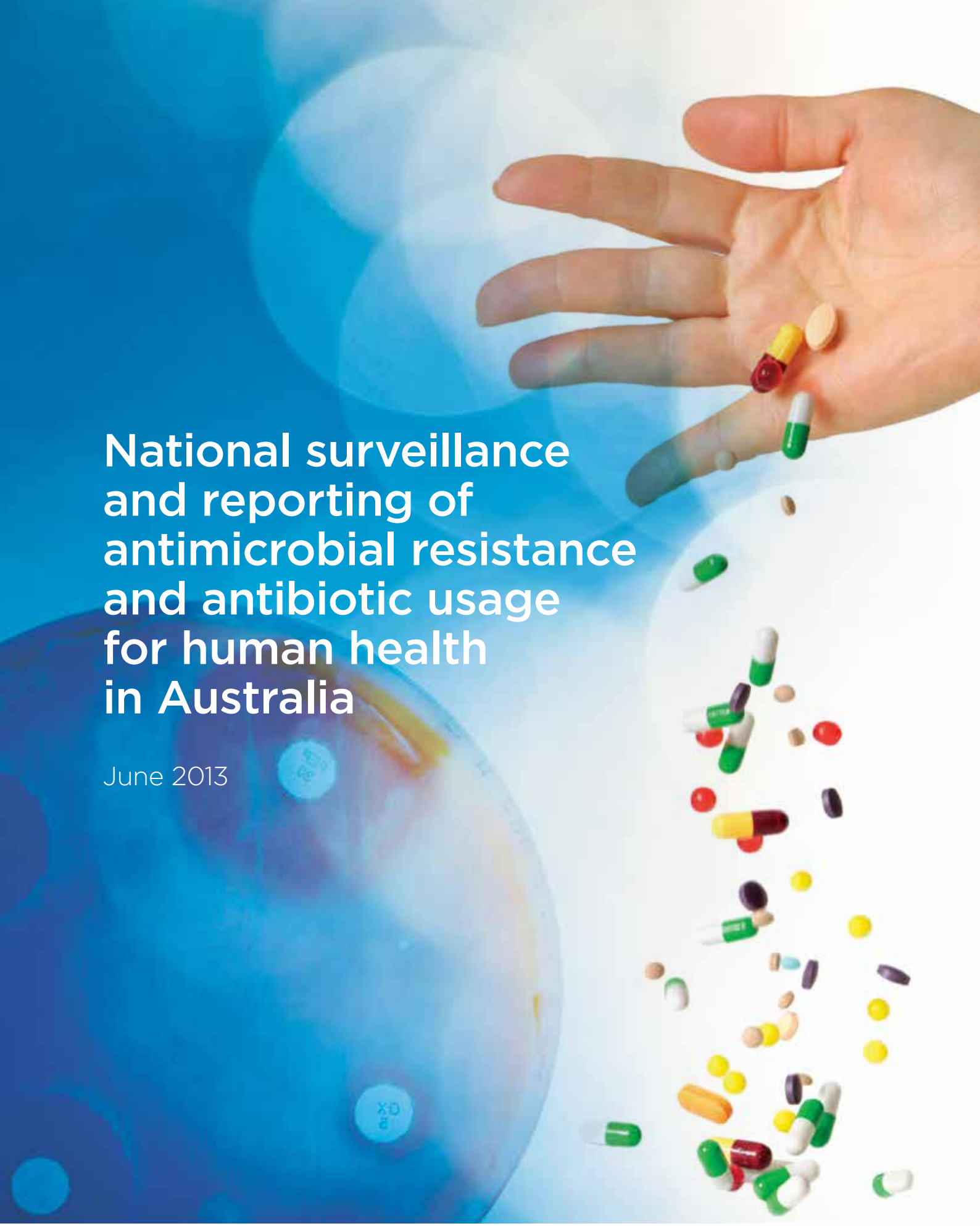

National surveillance and reporting of antimicrobial resistance and antibiotic usage for human health in Australia

June 2013

Antimicrobial Resistance
Standing Committee

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Disclaimer
This document is a review of the available evidence with respect to the science and systems for the surveillance and reporting of antimicrobial resistance and antibiotic usage. It is designed to provide information based on the best evidence available at the time of publication to assist in decision making. The science of antimicrobial resistance and antibiotic usage and the practices of surveillance and reporting are rapidly evolving. The authors, members of the Antimicrobial Resistance Standing Committee and the Australian Commission on Safety and Quality in Health Care give no warranty that the information contained in this document and any online updates available on the Commission's website or elsewhere is correct or complete, and shall not be liable for any loss whatsoever whether due to negligence or otherwise arising from the use of or reliance on this document.

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Acronyms and abbreviations

ACSQHC	Australian Commission on Safety and Quality in Health Care
AGAR	Australian Group on Antimicrobial Resistance
AHPPC	Australian Health Protection Principal Committee
AMR	antimicrobial resistance
AMRSC	Antimicrobial Resistance Standing Committee
ANSORP	Asian Network for Surveillance of Resistant Pathogens
ATC	Anatomical Therapeutic Chemical
CDC	Centers for Disease Control and Prevention
CHRISP	Centre for Healthcare Related Infection Surveillance and Prevention
DANMAP	Danish Integrated Antimicrobial Resistance Monitoring and Research Programme
DoD	US Department of Defense
EAGAR	Expert Advisory Group on Antimicrobial Resistance
EARS-Net	European Antimicrobial Resistance Surveillance Network
ECDC	European Centre for Disease Prevention and Control
ESAC-Net	European Surveillance of Antimicrobial Consumption Network
ESBL	extended-spectrum beta-lactamase
HAI	healthcare-associated infection
ICU	intensive care unit
JETACAR	Joint Expert Technical Advisory Committee on Antibiotic Resistance
LIS	laboratory information system
MRSA	methicillin-resistant *Staphylococcus aureus*
NARMS	National Antimicrobial Resistance Monitoring System
NAUSP	National Antimicrobial Utilisation Surveillance Program
ReLAVRA	*Red Latinoamericana de Vigilancia de la Resistencia a los Antimicrobianos* (Latin American Network for Antimicrobial Resistance Surveillance)
STRAMA	Swedish Strategic Programme for the Rational Use of Antibiotic Agents and Surveillance of Resistance
TESSy	The European Surveillance System
UK	United Kingdom
US	United States
VRE	vancomycin-resistant enterococci
WHO	World Health Organization

Preface

Antimicrobial resistance has been recognised as a global health priority by the World Health Organization. Australian governments have also taken significant action in establishing two committees to oversee national initiatives to prevent and contain antimicrobial resistance in Australia.

In February 2013 the Department of Health and Ageing and the Department of Agriculture, Fisheries and Forestry formed the Australian Antimicrobial Resistance Prevention and Containment Steering Group bringing together the secretaries of each Department, the Commonwealth Chief Veterinary Officer and the Chief Medical Officer. The Steering Group will provide governance and leadership on antibiotic resistance and oversee the development and implementation of a coherent framework for current and future work related to antimicrobial resistance.

In April 2012, the Australian Health Protection Principal Committee, and subsequently Australian Health Ministers Advisory Council endorsed the formation of the Antimicrobial Resistance Standing Committee (AMRSC). The standing committee was formed to oversee antimicrobial resistance in Australia, provide expert advice and recommend national priorities on issues relating to antimicrobial resistance.

Membership of AMRSC brings together representatives from the Commonwealth government and its agencies in human, animal and agricultural contexts, clinical experts and professional colleges.

The report – *National Surveillance and Reporting of Antimicrobial Resistance and Antibiotic Usage for Human Health in Australia* – was commissioned in response to a gap analysis undertaken by a multidisciplinary taskforce convened by the Australian Commission on Safety and Quality in Health Care in 2011. The gap analysis clearly demonstrated that there are a number of activities developed by the state and territory jurisdictions as part of their primary responsibility for managing infection control and some nationally coordinated surveillance activities funded by the Commonwealth. The Australian Commission on Safety and Quality in Health Care, in collaboration with Commonwealth agencies and professional organisations, is coordinating a national healthcare associated infection prevention program creating a mandatory national accreditation scheme which means over 1500 hospitals and health services will be taking active steps to address antibiotic resistance, standardising surveillance definitions, establishing a national hand hygiene initiative and antimicrobial stewardship programs, and providing education for clinicians.

However, the gap analysis also demonstrated a national surveillance system to determine how many patients were infected with resistant bacteria, how many died or had complications as a result of their infection, or an alert system to notify clinicians and policy makers of emerging and re-emerging highly resistant bacteria was now required as a matter of national importance.

Effective surveillance is the cornerstone of efforts to control antimicrobial resistance. At the local level, the data are used to formulate recommendations for rational antibiotic use, to develop standard treatment guidelines, and for ensuring that healthcare providers comply with recommendations. At a national level, data on resistance and use can inform policy decisions such as development or revision of essential medicines lists, and identification of priorities for public health action to reduce the impact of antimicrobial resistance, such as education campaigns or regulatory measures. Conversely, lack of surveillance can lead to misdirected and inefficient policies, wasting of limited resources, inappropriate therapy and ultimately human suffering and death through the inability to provide an effective drug to patients in need.

The report examines international antimicrobial resistance surveillance models, current activities undertaken by Australian surveillance units; activities undertaken by the Australian Group on Antimicrobial Resistance, and the National Antimicrobial Utilisation Program, and examines how reports from routine diagnostic laboratories might provide a source of data to contain antimicrobial resistance.

While acknowledging the importance of antimicrobial resistance and antibiotic use in veterinary and agricultural practice, the scope of this report is limited to bacteria in the context of human health.

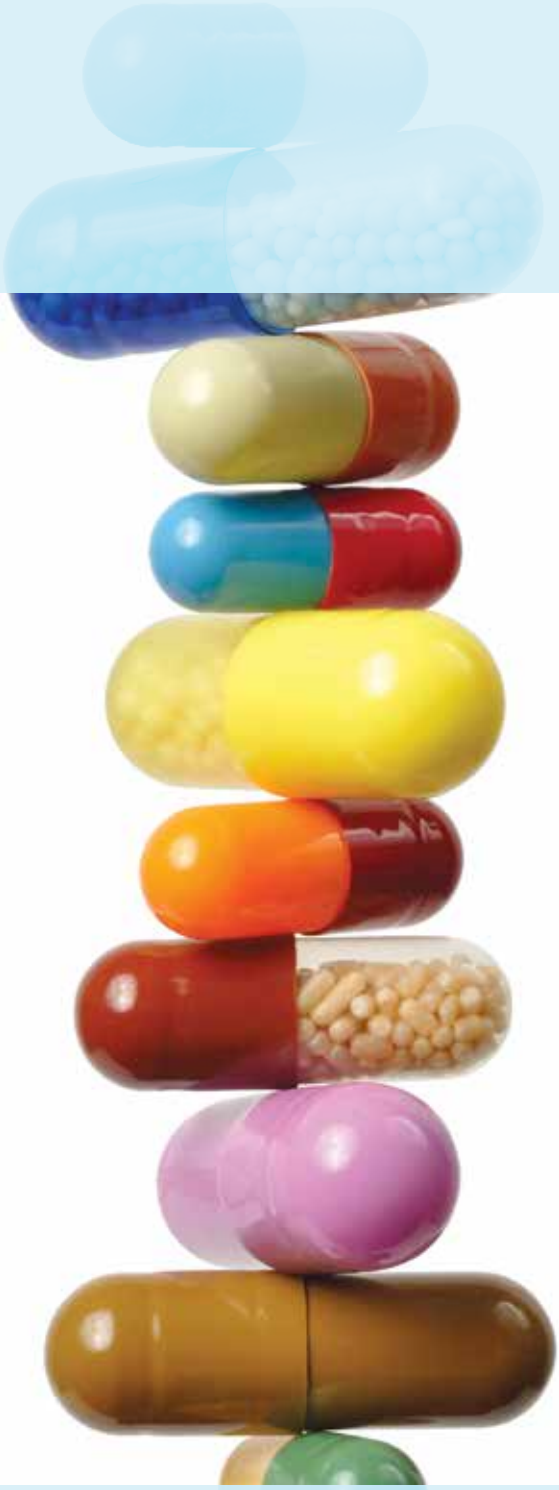
The report is consistent with Australia's Communicable Disease Control Framework, and proposes options applicable to the Australian context for short, medium and longer terms actions. The recommendations centre on national coordination using a 'One Health' framework linking together data on resistance and antibiotic use from humans, animals and agriculture to provide a national picture of AMR to guide action on preserving the effectiveness of antimicrobial agents.

