Warrnambool WTP	DAF/clarification/filtration	Alum	> 1000	Sewer
Casterton WTP	Clarification/filtration	Ferric chloride	100 to 500	
Macarthur WTP	Clarification/filtration	Ferric chloride	< 50	
Heywood WTP	Disinfection	N/A	100 to 500	N/A
Penshurst	Disinfection	N/A	< 50	N/A
Port Campbell WTP	Disinfection	N/A	100 to 500	N/A
Port Fairy WTP	Disinfection	N/A	500 to 1000	N/A
Portland WTP	Disinfection	N/A	> 1000	N/A
Purnim DP	Disinfection	N/A	< 50	N/A

10.2 Circular economy assessment of Wannon Water's alum use

As seen in Table 18, six of Wannon Water's six treatment plants use alum; five of these plants divert their solids to sewer, while at the Hamilton WTP solids are dried in on site drying beds. A summary of these six WTPs is shown in Table 19. A circular economy approach of the alum use at these WTPs is considered in the sections below.

Table 19 Summary of Wannon Water's alum using WTPs

Treatment plant	2020/21 water production (ML)	Estimated alum consumption		Estimated solids amount		Solids disposal method
		Dose rate (mg/L)	Annual volume (kL)	Volume (kL/y)	Mass (t DS/y)	
Warrnambool WTP	3800	35	200	3000 to 6000	120	Sewer
Hamilton WTP	1000	45	75	1000 to 2000	40	Drying beds
Camperdown WTP	850	20	30	250 to 600	11	Sewer
Cobden WTP	750	18	20	150 to 400	7.5	Sewer
Terang WTP	400	19	10	50 to 200	3	Sewer
Simpson WTP	35	33	2	25 to 50	1	Sewer

Alum consumption

Regarding the consumption of alum at each site, Wannon Water would ask the following questions:

– How much alum is being used at each site? Are there opportunities to optimise the dose rate to reduce consumption?
  - When was the last time dose rate was reviewed, including with jar testing?
  - Has raw water quality changed over time?
  - Is the historical dose rate of alum recorded, and has this changed over time?

– Is there sufficient storage volume for alum at each site? Can an increase in storage volume reduce the number of deliveries?

– How many deliveries are received per year? Do plants that only use a small volume of alum (e.g., Simpson and Terang) received deliveries as part of 'milk runs' to reduce the number of deliveries? If not, is there an opportunity to align deliveries for neighbouring plants?

The data in Table 19 shows that the Warrnambool and Hamilton WTPs are the largest users of alum, and any improvements to these plants would have the greatest impact for Wannon Water (in terms of both alum usage and sludge generation).

Considering the Warrnambool WTP, raw water is sourced from the Otway system and transferred to WTP via the North Otway pipeline. The raw water quality is therefore relatively stable, with large volumes of upstream storage to buffer any sudden changes in raw water quality from within the catchment. E.g., the plant does not experience sudden turbidity spikes following a large wet weather event. As a result of this:

– The alum dose rate (and hence consumption rate is fairly stable). Small adjustments are regularly made to the alum dose rate to meet the required turbidity targets.

– As changes to the raw water quality are slow, jar testing is not regularly undertaken.

There is an opportunity for Wannon Water to undertake periodic jar testing in order to reduce the alum usage at the Warrnambool WTP. However, based on the stable raw water quality this may not yield many significant changes to chemical dose rates.

How can a WTP reduce or optimise alum usage?

For WTPs that are prone to variable raw water quality or experience poor raw water quality (i.e. high turbidity and/or colour), investment in regular jar testing (even as frequent as weekly) can assist in reducing chemical usage. Regular maintenance of dosing systems, including drop tests for chemical dosing pumps, should also be undertaken to ensure that the nominated dose rates are actually being achieved. More regular jar testing may also be required when a solids handling system is approaching capacity or is a bottleneck for the treatment process.

Solids production and management

Five of Wannon Water's six alum using WTPs dispose of their solids directly to sewer. The solids are then managed with the biosolids at their respective WWTPs. This case study will consider potential options to divert the solids from the Warrnambool WWTP.

