Shawview Consulting

White paper

Measuring, Managing, Mitigating

Gaining a One Health perspective on removing antimicrobial residues from water

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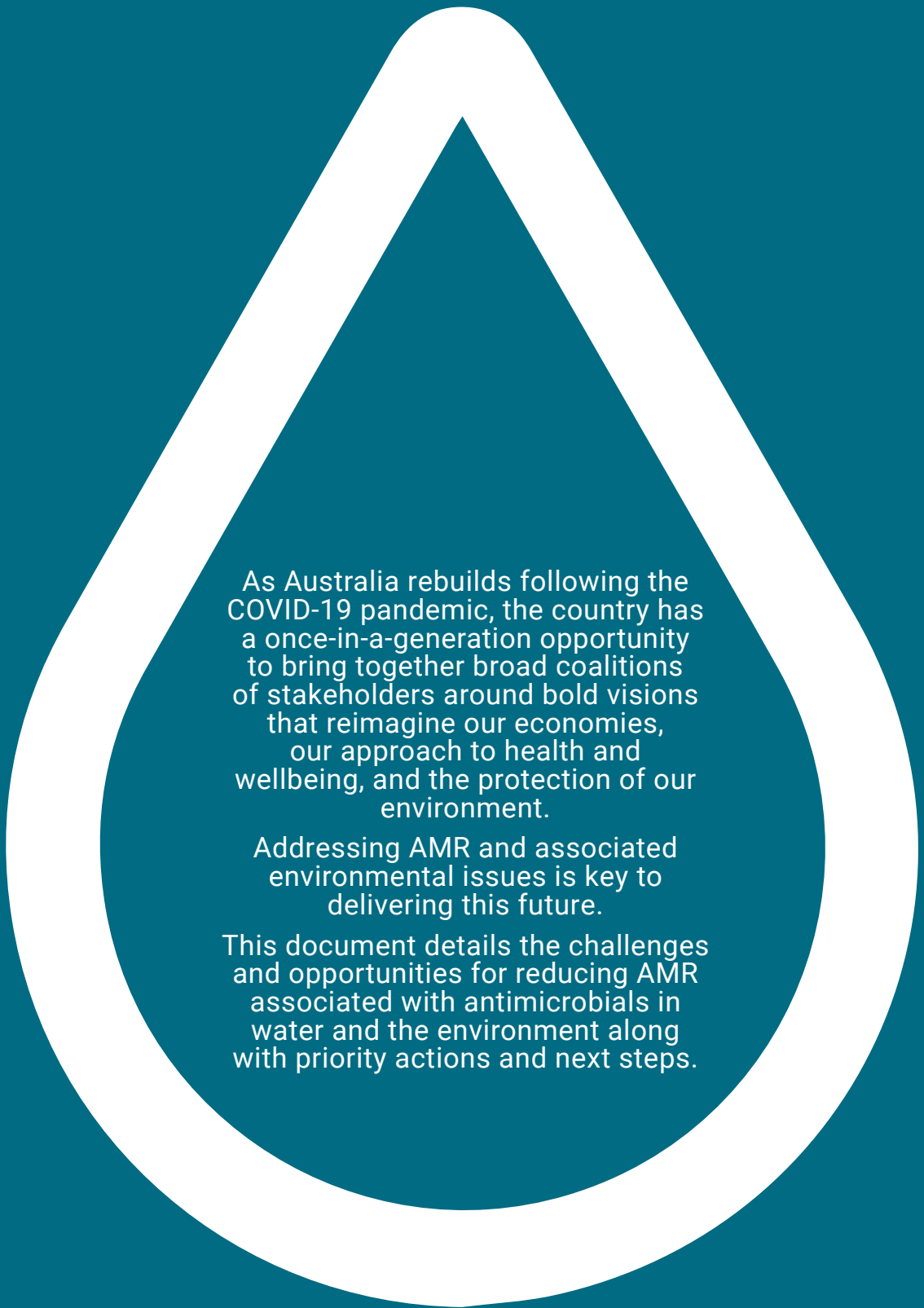
This white paper synthesises the results of discussions held during a workshop entitled Measuring, Managing, Mitigating: gaining a One Health perspective on removing antimicrobial residues from water, that took place on 14 March 2023 at the National Press Club of Australia in Canberra.

The workshop was co-convened by CSIRO's Minimising AMR Mission, the Solving Antimicrobial Resistance in Agribusiness, Food and Environments Cooperative Research Centre (SAAFE CRC), the Department of Agriculture, Fisheries and Forestry (DAFF) and MTPConnect's Australian Antimicrobial Resistance Network (AAMRNet). Science and Technology Australia facilitated the discussions, which were held under 'Chatham House Rule', whereby participants are free to use the information received but the identity of the speaker(s) cannot be revealed. Shawview Consulting contributed expertise and synthesised the discussions for this report.

This document does not aim to endorse the views, opinions, and claims arising at the workshop, and does not necessarily represent the views of Shawview Consulting, the workshop conveners or any of the organisations represented at the workshop; rather, it is intended to serve as a stimulus for further discussion.

Contents



As Australia rebuilds following the COVID-19 pandemic, the country has a once-in-a-generation opportunity to bring together broad coalitions of stakeholders around bold visions that reimagine our economies, our approach to health and wellbeing, and the protection of our environment.

Addressing AMR and associated environmental issues is key to delivering this future.

This document details the challenges and opportunities for reducing AMR associated with antimicrobials in water and the environment along with priority actions and next steps.

Executive summary

Background

Antimicrobial resistance (AMR) occurs when microorganisms, such as bacteria, fungi, or parasites, evolve to become resistant to antimicrobial treatments to which they were previously susceptible. The loss of effective antimicrobials to treat infectious diseases is considered one of the most urgent threats to global health.

Beyond human medicine, AMR is also a major threat to food security and the global economy with a wide range of plant and animal industries being highly dependent on antimicrobials to control the spread of infectious diseases and maintain productivity.

While AMR is widely understood as a problem relating to human and animal health, there is growing evidence that the environment also has a significant and complex role in its proliferation. Increasingly, therefore, global efforts to address AMR adopt a 'One Health' approach - an integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals, and ecosystems.

One Health recognises the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and inter-dependent. The approach mobilises multiple sectors, disciplines, and communities and is also a guiding principle for *Australia's National Antimicrobial Resistance Strategy - 2020 and Beyond* which calls for greater leadership, collaboration, and action to address a range of AMR-related issues.

Roundtable

Within this context, a government and industry roundtable "*Measuring, Managing, Mitigating: Gaining a One Health Perspective on Removing Antimicrobial Residues from Water*" was held in Canberra, Australia on 14 March 2023. The Roundtable was convened by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Minimising Antimicrobial Resistance Mission in partnership with the Solving Antimicrobial Resistance in Agribusiness, Food, and Environments Cooperative Research Centre (SAAFE CRC), the Department of Agriculture, Fisheries and Forestry (DAFF) and MTPConnect's Australian Antimicrobial Resistance Network (AAMRNet).