Marilyn Cruickshank RN, PhD, FACN
Chair
Antimicrobial Resistance Standing Committee

Recommendations

AMRSC recommends the **enhancement** of existing Australian systems of data gathering and reporting on patterns of AMR and antibiotic use, and **establishing** national coordination through a single national coordinating centre to oversee the following activities:

1. Reporting on the number and outcomes of patients infected with resistant bacteria, and establishing an alert system to notify clinicians and policy makers of emerging and re-emerging highly resistant bacteria.
2. Collecting and collating national data on AMR and antimicrobial use in humans from healthcare facilities and the community to provide information on resistant organisms and illness due to these organisms, and the impact of usage patterns on the development of bacterial resistance that would inform national action.
3. Linking together resistance data from humans, animals and agriculture to provide a national picture of AMR to guide action on preserving the effectiveness of antimicrobial agents.
4. Fostering and complementing scientific research in Australia in the AMR field.
5. Providing advice to regulatory authorities (e.g. the Therapeutic Goods Administration, Pharmaceutical Benefits Committee, Australian Pesticides and Veterinary Medicines Authority) when required to facilitate optimum antibiotic availability and accessibility.



Executive summary

Antimicrobial resistance (AMR) is a leading worldwide threat to the wellbeing of patients, and the safety and quality of health care.

Although they have been available only for the past 80 years, antibiotics are accepted as an essential part of everyday health care, both in hospitals and in the community. Indeed, many current medical practices, such as major abdominal surgery, cancer chemotherapy, organ transplantation, joint replacement and neonatal care, are not possible without their use – without antimicrobials, mortality and morbidity during these procedures would be too great. AMR is developing at an alarming pace. Resistance often occurs within months of the release of new antimicrobials, and the resistance incidence rates outstrip drug discovery and the development of new antibiotics. The world is now facing the very real possibility of a return to non-treatable infections, severe limitations on medical procedures and escalating healthcare costs.

Surveillance and reporting of AMR and antibiotic usage is central to their prevention and containment. Data generated through surveillance of AMR and antibiotic usage are complementary and fundamental to everyday practices. At the local level, the data are used to formulate recommendations for rational antibiotic use and standard treatment guidelines. At a national level, data on resistance and antibiotic use inform policy decisions, such as antibiotic guideline development or revision, and identify priorities for public health action, such as education campaigns or regulatory measures. Without comprehensive and coordinated surveillance systems, efforts to prevent and contain AMR may be misdirected and inefficient, whereby poor practices such as inappropriate therapy result in wasted limited resources, and harm and human suffering through the inability to provide an effective drug to patients in need.

Globally, there are a number of different programs for the surveillance of both AMR and antibiotic usage. The most comprehensive and effective programs identified are those run by the European Centre for Disease Prevention and Control (combining the European Antimicrobial Resistance Surveillance Network [EARS-Net] and the European Surveillance of Antimicrobial Consumption Network [ESAC-Net]), the Danish Integrated Antimicrobial Resistance Monitoring and Research Programme, and the Swedish Strategic Programme for the Rational Use of Antibiotic Agents and Surveillance of Resistance. Currently, Australia does not have a comparable program. In Australia, states and territories have primary responsibility for the surveillance and management of infections in hospitals and public health infection control, including ensuring appropriate clinical treatment and managing the risks of healthcare-associated infections. The Australian Government has a similar responsibility in the areas of aged care and general practice. A number of AMR surveillance activities have been developed by state and territory jurisdictions as part of their primary responsibility for managing infection control, and several nationally coordinated AMR surveillance initiatives are funded by the government.

Without comprehensive and coordinated surveillance systems, efforts to prevent and contain AMR may be misdirected and inefficient, whereby poor practices such as inappropriate therapy result in wasted limited resources, and harm and human suffering through the inability to provide an effective drug to patients in need.

These include:

- state and territory government programs for monitoring AMR, such as Healthcare Infection Surveillance Western Australia, the Centre for Healthcare Related Infection Surveillance and Prevention (Queensland), the Victorian Nosocomial Infection Surveillance System and the Tasmanian Infection Prevention and Control Unit
- the Australian Group on Antimicrobial Resistance (AGAR), which provides prevalence data on important AMR pathogens in Australian hospitals and the community
- the National Antimicrobial Utilisation Surveillance Program (NAUSP), which collects data on antibiotic consumption from hospitals in all Australian states and territories
- Australia's high-quality, accredited pathology services, which contain key information on bacteria and their resistance patterns. Some of these laboratories contribute to regional surveillance networks for monitoring AMR in the Asia–Pacific region and South Africa through the SENTRY antimicrobial surveillance program.

Although each of these programs contributes to knowledge of resistance trends in Australia, there is no overall national mechanism for correlating the existing data to coordinate remedial interventions. Examining the experience of overseas programs would provide Australia with useful information in establishing a comprehensive and nationally coordinated system.

There have been previous attempts to establish a nationally coordinated AMR management program in Australia. The recommendations of the Joint Expert Technical Advisory Committee on Antibiotic Resistance and the Expert Advisory Group on Antimicrobial Resistance were a blueprint for such action; however, at the time, structures were not in place to facilitate the complete adoption of those recommendations. There have since been significant scientific, technological and policy changes in Australia, which have yielded a variety of enablers for change and success. These include:

- an agreement between the Australian Government and the state and territory governments to pursue health reform, and improve quality and safety using structured processes and programs
- the establishment of the Australian Commission on Safety and Quality in Health Care, which is responsible for developing and implementing initiatives related to quality and safety matters in health care with high-level governmental and industry support
- a multijurisdictional, interdepartmental Antimicrobial Resistance Standing Committee (AMRSC) from within the Australian Health Protection Principal Committee under the Council of Australian Governments' Standing Council on Health structure that is charged with developing strategies to address AMR.

AMRSC prepared this report – *National Surveillance and Reporting of Antimicrobial Resistance and Antibiotic Usage for Human Health in Australia* – to help Australia achieve comprehensive surveillance of both AMR and antibiotic usage. It presents a review and analysis of national and international systems for the surveillance and reporting of AMR and antibiotic usage relative to the needs and characteristics of the Australian context. AMRSC has determined that there are two broad options for the future. The first is to **enhance** existing systems and processes as the basis for a national platform, and develop these systems to achieve national objectives; and the second is to **construct** a new national system 'from the ground up', with design taking into consideration the desirable attributes of Australian and existing international systems that were identified in the literature review.

Executive summary

AMRSC recommends the **enhancement** of existing Australian systems of data gathering and reporting on patterns of AMR and antibiotic use, and **establishing** national coordination through a single national coordinating centre to oversee the following activities:

1. Reporting on the number and outcomes of patients infected with resistant bacteria, and establishing an alert system to notify clinicians and policy makers of emerging and re-emerging highly resistant bacteria.
2. Collecting and collating national data on AMR and antimicrobial use in humans from healthcare facilities and the community to provide information on resistant organisms and illness due to these organisms, and the impact of usage patterns on the development of bacterial resistance that would inform national action.
3. Linking together resistance data from humans, animals and agriculture to provide a national picture of AMR to guide action on preserving the effectiveness of antimicrobial agents.
4. Fostering and complementing scientific research in Australia in the AMR field.
5. Providing advice to regulatory authorities (e.g. the Therapeutic Goods Administration, Pharmaceutical Benefits Committee, Australian Pesticides and Veterinary Medicines Authority) when required to facilitate optimum antibiotic availability and accessibility.

For Australia, improving national AMR and antimicrobial use surveillance is a critical next step in an expanded strategy for the prevention and containment of AMR. The surveillance will provide ongoing data to give an accurate picture of what is happening across the country, and provide trends about changing patterns of resistance and the impact on patients. National coordination in the context of human health is central to AMR management and, in time, should extend to other organisms and contexts such as veterinary usage and surveillance of bacterial resistance in animals, agriculture and food. Linking data from animals, agriculture and food with that of humans is fundamental to the comprehensive prevention and containment of AMR.

For Australia, improving national AMR and antimicrobial use surveillance is a critical first step in an expanded strategy for the prevention and containment of AMR.

1

Surveillance and reporting of antimicrobial resistance and antibiotic usage in Australia

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1.1 Antimicrobial resistance and antibiotic usage – a global threat to human health

Antimicrobial resistance (AMR) is not a recent phenomenon, but it is a critical health issue today. Over several decades, to varying degrees, bacteria causing common infections have developed resistance to each new antibiotic, and AMR has evolved to become a worldwide health threat. With a dearth of new antibiotics coming to market, the need for action to avert a developing global crisis in health care is increasingly urgent … The World Health Organization (WHO) has long recognized AMR as a growing global health threat, and the World Health Assembly, through several resolutions over two decades, has called upon Member States and the international community to take measures to curtail the emergence and spread of AMR … On World Heath Day 2011, WHO again highlighted AMR and urged countries to commit to a comprehensive financed national plan to combat AMR, engaging all principal stakeholders including civil society.

Dr Marie-Paule Kieny[1]
Assistant Director General, Innovation,
Information, Evidence and Research
World Health Organization

Antimicrobial resistance (AMR) is an important global public health priority, with the World Health Organization calling for urgent action.[1, 2] Globally, the threat of AMR features more and more in the new and popular press. For example, in the United States (US), a 'Dead Brooklyn boy had drug-resistant infection' (26 October 2007, *New York Times*[3]). In the United Kingdom (UK), there are warnings that 'Antibiotic-resistant diseases pose "apocalyptic" threat' (23 January 2013, *The Guardian*[4]). In Australia, AMR is reported to be the 'Greatest threat to human health' (16 February 2011, *Sydney Morning Herald*[5]) because of the 'Rise of the superbugs' (29 October 2012, *Four Corners*, ABC television[6]). Some resistant bacterial pathogens that were once primarily the concern of hospitals are now seen more often in the community, and patients are arriving in hospitals carrying resistant bacteria acquired in the community setting. These bacteria cause opportunistic infections that are difficult to treat, and impact clinical care. AMR contributes to increased patient morbidity and mortality, complexity and duration of treatments, and hospital stay, resulting in substantial increases to healthcare system costs and financial burden to the community.[7, 8]

The evolving threat that AMR presents to human health is demonstrated by international evidence and data, which are validating an increase in AMR pathogens responsible for infections in healthcare facilities and in the community.[9] The number of antimicrobial-resistant pathogens is increasing at an alarming rate. Moreover, the prevalence of resistance of human pathogens to all clinically important antibiotics is rising at varying levels in different parts of the world; the highest levels outside of Europe are observed in Asia, Africa and South America.[7] The situation is exacerbated by the ability of many bacteria to share genetic material and pass on resistance genes, as well as by international travel and medical tourism. To understand the challenges AMR presents to human health and society more broadly, it is useful to explore its scientific foundations.

1.2 Microbes, antimicrobials and antibiotics

Microbe is a term used to describe organisms that are too small to be seen with the naked eye. The term can be used to encompass bacteria, fungi, parasites and viruses. Although many microorganisms exist in a symbiotic, commensal or innocuous relationship with humans – some are essential to life – others cause significant morbidity and mortality. Some exist as part of the 'normal flora' of the human body under normal circumstances, but can create opportunistic infections in altered surroundings, such as after a dental extraction or penetrating injury, or when a person is immunocompromised due to illness or chemotherapy. Under these circumstances, it is desirable to either stop the replication or impede the growth of the microorganism that is contributing to a diseased state.

Some of the earliest antimicrobials were compounds derived from a species of fungus, *Penicillium rubens*.[10] The discovery that, if grown on an appropriate substrate, this species would inhibit the growth of bacteria is credited to Scottish scientist and Nobel Laureate Alexander Fleming in 1928. An Australian Nobel Laureate, Howard Florey, later worked with colleagues to transform this discovery into a medicine, penicillin. Introduction of sulfonamides or 'sulfa drugs' in the early 1930s heralded the beginning of the modern era of antibiotic discovery and use, which are fundamental to contemporary health and medical practice today.

