Technology and policy approaches that enhance the beneficial use of biosolids

Hilary Hall 2023 Churchill Fellow

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Hilary Hall

26 September 2024

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Of course, this wonderful experience would not have happened if it wasn't for the sponsorship, support and inspiration of The Winston Churchill Memorial Trust. It is a great privilege to be recognised by the Trust and to be empowered to travel, learn, network and share knowledge.

Acknowledgement of Country

I acknowledge the Traditional Owners of the Country that I work on throughout Australia and recognise their continuing connection to land, waters and culture. I pay my respects to their Elders past and present, and I acknowledge emerging leaders. Moreover, I express gratitude for the knowledge and insight that Traditional Owners and other Aboriginal and Torres Strait Islander people contribute to our shared work in Australia.

I pay respects to all Aboriginal and Torres Strait Islander communities. I recognise that Australia was founded on the genocide and dispossession of First Nations people and acknowledge that sovereignty was not ceded in this country. I embrace the spirit of reconciliation, working towards self-determination, equity of outcomes, and an equal voice for Australia's First People.

Introduction

ENHANCING THE BENEFICIAL USE OF BIOSOLIDS

Biosolids are a by-product of the treatment of our sewage. They are a valuable source of nutrients, organic matter and beneficial microbes, enhancing soil health and reducing synthetic fertiliser use. However, their use is under increasing scrutiny from environmental regulators, due to concerns relating to contaminants such as pathogens, heavy metals and PFAS “forever chemicals”. Biosolids are easy targets for increased regulation which can impact on their use as a soil conditioner, yet they represent a metabolic connection between humans and the soil that has existed for millennia.

Chemicals used in food, clothing, cosmetics and pharmaceuticals can transfer from us into sewage and biosolids. "End-of-pipe" treatment is part of the solution, but the regulatory control of contaminants at source can protect biosolids quality and enhance the beneficial use of biosolids. My research will inform biosolids strategies and management at a local, state and federal level, bringing the best approaches from around the world, to the benefit of the Australian water sector, farmers and communities.

Our understanding of environmental contaminants is rapidly expanding, as are solutions to address their impacts. Through this Fellowship, I have discovered biosolids treatment technologies, and learnt how different government policies and environmental regulations can enhance (or hinder) the beneficial use of biosolids.

ABOUT ME

I am a consulting engineer with more than 13 years’ experience in wastewater treatment and biosolids use. My work has exposed me to the technologies used in Australia to treat biosolids, and the policy and regulatory landscape that govern their use. Through my networks within the water industry and experience in operations, I have a deep understanding of the challenges of biosolids management.

The sources and fate of pollutants in sewage and treatment plants is of particular interest, and I have led contaminant investigations in surfactants, heavy metals and PFAS.

When advising on biosolids strategies, technology choices and environmental management, I want to provide the Australian water industry with the best approaches from around the world. I want to know the breadth of technologies available to us, how regulation can support sustainable biosolids use, and how government policy can limit contaminants in our wastewater and in doing so reduce our exposure to harmful chemicals. I believe that what is good for biosolids is good for us all.

The Australian water industry has a strong culture of knowledge sharing and a deep care for people. Water utilities are thirsty for knowledge about international best practices that reduce greenhouse gas emissions, create healthy communities and circular economies. This Fellowship will enable me to generously give back to the industry that has supported and nurtured me.

CONTACT DETAILS

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KEYWORDS

Biosolids	Circularity	Anaerobic digestion
Environment	Contaminants	Sludge
Wastewater	Environmental risk	Environmental regulation

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Executive Summary

Biosolids are a nutrient-rich by-product of sewage treatment. In Australia, they are primarily applied to farmland, contributing to soil health and fertility.

Biosolids are a wonderful example of circular resource use, which has been practiced for millennia. They are created as a result of our consumption of food, and following treatment, can be spread onto farmland to grow more food.

Unfortunately, chemicals used in food production, clothing, cosmetics and pharmaceuticals can transfer from us into biosolids, threatening their sustainability. My research investigated treatment technologies and policy approaches that minimise contaminants in sewage and biosolids, to ensure the long-term sustainability of biosolids use, primarily as a soil conditioner on agricultural land.

Travelling throughout Europe I was exposed to a variety of biosolids management approaches and learnt how connected regulation is to a region's environment and land use. I had the opportunity to reflect on the similarities and differences in approaches between Australia and Europe. I have concluded that our issues and opportunities have a lot in common. There certainly isn't a single solution. Instead, there are many pathways to achieving beneficial use which navigate regulatory requirements, and balance user needs and affordability.

Based on my findings and experiences, I recommend the following actions to enhance the beneficial use of biosolids in Australia:

- **Implement national regulations:** The standard set by the European Union provides an excellent framework for smaller municipalities to implement, and does the 'heavy lifting' on research, consultation and standardisation.
- **Build circularity and resource recovery into biosolids regulation:** Biosolids primarily consists of elements that are beneficial to soils (organic matter and nutrients) and therefore biosolids regulation should seek to maximise the use of these elements on our poor-quality Australian soils.
- **Control problematic contaminants at a national level:** Individual water utilities have little influence over the importation, use and disposal of a host of persistent and harmful chemicals. It is essential that governments (federal or state) lead on reducing the presence of these chemicals in our lives.
- **Implement source control before treatment:** There are always actions that water utilities can take that can reduce contaminants entering wastewater and polluting biosolids, and I am certain these actions will always be cheaper than treatment processes.
- **Leverage biosolids to create local circular economies:** Consider how biosolids can benefit the area near a wastewater treatment plant, if there are other bioresources available for co-processing and how maximum benefit can be created by a community-scale circular economy.
- **Employ technologies that enhance biosolids:** Technology selection should be led by value creation, as a quality product will always be a more sustainable choice than a treated waste.

This Fellowship is relevant to water utilities and treatment plant operators, environmental regulators, and anyone interested in ensuring that biosolids continue to contribute to the health of Australian soils.

"Biosolids are not the cause of environmental pollution, they are the first victim."

– Horst Müller

1 Itinerary

1.1 INVESTIGATION APPROACH

The focus of my investigation was the European Union (EU), as there is a similar level of environmental regulation and wastewater treatment to Australia both at an EU level and within individual member states. EU regulation sets a minimum standard for wastewater treatment and there is an expectation that all countries within the EU will achieve this standard. Europe has many countries with industrial and commercial development in line with Australia, and a mix of urban, regional and rural populations. This provides a wealth of comparable examples for the Australian water industry.

From my work in the Australian water industry, I know that our utilities and regulators look to engineering powerhouses such as Germany, France and Scandinavia for best practice approaches to biosolids treatment technology. Australians also look to the EU as having some of the most progressive environmental protection regulation, with many European countries leading the world in waste reduction, implementing circular economies and reducing greenhouse gas emissions.

Having previously worked as a consulting engineer in the United States of America, I have been able to follow their progress in relation to environmental regulation and treatment technologies over the years, whereas the EU remained somewhat a mystery to me.

1.2 ITINERARY

Planning my travel itinerary involved contacting a network of biosolids professionals to identify key specialists in treatment and regulation, and people that have direct access to wastewater treatment plants (WWTPs) to arrange site visits. The ‘anchor’ of my trip was the IFAT Trade Fair for Water, Sewage, Waste and Raw Materials Management, as this trade show is only held every two years. As the largest water and waste industry trade show in the world, it was expected that this event would provide a wealth of knowledge in the one location. Other locations in my itinerary were chosen based on the contacts identified and recommendations received.

Table 1-1: Fellowship itinerary

LOCATION & DATES	ACTIVITIES & CONTACTS
Paris, France 6 May (2024)	Self-guided tour of the Paris Sewer Museum
Munich, Germany 13-17 May	IFAT Trade Fair for Water, Sewage, Waste and Raw Materials Management. The purpose of attending this event was to see the latest in treatment technologies for sewage and biosolids. Met with representatives from the International Solid Waste Association (ISWA) and attended their panel sessions and presentations. Met with technology specialists from around the world and attended a wide range of technical presentations.
Upper Austria region, Austria 20 – 24 May	Spent the week with biosolids specialist Horst Müller to tour biosolids treatment facilities and farms in Austria. Time was also spent with employees of Horst’s consulting firm, Mueller-Umwelttechnik (Müller Environmental Engineering). Sites visited included: ▪ Drexler Horticulture (with dry anaerobic digestion and composting) ▪ Bad Haller Quality Compost ▪ VFI Ennsdorf Mill (with dry anaerobic digestion) ▪ Wallern wastewater treatment plant

LOCATION & DATES	ACTIVITIES & CONTACTS
Copenhagen & Roskilde, Denmark 27 & 28 May	Met with treatment plant designer Steen Nielsen to tour sludge treatment reed beds, used extensively in Denmark. Sites visited included: ▪ WSP (engineering consultancy) office, Roskilde ▪ Kallerup Sludge Treatment Reed Bed (STRB) system ▪ Haslev STRB system ▪ Greve STRB system
Manchester, England 3 June	Met with Rick Lancaster, Global Bioresources Director for AtkinsRealis, and Dr Ali Osman, Production Manager, United Utilities Tour of the Davyhulme Wastewater Treatment Works
Bedford, England 6 June	Met with Jane Gilbert, Carbon Clarity and Kate Lister, BioGen Tour of the BioGen Bygrave Anaerobic Digester
London, England 7 June	Met with Matt Stewart, bioresource specialist, AtkinsRealis
Brussels, Belgium 10 June	Met with biosolids and policy experts from the European Federation of National Associations of Water Services, the European Federation of Agricultural Recycling and the European Association of Public Water Operators