The roundtable focused on the problem of antimicrobial residues entering the environment from a range of sources including pharmaceutical manufacturing effluent, domestic and hospital sewage outflows, the spreading of manure and biosolids on agricultural lands, and the use of antimicrobials in plant industries and aquaculture.

While there is still considerable scientific uncertainty on the degree of risk posed to human health, there is growing evidence that such discharges can promote the emergence of AMR even at relatively low antimicrobial concentrations.

Roundtable pre-reading consisted of "*An action assessment framework to address antimicrobial resistance*", a green paper prepared by senior economists from the University of South Australia and sponsored by CSIRO.

The paper outlines how an economic lens can be applied to identifying the most efficient and effective approach to addressing AMR with a specific focus on antimicrobial residues in wastewater.

Presentations from the University of South Australia, SAAFE CRC, and Shawview Consulting provided context on the prevailing scientific and economic dimensions of AMR and associated environmental challenges, and an overview of ongoing global initiatives aimed at addressing the issue.

Discussion sessions focused on awareness of AMR, particularly in relation to water and the environment, barriers to behavioural change, and the actions and next steps that need to be taken to mitigate the impact of antimicrobial residues in the environment.

Outcomes

All participants acknowledged and agreed that antimicrobial residues in the environment are a global threat with the potential to impact a wide range of industries, ecosystems, and communities. Roundtable discussions identified various stakeholders bearing distinct responsibilities in addressing this issue including government bodies and related agencies, industry players, the healthcare sector, non-profit organisations. The role of solution providers, policymakers, and payers (public and private sector) was also emphasised.

Several key issues emerged from the Roundtable. The complex and multi-dimensional nature of the challenge means that leadership is required from government at a local, national, and global level. However, the inclusion of private industry and non-government stakeholders across a range of sectors is also needed for the effective development of policies, tools, and actions to manage AMR. A lack of common standards and definitions was identified as a barrier to establishing multi-stakeholder collaborations. Furthermore, insufficient, and sporadic monitoring of AMR within the environment means there is no baseline understanding of the scale of the problem in Australia and the efficacy of any actions taken will be difficult to ascertain.

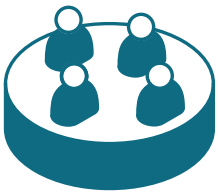
Participants concluded that Australia must take action to prevent and reduce the impact of antimicrobial residues in the environment. These efforts require broad public acceptance and true collaborative efforts from a wide range of sectors. Stakeholders from a diverse range of backgrounds and industries need to work together to address these issues of critical importance.

Develop Awareness and Advocacy Initiatives

- Appoint an AMR emissary as an advocate for AMR policies and practices, including national environmental concerns, while monitoring and reporting on their implementation.
- Execute a comprehensive public information campaign to raise awareness about the emergence and spread of AMR in the environment, with a particular emphasis on the impact of contaminants.

Establish Leadership and Collaboration

- Adopt a whole-of-government approach at the federal, state/territory, and local levels to effectively address AMR and its environmental issues.
- Prioritise AMR discussions and actions by including it on the national cabinet agenda, facilitating engagement and collaboration among all levels of government.
- Enhance Australia's participation in the Global Leaders Group on AMR and actively contribute to the G20 agenda on this issue.



Foster Stakeholder Engagement and Create Environmental AMR Action Plans

- Develop sector-specific action plans to address antimicrobial inputs from various industries (e.g., hospitals, wastewater utilities, agriculture, aquaculture, pharmaceutical, scientific), considering the unique circumstances and economic aspects of each sector in tackling AMR.
- Explore the implementation of mandatory regulations and standards for public and private organisations in Australia to comprehensively address AMR-related issues.

Implement Monitoring and Research Initiatives

- Implement a sustainable program to monitor antimicrobials in water systems and the environment, establishing baseline data to assess contamination levels.
- Allocate additional funding for research evaluating the impact of antimicrobial residues on the emergence of AMR in the aquatic environment and how this intersects with public health.
- Develop standards defining the maximum permissible levels of antimicrobials, antimicrobial-resistant bacteria, and antimicrobial resistant genes in receiving environments.

Background

What is antimicrobial resistance (AMR)?

Antimicrobials are substances that affect the survival, growth, or reproduction of microorganisms. They include antibiotics (which target bacteria), antifungals, antivirals, and a range of antiparasitics. Most antimicrobials are naturally occurring compounds. However, since the mid-20th century, their widespread use (and misuse) in medicine and agriculture has led to the emergence of antimicrobial resistance (AMR) whereby microorganisms are becoming less susceptible to the effects of antimicrobials.

In medicine, AMR means that antimicrobial treatments employed to cure infections are progressively losing their effectiveness, increasing the likelihood of severe outcomes (including death) and the transmission of disease to other people. The global prevalence of multidrug-resistant pathogens is rising. In 2019, an estimated 4·95 million people died with a resistant bacterial infection with 1.27 million of those deaths directly attributable to AMR[1].

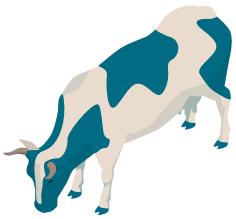
The same report calculated that in Australia there are 1600 deaths due to AMR each year. Modelling suggests that, by 2050, the annual number of AMR-related deaths could reach 10 million, with many 'everyday' infections becoming untreatable and standard medical procedures that currently rely on antimicrobials (e.g., childbirth, joint replacements, chemotherapy) carrying a high risk of complications due to infection[2].

Importantly, the potentially devasting impacts of AMR are not constrained to human health. Many plant and animal industries are now critically dependent on antimicrobials for treating and preventing disease and for improving productivity. The loss of effective antimicrobials to AMR will threaten the commercial viability of primary producers along with the jobs and economic activities they support.

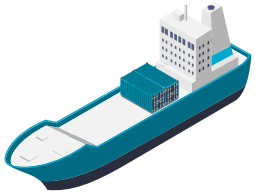
Worldwide by 2050, AMR will result in:

More than 10 million deaths from infections that were previously treatable with antibiotics.[1]

An increase of over 28 million people living in extreme poverty.[2]



A global decrease in livestock production of up to 7.5%.[2]



A reduction in real global exports by 1.1%.[2]

An increase in global AMR healthcare costs from $300 billion to greater than $1 trillion per annum.[2]

US$1.35 trillion dollars in costs for the Western Pacific region over the next ten years[3]

1 The Review on Antimicrobial Resistance (2016) Tackling Drug-Resistant Infections Globally: Final Report and Recommendations.
2 Drug-resistant infections: a threat to our economic future (2016) Washington, D.C. World Bank Group.
3 Reviews in Health Care 2016; 7(1): -16

Figure 1: The predicted impact of antimicrobial resistance by the year 2050 if no actions are taken to intervene.