Antibiotics used against bacteria are the most commonly recognised form of antimicrobials. Other types of antimicrobials are used against viruses (e.g. human immunodeficiency virus [HIV] or influenza virus) or against parasites (e.g. *Plasmodium* spp. that cause malaria), and as disinfectants. For the purposes of AMR in this document, the focus is on the antibiotics that are used to treat bacterial infections. The importance and role of antibiotics in medicine for the treatment and control of infectious diseases in humans and domestic animals are irrefutable. Antibiotics used for treatment and prophylaxis are also critical to the success of complex surgery, intensive care, organ transplants, and survival of immunosuppressed and older people.[2]

Antibiotics suppress the growth of bacteria and the infections they cause by stopping bacterial cell division (bacteriostatic), thus preventing bacterial growth, or by killing the bacteria themselves (bactericidal).There are a large number of antibiotics available for the treatment of bacteria that cause infections or infectious diseases (within differing classes of structurally related agents and/or with similar mechanisms of action – refer to Table 1). The largest group are beta-lactam antibiotics, and include penicillins, cephalosporins, carbapenems and monobactams. Other antibiotic groups include aminoglycosides, tetracyclines, macrolides, fluoroquinolones and glycopeptides. Some antibiotics are effective against a limited range of infectious agents (narrow spectrum); others are effective against many different pathogens (broad spectrum). Antibiotics in the same families are generally used in both human medicine and animal husbandry.

Table 1: Mechanism of action of different groups of antibiotics

Mechanism of action	Antibiotic group
Inhibits cell wall synthesis	Beta-lactams (penicillins, cephalosporins, carbapenems, monobactams), bacitracin, glycopeptides
Inhibits protein synthesis	Aminoglycosides, aminocycitols, amphenicols, macrolides, lincosamides, streptogramins, tetracyclines
Interferes with cell membrane function	Polypeptides
Interferes with DNA or RNA synthesis	Quinolones, rifamcyins
Inhibits metabolism	Sulfonamides, sulfones, trimethoprim, nitrofurans, nitroimidazoles
Unknown	Polyethers

It has long been assumed that the challenges of AMR would be overcome by the ongoing development of new compounds. Since the innovation of antibiotics, new classes of antibiotics have been discovered, existing antibiotics and synthetic components to combat emerging resistant bacteria have been modified and adjusted, and the clinical qualities of existing antibiotics have been improved.[2] However, for many bacterial pathogens, resistance to last-line antibiotics, such as carbapenems, fluoroquinolones, glycopeptides and third-generation cephalosporins, is now commonly found in Australian hospitals and, to an increasing extent, in the community.[11]

In addition, there has been an alarming decline in antibiotic development over time.[11]

1.3 The problem of antimicrobial resistance

The term 'antimicrobial resistance' is used to describe microorganisms that have developed the ability to resist the antibiotics or other antimicrobials that have been in use. When antibiotics were first introduced in the 1930s and 1940s, they were regarded as 'miracle drugs' because they brought about significant reductions in mortality due to bacterial diseases that had high fatality rates, offered faster recovery from infectious illnesses and were used extensively during World War II to treat injuries. Antibiotic use then expanded into prophylactic applications, where antibiotics are given to prevent an infection – for example, during surgery, when normally sterile body tissues are exposed to non-sterile areas such as the mouth or gut. With the advent of transplant surgery that requires artificial immunosuppression of the patient to prevent rejection of the transplant, antibiotics became essential for preventing and treating infections in people whose immune system was not able to combat infections from bacteria that exist in the normal environment.

However, within several years of the introduction of antibiotics, bacteria began to develop mechanisms to combat the antibiotics in use. In the presence of the antibiotic, these bacteria gained a selective advantage and then became predominant in the changed environment. Bacteria have a number of means of sharing genetic material, sometimes between unrelated species, and this led to further expansion of the resistant strains. All antibiotics in common use for human health have been impacted by this phenomenon. Figure 1 shows the time lag between clinical introduction and first appearance of resistance for a range of antibiotics.[12]

Although some antibiotics enjoyed several decades of use before resistance was seen, for others the time difference has been much shorter. Some antibiotics, notably vancomycin, were highly valued because of their ability to treat infections that had become resistant to other commonly used antibiotics. The level of vancomyin resistance now seen is a cause for significant concern, and some types of bacteria that carry this resistance, such as vancomycin-resistant enterococci, have changed their profile from being organisms of little concern in human health to a cause of significant morbidity and mortality, particularly in hospital settings.

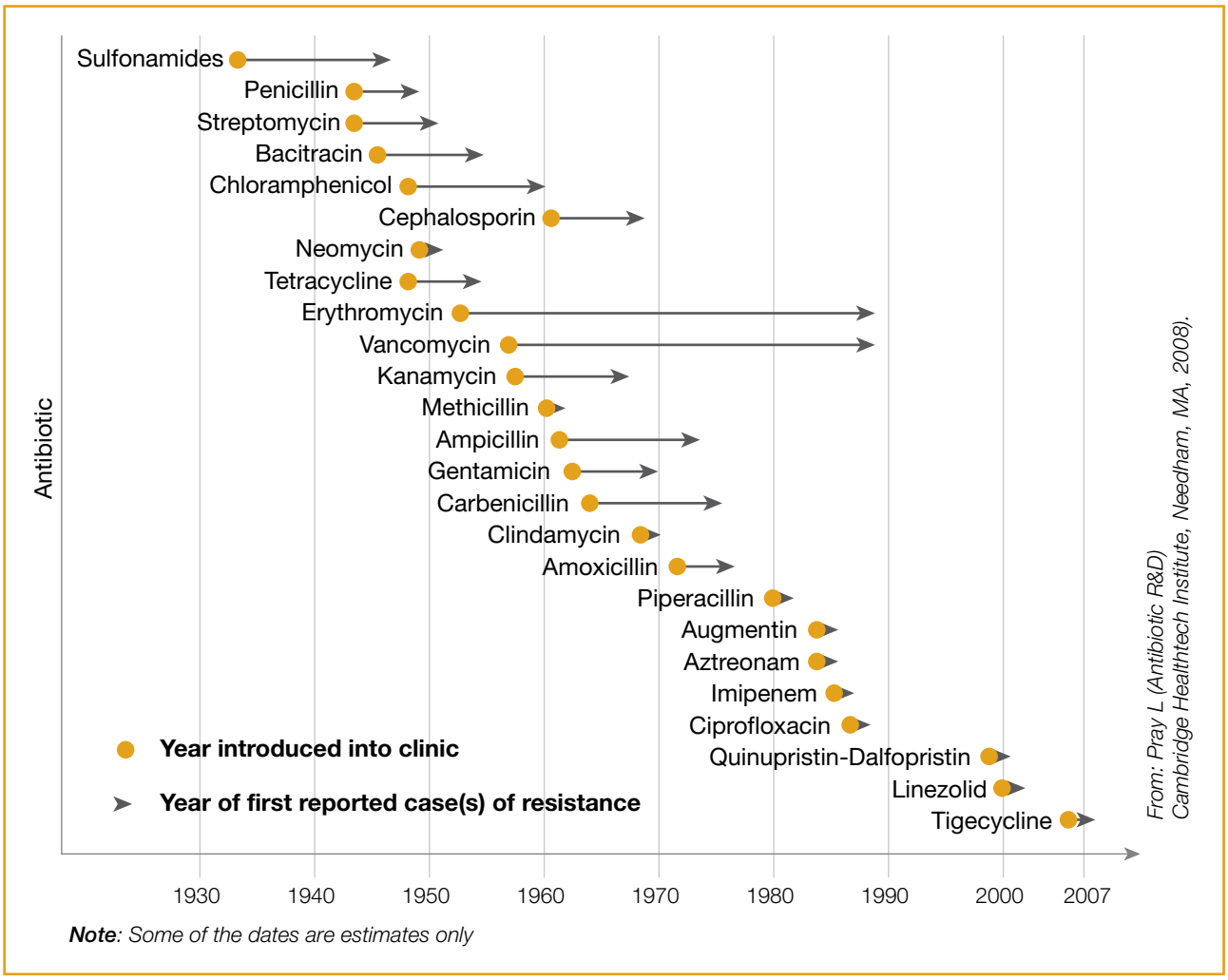
If antibiotics continue down the path that has been observed for the previous several decades and lose their clinical power, diseases that once had a high fatality rate and are now regarded as being of minor health concern in developed societies have the potential to become serious health threats once again. The risk associated with many medical and surgical procedures that have become relatively commonplace will also dramatically increase.

In addition to the obvious cost to human health, there are large financial implications for society, because relatively low-cost therapies will be replaced with high-cost drugs and other interventions to achieve better health outcomes.

1.3.1 Emergence of antibiotic resistance

The emergence of AMR is determined by a complex (and largely uncertain) interaction of environmental, epidemiological, clinical and behavioural factors.[13] There is overwhelming evidence that the use and overuse of antibiotics has been a powerful selector of resistance.[14] AMR occurs when antibiotic levels that would normally prevent the growth of or kill a particular bacterium become ineffective because of a change in the bacterium. An antibiotic is no longer clinically effective when this occurs at a therapeutic dose for treatment of infection.

Figure 1: Time lag between an antibiotic being introduced to clinical use and the first appearance of resistance



***Note**: Some of the dates are estimates only*

There are two stages in the emergence of antibiotic-resistant bacterial strains:

1. **Genetic mutation or gene acquisition** – resistance arises due to a mutation(s) in the DNA sequence of the relevant gene(s) in the bacterial chromosome, or because the existing antibiotic resistance gene is transferred into the bacterium from another resistant bacterium (gene acquisition or horizontal gene transfer).

2. **Selective advantage** – once a resistance gene or mutation is present (and expressed), the cells containing it are able to grow in the presence of the antibiotic and therefore increase in numbers at the expense of susceptible cells. Naturally resistant organisms are also favoured. The total amount of antibiotic used is a general indicator of the selection pressure and continuous exposure to an antibiotic provides the strongest selection pressure.

1.3.2 Spread of antibiotic resistance

Resistant bacteria can move from one environment to another (e.g. animal to human or vice versa). Such spread can occur through direct contact (e.g. between animal and human) or indirectly (e.g. in food or water). The global spread of resistant organisms is well documented, and presumably due to movement of hosts or contaminated products between locations (including between continents).[15]

Resistance due to mutations in the bacterial genome is spread by transmission of the bacterium, whereas horizontal gene transfer allows for resistance to be spread between commensal and pathogenic bacteria and vice versa, and also between different species of bacteria. The most frequent mechanism underpinning AMR is horizontal gene transfer between a resistant bacterium and a susceptible one. This occurs in the absence of selection.[2]

1.3.3 Factors contributing to antimicrobial resistance

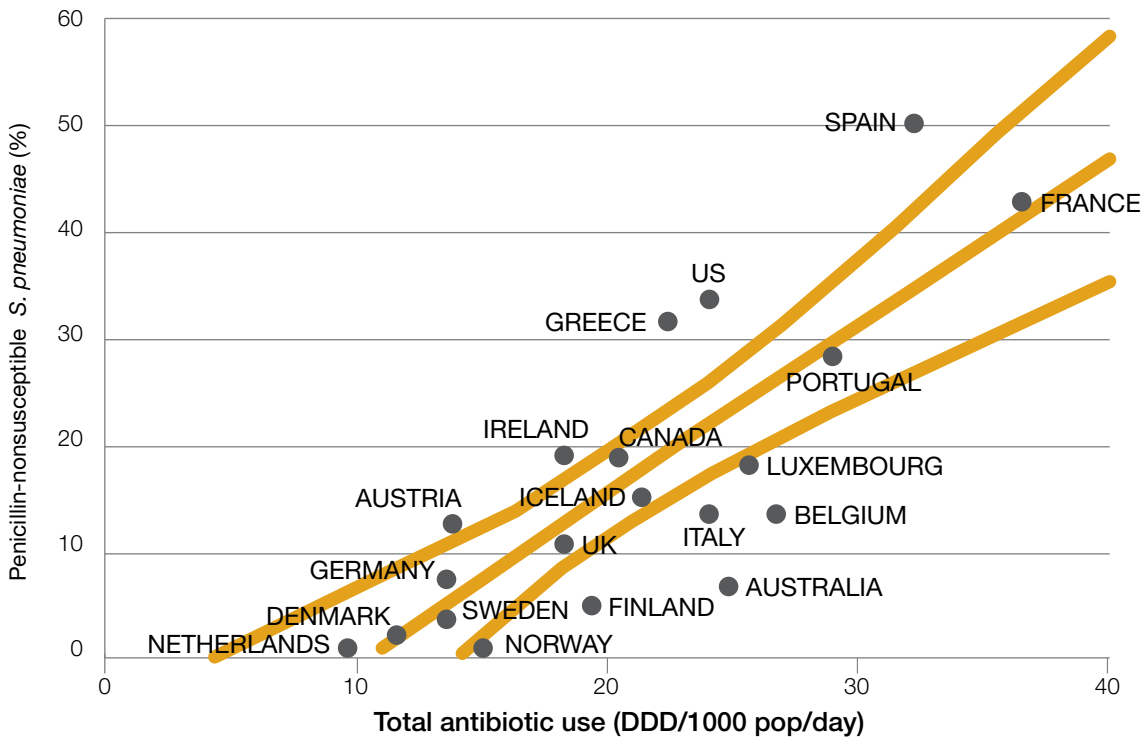
Antibiotics are a key contributor to the development and spread of AMR, but it is important to realise that AMR is driven by both appropriate and inappropriate use of antibiotics. Some issues of particular concern include:

- the inappropriate use of antibiotics, such as taking antibiotics to treat an upper respiratory tract infection that is caused by a virus
- a lack of compliance with appropriate antibiotic therapy, such as missing doses or ceasing a course of antibiotics before cure, in which case, bacteria are exposed to less-than-effective doses of the active agent, which facilitates their ability to develop and spread resistance
- treatments that are prolonged beyond cure, leading to resistance in commensal bacteria, which can be transferred to pathogenic bacteria
- prolonged use of prophylactic antibiotics
- the use of antibiotics in primary industries.