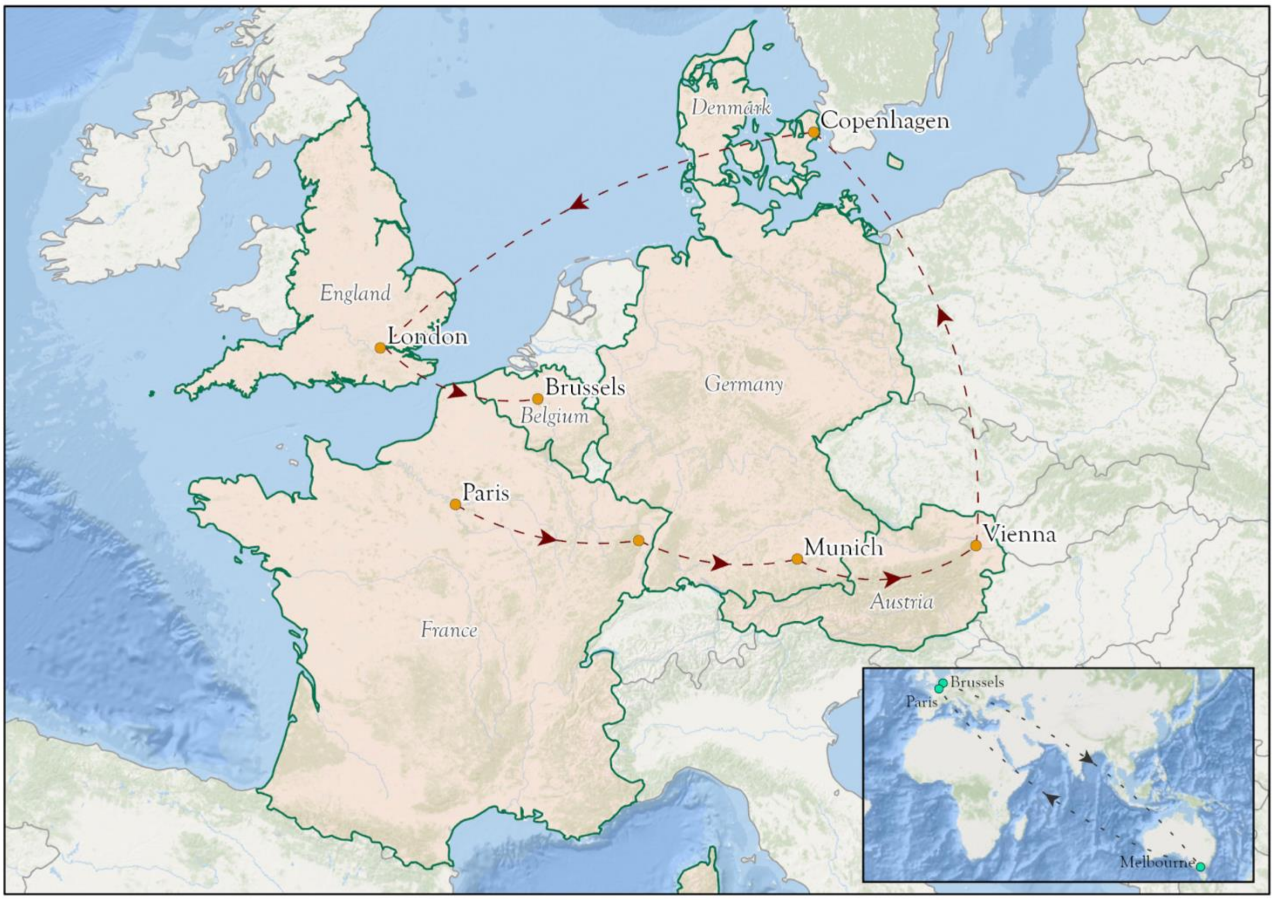

Figure 1-1: Map of my travel route

2 Background

Biosolids are the solid by-product of wastewater treatment and are used as a soil amendment, similar to compost. Australia produces around 1.5 million wet tonnes of biosolids annually[1], and they are a rich source of nutrients, organic matter and beneficial microbes. When applied to farmland, they improve soil health, increase soil carbon and reduce synthetic fertiliser use. Farmers that use biosolids on their paddocks experience soil health benefits well beyond their nutrient value alone and become strong advocates.

Historically, human excrement was worked into soil to improve fertility, which became more important as we progressed from hunter-gatherers to agriculture. Once our societies became organised into towns and cities, the need for more effective management of our waste became necessary, eventually resulting in the transition from solid waste to liquid waste, with the advent of modern sewage systems which use large quantities of water for transport. As a result, there were more pathways for pathogens to spread from sewage into drains, creeks, rivers, lakes, groundwater and oceans.

Also, with industrialisation came a wider range of contaminants that can enter the sewage system. Chemicals used in food production, textiles manufacturing, cosmetics and pharmaceuticals wash off our bodies and clothes and are excreted by us. "End-of-pipe" treatment is part of the solution, but the regulatory control of contaminants at source can protect biosolids quality and enhance the beneficial use of biosolids, returning their value to the soil.

Karl Marx noted the disconnect that industrialisation brought to "the metabolic interaction between man and earth" when farmers moved away from using human excrement and instead relied on synthetic fertilisers to provide nutrients for their crops. This phenomenon has since been termed the "metabolic rift"[2] and reflects the linear use of resources that has come with industrialisation. It is unsustainable for us to continue to use resources this way, and therefore a circular economy, where resources are kept in circulation at their highest use, is needed. Biosolids are the original circular economy, and the history of sanitation demonstrates that treated sewage sludges can be valued by farmers.

Because of their pathogen and contamination risk, the use of biosolids is regulated by government. To permit the beneficial use of treated biosolids in agriculture and landscaping, we consider how the biosolids have been treated, the level of contamination, and the rate at which they are to be applied to the land. Therefore, biosolids management interfaces with both treatment and regulation.

Governments and water utilities are struggling to navigate policy directives to reduce greenhouse gas emissions, develop circular economies, minimise waste and keep water bills affordable. These goals can be in tension with EPA pressure to reduce environmental risks. This is why it is essential that we diversify our thinking and have access to effective, low energy treatment processes, supported by regulation that facilitates resource recovery.

At its core, my project is about capacity building in the Australian water industry. Greater knowledge of biosolids management is needed, as the regulation is complex, the investment in infrastructure is considerable and changes take a long time to implement.

My project is also relevant to the use of other organic waste streams, such as those produced by piggeries, dairies, chicken farms, and food processors. The circular approach is a new way of thinking and is a paradigm shift in how we manage resource recovery, yet we are often burdened with regulation and treatment processes

[1] https://www.biosolids.com.au/guidelines/australian-biosolids-statistics/

[2] Kawa, N.C, Ding, Y, Kingsbury, J, Goldberg, K, Lipschitz, F, Scherer, M and Bonkiye, F (2019) *Night Soil: Origins, Discontinuities, and Opportunities for Bridging the Metabolic Rift*. Ethnobiological Letters, 10(1):40-49

that are a product of our linear economy. Ultimately, what is good for biosolids is good for our environment, and our health and wellbeing. Reducing our exposure to chemicals, minimising resource-intensive treatment and optimising resource recovery should be our goal. Biosolids must be circular by design… and by necessity.