AMR and the environment

While action on AMR was initially confined to the human and animal health sectors, the environment has a significant and complex role in the evolution and spread of AMR[3]. There is growing evidence for the transmission of resistant microorganisms via water, plants, and soil as well as the movement of humans and other animals and the transportation of animal- and plant-based food and feed.

Recent research has shown the potential for humans to become colonised by microorganisms carrying genes for AMR via, for example, exposure to contaminated food or bathing waters (see breakout below).

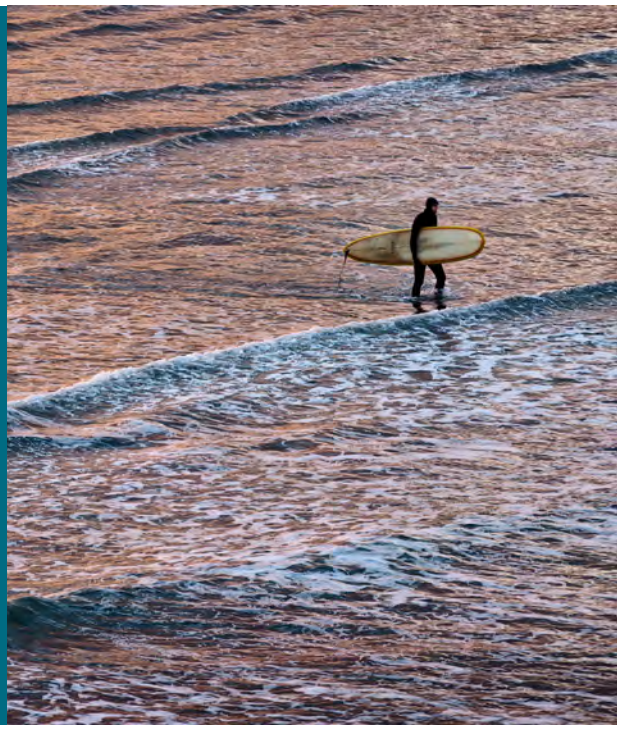
The effects of AMR may also be compounded by other environmental concerns[4,5]. For example, contaminants including metals and microplastics can exacerbate the emergence of AMR in sediments and waters that are subject to industrial pollution. Climate change contributes to conditions such as warmer temperatures that increase microbial growth rates, as well as flooding and sewage overflow that spread AMR pathogens.

Of particular concern is the discharge of antimicrobials into the environment[6]. These residues can disrupt soil microbiomes and the critical functions played by microorganisms in decomposing plant waste and fixing nitrogen with potential negative consequences for plant growth and agricultural productivity. They can also cause toxicity to aquatic microorganisms, disrupting aquatic ecosystems.

Discharges of antimicrobial residues can also result in the creation of AMR 'hotspots' in which conditions favour the selection of resistant microbes and the transfer of genes that convey resistance from one microorganism to another. There is growing evidence that even very low concentrations of antimicrobials (insufficient to kill microbes) can still provide a selection pressure that favours the proliferation of resistant microorganisms and promotes the transfer of resistance genes between microorganisms[7].

The Beach Bums study

Researchers at the University of Exeter (UK) conducted a survey of bathing waters in England and Wales. They found that 11 of 97 samples were contaminated with *E. coli* bacteria carrying blaCTX-M, a gene that conveys resistance to antibiotics called cephalosporins. The researchers then looked at the gut microbiomes of 143 surfers – a group at high risk of exposure to contaminated bathing waters – finding that 9 (6%) had been colonised by blaCTX-M-bearing *E. coli* compared with 2/130 (1.5%) of non-surfers. The results suggest that surfers (and most likely ocean swimmers) are at increased risk of exposure and colonisation by clinically important antibiotic-resistant *E. coli*. Further research is needed to determine environmental AMR transmission pathways and health implications.



Sources of antimicrobial residues in the environment

Figure 2 provides a simplified representation of the main pathways for antimicrobials to enter the environment and thus contribute to AMR.

In an international context, concern has focused on antimicrobial residues in environmental discharges from pharmaceutical manufacturing plants. In June 2023, the AMR Industry Alliance launched a certification scheme for its manufacturing standards in partnership with the UK's national standards body, BSI8. Alliance members have committed to implement these standards by 2027 and are required to review their production processes against these standards.

Australia does not have an active pharmaceutical ingredient (API) antimicrobial manufacturing industry (relying on importation of API antimicrobial compounds, primarily from India and China). However, there are many other sources of antimicrobial residues that are relevant in an Australian context. Notably, wastewater treatment facilities are not designed to remove antimicrobial residues from industrial, domestic, or hospital sewage.

Discharges from wastewater treatment plants are therefore significant point sources of antimicrobials in the environment. Sewage spills can also introduce antibiotic residues into the surrounding environments.

Agriculture is another major source of antimicrobial residues through the spreading of animal waste (manure) or processed human waste (biosolids) as fertiliser. Antimicrobials are also sprayed onto crops to protect against plant pathogens. Antibiotics are not currently used by plant industries in Australia, but antifungals are widely used, particularly in broadacre farming and viticulture[9]. Run-off from agricultural soils can result in antimicrobials entering surface waters such as rivers and lakes. Antimicrobials are also directly added to water systems through their use in aquaculture.

One of the major challenges in addressing antimicrobial residues in the environment is that impacts of antimicrobial pollution are typically not borne by those responsible for emissions. As such, only a coordinated and sustained cross-sectoral response to AMR is likely to be successful.