More antibiotics are used on animals in Australia and other developed nations than for human treatments. According to the JETACAR Report, approximately 700 tonnes of antibiotics are imported each year into Australia, and 550 tonnes (78%) are used as 'growth promoters' in food animals or for the treatment of sick animals.[110] This report discusses the linkages that were reported between the use of some antibiotics in animals and the increase in resistance in bacteria isolated from humans; spread was thought to occur either by direct contact or via the food chain. The report also describes work that has been done in Australia since the late 1990s to address these linkages.

Much work has also been done to look at the association between the level of use of antibiotics in different countries, and the incidence of resistant bacteria that are isolated. Figure 2 provides data from a study that looked at total antibiotic use in 20 industrialised countries by defined daily dose per 1000 population per day, and showed how increased antibiotic consumption correlated with a higher percentage of *Streptococcus pneumoniae* isolates that were resistant to penicillin.[16]

Figure 2: Relationship between total antibiotic consumption and *Streptococcus pneumoniae* resistance to penicillin in 20 industrialised countries



DDD/1000 pop/day = defined daily dose per 1000 population per day

1.3.4 Cross-resistance and co-selection

Many mutations or single transferable antibiotic resistance genes confer resistance to some or all members of an antibiotic family. Exposure to one antibiotic can select for resistance to other antibiotics of the same class (cross-resistance). Resistance can be selected across structurally unrelated antibiotic classes by co-selection. The fragments of genetic material that carry antibiotic resistance determinants often carry more than one resistance gene and determine resistance to more than one antibiotic group. When this genetic material transfers between bacteria, all the resistance genes are transferred together (co-transfer).[2] Exposure to one class of antibiotic may then select for resistance to an unrelated class.

1.4 Reversing trends in antimicrobial resistance

One concern that affects AMR is the lack of new antibiotics being developed. Two factors are thought to contribute to this paucity of new products. First, in the current world of complex treatments and interventions, pharmaceutical companies pursue more profitable causes than the development of new types of antibiotics. Second, it is difficult to justify the expenditure required for research and development in a commercial environment when it has been demonstrated that resistance to a new antimicrobial is likely to emerge within a foreseeable timeframe, rendering the new product less marketable. Therefore, although we must find ways to promote research into new antimicrobial agents, we cannot rely on this alone to solve the problems. Lowering levels of antibiotic use and comprehensive and coordinated surveillance are two alternative methods to combat AMR.

Although we must find ways to promote research into new antimicrobial agents, we cannot rely on this alone to solve the problems.

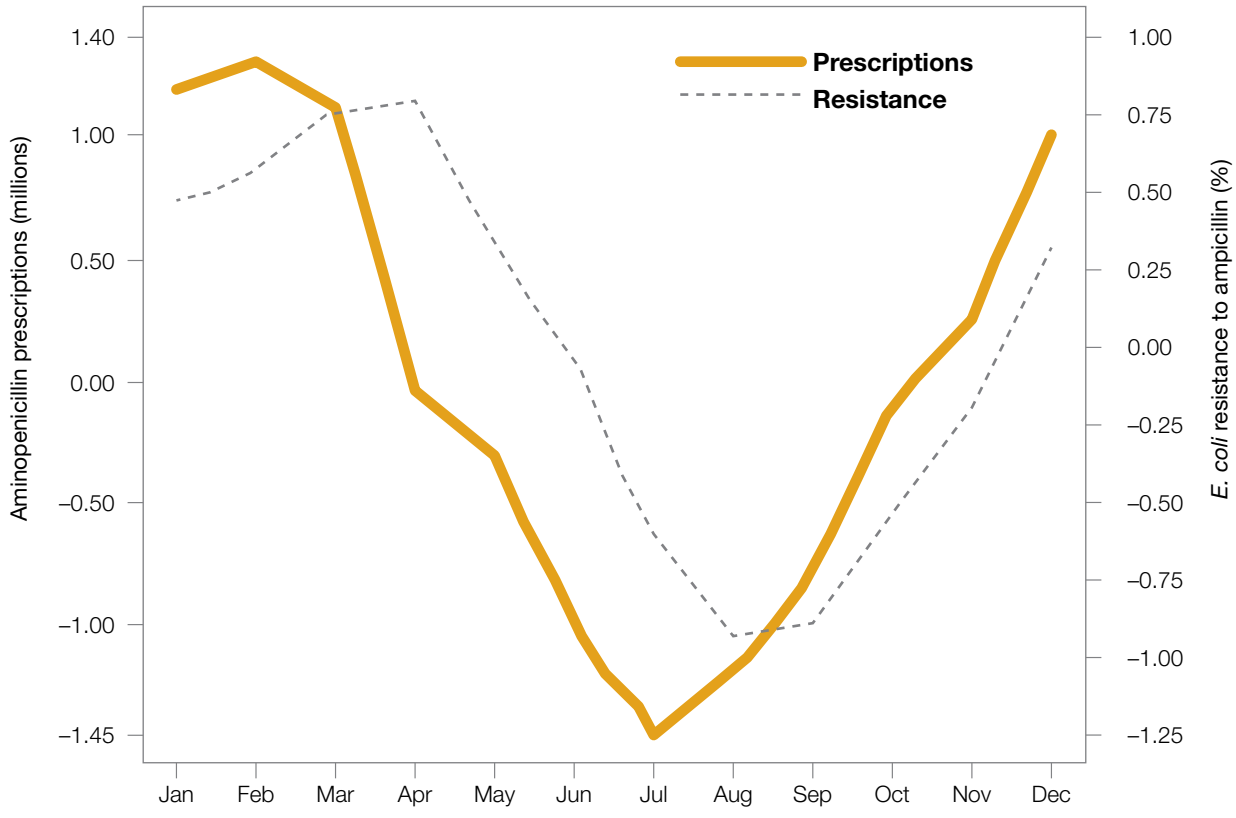
1.4.1 Lowering levels of antibiotic use

A recently published nine-year study in the US highlights the importance of taking action in both hospital and community settings to address AMR, and was done by correlating antibiotic consumption levels against the detected level of AMR. Datasets covering 70% of all antibiotic prescriptions were correlated with antibiotic resistance data from more than 300 microbiology laboratories across the US from 1999 to 2007. Antibiotic prescribing data indicated a higher use of certain antibiotics in winter seasons each year. The seasonal upward and downward trends in consumption of antibiotics were matched by increases and decreases in certain AMR patterns, with a one-month lag between the change in consumption and change in resistance (Figure 3).[17] The chart shows the mean monthly seasonal variation for aminopenicillin prescriptions, mapped against *Escherichia coli* resistance to ampicillin.

Further, some European countries have banned the use of certain types of antibiotics in food animals, and other changes in practice have been achieved through widespread but voluntary changes in farming practice. This has been followed by a significant reduction in the level of AMR in clinically important bacteria. Such studies demonstrate that using fewer antibiotics leads to lower prevalence of AMR in certain populations, which is encouraging.[17]

'Biological fitness cost' may be one reason that a change in the level of use of antibiotics results in less resistance. For example, resistance may be developed against an antibiotic that attacks the bacteria's cell wall. If a mutation changes one of the amino acids used to make up a cell wall protein – and the altered protein is resistant to the impact of the antibiotic – the bacteria with the altered cell wall protein will continue to divide and dominate the bacterial population in the presence of the antibiotic. The manufacture of the altered protein, however, may be less efficient than the wild-type protein, resulting in slowed growth of the altered bacteria, or may require higher energy input and place greater stress on the bacterial metabolism.[18] Once the antibiotic is removed, the wild-type bacteria will then have the selective advantage and can easily dominate the population, potentially to the extent that, over time, the resistance mutation disappears from that population.

Figure 3: Seasonal patterns of high-use antibiotic prescriptions and *Escherichia coli* resistance in the United States



***Source**: Sun et al 2012*[17]

1.4.2 Comprehensive and coordinated surveillance

Comprehensive and coordinated surveillance and reporting is the cornerstone of efforts to control AMR.[8] The information generated through surveillance of AMR and antibiotic usage is complementary. At the local level, the data are used to formulate recommendations for rational antibiotic use and standard treatment guidelines. At a national level, data on resistance and antibiotic use together inform policy decisions such as development or revision of antibiotic guidelines, and identify priorities for public health action, such as education campaigns or regulatory measures. Conversely, lack of surveillance can lead to misdirected and inefficient policies, wasting of limited resources, inappropriate therapy and, ultimately, human suffering and death through the inability to provide an effective drug to patients in need.

The World Health Organization (WHO) has been active in antimicrobial resistance and antibiotic usage for many years. In 1988, WHO announced the *Global Strategy for Containment of Antimicrobial Resistance*[19] to contain the spread of antimicrobial-resistant bacteria and prevent new antimicrobial-resistant bacteria from emerging. This strategy called on Member States to implement programs to prevent AMR, including surveillance, education and policy development. Programs were encouraged to extend surveillance to neighbouring countries or regions where appropriate, including countries that are less developed (Figure 4).

Comprehensive and coordinated surveillance and reporting is the cornerstone of efforts to control AMR.

WHO recommended that the program's priorities be based on local epidemiology, and existing resources and infrastructure; the specific features would be largely dependent on the types of infections seen most frequently and the local healthcare setting. At a national level, priority objectives included monitoring infection and resistance trends; developing standard treatment guidelines; assessing resistance-containment interventions; and setting up an early alert mechanism for novel resistance strains, and prompt identification and control of outbreaks.[20] To support surveillance at multiple levels, the WHO Collaborating Centre for Surveillance of Antibiotic Resistance developed and supported WHONET software to manage and share microbiology test results (see Section 2.1.2 for more information on WHONET). WHONET is used in more than 110 countries to support local and/or national surveillance in more than 1700 laboratories (clinical, public health, food and veterinary). In most of these countries, the WHONET software is used as a core component of the national surveillance program.[20]

On World Health Day in 2011, WHO released a six-point policy package calling on all countries to:

- commit to a comprehensive, financed national plan with accountability and civil society engagement
- strengthen surveillance and laboratory capacity
- ensure uninterrupted access to essential medicines of assured quality
- regulate and promote rational use of medicines in animal husbandry and to ensure proper patient care
- enhance infection prevention and control
- foster innovations and research and development of new tools.

In its 2012 report *The Evolving Threat of Antimicrobial Resistance: Options for Action*,[1] WHO identified the five most important areas to control antibiotic resistance:

- surveillance
- rational use in humans
- rational use in animals
- infection prevention and control
- innovation and research.