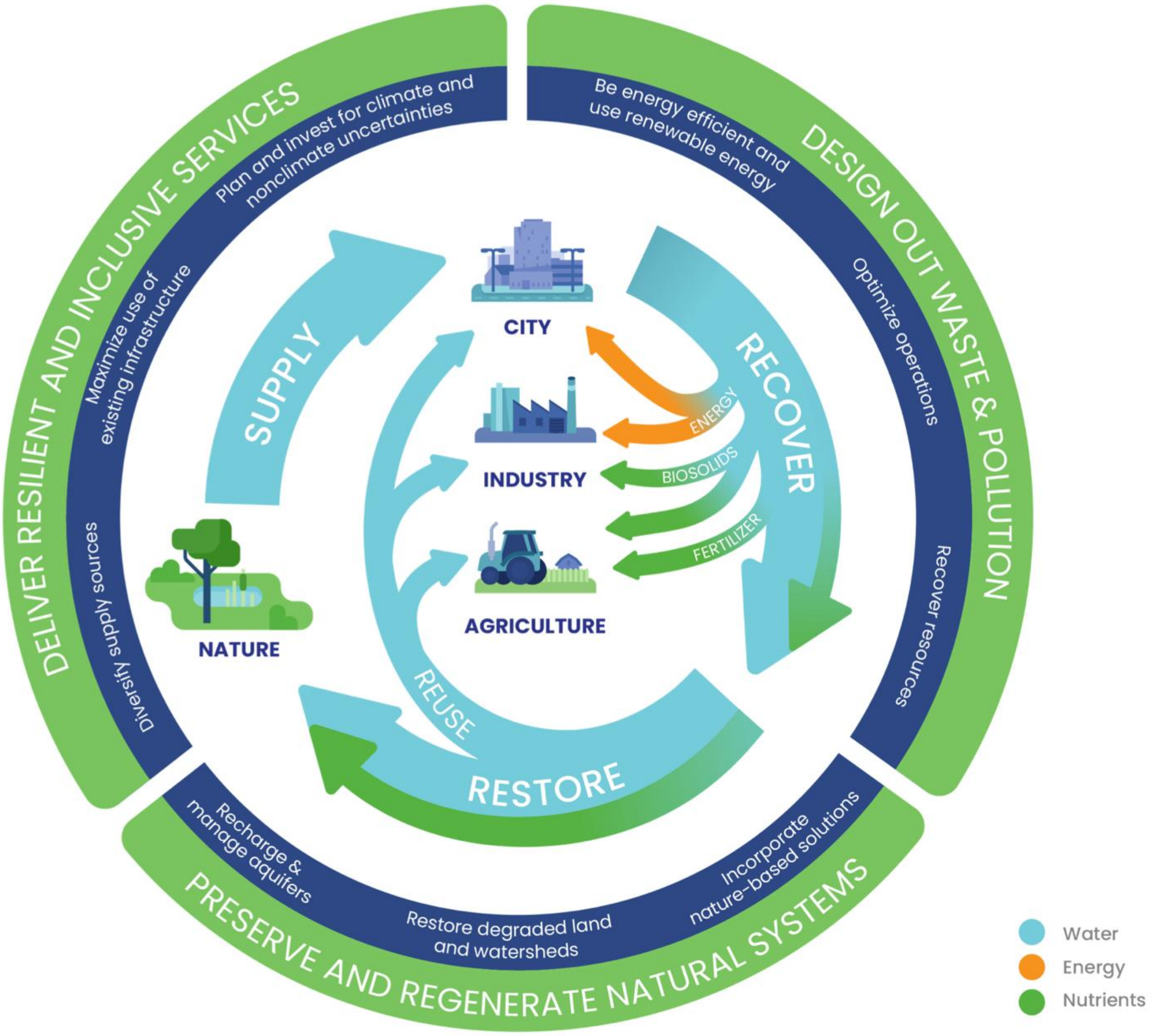

Figure 2-1: The Water in Circular Economy and Resilience (WICER) Framework developed by the World Bank's Global Water Practice, demonstrating the role wastewater and biosolids have in a circular economy[3]

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[3] World Bank Group, https://www.worldbank.org/en/topic/water/publication/wicer. Accessed: 22/8/2024

3 The Role of the European Union

3.1 WASTEWATER IN EUROPE

Sanitation in Europe has evolved dramatically over the centuries. After the fall of the Roman Empire, sanitation declined during the Middle Ages. Waste was often dumped in streets or rivers, leading to outbreaks of diseases like the Black Death. The Industrial Revolution in the 19th century saw urbanization worsen sanitation problems, prompting reforms like the introduction of sewer systems in cities such as London and Paris. By the late 19th and early 20th centuries, public health initiatives and modern sewage systems became widespread, significantly improving sanitation and reducing disease in Europe.

My travel started in Paris, and this provided me the opportunity to visit to the Paris Sewer Museum (https://musee-egouts.paris.fr/en/). Paris has a combined wastewater and stormwater system, and large underground galleries have been built over the last 150 years to provide sufficient capacity for wastewater and stormwater collection. Although the 'modern' sewer system has been developed in this time, the city has a history of conveyancing infrastructure dating back to 1370. The sewer galleries run throughout the city, mostly following the streets above, and sit only a few metres below the ground, above the Metro train tunnels.

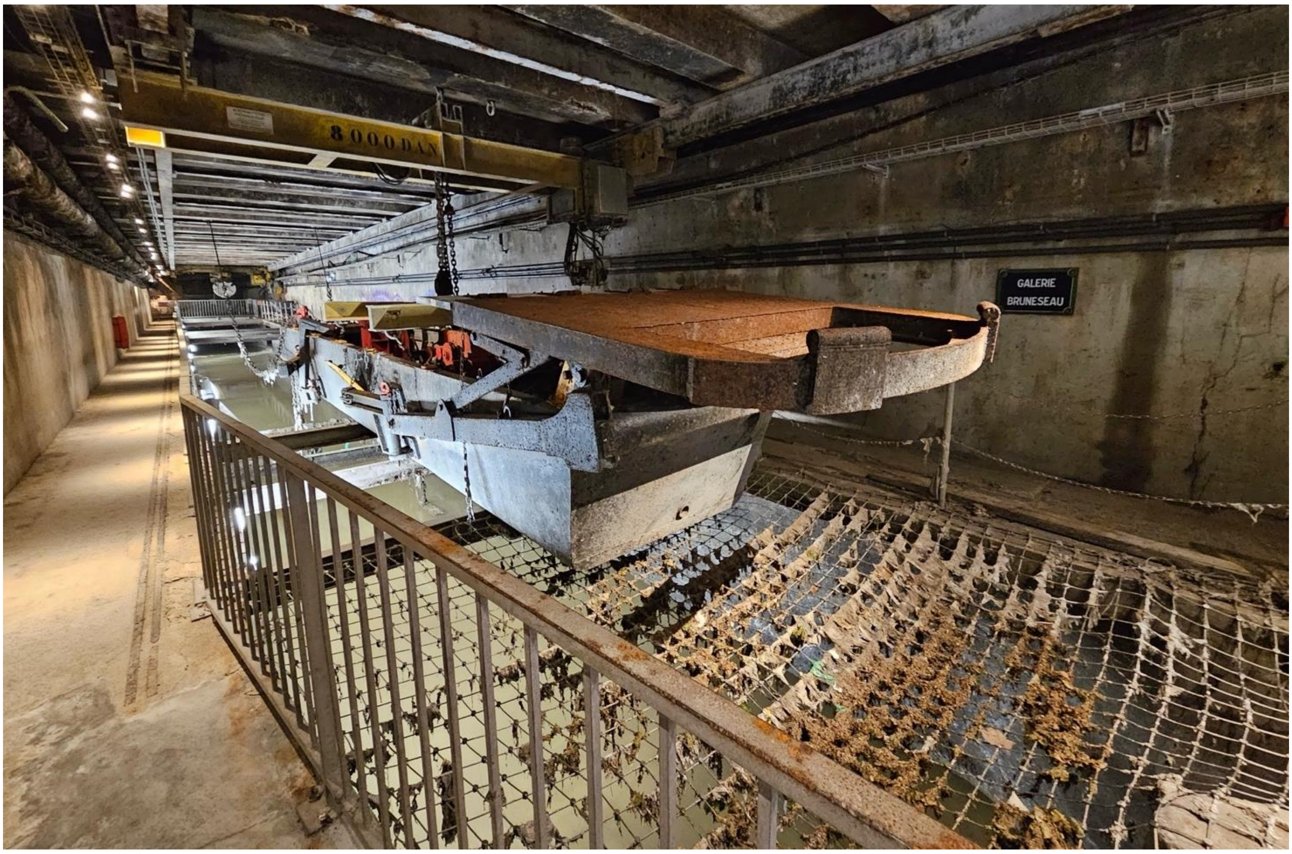

Figure 3-1: Inside the Paris Sewer Museum, housed within a working underground sewer chamber, May 2024

Initially, wastewater was conveyed to the Seine River, downstream of the city. But during the 1850's, there was keen interest in utilising the nutrients in the wastewater for agriculture, and this led to the construction of an irrigation system eventually covering 50 km^2 of agricultural land. Untreated wastewater was irrigated onto farmland from 1868 through to World War I. After this time, direct irrigation was phased out (due to urban encroachment and increasing flows) and replaced with six wastewater treatment plants followed by irrigation of the treated wastewater.

The sewer galleries are filled with an array of fascinating technologies. There is significant grit removal infrastructure, as the galleries have very little gradient and therefore grit accumulates rapidly. A suspended barge (Figure 3-1) is lowered into the flow and used to create an eddy that causes grit to accumulate, so that it can be pumped out efficiently. These barges are permanently installed throughout the sewer network and have been in operation since 1865.

The sewer galleries also house thousands of kilometres of water mains, fibre optic cables and other services. Paris is serviced by both potable water and non-potable water (untreated river water). The non-potable supply was installed specifically to water the spectacular gardens throughout the city, for which Paris is renowned.

The ingenuity, scale and history of the Paris sewers is incredible. Walking through an operational sewer made me appreciate how essential they are to the city above; all that beauty would not be possible without this infrastructure below. This example is repeated throughout the towns and cities of Europe, where the implementation of modern sanitation infrastructure throughout the 19th and 20th centuries has played a significant role in the health and living standards of millions of Europeans.

3.2 URBAN WASTE WATER TREATMENT DIRECTIVE

Wastewater treatment in Europe is robust and highly regulated, primarily guided by the EU's Urban Waste Water Treatment Directive (UWWTD). This directive requires member states to implement comprehensive treatment processes to protect water bodies from pollution. The expectation is that EU countries then implement these standards (as a minimum) with their own local regulations. There are potential penalties for countries that do not observe these minimums. Individual countries need to consider the unique aspects of their environment, population and legislation to determine how these minimum standards are implemented locally.

Figure 3-2: The European Parliament in Brussels, Belgium, June 2024

The current UWWTD is more than 30 years old and only required secondary treatment prior to discharge to waterways. The proposed new directive will have several fundamental, and ambitious, new requirements:

- Tertiary treatment minimum for discharge to waterways
- Quaternary treatment minimum for discharge to land (including agricultural reuse)
- Extended producer responsibilities (EPR) for chemical manufacturers or suppliers to pay for treatment plant upgrades.