The current solids handling process at the WTP and STP includes the following:

- Collection of sludge from the clarifier and DAF in a sludge tank
- Collection of washwater from the filters in backwash equalisation tank, which is then pumped into a sludge thickener. Settle sludge from the thickener gravitates to the sludge tank, while supernatant from the sludge thickener is returned to the head of the plant
- Sludge from the sludge tank is pumped to sewer. This sludge is estimated to be in the range 2-4% dry solids
- The solids generated from the WTP are transferred to the Warrnambool STP through the sewer network and eventually form part of the biomass in the plants aerated tanks
- At the Warrnambool STP, nutrient rich biosolids are periodically removed from the treatment process and dewatered mechanically using a centrifuge to approximately 20% dry solids
- Biosolids are transported to one of Wannon Water's dedicated biosolids handling facilities. These facilities accept biosolids from several of Wannon Water's WWTPs, and the biosolids are dried here in windrows for at least three years to meet EPA guidelines. As reported in Wannon Water's annual report[37], 100% of these solids are reused and have been for at least the last 5 years

Table 20 shows the annual hydraulic load to the Warrnambool STP and the approximate amount of biosolids from this plant. The estimated contributions from the WTP are also shown. The disposal to sewer of the solids from the WTP contributes approximately 0.1% of the total flow to the STP, however the solids are estimated to contribute 6% of the total biosolids.

Table 20 Warrnambool STP typical flows and biosolids generation

STP inflow (ML/y)	WTP sludge volume (ML/y)	WTP sludge as % of total STP inflow	Annual STP biosolids (wet t/y)	STP biosolids (t DS/y)	WTP solids (t DS/y)	WTP solids as % of total of biosolids
5000 to 6000	3 to 6	0.1%	11,000	2000	120	6%

For Wannon Water to consider alternative reuse opportunities for the alum containing WTP solids (e.g. alternative application to land or use in construction), the sludge from the WTP would require additional thickening. Wannon Water would then need to consider the following.

Potential reuse opportunities

What are the potential reuse opportunities for alum containing WTP solids in Warrnambool and surrounding areas? Based on the feasibility of reuse opportunities described in section 9, as well as the abundance of farming in this regional area, application of solids to land for agricultural reuse would likely be a preferred option.

Technical considerations

Based on the potential reuse opportunities, what would be the desired % dry solids at the WTP? What infrastructure would be required to achieve this increase dry solids? The following questions would aid in determining a preferred technical solution:

- How much sludge will be treated?
- Is there sufficient space on site?
- How much will the new infrastructure cost to build and then to operate? Ongoing costs include labour for operation and maintenance, power, and chemical usage (e.g., polymer to aid thickening)
- What will happen to the supernatant produced from the thickening process? Can it be returned to the head of the plant, and does it require any additional treatment to reduce the potential recycling of pathogens?

[37] Wannon Water Annual Report (2021/2022)

Based on the volume of sludge that is produce and space constraints at the WTP, an option such as mechanical thickening with a centrifuge would likely be a preferred solution.

Benefits to eliminating disposal to sewer

Eliminated the solids load from the WTP to the STP would reduce the amount of inert solids in the biomass at the STP by approximately 6%. This would have the following benefits:

– Increase in treatment capacity at the STP
– Reduced costs and carbon emissions associated with the dewatering of biosolids (pumping, centrifuge operation and chemical consumption)
– Reduced costs and carbon emissions associated with the trucking of biosolids from the Warrnambool STP to Camperdown or Hamilton for drying
– Additional space at biosolids handling facilities for biosolids
– Potentially improved end product for farmers (with a higher value) due to the removal of the somewhat neutrally beneficial water treatment plant solids (especially compared with the nutrient rich organic biosolids)

Drawback to eliminating disposal to sewer

– How much does the disposal of alum sludge to sewer assist with the removal of phosphorous at the STP? The STP is currently being upgraded to increase treatment capacity, and this will include alum dosing for phosphorous removal. Diverting the WTP solids from the sewer for other uses may increase the required alum dose at the STP to meet Wannon Water's EPA licence requirements
– Is Wannon Water able to find a business that is able accept the solids from the WTP? As Wannon Water already has 100% reuse of its biosolids, the WTP solids are already being beneficially reused (albeit with a three-year holding period at the biosolids facilities). Key considerations will be:
  - How much of the solids will a third party be able to accept?
  - Will Wannon Water need to pay a third party to take the solids, will there be no cost, or will this be a revenue stream?
  - Where is the business located, and are the transportation costs and carbon emissions lower than the current transporting of biosolids?
  - If Wannon Water is unable to find a business that is willing to take the required amount of solids, space will be required for stockpiling. Alternatively, sludge could be diverted back to the STP

A detailed study by Wannon Water would be required to determine the cost to benefit ratio of eliminating sewer disposal of the WTP solids. As the WTP solids are already being reused beneficially in the biosolids, this study would need to focus on the cost and carbon savings associated with any change.