Figure 4: A poster developed to raise awareness of antimicrobial resistance

Political commitment is highlighted as one of the policy actions in the 2011 World Health Day six-point policy package and is recognised as an indispensable prerequisite for action in the five focus areas.

Many of the barriers to having a coordinated system of surveillance and reporting, and the limitations of existing antimicrobial containment initiatives, are known. The surveillance of AMR pathogens may be sporadic, largely due to technical and financial constraints.[15] More informal networks may collect selective information, albeit with considerable delay.[15] A lack of information technology (IT) infrastructure is frequently cited as a barrier to the implementation of comprehensive AMR surveillance and antibiotic usage programs. Lastly, while several networks provide guidance for reporting AMR, none have successfully functioned as an early warning system.[15]

1.5 Antimicrobial resistance and Australia

Australia is a developed country, comparable in geographic size to western Europe or the US mainland, and has a population of approximately 22.7 million.[21] The Australian health system comprises a set of public and private service providers in multiple settings, supported by a variety of legislative, regulatory and funding arrangements. Responsibilities for healthcare costs are distributed across the three levels of government, nongovernment organisations and individual Australians. Public-sector service provision is the responsibility of state and territory governments for public hospitals; and a mixture of Australian Government, and state, territory and local governments for community and public health services. From 2008 onwards there has been extensive health system reform in Australia, affecting the way services are delivered and funded.

Overall coordination of the public healthcare delivery system is the responsibility of Australian Government and state and territory government health ministers, collectively referred to as the Standing Council on Health (SCoH), supported by the Australian Health Ministers' Advisory Council (AHMAC). The major health funding agreements are bilateral agreements between the Australian Government and each state and territory, with the broad parameters being agreed multilaterally by SCoH. Strategic public health and other partnerships are negotiated in similar ways. There is a variety of organisations with strategic function and oversight for health-related matters in Australia. The National Health and Medical Research Council advises governments, other organisations and health workers on a wide range of health matters, and allocates substantial medical research funds provided by the Australian Government. Other relevant government agencies include the Health Care Committee, the Australian Health Ethics Committee and the Research Committee that oversees most Australian Government medical research funding. The Australian Government Department of Health and Ageing advises the ministers with portfolio responsibility for health and aged care. The Health Insurance Commission and its Medicare offices administer enrolment in Medicare, claims for Medicare benefits, pharmaceutical benefits and other Australian Government programs. The states and territories have varying arrangements for advising their ministers, and for administering public hospital and other healthcare programs.

Between 2009 and 2010, Australia's total public-sector health expenditure was around $121.4 billion, or 9.4% of its gross domestic product.[22] During this time, more than two-thirds of this expenditure was funded by the Australian Government; state, territory and local governments funded the remaining amount. The Australian Government's major contributions include the two national subsidy schemes – the Medicare Benefits Scheme (MBS) and the Pharmaceutical Benefits Scheme (PBS, which includes the Repatriation Pharmaceutical Benefits Scheme [RPBS]). The Australian Government and state and territory governments also jointly fund public hospital services. These schemes are supplemented by social welfare arrangements, with larger rebates provided for individuals or families who receive certain income-support payments (such as for unemployment or disability). Additional government programs aim to improve access to health services in regional and remote Australia, or provide access to allied health services for people with chronic and complex conditions (such as diabetes or mental illness). There are also special healthcare arrangements for members of the Australian Defence Force and their families, and for war veterans and their dependants. Private health insurance schemes contributed 8% of the funding for the overall health system during 2009–10, with accident compensation schemes contributing another 5%. Finally, individuals make out-of-pocket contributions to the costs of services, mostly in the private sector, amounting to 18% of total funding during 2009–10.[22]

Australia is well served by high-quality, accredited pathology laboratory services in both the public and private sectors, which generate key information on bacterial isolates and their antibiotic resistance patterns. Such data are critical to coordinated AMR surveillance systems.

Australia, however, has no national coordination of these data. Existing national and state-based AMR surveillance activities are often voluntary, and they operate without systematic oversight and leadership at the national level. Before the formation of the Antimicrobial Resistance Standing Committee (AMRSC; see Section 1.6), there had been no national coordination of activities, comprehensive national reports on antibiotic use and resistance, or capability to readily link antimicrobial usage and resistance data at a national level. Moreover, there is no single entity that fulfils such a role at a national level.

One of the deficits in Australia's ability to respond to the threat of AMR is the lack of information on how widespread the problems are, whether there are different clinical practices in different places that have produced better or worse outcomes, and whether initiatives that seek to address AMR are successful. This is primarily due to the lack of comprehensive systems to measure antibiotic consumption or AMR levels in different settings.

Australia has the data needed to measure AMR; however, it exists within separate laboratory information systems of the various private and public-sector pathology providers across the country. For example, large numbers of community and hospital patient samples are submitted for bacterial culture and antibiotic susceptibility testing of any potential pathogens that are isolated and identified. The pattern of susceptibility and resistance for individual bacterial isolates is recorded in the laboratory computer database as an antibiogram, with the information then being returned to the treating clinician to guide therapy. By retrospectively reviewing large amounts of data over periods of time, a 'cumulative antibiogram' can be generated for each bacterial species of interest. The cumulative antibiogram information can then be used to guide empiric treatment approaches, develop guidelines and monitor changes in resistance patterns over time or between locations. Data measuring antibiotic consumption are more fragmented. Hospital usage is collected through the National Antibiotic Usage Surveillance Program (NAUSP), while most community usage data is collected by Medicare Australia for the Department of Health and Ageing. Some progress has been made in recent years to improve the collection of hospital data through NAUSP, which is explored further in Section 3.2.8. The integration within a comprehensive and coordinated system of surveillance and reporting is important to the efforts of NAUSP and DoHA.

1.6 Antimicrobial Resistance Standing Committee

In 2011, the Antimicrobial Resistance Colloquia, supported by the Australian Commission on Safety and Quality in Health Care (ACSQHC), was held in Sydney. Using a gap analysis, the colloquia established what interventions are in place for monitoring and preventing AMR in Australia. Surveillance was determined to be Australia's largest deficit, and it was widely recognised that strategies to address AMR are needed. These strategies need to include research, infection control interventions and surveillance.

Following on from the colloquia, the first AMRSC meeting was held in Sydney in April 2012. The function of AMRSC is to develop a national strategy to address AMR. This includes overseeing an integrative approach to the national strategy through coordination of current national activities, such as:

- a comprehensive national surveillance and reporting system for AMR and antibiotic consumption
- education and stewardship programs
- infection prevention and control guidelines
- research into all aspects of AMR
- a review of the current regulatory system applying to antibiotics
- community and consumer campaigns.

AMRSC will oversee AMR management in Australia under the auspices of the Australian Health Protection Principal Committee (AHPPC), which currently has five subcommittees: the Communicable Diseases Network Australia, the Public Health Laboratory Network, the Environmental Health Standing Committee, the National Health Emergency Management Standing Committee and the Blood Borne Viruses and Sexually Transmissible Infections Standing Committee. Now endorsed, the AMRSC will join the other subcommittees reporting to AHPPC and in turn to AHMAC.

1.7 National Surveillance and Reporting of Antimicrobial Resistance and Antibiotic Usage for Human Health in Australia – scope and specific questions

Conducted within the auspices of AMRSC, this report examines the current activities for the surveillance of AMR and antibiotic usage within Australia, to determine the enablers of, and barriers to, establishing a nationally coordinated approach to the surveillance of AMR and antibiotic usage. The report is based on a study that was guided by three key questions, all with respect to human health:

- What activities for the reporting and surveillance of AMR and antibiotic usage currently occur globally?
- What options or models for a nationally coordinated approach to the reporting and surveillance of AMR and antibiotic usage are most applicable to the Australian context?

Surveillance and reporting of antimicrobial resistance and antibiotic usage in Australia

- What are the enablers of, and barriers to, the establishment of a nationally coordinated approach to the reporting and surveillance of AMR and antibiotic usage in Australia?

Examining existing activities was central to the study and this report, including activities undertaken by state and territory surveillance units, as well as by other groups, such as the Australian Group on Antimicrobial Resistance (AGAR) and NAUSP. This report also examines enablers and barriers to a national coordinated approach to the surveillance and reporting of AMR and antibiotic usage across Australia.

This report examines the anticipated barriers to national coordination of the surveillance and reporting of AMR and antibiotic usage, such as funding, antibiogram agreement and data ownership. These barriers could be overcome by ongoing activities and by facilitating dialogue on other salient issues that may guide broader level strategic ideas. This dialogue with key stakeholders within AMRSC informed a set of assumptions that were used to guide the study and preparation of this report:

- **Scientific** – each state and territory has a different system(s) and agreement is essential on what terms mean across the range of activities, and these need to be able to be identified in a scientific manner.
- **Partnership** – effective and ongoing collaboration between interdisciplinary stakeholders from various jurisdictions (e.g. Australian Government, state and territory governments, nongovernment organisations) is achievable to create a systemic environment to enable users to undertake clinical work.
- **Technical** – central (e.g. enterprise data warehouse) and local IT infrastructure is available to enable timely data exchange and analysis.
- **Financial** – the costs of maintaining a comprehensive and prospective national AMR surveillance program should not drain resources from national health priorities, and should aim to be cost neutral in line with international best practice models.
- **Governance and policy** – work already undertaken by various stakeholders in the field of AMR is recognised and integrated where feasible, especially where localised responses have been developed to meet local needs.
- **Operational** – the national model should be driven by data from pathology laboratories (public and private), and initially focused on human health within a communicable disease control framework. However, food and animal sources of AMR remain important program components that can be integrated into an existing structure in the future.

AMRSC approved this study and its scope with the following notations and recommendations:

- The scope of this study is limited to bacteria in the context of human health in the first instance, while acknowledging the importance of AMR in other organisms and contexts, such as veterinary usage and surveillance of resistance in animals.
- The study will focus on specific bacteria that are of greatest significance, which are yet to be determined.
- A critical function of the study and the report is to inform audiences and stakeholders outside of AMRSC and its members of the importance of AMR, to leverage support and agreement for the success of future strategies. The study and ensuing report will assist both experts and non-experts to contribute and participate in the broader collective efforts. The study will emphasise and draw on the significant existing but disparate programs or work in promulgating collaborative strategies for the future.
- An approach inclusive of both public and private pathology sectors is important to the broader success of the study and the ensuring strategy.
- The study and recommendations will be mindful of, and sensitive to, the activities and programs of authorities in the international and regional contexts, in particular, WHO.
- The study and recommendations will be sensitive to relevant technical, scientific, governance, policy, financial and jurisdictional levers and constraints. Fundamental to the success of future strategies will be prudent, collaborative agreement on the ownership of, access to, and utility of data that are gathered, generated and stored.
- The study and recommendations will be consistent with Australia's Communicable Disease Control Framework and adopt the principle of One Health.
- The final report will present possible and preferred models and strategies for consideration.

2

The global context: existing programs and activities

The global context: existing programs and activities

This section presents an analysis of global efforts and programs related to the surveillance of antimicrobial resistance (AMR) and antibiotic use (Appendix 2 provides the basis for this analysis). It lists related programs in all regions of the world at supranational, national and local levels, and provides information that is in the public domain regarding the status, focus of activity and other parameters for each.

Key question

What activities for the surveillance and reporting of antimicrobial resistance and antibiotic usage currently occur globally?

2.1 An overview of global surveillance and reporting systems

AMR surveillance systems have been implemented in many countries at regional, national and supranational levels. However, few countries have well-established national networks that regularly report relevant and timely data on AMR and antimicrobial usage trends. Activities undertaken vary in their scope and magnitude; some focus on specific species and a small number of antimicrobial agents, while others are far more inclusive. Some programs are sponsored by governments, and others are funded by international bodies, industry or learned societies.