It is expected that the pharmaceutical and personal care products (PCP) industries will set up new EPR organisations for administering the financing of payments to the water sector. It is also expected that they will either pass the additional costs through to the consumer or reduce their profit margins. The EPR schemes are to be in place by 2025, with compliance for micro-pollutants being phased in after this funding is made available. That is, micro-pollutant compliance is achieved first at large and 'at risk' WWTPs (from 2030), through to all WWTPs (from 2040).

Europe's groundwater resources are under pressure from nitrate contamination and there is a surplus of nitrogen in soils in Czechia, Denmark, Germany, Hungary, Ireland, Italy, the Netherlands, Spain and large parts of France[4]. With groundwater supplying 65% of Europe's drinking water and 25% of its irrigation water, groundwater protection is critically important.

Requirements for compliance are structured based on the size of the treatment plant (in terms of population equivalent). This is in recognition that 46% of the wastewater load is treated by less than 2% of WWTPs (that is, the larger sites with >100,000 PE)[5]. This reflects the relative contribution of larger sites to achieving EU-level goals for CE and reducing GHG emissions and acknowledges that larger sites are more cost-effective and can manage a higher administrative burden.

Additionally, some requirements are being 'phased in' for the different size WWTPs (and also considering the sensitivity of some receiving areas), with measures being applied progressively through to 2040.

Key drivers and policy responses for the updated UWWTD for the EU water sector are provided in the following table. This document will apply to all communities with more than 1,000 PE, with connection to a WWTP. Although it's focus is on wastewater treatment, it "sets the scene" for WWTP obligations for the next 20 years.

Table 3-1: Drivers and policy responses in the proposed updated UWWTD

DRIVERS	POLICY RESPONSES
Reduce greenhouse gas emissions Achieve energy neutrality of WWTPs	Set an objective of energy neutrality by 2040 for all WWTPs above 10,000 PE Energy audits for all facilities above 10,000 PE Encourage the utilisation of biogas production, while reducing methane emissions

[4] https://www.eea.europa.eu/publications/europes-groundwater

[5] European Union (2022) Proposal for a directive of the European Parliament and of the Council concerning urban wastewater treatment (recast). Accessed: https://environment.ec.europa.eu/document/download/a936c2d5-2e3a-4eb1-a7c6-41ec98f3e72f_en?filename=Proposal%20for%20a%20Directive%20concerning%20urban%20wastewater%20treatment%20%28recast%29.pdf on 19/5/2024

DRIVERS	POLICY RESPONSES
Reduce pollution of the environment	Revise the limit values for pollutants in treated water quality Additional contaminants to be added (compared to the previous 1991 UWWTD) Set a minimum obligation of **secondary treatment** for all WWTPs >1,000 PE Set a minimum obligation of **tertiary treatment** for all WWTPs >100,000 PE and all WWTPs >10,000 PE that are in sensitive areas Set a minimum obligation of **quaternary treatment** (for removal of micro-pollutants) for: ▪ By 2035, all WWTPs >100,000 PE ▪ By 2040, all WWTPs >100,000 PE and all WWTPs >10,000 PE located in sensitive areas Apply a risk-based approach, and take additional measures above the minimums to address risks to the environment and human health
Move the EU to a more circular economy	Increase recovery of nitrogen, phosphorus, and to a lesser extent, organics Increase reuse of treated water Set minimum standards for reuse and recycling of phosphorus and nitrogen from sludge Apply the waste hierarchy to minimise sludge production and maximise reuse of resources
Improve human health	National wastewater monitoring schemes to be established, which monitor parameters relevant to public health Monitor antimicrobial resistance in WWTPs >100,000 PE
Increase access to sanitation and compliance throughout the EU	Address the challenges of managing wastewater and sewage sludge in cost-effective ways Identify communities without access to sanitation, and assess options for providing sanitation facilities
Improve governance and transparency of the sector	Keep the UWWTD as simple as possible to make it easier to implement, and remove any obsolete requirements from the text Limit reporting to essential elements for assessing compliance or tracking progress on emission reductions.
Ensure polluters pay for the increased treatment impacts of their products	Implement extended producer responsibility (EPR) for micro-pollutants: ▪ Targets producers of pharmaceuticals and personal care products (PCPs) ▪ These companies must contribute to the cost of quaternary treatment, where their products lead to the pollution of wastewater (based on the quantity and toxicity of their products) ▪ Financially incentivise the replacement of harmful products with less harmful ones

It is estimated that by 2040, when the proposed UWWTD is fully implemented, the EU will achieve:

- 230,000 tonne reduction in nitrogen and 30,000 tonnes reduction in phosphorus to the environment.
- Reduction in avoidable GHG emissions by 37%.
- Total cost of implementation will be less than the expected benefits, and that this will be valid in all EU countries. Costs will be covered by water rates (51%), government budgets (22%) and the EPR system (27%).

3.3 SEWAGE SLUDGE DIRECTIVE

There are 28 countries within the EU generating in total more than 8.7 million tonnes of biosolids annually. Land application is the most common use for biosolids, with approximately 50% of all biosolids being used on land. A further 27% is incinerated and only 8% go to landfill[6]. Key factors influencing the use of biosolids throughout Europe are the sensitivity of the receiving environments, availability of excess manure and digestates, and concerns about contamination.

The current EU sewage sludge directive (SSD) was published in 1986 and sets the minimum standard in sludge management for all EU member states. Being more than 40 years old, it needs updating. However, many countries have national and regional regulations that consider a wider range of contaminants. There is technical interest in updating this Directive, but it is not a pressing political concern.

Key parts of the SSD are:

- Reduce environmental impacts of heavy metals in soils where sewage sludges and biosolids are applied (with limits set for cadmium, copper, nickel, lead, zinc, mercury, chromium)
- Increase the use of sewage sludge/biosolids in agriculture
- Protect human and animal health by limiting application times and specifying holding times for fruit and vegetables, and pasture used for animal feed
- Requirements for documentation and record keeping (which were updated in 2019 and apply from 2022).

3.4 MEETING WITH EU REPRESENTATIVES

I spent the final week of my Fellowship travels in Brussels, a wonderfully historic city known as the "Capital of Europe" due to the many EU institutions that are based there. The purpose of my time in Brussels was to meet with EU water and biosolids organisations. As Chair of the European Federation of Agricultural Recycling (EFAR), Horst Muller, my contact in Austria, had arranged for me to meet with other EFAR delegates over lunch. We also attended a meeting with representatives from the European Federation of National Associations of Water Services (www.eureau.org) and the European Association of Public Water Operators (www.aquapublica.eu).

The purpose of this meeting was to discuss details regarding a comprehensive EU-wide biosolids contaminant sampling program, with the goal of providing insights into a broader range of contaminants than are currently regulated, and to provide comparable data across all EU countries. It was interesting to listen to the discussion on the range of contaminants to be tested, and the logistics involved in conducting such a large-scale sampling program.

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[6] EurEau (2021) Europe's Water Figures. https://www.eureau.org/resources/publications/eureau-publications/5824-europe-s-water-in-figures-2021/file, accessed: 18/8/2024

Figure 3-3: Meeting with representatives from EU water and agricultural recycling associations, Brussels, June 2024

I also had the opportunity to present on the purpose of my Fellowship, how biosolids are managed in Australia and what I had learnt during my travels. It was wonderful to have the opportunity to reflect on the similarities and differences in approaches between Europe and Australia. I have concluded that our issues and opportunities have a lot in common. There certainly isn't a single solution; instead, there are many pathways to achieving beneficial use which navigate regulatory requirements, user needs and affordability.

4 National biosolids regulations

4.1 GERMANY

More than 1.7 million tonnes of biosolids were produced in Germany in 2021, with incineration and ash disposal being the predominant management approach (>65%) and the remainder applied to land[7]. In 2017, Germany introduced legislation that phases in a ban on biosolids application to land[8], which translates as the *Ordinance on the Reform of Sewage Sludge Utilisation*. Over a 15-year period, WWTP operators will need to implement treatment solutions based on the following points:

- WWTP that service >100,000 equivalent population (EP) will need to implement a solution by 2029
- WWTP that service 100,000 – 50,000 EP will need to implement a solution by 2032
- Sewage sludge with a minimum phosphorus content of 20 g P/kg total solids must recover at least 50% of this phosphorus or reduce the phosphorus content to <20 g P/kg total solids
- At least 80% of phosphorus contained in sewage sludge ash must be recovered.

There is no timeline for implementation of these requirements for smaller WWTP (<50,000 EP) and these sites can continue to apply biosolids to land indefinitely.

There are several aspects that have contributed to this approach in Germany. Germany has a long history of meat production (chickens, pigs, dairy), a relatively dense population and access to copious volumes of high-quality surface and groundwater. As industrial volumes of manures and sludges have been applied to German farmland for more than 200 years, the concentration of salt and nutrients have increased to the point that there is widespread environmental risk, particularly nitrogen risk to groundwater. This is very different to Australia, as our soils have generally much lower fertility.

In addition, Germany is acutely aware of its dependence on foreign rock phosphate as fertiliser for agriculture. Previous biosolids regulation favoured incineration processes (because of contaminant limits only one third of biosolids were applied to land in 2016[9]), but this regulation did not stipulate the recovery of any beneficial resources from biosolids. The updated regulation recognises the importance of phosphorus recovery to Germany's circular economy.