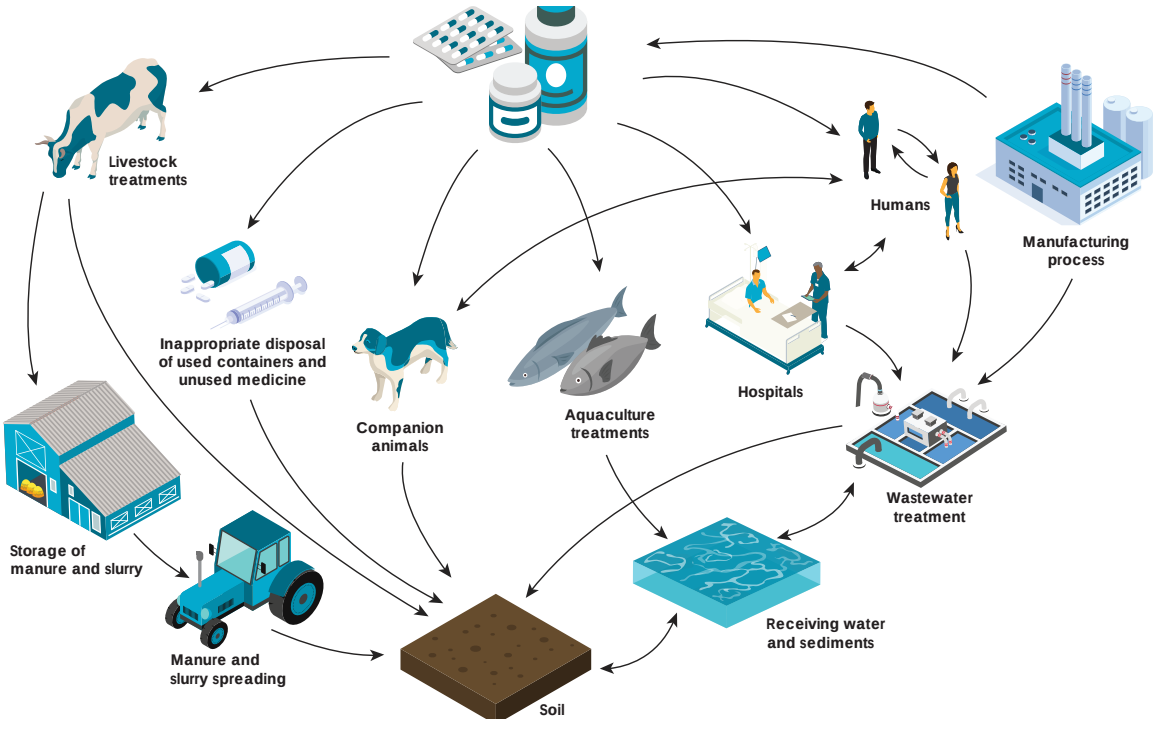


Figure 2: Routes by which antimicrobials can enter the environment. Adapted from Boxall, A. The environmental side effects of medications[10]

The One Health approach to AMR

Given the growing understanding of its environmental aspects, AMR is increasingly seen as a 'One Health' problem[11]. Originally developed as a framework for understanding zoonotic disease, One Health recognises that the health of humans, animals, plants, and the environment are inextricably linked.

The application of 'One Health' to AMR is gaining traction internationally and has been adopted as a strategic framework by organisations including the World Health Organization (WHO) and the United Nations. This has led to the formation in 2022 of the "Quadripartite Alliance" between the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme (UNEP), the WHO, and the World Organization for Animal Health (WOAH) to "catalyse a global movement for action against AMR by fostering cooperation between a diverse range of stakeholders at all levels across the One Health spectrum"[12].

A cross-sectoral One Health framework has also been adopted for Australia's National Antimicrobial Resistance Strategy[13]. Endorsed by the Council of Australian Governments, it outlines a 20-year vision for addressing AMR in Australia (see Figure 3).

Objective 1 of the Strategy calls for clear governance for AMR initiatives and identifies clear responsibilities across different levels of government. Four 'pillar objectives' concurrently address the challenge of AMR by reducing AMR spread, increasing engagement, and improving antimicrobial stewardship and AMR surveillance. Supporting these are two further objectives that seek to identify and encourage cross-sectoral research collaboration and global collaboration and partnerships.

The National Strategy document provides a broad organising framework aimed at guiding AMR initiatives. However, it does not, nor was intended to, provide a detailed plan for addressing specific AMR-related issues such as the discharge of antimicrobial residues into the environment.

Thus, in March 2023, a roundtable was held in Canberra, bringing together a diverse group of participants to discuss the issue of AMR and the environment and to begin the process of developing strategies for addressing antimicrobial pollution.

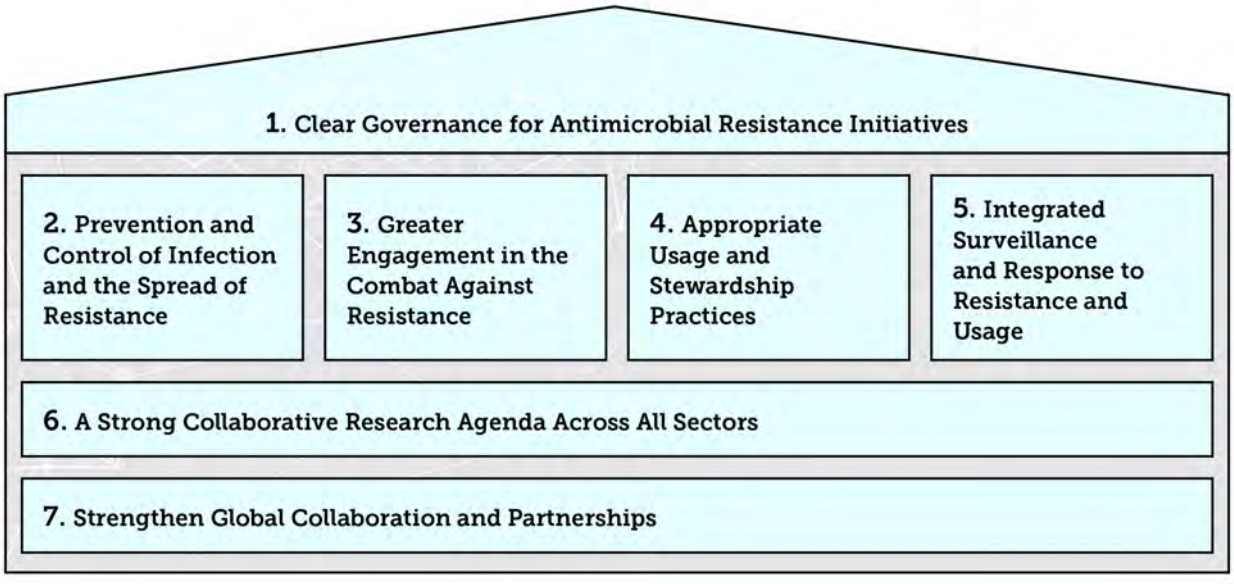


Figure 3: Australia's National Antimicrobial Resistance Strategy – 2020 and beyond.


“In the difficult fight against AMR, adopting a One Health approach in decision-making is critical”.
Professor Erica Donner,
Research Director, SAAFE CRC

Roundtable

Participants

On 14 March 2023, the Minimising AMR Mission, SAAFE CRC, and AAMRNet organised a roundtable in Canberra to discuss the environmental presence of AMR. Objectives of the roundtable were to understand the systemic changes needed to encourage stakeholders (including regulators, policymakers, industries, healthcare professionals and the public) to adopt interventions that help minimise antimicrobial residues in the environment; and to develop a set of priority actions, recommendations, and next steps for key stakeholders.

The Roundtable's 28 participants were multi-stakeholder and included representatives from industry, government, academia, and not-for-profit organisations.

A list of participating organisations can be found in Annex 3.

Misha Schubert, the CEO of Science & Technology Australia, facilitated the discussions. Our expert panel included specialists in AMR from CSIRO and SAAFE CRC; senior economists from the University of South Australia; environmental, social, and governance specialists from Herbert Smith Freehills and Shawview Consulting; and an international expert on global trends in AMR and environmental issues in India.

Green paper

Prior to the Roundtable, the University of South Australia was commissioned to develop a green paper with an economic and action assessment framework to help inform discussions[14]. The Green Paper is targeted at government and industry, although the framework offered in the report is applicable to other groups.