11. Conclusion

The use of alum in the water industry is primarily driven by its use in drinking water treatment. The usage is a function of raw water quality, and the need to produce high quality and safe drinking water. Alternative coagulant chemicals are available in the market; however these have similar supply chain and sludge waste considerations that would need to be addressed.

For individual water utilities, the footprint of their alum use is driven by geographical considerations. As outlined above, the demand for alum is related to raw water quality, over which there is limited influence. The carbon footprint is also driven by transport requirements, with utilities remote from Melbourne incurring additional transport costs and carbon impacts.

For reuse opportunities, the following general conclusions can be drawn:

– The pathway to agricultural reuse via application to land (as described in 7.3.4) is best led by regional water utilities. They are well placed to establish interest in reuse in within their region, noting that this will require contact with individual farmers to understand their requirements and ability to reuse sludge wastes
– The pathway to industrial reuse is likely to sit better with larger urban based utilities, in part due to having a larger stream of alum waste to utilise. The process might be different to that for agricultural reuse, with an expression of interest type process or similar being used to “advertise” the resource and seek innovation from industry for its reuse
– Alum recovery at water treatment plants for reuse as coagulation requires further treatment processes and introduces additional plant and operational complexity, likely including additional chemicals. The benefit of such an approach will depend on its ability to preserve security of supply for this critical chemical and will be influenced by scale of the treatment plant with economies of scale making larger plants more likely to be viable
– Disposal to sewer to assist phosphorus removal at wastewater facilities provides an additional benefit for the alum, however the degree to which it provides circularity depends on the end use of the produced biosolids

Appendices

Appendix A

Survey results

Water Authority	How many WTPs do you own/operate?	How many of these WTPs use alum as a coagulant?	How many WWTPs do you own/operate?	How many of these WWTPs use alum?	Is your alum delivered as a liquid or powder?	Approximately how many kL or tonnes of alum do you have delivered annually?
Barwon Water (VIC)	8	2	11	1	Liquid	354.7 t
East Gippsland Water (VIC)	9	0	11	0	N/A	n/a - we use aluminium chlorohydrate approx 150 tonnes per year
Goulburn Valley Water (VIC)	31	30	26	4	Liquid	2,600 tonnes
Icon Water (ACT)	2	1	1	0	Liquid	unknown
Melbourne Water (VIC)	15	1	2	0	Liquid	4100 tonnes
SA Water (SA)	33 (18 operated, 15 operated by others)	20	23 (18 operated, 5 operated by others)	6	Liquid	Approximately 36,000 tonnes per annum is purchased across SA Water operated sites, including those operated by key operating partners.
Seqwater (QLD)	36 conventional	19	0 - Seqwater operates a small number of WWTP at recreation areas	0	Liquid	32,000 tonne in "normal" years 45,000 tonne in a "wet" year (BJH)
South Gippsland Water (VIC)	8	4	10	2	Liquid	350 tonnes
Wannon Water (VIC)	12	5	17	Zero plants use it, very occasional use at Wbool WRP to assist settling	Liquid	700 tonnes per annum