These are the two key factors that have influenced the decision to ban biosolids to land and set minimum requirements for phosphorus recovery from sewage sludge.

However, based on the presentation I attended and conversations I had with German wastewater engineers while I was at IFAT, the recovery of phosphorus from incinerated biosolids ash is having mixed success at full scale. The most commonly used process for this is wet chemical extraction. This involves washing the ash with sulphuric acid to produce phosphoric acid, followed by ion exchange of the acid leachate. Unfortunately, the process produces large volumes of acidic waste and concentrates heavy metals, requiring further treatment to manage these aspects. Further, some phosphorus remains bound in a form that is unavailable to plants/crops.

7 https://www.statista.com/statistics/1393771/sewage-sludge-generation-europe/
8 https://www.bmuv.de/en/law/sewage-sludge-ordinance
9 https://www.bmuv.de/en/topics/water-management/circular-economy-overview/overview-types-of-waste-and-waste-flows/sewage-sludge

4.2 AUSTRIA

Austria has different biosolids regulations throughout the country, with land application permitted in some of its nine regions and not others. Even the allowable limits for contaminants vary from region to region. A key reason for the variability in Austrian regulation is the difference in receiving environments. Austria has only one major city, Vienna, with the remaining landscape divided between flat, productive rural areas, and the sparsely populated, mountainous Alps.

The productive rural areas in Austria consist of dense agricultural production, with seemingly all cleared land used to grow a wide variety of cereal grain crops. Almost all livestock are raised in barns, providing a further source of concentrated nutrients for either direct land application or anaerobic digestion (and land application of the resulting digestate).

Figure 4-1: Barn-raised pigs in rural Austria – note the roof-mounted arm which is used for cleaning out the pig stalls, May 2024

Of the 234,000 dry tonnes of biosolids that were produced in Austria in 2018, approximately 40% were applied to land and a further 53% were incinerated[10].

Coincidentally, whilst I was undertaking my Fellowship travels, Austria introduced nation-wide regulation that makes phosphorus recovery from sewage sludge mandatory from 2033 for WWTP >20,000 EP. Similar to Germany, there are also minimum phosphorus recovery rates[11].

[10] https://water.europa.eu/freshwater/countries/uwwt/austria
[11] European Sustainable Phosphorus Platform, https://www.phosphorusplatform.eu/scope-in-print/news/2538-austria-adopts-phosphorus-recycling-obligation. Accessed 18/8/2024

4.3 UNITED KINGDOM

In the UK, sewage sludge treatment is commonly undertaken at sludge treatment centres, where primary and secondary sludges are trucked on a regular basis. More than 3.6 million tonnes of biosolids are applied to land each year in the UK, representing 87% of total biosolids production[12].

The land application of biosolids in the UK is guided by the *Sludge (Use in Agriculture) Regulation 1989*. This regulation specifies the conditions that allow biosolids to be used on land, including management of environmental risks, risks to public and stock health, and record keeping. This regulation is complemented by the *Sewage sludge in agriculture: Code of practice for England, Wales and Northern Ireland*. Interestingly, contaminants in biosolids are known as "potentially toxic elements" and the range of contaminants considered is similar to Australian biosolids management (nutrients and heavy metals).

Figure 4-2: Biosolids delivered to a farm near Bedford, England, ready for spreading, June 2024

The UK Environment Agency is currently reviewing the existing regulations, with three key principles to guide the regulatory update:

1. Modernise and clarify the regulatory framework.
2. Develop a consistent approach with the water and waste industry.
3. Identify and assess emerging risks.

The updated regulations are expected to consider the risks posed by organic and inorganic chemicals, anti-microbial resistance, and microplastics.

[12] https://www.water.org.uk/waste-water/extracting-resources-sewage#:~:text=Currently%2C%20around%2087%25%20of%20treated,organic%20matter%20for%20growing%20crops

4.4 DENMARK

Denmark produced more than 100,000 dry tonnes of biosolids in 2018, with 88% being applied to land and only 11% incinerated[13]. The Danish Ministry of Environment and the Danish Environmental Protection Agency are responsible for administering wastewater and biosolids legislation, under the Danish Water Sector Reform Act.

Denmark has three classifications of sewage sludge treatment:

- Untreated sludge that undergoes dewatering (which is then only suitable for disposal or thermal treatment/energy recovery)
- Sludge that undergoes anaerobic digestion
- Sludge that is treated in sludge treatment reed beds[14].

Wastewater processors determine biosolids uses based on these classifications. In 2017, further regulations were introduced which limit biosolids application based on phosphorus, thereby increasing the area of land needed for biosolids spreading.

[13] https://water.europa.eu/freshwater/countries/uwwt/denmark
[14] DANVA (2020) Water in figures 2020. https://www.danva.dk/media/7251/2020_water-in-figures_web.pdf accessed 18/8/2024

5 Treatment approaches

5.1 OVERVIEW

This section details treatment facilities that I toured throughout my Fellowship. It is not an exhaustive list of the biosolids treatment processes used in Europe, but rather a collection of operational sites with commonly used technologies.

5.2 ANAEROBIC DIGESTION

Austria has many excellent examples of local, circular resource use. Small to medium sized (10,000 – 100,000 EP) mechanical WWTPs treat combined stormwater and sewage from a collection of towns and villages, typically with biological nitrogen reduction and alum or ferric dosing for phosphorus reduction. Sludges undergo stabilisation and/or composting, prior to land application.

Other local feedstocks are available for co-processing, including agricultural wastes (crop residuals and manure from barns), wood chips, green waste and food waste. Anaerobic digestion (AD) is common as there are plenty of suitable feedstocks and demand for heat and renewable electricity, and digestate is applied on local farms.

An example of this is the Wallern WWTP, located in north-western Austria and operated by RHV Trattnachtal. This facility services 70,000 EP and biologically treats a combined influent of wastewater and stormwater. Sludge from the WWTP (mainly primary sludge from the primary sedimentation tanks) is combined with industrial and commercial feedstocks, most notably wastewater from a local dairy processor. The blended sludge is anaerobically digested and the resulting digestate is dewatered and applied to local farmland.

Figure 5-1: The two anaerobic digester tanks at the Wallern WWTP, Austria, May 2024

Figure 5-2: Dewatered digestate at the Wallern WWTP being discharged from a screw conveyor into the waiting spreading rig, Austria, May 2024

During my time in the UK, I spent a day with organic waste specialist Dr Jane Gilbert, Carbon Clarity. Jane has a wealth of knowledge in composting and digestate management and has helped to develop some excellent documents for the International Solid Waste Association (www.iswa.org), the European Compost Network (www.compostnetwork.info), and training material for the Chartered Institution of Wastes Management (www.ciwm.co.uk).

We visited the Biogen Bygrave Anaerobic Digester, located about 65 km north of London. Compliance Director Kate Lister kindly showed us around the site, which processes 54,000 tonnes/year of food waste and generates renewable electricity and stabilised liquid digestate. Along with the waste receival facility and process tanks, two huge storage tanks are used for holding digestate outside of the allowable spreading season (February to September, although this can be shortened by wet weather). Their scale was impressive.

Figure 5-3: Biogen Bygrave feedstock receival shed, including unloading areas, blending systems and air extraction system, UK, June 2024

Figure 5-4: Biogen Bygrave digestate storage tanks, which store digestate outside of the land application season, UK, June 2024

Anaerobic digestion is a very common technology used throughout Europe for treating wastewater sludges and a range of other organic waste streams. This is because European WWTPs typically include primary sedimentation tanks that generate primary sludge, which is an excellent feedstock for anaerobic digesters. In Australia, primary sedimentation is far less common and therefore our WWTPs tend to require aerobic digesters for sludge stabilisation. However, with regulation limiting organic waste to Australian landfills, there is growing interest, and need, for more anaerobic digesters.

5.3 SLUDGE TREATMENT REED BEDS

Denmark was included in my itinerary so that I could visit sludge treatment reed beds (STRBs) and learn about their design and operation from international expert, Steen Nielsen. I first heard about STRBs a few years ago and thought they would be very well suited to medium-sized mechanical WWTPs in regional Australia. But without any systems in Australia, I had to take this opportunity to visit some!

STRBs are a low-energy technology used to stabilise and dewater sludge. They are particularly well suited to treating secondary waste activated sludge (WAS). A system consists of a set of reed beds, usually 10 or more. Each bed has a liner and a gravel drainage layer, topped with growing media (soil or dewatered biosolids) which is planted with reeds. WAS is pumped from the bioreactor into one bed at a time, putting a thin film over the bed before moving to the next. The sludge dewaters over time, with high-quality filtrate flowing through to the underdrain system, returning to the WWTP for re-processing.

Figure 5-5: Sludge treatment reed beds after multiple years of reed growth, Kallerup STRB, Denmark, May 2024

Some of the aspects of this technology I find remarkable are:

- They are passively aerated by the hollow reeds and filtrate pipes, which extend up to the surface along one side of each bed. No energy is needed for mechanical / forced aeration.
- The systems are designed for a minimum 10-year operating cycle, so that once constructed, they store at least 10 years of sludge and then only one bed is emptied each year. In Steen's experience, beds often achieve operating periods beyond this, depending on sludge dewatering characteristics and climate.
- They are incredibly low energy, with power only needed for pumping WAS to the beds, returning filtrate to the WWTP, and for digging out the biosolids.
- They require no chemicals at all.
- In Europe, they achieve 20-40% dry solids in the finished biosolids, but in hotter climates can achieve up to 50% dry solids.
- The resulting biosolids are stable, odourless, friable and nutrient rich. In fact, the biosolids become better fertiliser over time, as chemically-bound phosphorus is mineralised, resulting in an increase in plant-available phosphorus in the final biosolids.