Format

The Roundtable format included a combination of presentations, a moderated Q&A session, and three engaging, multi-stakeholder discussion sessions, which were carefully transcribed.

"Success in this workshop will be determined by whether or not participants here seek to do something different in each of their respective roles as a result of this roundtable".

Professor Branwen Morgan, Minimising AMR Mission Lead, CSIRO

Presentations

Four keynote presentations addressed the challenges and existing strategies in managing the relationship between water, the environment, and AMR.

UniSA Green Paper – An action assessment framework for managing antimicrobial residues. Presentation by Professor Lin Crase and Dr Bethany Cooper, University of South Australia.

One Health, One Water. Presentation by Professor Erica Donner, Research Director, SAAFE CRC.

International examples and opportunities. Presentation by Dr Brendan Shaw and Siddhartha Prakash, Shawview Consulting

Environmental, social, and corporate governance (ESG): how does AMR intersect? Discussion with Heidi Asten, Herbert Smith Freehills, and Unjela Kaleem, Shawview Consulting.

Discussion sessions

For the discussion sessions, participants were split across four tables ensuring cross-sectoral representation.

The first set of roundtable discussions covered introductory topics such as participants' awareness of AMR, particularly as they relate to the environment and water, and how their organisation understands and manages these issues.

The second discussion considered the need for behavioural change and explored the barriers and facilitators to change.

The third and final discussion session was focussed on actions and next steps, identifying the priority areas and considering the feasibility of strategies and interventions that could be rapidly adopted to drive progress.

Four major themes that informed the recommendations emerged. These were:

- **awareness and advocacy;**
- **leadership and collaboration;**
- **stakeholder engagement and action plans;**
- **research and monitoring.**

Awareness and advocacy

Synthesis of Roundtable Discussions

Education campaigns are needed for various sectors, stakeholders, and the community on the risks from antimicrobial residues in the environment.

AMR and its interaction with the environment is an emerging issue in Australia. While there is a general understanding of AMR as a One Health challenge, there is a more limited awareness of antimicrobial contamination in the environment, its potential contribution to AMR, and its impact on human health.

The fact that AMR is a 'long-term' issue may mean that it does not attract the same urgent attention as a short, sharp crisis such as COVID-19.

Previous education campaigns have successfully generated behavioural changes among doctors and patients as they have become more aware of the risks of overprescribing or unnecessarily taking antibiotics. Similar campaigns are now needed to raise awareness of the environmental consequences of antimicrobial use[15].

A prominent advocate to champion the cause of AMR is needed. This advocate would play a crucial role in increasing awareness and promoting action on AMR across sectors and communities. Consideration could be given to selecting this advocate from amongst state or territory leaders who have a genuine interest in and commitment to addressing the issue.

Awareness-raising and communication need to be evidence-based.

Communication about AMR to stakeholders, researchers, governments, and the broader community should stress the immediacy and urgency of the problem to encourage behaviour change.

Important components for developing public-facing communications include clear articulation of the issues and the risks of inaction as well as the potential options for action.

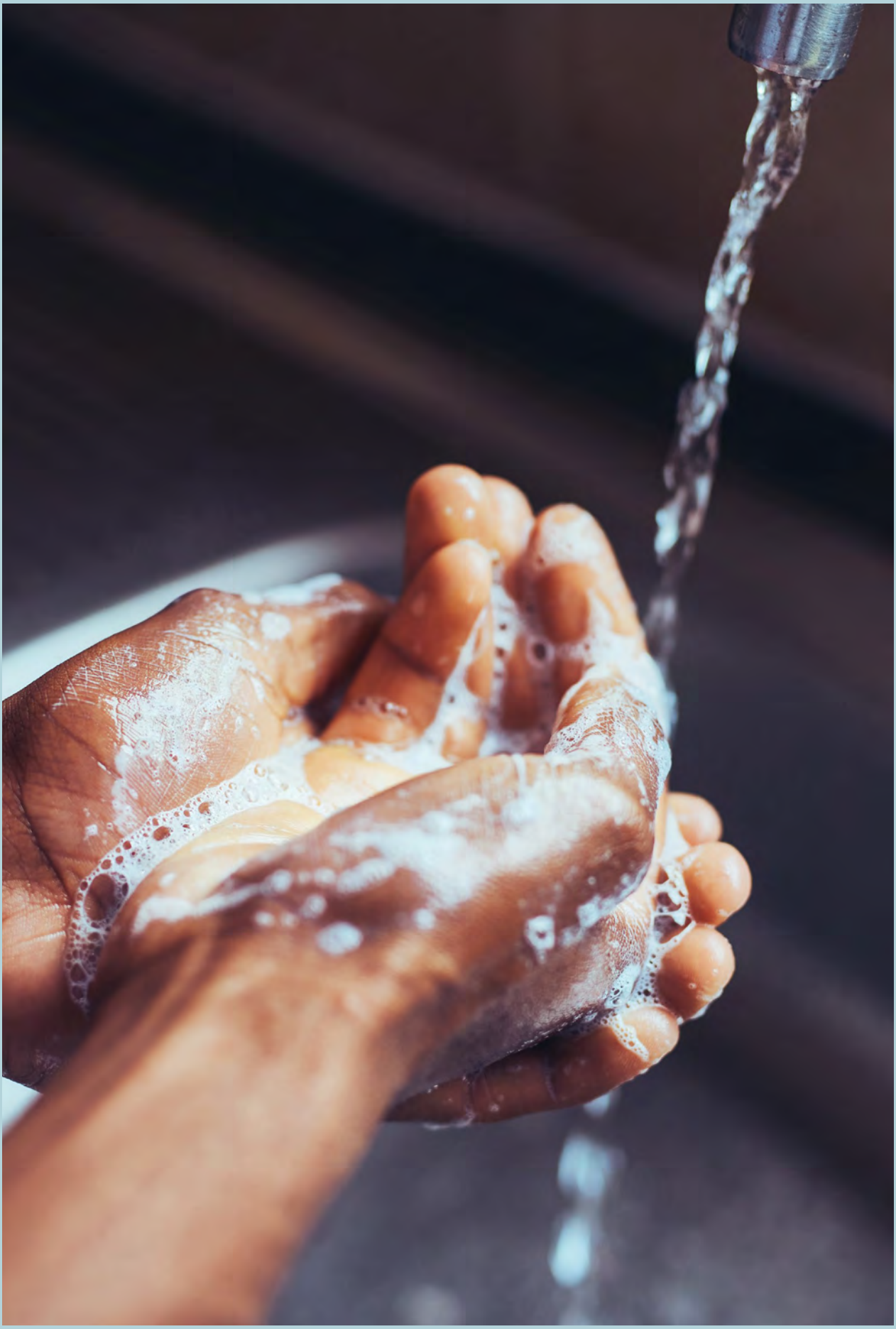
Agreed and consistent definitions are needed when referring to AMR and environmental challenges so that all stakeholders are better able to understand and discuss the concerns and obstacles to change. Consistency of language is important when discussing what to monitor, which indicators are relevant, and the potential impacts in the face of inaction.