Water Authority	Do have a preferred volume of alum to be stored on site?	Please describe any supply issues you have had with alum	Have you completed a circular economy review on the use of alum or any aspect of its supply chain? If so, please provide details
Barwon Water (VIC)	No due various assets being built to various requirements. For new assets we typically design for minimium of 14 days min storage at Max demand	Not specifically with this product that I am aware. However, generally across the board we have experienced interruptions to supply chains due to economy and natural disasters. Fuel Levy has been applied for the past 12 months, however the unit price is linked to Contract so price increases are managed formally and peridically.	We have been working with some industry contacts to look at potential off take arrangements, such as road base.
East Gippsland Water (VIC)	n/a	n/a	no
Goulburn Valley Water (VIC)	No, limited to asset/storage size.	Transport. Low stock.	No
Icon Water (ACT)	The SMCs gauge this based on current demand and supply reliability, but I'd estimate around 14 days stock at average demand would be the minimum desired stock level.	Covid disruptions have led to short-term delivery delays, and breakage of the Eastern-Western Australia rail link due to flooding in February 2022 led to serious supply chain disruptions for the whole Eastern Australian water industry, which had to be carefully managed at Icon Water through an IMT.	No
Melbourne Water (VIC)	30 days chemical storage at average demand	The raw material for manufacture of alum by Ixom is sourced from Alcoa in Perth and transported via the Indian-Pacific railway. In early 2022, the railway was damaged by flooding which cut off supply of the raw material. There is an alternative supplier of raw material, in Queensland however they struggled to meet the demand following the incident. The railway line was again affected in late 2022 by a train derailment.	We have looked at Optimisation of Water Treatment Solids Management with Black & Veatch in 2011, including triple bottom line assessment of solids management technology options.
SA Water (SA)	On site storage is typically driven by the storage capability and not necessarily an ideal storage duration. WWTPs generally can store product for longer, whereas WTPs turn over more quickly. Across all alum sites, including operating partner sites, if tanks are at full capacity, on average the stock could last an approximately 57 days at peak demand. However, there are some outlier examples at either end of the "days left" scale.	- Continuity of supply is steady, particularly given we have local manufacturing here in Adelaide. - In Feb 2022 we were affected by a rail outage, affecting the ability for the supply chain to move by rail aluminium trihydrate (key raw material) from WA to SA. This disruption to rail last around three weeks, however, in that time we employed a range of measures to ensure we could continue to treat water.	No. SA Water is not aware of any past circular economy review on the use of alum (or any aspect of the supply chain).
Seqwater (QLD)	14 days at maximum dose, average plant flow; or b. 28 days at average dose, maximum plant flow	For Seqwater the supply of Alum has been heavily impacted first by the floods in in SA in early 2022 (broken supply lines from WA to Victoria) then by the ongoing wet weather on the Australian East Coast during 2022. As a consequence of the SA flood, a large number of regional NSW alum customers moved their source from Melbourne to Omega in SEQ. Then with the ongoing wet weather there was an almost doubling of demand for Alum out of Omega's two sites in SEQ. This caused multiple small delays in alum supply to Seqwater sites.	Gap analysis and reviews have been performed on the alum supply chain/s, including raw material inputs.
South Gippsland Water (VIC)	Varies depending on the treatment plants but typically for larger treatment plants about 40 days average demand and 30 days peak demand	No real supply issues other than shortage issues during the rail outage in 2022. Price increases for all chemicals have increased. Alum unit costs have doubled in the past 3 years.	No, not as yet
Wannon Water (VIC)	No	None, but some warnings about shortages	No

Water Authority	Apart from day-to-day operational tests, have you completed any specific work or reports to optimise your alum doses?	If known, can you provide an estimate of alum sludge volume produced per annum, including DS%?	Considering WTPs only, where does most of your alum sludge go?
Barwon Water (VIC)	Flowmeters on all chemical dosing systems		Sent to landfill
East Gippsland Water (VIC)	n/a	n/a	Sent to landfill
Goulburn Valley Water (VIC)	No	1053 dry solid tonnes per year	Well distributed between both options
Icon Water (ACT)	Not recently. Some testing was done when introducing PACl (MegaPac10) at Stromlo WTP, and some trials were also conducted to compare against Aluminium ChloroHydrate (ACH), but these have not progressed in several years.	438 tonnes/FY(21/22), 599 tonnes/FY(20/21), 1,730 tonnes/FY(19/20), 741 tonnes/FY(18/19). Depends on how much we use the plant. DS% approximately 17%.	Sent to landfill
Melbourne Water (VIC)	Between 2018 and 2023, we have been investigating the implementation of feed forward control for Alum dosing (currently flow-paced control is used only) to the Winneke clarifiers using a Zetasizer or Streaming Current Meter. This has proved challenging due to questions around the accuracy and reliability of these instruments, but the work is ongoing.	Approx. 5000 tonnes	Sent to landfill
SA Water (SA)	•WTC- Coag (Water Treatment Control for Coagulation), Coagulation Model update – internal report 2022 •Coagulation Strategy Study - Internal communication 2018, Assessment of 9 commercially available aluminium-based coagulants	Total across all 18 plants = 26 475 tonnes, approx. 15-25% DS	Sent to landfill (with a much smaller percentage/proportion used for rehabilitation purposes)
Seqwater (QLD)	We use models to optimise alum dose.	- 47,443 tonnes of wet sludge to Seqwater Storage Areas - 1,901 tonnes of residuals to sewer *All data is from the 21-22 FY, please note residuals production was increased this financial year as a result of A) dirty water from flood events of 2022 or B) dirty water associated with poor raw water quality in the Brisbane River since November 2021	Seqwater's Sludge Storage Areas where it is processed for beneficial reuse (mostly soil manufacturing). In the 21/22 FY , 22 879 tonnes of Sludge was transported from Seqwater's storage areas to beneficial reuse. It is the intention that all Sludge sent to Seqwater's Sludge Storage Areas will be processed for beneficial reuse.
South Gippsland Water (VIC)	Chemical dose rates and usage is regularly reviewed. Further development of reporting and target dose rate ranges is currently being undertaken.	Approximately 35-60 tonnes per year	Sent to landfill
Wannon Water (VIC)	No	149 tonnes (dry) per annun of total water treatment sludge	Sewer