Given the space availability in Australia, particularly for regionally-located WWTPs, and warm climate relative to Denmark, this technology should be well suited to many locations in Australia.

Steen and I visited three operating STBR sites, and it was brilliant to see how different they are to conventional sludge treatment systems. These sites had wildflowers, lush reeds, no odours, no trucks and silence.

Figure 5-6: Valves on the sludge loading (influent) pipelines, located in a dry well adjacent to the reed beds, Haslev STRB, Denmark, May 2024

Of course, these benefits come at a cost of surface area, with STRB systems requiring a similar footprint as the rest of the WWTP infrastructure. But considering they replace all the steps in sludge treatment (thickening, digestion, dewatering and 10 years of biosolids storage), perhaps their footprint isn't so large in comparison to what would be needed otherwise. Nonetheless, they are suited to sites that have space, or where additional land is available. In Denmark, there are STRB systems located up to 4 km from a WWTP, with a dual pipeline (one for WAS, one for filtrate) connecting the two sites.

Figure 5-7: Air ventilation pipes (which become the filtrate pipes), Greve STRB, Denmark, May 2024

5.4 THERMAL HYDROLYSIS PROCESS

I had the opportunity to visit the Davyhulme Wastewater Treatment Works, which is the largest sludge processing facility in the UK. Rick Lancaster, Global Bioresources Director, AtkinsRéalis, and Dr Ali Osman, Production Manager, United Utilities, took me on a tour of this facility, explaining both the history of the site and current operations.

Primary and secondary sludge from the onsite wastewater treatment plant, along with dewatered sludge imported from treatment plants in the surrounding region, are treated at this facility. The site treats more than 100,000 dry tonnes of biosolids a year, servicing an equivalent population of around 5 million people. When it was constructed in 2013, it was the largest sludge processing facility in the world but has since been superseded by larger facilities in China and the UAE.

At this scale, advanced technology is necessary to keep the footprint low and the production rate high. Given the urban setting, on the outskirts of Manchester, the site is centrally located to receive sludge from other treatment plants. However, the urban location also means that the process must reliably achieve stabilised sludge on a space-constrained site. Therefore, significant process design has gone into sludge receival and blending, prior to treatment. The management of truck traffic on the site is another key operational consideration, with up to 31 trucks arriving per day.

To achieve rapid unloading, the receival area is designed to accept two trucks at a time. Sludge is fed into a series of storage silos and blending tanks, which homogenise and heat the sludge prior to treatment. The pre-treatment steps are critical to the smooth operation of the whole facility, as it can handle inconsistent sludge delivery times and quality and improves the performance of the main stabilisation processes.

Figure 5-8: Davyhulme WWTW sludge receival area, including truck washing area, weighbridge and storage silos, UK, June 2024

The facility uses the Cambi system, a thermal hydrolysis process (THP) which breaks down sludge prior to anaerobic digestion. The THP reduces digester residence time, improves biogas recovery and enhances sludge dewaterability, making it a critical process addition for a facility of this size.

Figure 5-9: Davyhulme WWTW sludge storage soils (right) and Cambi process tanks (centre), UK, June 2024

The resulting dewatered biosolids from this facility are applied to farmland, with a team of people managing logistics, regulatory compliance and farmer relationships.

Two giant orbs dominate the site – these are the biogas storage tanks, which store up to 9,000 m^3 of biogas each. Five combined heat and power (CHP) engines generate 8 MW of renewable electricity, and all the heat needed for sludge pre-heating and the Cambi process.

Figure 5-10: One of two 9,000 m^3 biogas storage tanks at the Davyhulme WWTW, UK, June 2024

Figure 5-11: One of Davyhulme's biogas-powered boiler units which provides steam to heat the Cambi process tanks, UK, June 2024

The Davyhulme site demonstrates the extraordinary resources that can be extracted from wastewater sludge.

5.5 TECHNOLOGY CENTRAL - IFAT TRADE SHOW

I spent a very big week in Munich visiting IFAT (www.ifat.de/en), the largest water and waste trade fair in the world. It was truly jaw-dropping and like nothing I've ever seen. The venue is so large there is a train station at either end. The following photo shows one of the trade show pavilions… and there are 18 of them! In addition, a material processing equipment and demonstration area was set up outside, and this occupied a further 12 hectares (ha).

Throughout the week there was a variety of presentations, with key topics including PFAS treatment, the production and use of hydrogen as an alternative fuel source, and the transition to a circular economy. I attended several presentation and panel sessions hosted by the International Solid Waste Association (ISWA), which provided excellent insights into the challenges of waste management throughout the world, not only in developed countries.

Figure 5-12: One of the 18(!) trade show pavilions at IFAT Munich, May 2024

Inside the pavilions, I was amazed at the breadth of equipment available and the quality of the technology. A process engineers dream! The mixers, aerators, centrifuges, belt filter presses, thermal driers and solar driers were of particular interest to me. From the conversations I had with the equipment vendors, it was also interesting to learn which technologies are preferred in different regions, as they typically supply throughout Europe, Asia and the Arab States.

Figure 5-13: Equipment on display at the IFAT trade show, May 2024

In addition to the exhibitors, there were many informative sessions on topics such as the German water sector, hydrogen, waste to energy, PFAS and contaminants, circular economy, and industry associations. I found these particularly useful, as they provided a bigger picture than what individual technology providers could. These sessions helped me to develop an understanding of sludge management in Germany, how Germany compares with other European countries, and key issues for the future.

I met with some wonderful specialists from around the world and had many conversations about the similarities and differences between approaches to biosolids and organic waste management. There are certainly many similarities (contaminants, nutrient management, circular economy), but it was particularly interesting to learn how much a country's regulation is influenced by their environment, population and historical land use. Regulation is not transferable without understanding local context.

5.6 LOCAL CIRCULAR ECONOMIES

During my travels I spent a week in the picturesque Austrian countryside, touring WWTPs, anaerobic digesters and composting facilities. My generous host was Horst Müller, Director of MüllerUmwelttechnik (Müller Environmental Engineering, https://www.mueller-umwelttechnik.at) and Chair of the European Federation for Agricultural Recycling (www.efar.be).

MüllerUmwelttechnik is a consulting company that undertakes assessments for the land application of biosolids, completing soil sampling and preparing application management plans to meet regulatory requirements. In addition, they design composting facilities and anaerobic digestors, with a particular interest in dry anaerobic digestion technology.

I stayed in the delightful village of Haag in Upper Austria, a couple of hours west of Vienna, towards the German border. The facilities we toured service small to medium-sized populations, which reflects the local landscape – homes and businesses clustered in small villages, surrounded by a tapestry of cereal crops, forests and waterways. The crops are densely planted right up to the roadside, and farm animals are primarily housed in barns. The farms are small (typically 5 – 50 ha), but production is intense and diverse.

Figure 5-14: The Austrian countryside, overlooking the village of Haag, in Upper Austria, May 2024

During my time with Horst in Austria, we visited several sites that use dry anaerobic digestion to produce biogas. These facilities have been designed and install by MüllerUmwelttechnik[15]. The process involves locking dry organic materials in air-free cells for 2 – 4 weeks, with digestate recirculation to enhance the anaerobic digestion process. Biogas is drawn out of the cells and used to generate heat and electricity. The remaining solid material (after digestion) is then suitable for composting, and for ‘seeding’ the next batch of organic waste.

Figure 5-15: Dry AD cells at Drexler Horticulture, Upper Austria. This business grows seedlings for residential and commercial customers and operates the dry AD cells and a compost facility as part of its operations. Compost is used onsite and sold, and biogas provides heat to the greenhouses. May 2024

Figure 5-16: Dry AD cells at the VFI Oil Mill, Ennsdorf, Upper Austria. This business processes sunflower seeds, canola seeds and soyabeans into oils. The dry AD cells utilise organic wastes such as the sunflower seed shells to generate heat for keeping stored oil liquid. May 2024

Although these examples did not utilise biosolids, they demonstrate the value that can be derived from locally-available organic waste streams.

[15] https://www.3a-biogas.com/en

6 European approaches to source control of contaminants

6.1 INTRODUCTION

Contaminants management has always been part of the regulated uses of biosolids. As detailed in Section 3.3, the EU has historically limited heavy metals, required pH monitoring, and required that nutrients are used according to crop needs. Since the EU Sewage Sludge Directive (SSD) was published in 1986, individual countries have published and revised their regulations and contaminants, and many now include limits for a much broader range of contaminants that the SSD. The following sections provide an overview of progress on the control and regulation of PFAS and microplastics.

6.2 PER- AND POLY-FLUORALKYL SUBSTANCES (PFAS)

6.2.1 EU REGULATORY APPROACHES

The risks to human health and the environment from PFAS use are now better understood and are becoming political issues for many governments in developed countries. There are now many governments and industry groups that are pursuing bans for PFAS, which will significantly reduce the quantity of PFAS used in industry and society. Even EU parliamentary candidates are campaigning on a platform of supporting PFAS bans.