Next steps

The environmental aspects of AMR should be clearly explained to the general public, government, and relevant industry sectors. Greater political and policy priority should follow within and across the public and private sectors.

Specifically, it is recommended that:

- An AMR emissary is appointed as an advocate for AMR policies and practices, including addressing national environmental concerns, and to monitor and report on the implementation of these measures.
- A comprehensive public campaign is executed to raise awareness about the environmental stressors and contaminants that enhance AMR.



Leadership and collaboration

Synthesis of Roundtable Discussions

Federal, state and territory, and local governments need to provide leadership on AMR.

In Australia, there is a lack of assigned responsibility for the environmental dimensions of AMR and a lack of accountability for actions that might cause significant health or environmental issues.

Government leadership is essential given its role in setting strategy, policy, and regulatory standards. However, addressing environmental AMR will require political will, capacity, and resourcing.

Governments need to take a long-term investment perspective that recognises the time required to see the impact that interventions have on local communities, the environment, and health outcomes.

Greater policy connectivity between economic, environment, and health areas is required.

The emission of antimicrobial residues lies at the intersection of health policy, environmental policy, and business policy and involves multiple public and private sector organisations and levels of government. However, the 'siloing' of policymaking means that no one organisation or sector is taking responsibility or leading a response.

A high-level, whole-of-government, approach is therefore needed to coordinate action with industry sectors to develop monitoring and mitigation efforts to prevent antimicrobial residues from entering the environment.

Expanding the 'One Health' approach with government, other stakeholders, and the broader community is important. Australia's National Antimicrobial Resistance Strategy identifies the environment as a key issue in AMR, and implementing the recommendations within the strategy would be an efficient path forward.

Governments, experts, and private industry should create open forums for collaboration with policymakers to drive alliances and find innovative solutions that are of mutual benefit.

The role of the private sector in contributing to and responding to AMR requires clarification. Consideration should be given to incentives that would encourage the private sector to act.

Ultimately, all those with a role in contributing and mitigating AMR should be engaged in delivering solutions. The various contributors to antimicrobial residues in the environment, including hospitals, aged care facilities, wastewater and sewage treatment plants, agriculture and aquaculture industries, and pharmaceutical industries need to take individual and collective responsibility for their environmental impacts.

The Australian Government could increase its contributions to global efforts that specifically target AMR.

Australia can learn from the experiences of other countries and global partnerships built to share common standards and best-practice.

In the Asia-Pacific region, India and China are the major players and together are the largest suppliers of antibiotics to the global market. Nonetheless, Australia can help drive change through sustainable or 'green antimicrobial procurement' processes whereby the environmental impacts of antimicrobial manufacturing are considered alongside steps taken by the manufacturer to ensure zero liquid waste. A potential model for this approach is the UK's procurement plan for antibiotics – currently at the pilot and consulting stage – which explicitly includes weighting for environmental criteria[16].

There are other incentives and disincentives to minimise environmental contamination from the antibiotic manufacturing process that could also be considered, noting that these have a range of implementation difficulties[17].

More broadly, Australia has an opportunity to advocate for and lead efforts in the Indo-Pacific region that could help low and middle-income countries access and implement the technological innovations needed to reduce environmental AMR. This in turn would reduce Australia's AMR risk. As COVID-19 showed, global health issues can quickly transcend national borders, disrupt medical supply chains, and exacerbate regional health inequities.

The United Nations General Assembly 2024 High-level Meeting on AMR is an opportunity for Australia to commit to new, clear targets and practical steps to address AMR.

Next steps

AMR is a complex and multi-dimensional challenge that requires a holistic One Health response with leadership from government to address the wide-ranging impacts of AMR across the economy and society.

Specifically, it is recommended that:

- A whole-of-government approach is adopted at the federal, state/territory, and local levels to effectively address AMR.
- AMR discussions and actions are prioritised by including it on the national cabinet agenda, facilitating engagement and collaboration among all levels of government.
- Australia increases its level of involvement with the Global Leaders Group on AMR and takes a leadership role in the G20 agenda on AMR.

Stakeholder Engagement and Action Plans

Synthesis of Roundtable Discussions

Clear and easily understood definitions and standards are crucial to addressing the presence of antimicrobials in the environment and mitigating the associated risks.

Critical first steps include defining the scope of the problem in Australia, clarifying the presence of antimicrobials in the environment, outlining measurement methods, and identifying potential sources.

In taking these steps, it becomes feasible to determine the relevant stakeholders who should participate in consultative discussions and to identify potential risks, barriers, challenges, or opportunities. Clear definitions and standards serve as the foundation for collaborative efforts among all stakeholders.

Interventions for addressing environmental AMR should be evaluated using an economic lens.

The development of Environmental AMR Action Plans can accelerate the process of managing antimicrobial residues. However, it is essential that decision-makers assess uncertainties in our understanding of environmental AMR. These uncertainties can lead to inaction by stakeholders but can also lead to over-investment in inefficient projects.

Action plans should also consider whether or not the action is reversible, the cost/benefit, and the level of risk associated with the intervention. Increasing our understanding of AMR will reduce uncertainty and support better-informed decision making.

Due to the complexities of AMR, both from an economic and scientific perspective, it is important to consider multiple approaches using evidence-informed decision making, rather than rigidly pursuing one course of action. For example, residues may be removed from waste flows via enhanced treatment either ‘at source’ or at the ‘end of pipe’ (i.e., just before discharge into the environment) and the most efficient method may depend on a wide range of factors.

Consideration should also be given to who ultimately pays for efforts to address environmental AMR. For example, if manufacturers of antimicrobials are required to reduce their emissions of residues or water companies are required to upgrade their treatment facilities to remove such residues, these costs are likely to be passed on to consumers. This will have greatest impact on lower socio-economic groups and may lead to resistance to change from consumers more generally.

"ESG discussions in relation to AMR have thus far been largely a 'tick box' exercise, rather than being viewed as a serious policy challenge that requires real, long-lasting solutions".

Heidi Asten, Herbert Smith Freehills

The Green Paper from the University of South Australia is an accessible document providing an action framework to inform priorities in relation to AMR and to help guide policy decisions. A natural next step is for Governments to apply the action assessment framework to policy decisions and/or to the evaluation of policy interventions.

Policy tools including grants, loans, and regulatory standards can be used to drive industry change.

The preservation of effective antimicrobials is a public benefit but there is currently little incentive for private organisations to address AMR-related environmental issues. For example, in the agricultural sector, there is some awareness of AMR in relation to soil contamination, but there has been little commercial incentive or encouragement to act to reduce antimicrobial residues.

Policy makers need to consider whether recommendations and voluntary standards will drive behaviour change or whether mandatory regulations and standards, such as extended producer responsibility[18], will be required.