Water Authority	Please describe if you have investigated the recovery or recycling of alum from sludge?	Have you previously used or ever considered using coagulants other than aluminum-based types? If yes, please briefly describe why and which alternative were considered?	What other types of coagulants do you use?
Barwon Water (VIC)	Yes	Ferric at some sites a long time ago but these chemicals introduce Iron residual into the system which builds up on pipes and resutls in water quality issues. Organic coagulants as a secondary coagulant	- Aluminium Chlorohydrate (ACH) - PolyDADmac
East Gippsland Water (VIC)	We have not done any of our own investigations but have reviewed studies undertaken by others i.e. Smart Water Fund - GHD Alum Sludge Reuse Investigations 2015, and we are watching this study with interest.	Don't believe so.	Aluminium Chlorohydrate (ACH);Polyaluminium Chloride (PAC);Ferric Sulphate;
Goulburn Valley Water (VIC)	No	No	Aluminium Chlorohydrate (ACH);Polyaluminium Chloride (PAC);Ferric Chloride;
Icon Water (ACT)	Yes – use as compost additive with green waste, use as mudbricks, currently looking at the use of sludge as a wetland soil growing media or in raingardens, looking to use as road base.	Yes – we conducted some work into using alternative coagulants PACl in jar tests with mixed efficacy results. We use Polyaluminium Chloride at our main water treatment plant. Have also conducted a basic desktop review of using FeCl but has not moved to any testing or trials. Main concerns were aesthetics (rust tinge to water), corrosive nature wear and tear on pumps, an reported weaker floc and need for greater alkalinity, may introduce unwanted heavy metals (chromium) given current supply is a by-product from scrap metal production.	Polyaluminium Chloride (PAC);Ferric Chloride;
Melbourne Water (VIC)	In 2009, beneficial reuse options were explored for sludge, but no investigation into recovery of aluminium has been carried out.	We have looked at changing to Ferric Chloride but had concerns with corrosivity.	Aluminium Chlorohydrate (ACH);
SA Water (SA)	Lab scale investigations are currently under way looking into the recovery of alum from sludge before drying (recycle stream through the WTP). SA Water is planning to implement at pilot scale in the future.	Lab scale testing of a broad range of ferrous, aluminium and organic based coagulants. Plant scale trials have all been aluminium-based products (alum, ACH, PACl).	Alum is used to treat most of the raw water across SA Water operations. ACH is used at some smaller regional WTP's across SA Water operations (IXOM PAC23 and Hardman Alchlor GOLD).
Seqwater (QLD)	Seqwater worked with DES to draft and finalise the End of Waste Code for Water Treatment Residuals (ENEW07503318) which allows the approved user to reuse sludge for application to land as soil ameliorant, soil conditioner and for the manufacturing of compost and soil for landscaping/garden use.	Central - a ferric chloride trial at Crosby in the mid-90s, however the outcomes would need to be further reviewed (note reports are not readily available).	ACH Polymers (multiple) (BJH)
South Gippsland Water (VIC)	Trialed alum sludge as a road base and landfill capping. Also investigated the viability of alum extraction and reuse opportunities.	Yes, ACH	Aluminium Chlorohydrate (ACH);Polyaluminium Chloride (PAC);
Wannon Water (VIC)	No specific studies at Wannon Water	Yes, depending on water chemistry we have used different types	ACH, PACL, Ferric

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