The **Stockholm Convention** currently restricts the use of PFOS, PFOA and PFHxS, with a restriction of PFHxA currently being established. The restriction of PFOS was implemented in 2009, followed by PFOA in 2020 and PFHxS in 2022. More than 186 countries comply with the Stockholm Convention, and therefore the impact includes many countries that manufacture PFAS, as well as those that use them.

An extensive study was undertaken by Ulrich *et al*[16] that assessed the concentration of PFAS in wastewater sludge samples from more than 1,100 treatment plants in Germany. These samples had been collected between 2008 and 2013, during which time the Stockholm Convention limits for PFOS and PFOA were enforced. The study showed a clear correlation between regulatory controls and reduced PFAS in sludge. They saw a 90% decrease in the measured PFAS in sewage sludge, from a total of 17 tonnes in 2008 to 1.5 tonnes in 2013.

From this research, we can appreciate how effective source control can be, and how quickly regulation can impact environmental contamination. A 90% reduction of PFAS in five years is very significant and is comparable to the time taken by a water utility to implement a major sludge treatment upgrade such as an incinerator. If assets are being installed with a 30+ year operating life, there is a significant risk that contaminant issues will be solved through source control well before a facility has achieved its processing life. This could therefore result in very costly unnecessary assets.

In 2023 the **European Chemicals Agency (ECHA)** published a proposal to restrict all PFAS, which is a different approach to the Stockholm Convention. The proposal came from authorities in Denmark, Germany, the Netherlands, Norway and Sweden, and includes “any substance that contains at least one fully fluorinated methyl or methylene carbon atom”. The proposal considers two approaches to implementing restrictions: either a full ban (manufacture and sale) within an 18-month transition period, or a ban with staged transitions for some industrial uses. The engagement period for the proposed ban has now closed and submissions are

[16] Ulrich, H, Freier, KP and Gierig, M (2016) Getting on with persistent pollutants: Decreasing trends of perfluoroalkyl acids (PFAAs) in sewage sludge. Chemosphere 161: 527 – 535

being reviewed, along with completion of risk assessment and socio-economic analysis. With widespread political support for the ban, it is expected to be implemented by 2026[17].

The **International Chemical Secretariat (ChemSec)** is an advocacy group driving the substitution of toxic chemicals to safer alternatives. Their research has identified some startling facts about PFAS production and the costs to society:

- 60% of all PFAS is manufactured by just 12 companies
- The global market size for PFAS was €28 billion in 2023
- The estimated annual healthcare costs in Europe from direct exposure to PFAS is €52 – 84 billion
- The total societal costs of dealing with the health and remediation of PFAS contamination is estimated to be €16 trillion per year[18].

ChemSec are co-ordinating the **Investor Initiative on Hazardous Chemicals**, on behalf of a group of large investment companies, to influence a reduction in the manufacture of PFAS. ChemSec are also instrumental in refuting claims by industry that PFAS are essential in the production of medical equipment, semiconductors, pharmaceuticals and renewable energy technologies. They provide detailed industry-specific information about where PFAS can be found and how to find safer substitutes.

3M, which is responsible for the production of 5% of the world's annual PFAS, has already announced that it will stop manufacturing PFAS by the end of 2025. An outcome which has been driven by thousands of PFAS-related lawsuits, which will continue well past the date they stop manufacturing[19].

Cosmetics Europe is the European association for cosmetics and personal care products and pushes for industry improvements in sustainability. They recommend that cosmetics manufacturers stop intentionally adding PFAS to cosmetics by December 2025[20], in alignment with the European Commission's Chemical Strategy for Sustainability. Cosmetic's Europe research suggests that PFAS are not typically added to European cosmetics.

Figure 6-1: An EU parliamentary campaign poster for Danish politician Christel Schaldemose at the Copenhagen Central Train Station, which translates to "Protect our children from PFAS", May 2024

[17] https://www.echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas
[18] https://chemsec.org/knowledge/all-you-need-to-know-about-pfas/
[19] https://chemsec.org/the-claim-that-pfas-are-critical-to-the-green-economy-is-complete-hyperbole/
[20] https://cosmeticseurope.eu/files/4216/9718/2125/Cosmetics_Europe_Recommendation_on_PFAS_updated.pdf

6.2.2 UNDERSTANDING SOURCES

It is prudent for any WWTP manager to accurately characterise the source of PFAS in their sewage and seek out options for source control, as these can be far cheaper to implement than full stream treatment technologies and transfer the risk burden to the waste producer. Only after source control options have been exhausted, should treatment approaches be considered.

For example, a significant investigation of sources of PFAS in Copenhagen's wastewater catchment identified that 40% of PFOS in the wastewater came from just two waste management companies[21]. Testing focused on industrial discharges in the catchment area, including waste management facilities, industrial laundries, laboratories, vehicle washing facilities and firefighting training areas.

Water utilities have control over their trade waste arrangements and the potential to manage sources of PFAS within their catchment by encouraging their trade waste customers to treat or remove PFAS from their wastewater prior to discharge and setting PFAS limits in their trade waste agreements. Investing tens of millions of dollars to thermally treat biosolids at a WWTP makes no sense if there are opportunities to treat individual industrial streams upstream of the WWTP. Treating PFAS at the WWTP makes the public responsible for the cost of industrial waste and is totally contrary to the "polluter pays" principle. Table 6-1 lists industries and activities that are key trade waste sources of PFAS.

Table 6-1: Key trade waste sources of PFAS in wastewater

SOURCE	JUSTIFICATION
Landfill leachate	Due to the widespread presence of PFAS in consumer goods, landfill leachate is likely to contain PFAS. If landfill leachate is discharged to the sewer without first undergoing treatment to remove PFAS, this could represent a significant point source of PFAS.
Electroplating wastewater	PFAS are permitted to be used in the electroplating industry, as this use is exempt under the Stockholm Convention bans. PFAS-containing mist suppressants are used in plating baths to trap the hexavalent chromium fumes that would otherwise be a risk to operator safety. *Fumetrol* is one of the mist suppressant brands commonly used in Australia and contains 5 – 10% PFOS.
Airports, military bases, firefighting training facilities, refineries	Groundwater contaminated with PFAS can also enter the sewer system (via infiltration) and this has occurred where firefighting foams have been used extensively, particularly for training purposes. This includes airports, military bases, firefighting training facilities and facilities that store and process hydrocarbons (i.e. refineries).
Textile & carpet manufacturing	The manufacturing of textiles (eg carpets, outdoor wear, uniforms and protective clothing) can involve treatment steps that use PFAS to protect the textiles against water, stain and oil penetration. PFAS compounds may therefore be present in wastewater produced at textile manufacturing facilities.
Industrial or commercial laundries	Similar to textiles manufacturing, PFAS used in textiles can be washed off during cleaning and therefore industrial or commercial laundries, particularly those that have uniform and/or protective clothing contracts, could transfer PFAS into wastewater.

[21] https://www.dhigroup.com/projects/tracing-sources-to-pfas-in-wastewater-treatment-plants

6.2.3 SUMMARY

Given the restrictions that are already in place, and the breadth of proposed regulation, I am more optimistic than ever that we can eliminate these harmful chemicals from all parts of our lives. Every day, the water industry is learning more about sources of PFAS, and we should implement actions to proactively manage sources before considering any end-of-pipe treatment.

Although the regulatory approaches discussed earlier have a European focus, they should have a significant impact on PFAS loads in Australia. Australia does not manufacture any PFAS and has relatively little manufacturing of products that contain PFAS. Therefore, products made to EU standards and sold in Australia should be PFAS-free in the future.

While we wait for wide-spread regulation to be implemented, water utilities can take actions to proactively manage PFAS by:

- Understanding the sources of PFAS in their wastewater catchments
- Setting effective trade waste controls where PFAS is found
- Eliminating as many sources as possible
- Maintaining a state of knowledge on PFAS risk in sewage and biosolids.

6.3 MICROPLASTICS

6.3.1 EU REGULATORY APPROACHES

The EU has essentially ‘parked’ the regulation of microplastics in biosolids for now, as there is insufficient data and testing methodologies to provide advice or limits. The lack of standardised definitions and testing protocols means that the available research is difficult to compare and therefore the evaluation of environmental risk from microplastics in biosolids is still years away. Key knowledge gaps include:

- Plant accumulation and pathways into the food chain
- Impacts to soil microbes, fungi and invertebrates
- Thresholds of impacts caused by the presence of microplastics.

Note that microplastics are potentially a much greater issue in EU biosolids than Australian biosolids, primarily due to European WWTPs commonly receiving both sewage and stormwater (that is, combined treatment). Pieces of rubber from vehicle tyres are a major microplastics pollution in stormwater. As almost no Australian WWTPs have combined treatment, this is unlikely to be a source of microplastics in Australian biosolids.

Although Germany is implementing a ban on biosolids application to land over the next 15 years, this is primarily driven by minimising the contamination caused by excessive use of nitrogen-rich fertilisers and soil amendments (including biosolids, manures and digestate). The ban is not driven by microplastics contamination, although it will be a co-benefit of this approach.