Comparisons can be drawn with the development of regulations governing the release of per- and poly-fluoroalkyl substances (PFASs) into the environment[19]. This process started with the collection of existing data and evidence to assess the problem and progressed to collaborative research to improve those datasets and document the problems and issues, before ultimately leading to a set of nationally consistent standards.

Addressing AMR should be considered central to good corporate governance

Corporations should address AMR as part of their Environmental Social and Governance (ESG) responsibilities. Awareness of AMR at an ESG-level is currently very low. There is, however, an awareness of supply-chains more generally and an increased focus on environmental sustainability and the opportunities for companies to promote themselves as being ESG-aware (rather than just complying with enforced regulations).

Companies, their executives, and company directors are increasingly required by law to consider a range of environmental risks facing their business. Companies should therefore consider the legal risks if any of their activities contribute to antimicrobial contamination and AMR. Proper management of AMR will help protect companies from future litigation or compensation claims.

Non-government organisations and activist groups are increasingly applying pressure on corporations to act on environmental issues[20].

Antimicrobials represent a 'nature-related risk' because they can perturb microbial communities that are part of healthy land and water ecosystems with knock-on effects for plants and vertebrates[21], potential loss of biodiversity, and ecosystem degradation. Antimicrobial pollution could therefore be considered within frameworks such as the Taskforce on Nature-related Financial Disclosures that seek to value and account for natural capital in the same way that climate-related risks are now considered by companies and financial institutions[22].

"Risk is where there is a probability for an outcome to occur. Uncertainty is where we lack the information to assign a probability to a certain outcome".

Professor Lin Crase and Dr Bethany Cooper, UniSA

Increased global collaboration is needed on regulatory standards for antimicrobial residues.

The pharmaceutical industry has provided leadership through the AMR Industry Alliance which developed standards for permissible levels of antimicrobial residues for its members and suppliers. However, much of the global industry is not covered by the Alliance and there are concerns that the Alliance standards are neither appropriate nor stringent enough.

A number of different sectoral players are becoming involved in these issues, such as the Global Leaders Group on AMR, some European governments, the WHO, as well as ongoing discussions in industry and the academic community.

For other industry sectors such as agriculture, aquaculture, and the hospital and medical sectors, there is a need for more comprehensive dialogue and collaboration on the issue of antimicrobial contaminants entering the environment. The Strategic Approach to International Chemicals Management is an example of environmental concerns being addressed through a multi-stakeholder approach, albeit at a multi-sectoral, international policy level[23].

Next steps

Policy experts and government decision-makers should work with industry and non-government stakeholders to ensure that supply chain activities are compliant with best practices, regulations, and standards. There are many contributors to antimicrobial residues in the environment including hospitals, aged care, manufacturing, industry, agriculture, aquaculture, and water utilities. These sectors should be actively involved in the policy response to minimise the impact of such pollution on AMR.

Specifically, it is recommended that:

- Sector-specific environment action plans are developed, tailored to address antimicrobial residues from various industries (e.g., hospitals, wastewater treatment plants, agriculture, aquaculture, pharmaceutical, scientific), considering the unique circumstances and economic aspects of each sector in tackling AMR.
- The implementation of mandatory regulations and standards for public and private organisations in Australia are explored to comprehensively address AMR-related issues.

Research and Monitoring

Synthesis of Roundtable Discussions

Research is one of the key early enablers for change in Australia.

There is currently a lack of data, information, and evidence regarding antimicrobial residues in the environment. This makes it difficult to assign responsibility and tasks.

Better data is needed to determine the scale of the problem, where the residues end up, and the significance of the residues. Research is also needed to determine who the major contributors are and how they can take action to prevent residues from entering the environment.

Agencies such as the European Union, UNEP and WHO are beginning to address these questions, but the work is in its infancy.

Monitoring of antimicrobial concentrations in waste discharges is seen as a high priority issue.

Currently, there is limited monitoring of antimicrobial concentrations in discharges from sewage treatment plants, agricultural, aquaculture, and other industries. The more data that is available about the scale of the problem and its impact, the better informed any policy, regulatory, or strategic response is likely to be.

Establishing baseline data on the current situation in Australia is one of the first steps to enable change. Ongoing environmental monitoring programs for AMR indicators in the environment would be the next step.

There are no Australian guidelines for water that reflect AMR risks.

The Australian Water Quality Guidelines (2018)[24] provide a risk management framework and guideline values that aim to protect against unacceptable levels of exposure to hazardous substances. However, the Guidelines do not currently include antimicrobials or any other pharmaceuticals.

Regulations for hospital waste and treatment generally apply to medical waste (infectious, hazardous, radioactive, and general) and do not cover drugs and antimicrobials entering the sewage waste system (i.e., through urine and faeces). For example, there is currently no mention of AMR in NSW Health's policy directive on *Clinical and related Waste Management for Health Services*[25]. However, this is due for renewal in 2025.

Predicted No Effect Concentrations (PNECs) are used to derive water quality guideline values based on potential to cause toxicity. Internationally, PNECs are now also being calculated for a range of chemicals based on potential for AMR to develop[26]. However, a standard approach for deriving AMR-PNECs will be needed to establish reliable benchmarks and monitoring protocols.

The development of new monitoring technologies will make environmental surveillance easier, quicker, and cheaper for all stakeholders.

Real-time monitoring and reporting technologies could be developed or adapted to give regulators confidence that public and private sector organisations are complying with standards.

Similarly, health funders, such as public or private health insurance agencies, may want certification of standards if they agree to pay higher prices for environmentally friendly antibiotics.

Next steps

The lack of data, information, and ongoing monitoring of antimicrobial residues in water systems and the environment more generally is a cause for concern in Australia as it is internationally. Greater investment in water monitoring is therefore needed to measure the scale and impact of the problem and, subsequently, to help develop policy actions to reduce antimicrobial concentrations. While there are emerging technologies to help monitor and manage antimicrobial residue levels, these need to be further developed and considered alongside the emerging international recommendations, with a plan for implementation in Australia.

Specifically, it is recommended that:

- A program to monitor antimicrobials in water systems and the environment is established to determine baseline data to assess contamination levels.
- Additional funding is allocated for research on evaluating the impact of antimicrobial residues on the emergence of AMR in the environment and how this intersects with public health.
- Standards defining the maximum permissible levels of antimicrobials, antibiotic resistant bacteria, and antibiotic resistant genes in receiving environments are developed.

Key issues, policy recommendations and next steps

The following table summarises the key issues from the Roundtable. It contains recommended action to address these issues, a recommended responsibility for who should be responsible in leading on these issues and actions, and links with Australia's National AMR Strategy 2020 & beyond.