2.1.1 Supranational surveillance systems

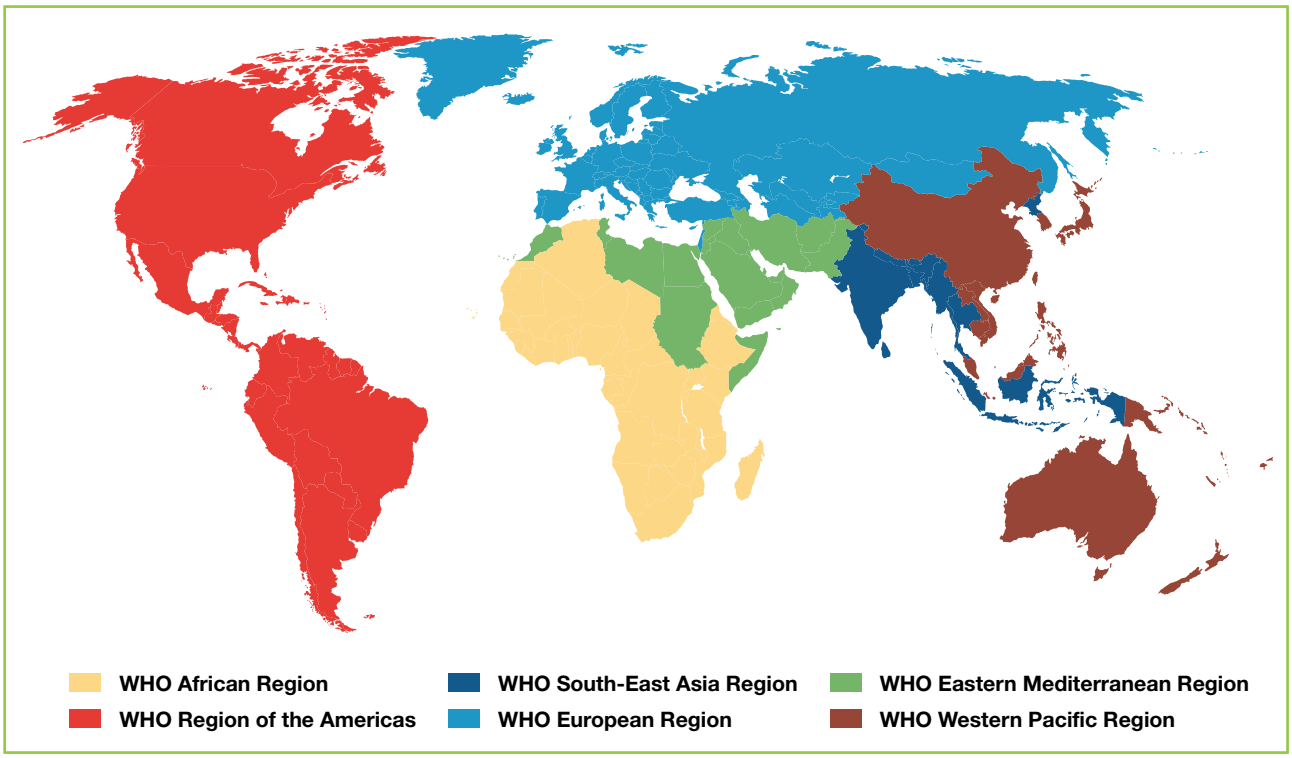
In its 2001 publication *WHO Global Strategy for Containment of Antimicrobial Resistance*,[23] the World Health Organization (WHO) lists AMR surveillance as a key strategy to address the growing global problems associated with AMR. WHO Member States are grouped into six geographical regions: the African Region, Region for the Americas, Eastern Mediterranean Region, European Region, South-East Asia Region and Western Pacific Region[24] (see Figure 5). WHO is active in seeking to create, promote, and support networks across these six groups, with varying levels of success.

It is notable that the major WHO global strategy seeking to galvanise international action to address AMR was launched in September 2001. At the same time, terrorist events and incidents – such as the posting of anthrax spores through the US mail service – shifted the attention of governments and policy makers onto security and bioterrorism,[25] taking energy and focus away from attempts to implement the AMR strategy. The emergence and potential for epidemics of antibiotic-resistant bacteria, such as the highly resistant NDM1 enzyme-containing 'superbugs' in India, Pakistan and the UK in 2011,[26, 27] are helping to bring back a focus and some urgency in addressing the AMR issue on a global scale.

Africa

The 46 Member States of the WHO Regional Office for Africa established the Integrated Disease Surveillance and Response (IDSR) system in 1998 as a comprehensive regional framework for strengthening national public health surveillance and response systems in Africa. It is coordinated by the WHO Regional Office for Africa. Initially, the system arose in response to emerging severe outbreaks of largely preventable diseases in African countries during the 1990s and focused on a range of infectious diseases. The scope of IDSR now extends beyond the scope of communicable diseases, and includes 40 priority diseases and conditions with well-known and efficacious responses and treatments available. The contribution by the African Region Member States is variable, and is heavily dependent on the level of resources available either within the participating country or from external funding support. The US Agency for International Development and the Centers for Disease Control and Prevention (CDC) provide financial support and practical guidance to the African program.

Figure 5: World Health Organization geographical regions



The Americas

The major surveillance program with WHO involvement in the Americas is the *Red Latinoamericana de Vigilancia de la Resistencia a los Antimicrobianos* (ReLAVRA), coordinated by the Pan American Health Organization. Using the WHONET information system, 21 countries and 521 laboratories from North America and Latin America contribute data to the program.[28] Available literature indicates that surveillance data related to both community and nosocomial sources include urinary tract infections, meningitis, diarrhoea and food-borne diseases, respiratory tract infections and sexually transmitted infections. Less information is readily available on the specific organisms that are monitored. A more comprehensive discussion of activities in the US is in Section 2.1.5.

Eastern Mediterranean

Although there have been active AMR surveillance programs in the Eastern Mediterranean Region in the past, these programs are currently inactive. St Luke's Hospital, Malta, coordinated the Antimicrobial Resistance in the Mediterranean (ARMed) program, which operated between 2003 and 2006. ARMed contributed data to the European network. The nine countries that participated in the project were Turkey, Tunisia, Egypt, Jordan, Morocco, Cyprus, Malta, Algeria and Lebanon.[29]

The WHO Regional Office for the Eastern Mediterranean has an active program to develop surveillance, forecasting and response capabilities across the region. One of the stated goals of the program is to support the establishment of centres of excellence in the fields of epidemiology, surveillance, infection control and laboratory diagnosis of emerging infections.[30] One initiative that started in January 2012 is the provision of technical support to the ministry of health in Afghanistan, to assess its existing disease surveillance system and attempt to qualify it so the same IDSR system used in the African region can be implemented.

Europe

WHO's *European Strategic Action Plan on Antibiotic Resistance*, endorsed by the WHO Regional Committee for Europe in September 2011,[31] recognises that a number of countries in the region do not have systems for surveillance of AMR, antibiotic use and hospital-acquired infections, but agreed that a key strategic objective is to strengthen AMR surveillance. The action plan cites the European Antimicrobial Resistance Surveillance Network as an example of good practice. Given that an active supranational network exists in Europe, there is less need for the direct involvement of WHO in developing and supporting systems in this region.

The pan-European system and some of the national programs are of particular interest and relevance to the Australian situation, and are discussed in greater detail in case studies in Section 3.

South-East Asia

Although a coordinated strategy with WHO has not been in place in the South-East Asia Region, a regional strategy for 2010–15 on the prevention and containment of AMR was launched by the WHO Regional Office for South-East Asia in June 2010. The strategy aims to comprehensively address interventions involving the introduction of legislation and policies that govern the use of antimicrobial agents, establish laboratory-based networks for the surveillance of resistance and assure rational use of these drugs at all levels of health care.[32] A key objective is to institute a surveillance system that captures the emergence of resistance, trends in its spread and use of antimicrobials in different settings. Where networks collecting data on AMR exist within countries, the strategy will be to bring data from those systems together; where no networks exist, the program seeks to establish them. The current situation and gaps have been assessed for Bangladesh, Bhutan, Cambodia, Fiji, India, Indonesia, Laos, Malaysia, Maldives, Mongolia, Myanmar, Nepal, Papua New Guinea, Philippines, Sri Lanka and Thailand.

Western Pacific

The Western Pacific Region, including Australia, is another region where WHO-coordinated surveillance programs have been active in the past. The Regional Programme for Surveillance of Antimicrobial Resistance was operated by the WHO regional office from 1990 to 2000, and involved 14 laboratories in 13 countries reporting on 26 species of bacteria across all sample types.[33]

A new working group has been formed to focus on AMR and, in October 2011, the Western Pacific Regional Committee asked Member States to take urgent action, including the monitoring and assessment of AMR across the region.[34] Implementation of the global policy in the region is constrained by lack of laboratory capacity to confirm AMR, and weak surveillance systems to detect it in a number of Member States. However, some accomplishments have been made, including:

- developing a training package on the rational use of antimicrobials for countries that are a part of the Association of South-East Asian Nations
- conducting national advocacy workshops on AMR
- increasing public advocacy on the rational use of antimicrobials
- providing technical support for pilot implementation of a minimum training package.

Future plans include finalising an AMR Technical Strategic Framework, supporting joint ventures to help countries develop comprehensive multidisciplinary national plans to address AMR and mobilising resources to support implementation of the AMR Technical Strategic Framework.[35]

2.1.2 WHO Surveillance Software – WHONET

In 1998, the WHO Collaborating Centre for Surveillance of Antimicrobial Resistance, based at the Brigham and Women's Hospital in Boston, developed WHONET to help gather comparable AMR data from across the world.[36–39] This freely available Microsoft Windows-based software can be used to enter AMR data for individual patient samples manually, or to capture data from automated laboratory systems. WHONET can then be used to analyse the results and forward them to wider networks in a standardised format using the same software. With WHONET, data can be analysed at a hospital level, across a local network, at a national level, or across one or more regions.

As many laboratories across the world, particularly in developed nations, already have laboratory information systems (LISs) and a certain level of automation, WHO also developed the BacLink data conversion facility that can facilitate data transfer from a LIS into WHONET, avoiding the need for manual data entry. WHONET development is ongoing, and notable recent progress includes SaTScan being included in the WHONET package. SaTScan is software that analyses spatial, temporal and space–time data, and is designed to perform geographical surveillance to detect clusters of disease, and perform repeated time-periodic disease surveillance for early detection of disease outbreaks.[40, 41] WHONET is currently used by more than 1700 laboratories in more than 110 countries.[20] Many of these countries use WHONET as a core component of their national surveillance program. In Australia, WHONET and BacLink are used in Tasmania and other states to develop cumulative antibiograms.

2.1.3 Other supranational surveillance programs

In addition to the programs in Sections 2.1.1 and 2.1.2, there are a number of other supranational surveillance activities:

- Programs to monitor resistance of a proprietary drug and clinically relevant comparators include Prospective Resistant Organism Tracking and Epidemiology for the Ketolide Telithromycin[42–45] (1999–2008), Meropenem Yearly Susceptibility Test Information Collection[46, 47] (1999–2008) and Tigecycline Evaluation and Surveillance Trial.
- Programs that test the susceptibility of defined pathogens include the Study for Monitoring Antimicrobial Resistance Trends, Global Landscape on the Bactericidal Activity of Levofloxacin, SENTRY (1997–present), and the Alexander Project[48] (1992–2001).
- Programs that collect data on all clinically encountered pathogens that antibacterials are prescribed for include The Surveillance Network (1997–present) and Surveillance Data Link Network.

Although some of these programs are publicly funded and supported, others operate as commercial ventures. Two of the programs have history in Australia – SENTRY and The Surveillance Network (TSN).

SENTRY Antimicrobial Resistance Program

SENTRY was established in 1997 by the Jones Group/JMI Laboratories through funding by GlaxoSmithKline,[49] and is designed to monitor the predominant pathogens and AMR patterns for both community-acquired and nosocomial infections on a global scale. A number of pharmaceutical companies, which vary from year to year, now fund it. A range of bacteria isolated from specimen types – including blood, respiratory, urinary, skin and soft-tissue samples – are forwarded to a reference laboratory for testing against a range of antibiotics, including new classes under development. The South Australian Women's and Children's Hospital in Adelaide receives isolates from a range of countries, including China, Taiwan, Japan, the Philippines, Singapore and Australia. Since 2010, the Women's and Children's Hospital laboratory has been the reference centre for host laboratories in Brisbane, Sydney, Melbourne, Perth and Auckland, as well as for the whole of Australia and New Zealand. Data from the SENTRY program compare AMR patterns with those of our regional neighbours. Globally, the SENTRY program is grouped into four regions: North America, Latin America, Europe and Asia–Pacific (Asia, Australia and South Africa). There are 35 countries involved, and between 100 and 140 laboratory participants.[50–53]

The Surveillance Network

TSN is an electronic surveillance database that collects strain-specific, qualitative and quantitative AMR test results daily from participating clinical laboratories. TSN is used to detect resistance patterns in real-time to answer key questions about antimicrobial development. There are more than 300 participating institutions in the US and the database holds continuous American records from 1998 to the present, and captures information on all clinically relevant bacterial pathogens and all available antimicrobial agents.[54] A broad range of reports are available to participants. The database is believed to have captured 42% of all bacterial susceptibility test results generated by Australian laboratories between 1997 and 2004,[55] with more than 14 million results captured between 1997 and 2002. Participants included 94 public-sector and 9 private-sector pathology laboratories. Participation was voluntary and the data collection was government funded. The Australian TSN data from 1997 to 2004 were purchased by the Australian Society for Antimicrobials.[56]

TSN is owned and operated by Eurofins, a private company incorporated in Virginia, US, that also provides laboratory services and support for clinical trials. The company was known as Focus Technologies at the time TSN was active in Australia. TSN has been used in other countries and regions outside the US, including Europe and Canada.