6.3.2 MANAGEMENT OPTIONS

Microplastics contamination is a significantly different beast compared to other contaminants. The EU hasn’t formally agreed on a definition, which adds to the difficulty of quantifying the problems and understanding the risks. From an analytical perspective, the isolation and measurement approaches are significantly different due to the range of polymers in use and size distribution of the microplastics fragments.

In 2023, the EU published a whitepaper on the effectiveness of washing machine filters to remove microplastics generated from clothing (known as microfibres)[22]. This paper calls for the EU to show international leadership in implementing solutions that prevent microfibres from entering the environment and identifies washing machine filters as an effective and near-term solution, as filters are already commercially available.

In 2020, France adopted a new law which requires that from 2025, all new washing machines must have a filter to capture microfibres from clothes washing. The UK parliament introduced a similar bill in 2022 which, in addition to requiring washing machine filters, also seeks to raise awareness of microplastics and promote the benefits of using filters to control microplastics in the environment.

6.3.3 PROTECTING HUMAN HEALTH FROM MICROPLASTICS

I suspect biosolids are only a minor source of microplastics into the environment, compared to other sources such as stormwater, litter, agricultural/horticultural plastics and fisheries plastics, paint and surface coatings, dust, geofabrics, industrial emissions, etc. Therefore, banning the land application of biosolids because of microplastics may do little to protect the environment from this contamination, and will prevent any benefits to soil health from biosolids being realised.

A 2020 study[23] estimated that 1,240 tonnes of microplastics are deposited on Australian farmland annually from biosolids use. But compared to the 100,000 tonnes of plastic waste generated in agriculture and forestry each year[24], we can gain an appreciation for the relative scale of the sources. Furthermore, Swedish research found that the magnitude of microplastics in soils is comparative between soils that have received biosolids and accumulation of microplastics from atmospheric deposition[25].

Despite the lack of microplastics research and the evidence of harm, I hope that governments around the world rapidly pursue a massive reduction in plastics manufacturing and use to control this vast source of pollution. With plastics production doubling from 231 million tonnes in 2002, to 450 million tonnes in 2019, it is incomprehensible that this much plastic is necessary.

6.4 DISCUSSION

Our regulatory history tells us that we can successfully land apply biosolids and manage contaminants through source control and setting upper limits. Understanding point sources of contamination in sewage catchments is a critical first step towards source control and minimising the cost of wastewater and biosolids treatment.

Persistent contaminants interrupt the circular flow of resources, and with all advanced economies now pushing for circular economies, there are bigger forces than the water industry pushing to reduce contaminants in waste materials. Pessimistically, chemical companies may continue to evade regulation by altering formulations or creating entirely new toxic compounds. However, with governments all over the world pursing circular economies, I'd like to think that in the future we will have better controls of toxins entering our society.

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[22] A Plastic Planet, Matter, PlanetCare, Xeros Technologies & 5 Gyres Institute (2023) Filtration as an effluective and near-term solution to reduce the release of microplastics in the environment. Accessed: https://www.textiletechnology.net/media/media/9/EU-Microplastics-Solutions-Whitepaper-89991.pdf, 17/8/2024

[23] Mohajerani, A & Karabatuk, B (2020) *Microplastics and pollutants in biosolids have contaminated agricultural soils: An analytical study and a proposal to cease the use of biosolids in farmlands and utilise them in sustainable bricks*. Waste Management, Vol 107, pp. 252-265

[24] AgriFutures & RMCG (2022) Agriculture, Fisheries and Forestry National Waste and Resource Recovery Roadmap

[25] https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/long-term-impacts-of-sludge-spreading-on-agricultural-land

7 Conclusion & Recommendations

Reflecting on what I have learnt throughout my Fellowship travels, there are many approaches that can enhance the beneficial use of biosolids in Australia. The following learnings and recommendations have been drawn from my experience in biosolids management in Australia, the immersive conversations, site visits and research I undertook during my Fellowship, and the time I had for thinking deeply about the many solutions to the challenging aspects of biosolids use.

Implement national biosolids standards: The EU Urban Waste Water Treatment Directive and Sewage Sludge Directive provide a benchmark for wastewater and biosolids management throughout Europe. This regulation sets a minimum standard and ensures that EU countries with fewer regulatory resources have a baseline for environmental protection. Australia could learn from this regulatory structure and implement national standards for the treatment and use of biosolids. Now that we have the federal EPA which will soon become an independent statutory authority, this body could be the administrator of a federal biosolids standard. State-based regulations or guidelines could still be applied, but the federal EPA would do the 'heavy lifting' on research, consultation and standardisation.

Build circularity and resource recovery into biosolids regulation: As countries around the world move away from linear economies that generate enormous volumes of waste, they seek to build circularity into all resource use. Organic wastes such as biosolids are the original circular economy and the history of sanitation demonstrates that treated sewage sludges can be valued by farmers. Regulation that sets minimum standards for resource recovery, such as Germany's biosolids legislation, provides a legal imperative for implementing management approaches that recover resources, not just manage contaminants. Biosolids are resources that can improve the health of degraded Australian soils, and reduce our use of synthetic fertilisers.

Control problematic contaminants at a national level: The breadth of controls for PFAS in Europe demonstrate how a multi-pronged, EU-led approach can result in a significant decrease in the use of harmful contaminants in our society. Regulation, advocacy and litigation are pressuring manufacturers to stop using PFAS. Individual water utilities have little influence over the importation, use and disposal of a host of persistent and harmful chemicals. It is therefore essential that governments (federal or state) lead on reducing the presence of these chemicals in our lives.

Implement source control before treatment: The presence of microplastics in biosolids is a reality, despite the lack of research on the topic. However, we don't need to wait for research to prove negative impacts to our environment from microplastics, nor do we need to ban the land application of biosolids because they contain microplastics. France is taking action by legislating microfibre filters on washing machines, an action that has been identified as an effective and realistic control measure. There are always actions that water utilities can take that can reduce contaminants entering wastewater and polluting biosolids, and I am certain these actions will always be cheaper than treatment processes.

Leverage biosolids to create local circular economies: In Austria, I visited many wonderful facilities that utilised locally available organic waste streams to generate renewable heat, electricity and soil amendments. Wastewater sludges can be suitable feedstocks for anaerobic digesters and compost processes, and can provide a base load of feedstock for year-round operations. The sites I visited in Austria demonstrated that smaller scale systems can be feasible and derive community-scale benefits.

Employ technologies that enhance biosolids: The sludge treatment reed beds in Denmark were a remarkable demonstration of passive, low energy technology that produces a high-quality biosolids product with very few inputs. Although the water industry and regulators can lean towards intensive, destructive processes, technologies that create quality products will always be a more sustainable choice than a treated waste.

8 Dissemination & Implementation

In addition to the report, I will seek out opportunities to share my experience and learnings with others in the Australian water sector.

During my travels, I published a travel blog, hosted by the RMCG website. This consisted of a weekly blog entry from each country visited, photos of the highlights and key findings. My blog was circulated weekly via my own email list of colleagues, clients, friends and associates in the water industry, and via RMCG's social media links. I thoroughly enjoyed writing these blog posts, as it gave me an opportunity to 'speak' freely, helped to keep my documentation organised and provided much of the content for this report.

In September 2024 I will be presenting on my Fellowship at the 4th Annual Biosolids Symposium in Perth, which is attended by biosolids researchers and professionals throughout Australia and is hosted by the Transforming Biosolids Australian Research Council Training Centre. I will also chair a panel of specialists, providing the conference attendees with an opportunity to hear about the aspirations and challenges of biosolids management.

In 2025, I expect to present my Fellowship experiences at conferences that I regularly attend, including the:

- Australian and New Zealand Biosolids Partnership National Conference, which will be held in Hobart, Tasmania, March 2025
- Water Industry Operations Association Victorian Conference, which will be held in Bendigo, Victoria, February 2025
- Australian Water Association's OzWater'25 Conference, which will be held in Adelaide, South Australia, May 2025.

My Fellowship is highly relevant to my day-to-day consulting work and I will continue to draw on my Fellowship experiences to provide my clients advice on the many strategic and operational aspects of biosolids management, the utilisation of organic wastes to create local circular economies, and opportunities for source control of contaminants.

9 Glossary & Definitions

Aerobic: a biological process that occurs in an oxygen-rich environment.

Anaerobic: a biological process that occurs in an oxygen-free environment.

Biochar: a by-product of the pyrolysis of organic matter.

Biosolids: usually used to describe treated sewage sludge that is fit for use but is sometimes used to describe dewatered sludges which are subsequently treated off-site.

Combined sewer: A sewer system that collects both wastewater and stormwater runoff from municipal areas.

EP: Equivalent population

EU: European Union

PFAS: per- and poly- fluoroalkyl substances.

Primary treatment: the first stage of treatment process used to treat wastewater. Typical technologies used for primary treatment include screening and grit removal.

Quaternary treatment: a fourth stage of treated process used to treat wastewater. Typical technologies used for quaternary treatment include membrane filtration, powdered activated carbon and ion exchange.

Secondary treatment: the second stage of treatment process used to treat wastewater. Typical technologies used for secondary treatment include aerobic bioreactors with or without nutrient reduction.

Sewage sludge: biological sludges that are generated during wastewater treatment. Primary sludge is generated by primary sedimentation processes; secondary sludge is generated by bioreactors.

Tertiary treatment: a third stage of treatment process used to treat wastewater. Typical technologies used for tertiary treatment include multimedia filtration, membrane filtration and disinfection.