Issue	Recommended actions	Lead responsibility	National AMR Strategy link
Lack of priority given to antimicrobial residues in the environment and water	Execute a comprehensive public information campaign to raise awareness about the emergence and spread of AMR in the environment, with a particular emphasis on the impact of contaminants. Appoint an AMR emissary as an advocate for AMR policies and practices, including national environmental concerns, while monitoring and reporting on their implementation.	Federal government CSIRO	3.1 – Develop and implement a coordinated, One Health communication strategy, as well as monitoring and evaluation, to support whole-of-society awareness and behavioural change 3.2 – Strengthen public and political awareness to champion and improve the understanding of the importance of combating AMR 3.3 – Create new and different key AMR messages that resonate with society 3.4 – Drive education and training initiatives across all relevant sectors and increase accessibility to evidence-based best-practice information
Environmental AMR is a complex and multidimensional challenge	Adopt a whole-of-government approach to AMR and its environmental issues at the federal, state/territory, and local levels Prioritise AMR discussions and actions by including it on the national cabinet agenda, facilitating engagement and collaboration among all levels of government. Enhance Australia's participation in the Global Leaders Group on AMR and actively contribute to the G20 agenda on this issue.	National Cabinet Federal-state ministers Federal government departments (DHAC, DCCEEW, DAFF, DISR, DFAT)	7.1 – Influence the global antimicrobial resistance agenda by active engagement and collaboration with other countries, multilateral organisations, and forums 7.3 - Participate in international surveillance and monitoring initiatives

Siloing of policy and responsibility for action	Develop sector-specific action plans to address antimicrobial inputs from various industries (e.g., hospitals, wastewater utilities, agriculture, aquaculture, pharmaceutical, scientific), considering the unique circumstances and economic aspects of each sector in tackling AMR.	Federal government State/territory governments Industry associations and sector representative.	1.2 – Develop, implement and/or maintain sector-specific action plans 1.3 – Maintain and expand linkages and opportunities between stakeholders across all sectors to provide a nationally coordinated approach to combating AMR
Lack of data and monitoring to inform strategy	Implement a sustainable program to monitor antimicrobials in water systems and the environment, establishing baseline data to assess contamination levels. Identify the best ways to introduce monitoring in different sites and water systems. Allocate additional funding for research on antimicrobial residue levels in Australian aquatic environments, evaluating the impact of antimicrobial residues their impact on the emergence of AMR in the aquatic environment and how this intersects with public health.	CSIRO SAAFE CRC Universities ARC NHMRC Federal government departments (DHAC, DCCEEW, DAFF, DISR) State/territory governments	2.2 – Maximise compliance with best-practice infection prevention and control and biosecurity measures through adherence to applicable legislation, targets, and accreditation standards 2.4 – Share information on emerging AMR trends to inform responses 4.2 – Develop and implement effective mechanisms to monitor, reward and enforce compliance with standards and best-practice approaches for appropriate and judicious antimicrobial use 4.3 – Use data on antimicrobial usage to inform antimicrobial stewardship policy and support the development of targeted, timely and effective responses 5.1 – Create a sustainably funded national One Health surveillance system that integrates human, animal, food and environmental usage and resistance data 5.3 – Implement national alignment of laboratory testing practices and reporting for AMR 5.4 – Implement national alignment of laboratory testing practices and reporting for AMR
Lack of common definitions and standards	Develop standards defining the maximum permissible levels of antimicrobials, antimicrobial-resistant bacteria, and antimicrobial resistant genes in receiving environments. Explore the implementation of mandatory regulations and standards for public and private organisations in Australia to comprehensively address AMR-related issues.	CSIRO SAAFE CRC	2.1 – Adopt evidence-based and nationally consistent standards for infection prevention and control and biosecurity 2.4 – Share information on emerging AMR trends to inform responses 6.4 – Support the translation of research findings into new approaches, applications, and policies to combat AMR

Annex 1: Acronyms

AAMRNet - Australian Antimicrobial Resistance Network

AMR – antimicrobial resistance

ANZG - Australia and New Zealand Guidelines

API - active pharmaceutical ingredient

COAG – Council of Australian Governments

CoE – Centre of Excellence

CSIRO – Commonwealth Scientific and Industrial Research Organisation

DAFF – Department of Agriculture, Forestry and Fisheries

DCCEEW – Department of Climate Change, Energy, the Environment and Water

DFAT – Department of Foreign Affairs and Trade

DHAC – Department of Health and Aged Care

DISR – Department of Industry, Science and Resources

EPA – Environment Protection Authority

ESG- environment, social and governance

EU – European Union

FAO – Food and Agriculture Organization

NHMRC – National Health and Medical Research Council

PFAS - Per- and Polyfluorinated Substances

PNEC - Predicted no-effect concentration

Q&A – questions and answers

RAMP – Responsible Antibiotics Manufacturing Platform

R&D – research and development

SAAFE CRC - Solving Antimicrobial Resistance in Agribusiness, Food, and Environments Cooperative Research Centre

UK – United Kingdom

UniSA - University of South Australia

UNEP – United Nations Environment Program

WHO – World Health Organization

WOAH – World Organization for Animal Health

Annex 2: Roundtable partners

The Commonwealth Scientific and Industry Research Organisation (CSIRO) is Australia's national science agency. In establishing its Missions Program in 2019, CSIRO joined a growing global community of policy practitioners, researchers and leaders experimenting with models to make good on the ambitious promise of mission-oriented innovation.

CSIRO's Minimising Antimicrobial Resistance Mission is working to halt the rising death rate and economic burden of antimicrobial resistance in Australia by 2030.

The Australian Antimicrobial Resistance Network (AAMRNet) is a multi-stakeholder expert group formed to address the impact of antimicrobial resistance (AMR) on human health. AAMRNet was established in 2020 by the Industry Growth Centre, MTPConnect, in response to the paper Fighting Superbugs: A Report on the Inaugural Meeting of Australia's Antimicrobial Resistance Stakeholders.

The Solving Antimicrobial Resistance in Agribusiness, Food, and Environments Cooperative Research Centre (SAAFE CRC) is an organisation established under the Australian Government's CRC Program. The CRC Program supports the development of technologies, products and services that help reduce Australian industry problems. SAAFE CRC is committed protecting Australia's food and agribusiness industries and their environments from the growing threat of AMR.

A Commonwealth Government Department, the Department of Agriculture, Fisheries and Forestry works to enhance Australia's agricultural, fisheries and forestry industries. Senator the Hon Murray Watt is the Minister for Agriculture, Fisheries and Forestry.

Annex 3: Participanting organisations

MTPConnect/ Australian Antimicrobial Resistance Network (AAMRNet)

Cancer Council

Australian Healthcare and Hospitals Association

EPA Victoria

CSIRO

Department of Agriculture, Fisheries and Forestry

Department of Climate Change, Energy, the Environment and Water

Department of Health and Aged Care

Herbert Smith Freehills

IPART

Peter Cullen Trust

Pfizer

Reef Restoration and Adaption Program

SAAFE CRC

Shawview Consulting

Sydney Water

Tas Water

University of South Australia

Veolia

Water Research Australia

Watertrust Australia

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