2.1.4 National surveillance systems

Sophisticated national antimicrobial use and surveillance programs exist. Denmark was the first country to establish a systematic and continuous monitoring program (Danish Integrated Antimicrobial Resistance Monitoring and Research Programme; DANMAP[57–59]) of antimicrobial drug consumption and AMR in humans (alongside animals and foodstuffs). DANMAP is widely recognised for demonstrating a reduction in the overall prevalence of antimicrobial-resistant bacteria through strategies to control antimicrobial use. Other antimicrobial agent resistance monitoring programs are now established in other northern European countries,

including Norway (NORM), Sweden (STRAMA[60–63]), Finland (FiRe, MIKSTRA[64]) and the Netherlands (NETHMAP[65, 66]). National eastern European AMR surveillance coordination efforts are also operational in Germany (SARI[67–75], MABUSE, KISS[75], GENARS), Bulgaria (BulSTAR[76]) and Austria (AURES[77]).

CDC coordinates many national current AMR surveillance activities in the US, including NHSN[78, 79] (previously NNIS), NARMS[80–82], Active Bacterial Core Surveillance (ABCs), and national tuberculosis, meningitis and gonococcal communicable disease programs that actively use AMR surveillance. Commercially funded US AMR surveillance programs focus on susceptibility testing of isolates from defined clinical infection samples (TRUST, AWARE, ARMOR).

Nationally coordinated surveillance of AMR has recently emerged in Canada through comprehensive programs (CIPARS and CNISP[83]), communicable disease surveillance activities (the Canadian National Centre for Streptococcus and the Canadian Tuberculosis Laboratory Surveillance System) or coordinated surveillance studies (CANWARD, CAN-ICU, CROSS, NAUTICA and CARS).[84, 85]

Substantial national AMR programs (current or inactive) were also identified in Asian countries, such as China (MOHNARIN, CHINET[86, 87], CARTIPS[88]), Korea (KONSAR[89–94], KARMS), Thailand (NARST[95–101]) and Singapore (The Network for Antimicrobial Resistance Surveillance).

National programs in other countries have demonstrated the ability for a coordinated approach to impact on AMR and improve both economic and health outcomes.[1]

2.1.5 Antimicrobial resistance surveillance in the US

In the US, AMR surveillance in bacteria of human origin is performed by a range of organisations that fall into three broad categories:

- government agencies surveying community and hospital populations
- US Department of Defense (DoD)
- commercial bodies that may be drug manufacturers, or may provide AMR surveillance as a service.

Information on commercial bodies is included in Section 3, and the following two sections focus on national level activities of government and DoD.

United States Government programs

CDC operates numerous surveillance systems that collect AMR data.[102] The Emerging Infections Program (EIP) is a network of 10 state health departments, along with their collaborators in local health departments, academic institutions, public health and clinical laboratories, and other federal agencies. EIP was established in 1995, initially involving four states, and currently monitors a population of approximately 41 million people, which roughly represent the entire US population with respect to a range of demographic indicators including age, sex, race and urban residence, along with health indicators such as population density, and proportion at or below the poverty line. A number of AMR-related subprograms fall within the remit of EIP, including the following core elements:

- **ABCs** is active, population-based laboratory surveillance for invasive bacterial disease caused by Group A and Group B *Streptococcus*, *Haemophilus influenzae*, *Neisseria meningitidis*, *Streptococcus pneumoniae*, and methicillin-resistant *Staphylococcus aureus* (MRSA). For each case of invasive disease in the population under surveillance, a case report is submitted and bacterial isolates are sent to CDC and other reference laboratories for additional laboratory evaluation.[103]
- **FoodNet** is active, population-based laboratory surveillance to monitor the prevalence of food-borne disease caused by seven bacterial and two parasitic pathogens. Organisms monitored are *Escherichia coli* O157:H7, and *Campylobacter*, *Listeria*, *Salmonella*, *Shigella*, *Yersinia*, *Vibrio*, *Cryptosporidium* and *Cyclospora* spp.
- **Healthcare-Associated Infections-Community Interface** is active population-based surveillance for *Clostridium difficile* and other healthcare-associated infections (HAIs) caused by pathogens such as MRSA, *Candida*, and multidrug-resistant Gram-negative bacteria.

Other CDC programs include:

- The **Gonococcal Isolate Surveillance Project (GISP)**, which was established in 1986 to monitor trends in AMR in *Neisseria gonorrhoeae*. It is a collaborative project between selected sexually transmitted infection clinics, five laboratories and CDC.
- **MeningNet**, which consists of more than 10 state health departments working in collaboration with CDC for passive surveillance of sepsis or meningococcal disease caused by *N. meningitidis*.

- **National Antimicrobial Resistance Monitoring System: Enteric Bacteria (NARMS:EB)**, which is a collaboration of CDC, the Food and Drug Administration and the US Department of Agriculture, which monitors AMR of human enteric bacteria, including *Campylobacter*, *Salmonella*, *E. coli* O157 and *Shigella* spp. A component of NARMS is the **National Antimicrobial Resistance Surveillance Team**, which conducts AMR surveillance and applied research in relation to both pathogenic and commensal food-borne enteric bacteria from food-borne disease outbreaks, focus studies and human isolate submissions.[104]
- **National Healthcare Safety Network**, which was established in 2005, facilitates the reporting of HAIs in patients and healthcare personnel. Monitoring multidrug-resistant organisms and *C. difficile*–associated disease is part of NHSN's patient safety component. NHSN arose from the combination of three legacy surveillance systems at CDC:
  - National Nosocomial Infections Surveillance system
  - Dialysis Surveillance Network
  - National Surveillance System for Healthcare Workers.
- **National Tuberculosis Surveillance System**, which has been in operation since 1953 to collect information on each newly reported tuberculosis case in the US.

The Interagency Task Force on Antimicrobial Resistance (ITFAR) was initiated in 1999 following a US congressional hearing about 'Antimicrobial resistance: solutions to a growing public health problem'.[105] It brings together multiple federal agencies to address AMR. In 2001, ITFAR published *A Public Health Action Plan to Combat Antimicrobial Resistance*, and this document was updated in 2012.[106] The first focus area for activity described in the plan is surveillance and includes the following goals:

1. Improve the detection, monitoring, and characterisation of drug-resistant infections in humans and animals. Achievement of this goal will be through a range of strategies and initiatives:
   a. The enhancement of systems such as the EIP, improved communications, query tools, and a web-interface for NARMS, and the expansion of GISP.
   b. Other initiatives to improve the accuracy with which the burden of AMR in healthcare settings can be assessed through the improvement of existing systems including EIP and NARMS.
   c. Assessment of the presence of antimicrobial-resistant organisms, such as MRSA, *C. difficile* and vancomycin-resistant enterococci (VRE) among food animals, retail meats and household environments.
   d. Identification of patient populations colonised or infected with AMR pathogens that are important in causing human disease, and for the transmission of resistance genes.
   e. Strengthening and expansion of multistate, national and international surveillance systems to ensure adequate sentinel surveillance of critical resistant phenotypes; more timely dissemination of AMR data will be a goal.
   f. Work with public health associations to define minimum surveillance activities at a number of levels; improvements to the accurate detection and identification of AMR by clinical and public health laboratories.
   g. Promotion of participation by microbiologists and public health workers in the design of systems to collect and disseminate AMR data.
   h. Collaboration with surveillance systems in other parts of the world to build global surveillance of AMR organisms.
2. Better define, characterise, and measure the impact of antimicrobial use in humans and animals in the US:
   a. Identify sources of antimicrobial use data for humans, animals, agriculture, aquaculture and other sectors. Develop a standard for collecting and reporting antimicrobial use data.
   b. Develop mathematical models to guide studies of use and resistance in humans and animals.
   c. Implement systems to detect the development and spread of resistance in microorganisms when new programs are implemented that may significantly impact antimicrobial drug use.

US Department of Defense programs

DoD has conducted international surveillance of infectious diseases for many years. In 1998, DoD surveillance activity was consolidated with the Armed Forces Health Surveillance Center (AFHSC) and Global Emerging Infections Surveillance and Response System (GEIS) Division; the latter was established in 1997 to coordinate surveillance efforts. The program's aim is to help protect all DoD healthcare beneficiaries and the global community through an integrated worldwide emerging infectious disease surveillance system.[107] AMR surveillance is one of five key focus areas for AFHSC–GEIS.

Surveillance includes enteric pathogens in South-East Asia, with a dramatic rise in AMR of this group recorded over the past several years.[108] The program is also concerned with healthcare-associated pathogens in operation theatres for the US Defense Forces. More than 30 000 US military personnel have been injured in Iraq or Afghanistan, and many have been at risk of serious complications from wound infections, often caused by Gram-negative organisms. Using networks linked by the program, laboratories have documented the geographic spread of AMR in common organisms, and this information has been used to advise local and national healthcare leaders on appropriate strategies. Surveillance has also been done in Egypt and Jordan, with emphasis on intensive care units, revealing a high prevalence of AMR in hospitals in both countries. During the fourth quarter of financial year 2012 (i.e. July–September), of 226 isolates tested in Egypt, the extended-spectrum beta-lactamase (ESBL) producer rate among *E. coli* was 70%, and about 60 % of *S. aureus* isolates were MRSA.[109]

Surveillance of antimicrobial-resistant strains in the Middle East and Afghanistan has revealed a significant rise in the prevalence of resistant strains of *Acinetobacter*, *Pseudomonas* and *Klebsiella* spp. and *E. coli*. Infections associated with these organisms impact DoD and Veterans Affairs healthcare institutions (due to prolonged hospital stays) and, as a result, incoming patients from Operation Iraqi Freedom, Operation Enduring Freedom (Afghanistan) and Africa were screened for *Acinetobacter*; more than 500 isolates were processed between October 2008 and March 2009[108] at the Landstuhl Regional Medical Center in Germany. Molecular typing is being used to understand the epidemiology and spread of the resistant organisms, and to enable better characterisation of infections due to AMR organisms from the point of injury, through the military healthcare system to tertiary care referral hospitals in the US.

The Navy Marine Corps Public Health Center takes an electronic approach to surveillance, where algorithms have been developed to interpret Health Level 7 (HL7) data from the DoD Composite Health Care System. Data are fed through the WHO BacLink application to WHONET, and trends in disease burden and AMR are analysed in close to real-time. Emerging AMR in *Acinetobacter baumannii*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa* and other pathogens of public health concern is identified rapidly, and action can be initiated. WHONET is used to generate facility-specific, DoD-wide and regional cumulative antibiograms, allowing comparison between groups and identification of trends over time.[38, 39] Electronic studies have been undertaken of a range of organisms, such as *Acinetobacter* spp., and various conditions, such as respiratory tract infection.

2.1.6 Antimicrobial resistance and antibiotic usage surveillance in Australia

More than a decade ago, the Joint Expert Technical Advisory Committee on Antibiotic Resistance[110] (JETACAR) recommended that an integrated national management plan for AMR be established in Australia, and include research, monitoring and surveillance. The JETACAR Report[110] outlined the importance of surveillance in addressing AMR at a national level by identifying changing trends and emerging resistance, and providing data on the magnitude and spread of AMR.

After the JETACAR Report, the Australian Government established the Expert Advisory Group on Antimicrobial Resistance (EAGAR), who commissioned a report on how to improve Australia's AMR response. The EAGAR Informal Report[111] recommended that a multidisciplinary, nationally coordinated, integrated surveillance program be developed, and that the program should consolidate existing surveillance programs. EAGAR estimated that AMR may cost the Australian healthcare budget more than $250 million per year, and cost the community as much as $500 million per year. Section 4 of this report provides further information regarding JETACAR and EAGAR.

There are several nationally coordinated AMR surveillance initiatives occurring independently within Australia. The Australian Group on Antimicrobial Resistance (AGAR) is under the auspices of the Australian Society for Antimicrobials, a learned society, which initially attracted commercial support and has been funded by the Australian Government Department of Health and Ageing (DoHA) since 2002.[112] AGAR has recommended implementation of a comprehensive, national, laboratory-based surveillance system that uses both passive and targeted surveillance with standard methodology. It has a broad laboratory membership, representing the major teaching hospitals in all Australian capitals and private pathology laboratories in most states. AGAR has provided prevalence data on important AMR pathogens in Australian hospitals and the community for the past 15 years (for more information, see Section 4).

The National Neisseria Network (NNN) is funded by DoHA to conduct resistance surveillance of *N. gonorrhoeae* and *N. meningitidis*. NNN comprises participating laboratories in each state and territory, which collectively operate the Australian Gonococcal Surveillance Programme and the Australian Meningococcal Surveillance Programme. This collaborative network of laboratories obtains isolates from as broad a section of the community as possible, and both public and private laboratories refer isolates to regional testing centres.[113]

The National Antimicrobial Utilisation Surveillance Program (NAUSP) began in 2004 and collects data on antibiotic consumption from all Australian states and territories. NAUSP is funded by DoHA, initially as a pilot study that was based on the existing South Australian Antimicrobial Utilisation Surveillance Program (AUSP). The South Australian Infection Control Service (Communicable Disease Control Branch, South Australian Government Department of Health) centrally maintains the national and statewide programs.[114, 115] The Drug Utilisation Sub-committee of the Pharmaceutical Benefits Advisory Committee undertakes regular reviews on drug use in the community, advises on changes in drug utilisation patterns, disseminates information on drug utilisation and contributes to educational initiatives that promote the quality use of medicines.

Australian laboratories have contributed to regional surveillance networks for monitoring AMR in the Asia–Pacific region and South Africa through SENTRY. As previously mentioned, TSN accumulated a comprehensive data collection in Australia between 1997 and 2004, demonstrating the potential for useful data to be collected in Australia. Several Australian state and territory government programs have been developed largely in isolation for monitoring AMR surveillance: Healthcare Infection Surveillance Western Australia (HISWA), the Centre for Healthcare Related Infection Surveillance and Prevention (CHRISP; Queensland), the Victorian Nosocomial Infection Surveillance System (VICNISS) and the Tasmanian Infection Prevention and Control Unit (TIPCU). Despite the recommendations of JETACAR and EAGAR, a comprehensive national surveillance program on AMR is still absent in Australia.

HISWA[116] was established as a voluntary program for private and public healthcare facilities in 2005. In 2007, the director general of health endorsed the recommendation of the Healthcare Associated Infection Council of WA (HICWA) that collecting key HAI prevalence data be mandatory. This program encompasses all public hospitals and licensed private healthcare facilities providing services for public patients in Western Australia. The HAI unit at the Communicable Disease Control Directorate manages HISWA, which coordinates a mandatory reporting program that collects data on several annually reviewed mandatory indicators. In addition, MRSA is a notifiable organism in Western Australia and all isolates are referred to a reference laboratory (Australian Collaborating Centre for *Enterococcus* and *Staphylococcus* Species (ACCESS) Typing and Research). The laboratory reports to the Health Department of Western Australia. Prevalence data are obtained for all the regions of Western Australia, and molecular typing provides information on local and imported strains of MRSA and VRE.[117]

CHRISP[118] guides and supports Queensland Health facilities to develop standardised and validated surveillance and analysis methods that allow timely recognition and intervention of infection problems. Data are used to estimate the magnitude of nosocomial infections in Queensland Health facilities, and detect trends in infection rates, AMR and nosocomial pathogens. Aggregate and de-identified data are reported to Queensland Health. Signal Infection Surveillance methodology has also been developed to provide a framework to investigate HAI in small- to medium-sized inpatient facilities and identify potential systemic issues requiring improvement.

The global context: existing programs and activities

VICNISS[119] was established in 2002 and collects and analyses data on HAI in acute-care public hospitals in Victoria. The program for larger 'Type 1' hospitals (i.e. more than 100 beds) is based on the National Healthcare Safety Network (CDC) methodology. Using clinically validated risk adjustment methods is a cornerstone of the system. Smaller, or 'Type 2', hospitals submit data on serious and antibiotic-resistant infections. Surveillance activities are targeted to patients who are at the highest risk of HAI (such as patients after surgery, and patients in adult and neonatal intensive care units). The centre receives data from all acute-care public hospitals in Victoria and began accepting data from private hospitals on a voluntary basis in 2009. Public hospitals are required to participate in the state surveillance program and large hospitals are expected to meet selected benchmarks or levels of compliance. The VICNISS Coordinating Centre analyses data from contributing hospitals, and reports quarterly on aggregate, risk-adjusted, procedure-specific infection rates to contributing facilities and the Victorian Department of Health. VICNISS collects antibiotic indicator data through the Quality Use of Medicines program. This information contributes to the development of accurate and reliable benchmarks against which hospitals and health services can assess their performance.

TIPCU[120] coordinates and supports AMR and antibiotic usage activities across a range of settings, including the private sector. TIPCU monitors HAIs and healthcare safety indicators, and releases quarterly HAI surveillance reports of Tasmanian public hospitals.

In New South Wales, the HAI program includes requirements for the monitoring of specific microorganisms in a number of settings, including *S. aureus* bloodstream infections, and multiresistant organisms such as MRSA in intensive care units and *C. difficile* in acute-care settings. Some data related to these infections are available in annual reports from the NSW Health Department website. The health department works with the NSW Clinical Excellence Commission (CEC) on HAI and related issues. CEC publishes information regarding AMR prevention and management, and develops and implements projects within clinical areas.

The South Australian Expert Advisory Group on Antimicrobial Resistance (SAAGAR) has terms of reference that include 'champion the adoption and funding of antimicrobial stewardship programs and advise on the types of programs and components that will be most useful for participating hospitals'.[121]

SAAGAR provides expert advice and interpretation on trends of antimicrobial usage. Much of the focus of this group is on improving antimicrobial usage. The SA HAI Expert Advisory Group reviews surveillance data for multi-resistant organisms and advises on trends and interventions in its scope of activities. South Australia promotes the Signal Infection Surveillance (SIS) approach for smaller hospitals. Annual reports are published that contain public and private-sector information for MRSA, vancomycin-intermediate/resistant *S. aureus*, VRE, ESBL-producing Gram-negative organisms, multiresistant *P. aeruginosa*, carbapenem-resistant *Acinetobacter* species, Enterobacteriaceae, plasmid-mediated AmpC beta-lactamase producers and metallo-beta-lactamase producers.

In the Australian Capital Territory, the Infection Prevention and Control Unit includes HAI surveillance, with ongoing monitoring of surgical site and bloodstream infections. Clusters and infection with unusual organisms are identified through the review of microbiology reports, patient records and regular ward rounds.[122]

Staphylococcus aureus bacteraemia (SAB) reporting is mandatory in Australian hospitals. In December 2008, the Australian Health Ministers' Conference (AHMC) endorsed a recommendation from the Australian Commission on Safety and Quality in Health Care (ACSQHC) that all hospitals establish surveillance of SAB. ACSQHC – in consultation with health professionals, jurisdictions and expert groups – developed and gained national agreement for the SAB surveillance case definition and dataset specification. All jurisdictions endorsed the 'Demographic Surveillance System: Surveillance of Hospital-Acquired SAB' at the November 2012 meeting of the National Health Information and Statistical Standards Committee. Subsequently, the National Health Information and Performance Principal Committee endorsed the dataset specification for the surveillance of hospital-acquired SAB for the purposes of surveillance, noting that further work is required around performance reporting. The dataset specification for healthcare-associated SAB has been lodged in METeOR,[123] the online repository of national data standards operated by the Australian Institute of Health and Welfare's Metadata Unit. The National Healthcare Agreement has included public hospital–associated SAB as a performance indicator and related benchmark since 2008, and this is reported on the MyHospitals website.[124]

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One of the most significant changes in relation to AMR at the health service level is the work of ACSQHC in development and implementation of Standard 3 of the National Safety and Quality Health Service Standards 'Preventing and Controlling Healthcare Associated Infection'. Standard 3 ensures that health services take active steps to promote the appropriate prescribing of antimicrobials and requires that all healthcare services have an antimicrobial stewardship program in place; that the clinical workforce prescribing antimicrobials has access to current endorsed therapeutic guidelines on antibiotics; that monitoring of antimicrobial usage and resistance is undertaken; and that action is taken to improve the effectiveness of antimicrobial stewardship. From 1 January 2013, the National Safety and Quality Health Service Standards were mandated in all Australian hospitals and health service organisations.[14] ACSQHC is an active contributor on antibiotic usage through the Antimicrobial Stewardship Advisory Committee and the Antimicrobial Stewardship Jurisdictional Network.

2.2 Key characteristics of existing systems

Twenty years ago, Neu et al wrote in relation to AMR surveillance that 'there are no reliable data in this area – simply fragments of information and anecdotes that we use to draw an overall picture'.[125] Since then, there has been much activity across the globe to address the paucity of coherent information, but the landscape is still fragmented. This section outlines the key characteristics and range of attributes exhibited by systems for AMR surveillance. Appendix 2 indicates the level of detail that is readily available about a large number of historic and current programs and systems. Although there are many programs described in Appendix 2, the range of attributes exhibited by these programs is discussed in more detail in Sections 2.2.1–2.2.16.

2.2.1 Program type

Internationally, a number of different types of programs are concerned with monitoring aspects of AMR. Of the programs listed in Appendix 2, the majority monitor AMR, although the approach taken varies. Some monitor and analyse antimicrobial consumption in isolation, while others – such as the broader European Centre for Disease Prevention and Control (ECDC) program, including the European Surveillance of Antimicrobial Consumption Network – analyse both AMR and antimicrobial consumption, and seek to link the selective pressures exerted by antibiotic consumption in the community with the occurrence of resistance.

2.2.2 Program scope

All of the programs listed in Appendix 2 deal with data related to human health. Some notable programs, such as DANMAP (Denmark), take a much broader view and gather information from a range of animal and food sources. These can include both antimicrobial consumption and resistance data in the case of animals, and the results of bacterial screening in the case of food. Domestic farming activities or imported foodstuffs can provide food data. The data can describe pathogens, such as *Salmonella* spp. or *Campylobacter* spp. isolates, or focus on the AMR characteristics of sentinel organisms that give an indication of the prevalence and change in resistance patterns.

2.2.3 Program status

A notable feature of the list in Appendix 2 is the number of programs that have ceased to operate. In some cases, this appears to be because the program operated as a project with a defined scope and timeline, and has reached its conclusion. In other cases, it appears that a failure of funding, governance or enthusiasm has occurred. There are, however, successful programs such as the Swedish Strategic Programme for the Rational Use of Antibiotic Agents and Surveillance of Resistance (STRAMA) that have been running for more than a decade and demonstrate consistent output from year to year.

2.2.4 Program focus

Programs vary significantly in their focus. For example, some are clearly focused on food-related and enteric organisms, and others are concerned with invasive pathogens and only collect data related to sterile sites and fluids. Some, such as the European Antimicrobial Resistance Surveillance Network (EARS-Net), concentrate on a defined list of microorganisms, while others, including the British Society for Antimicrobial Chemotherapy, focus on disease-related groupings, such as upper or lower respiratory tract infections. A number are concerned with a single or very small range of pathogens – for example, the European Gonococcal Antimicrobial Surveillance Programme collects data on *N. gonorrhoeae* susceptibility, while CTLSS (Canada) collects surveillance data on *Mycobacterium tuberculosis* and other *Mycobacterium* species.

A further set of program characteristics that can be used to group and describe these programs is the extent to which they focus on AMR surveillance, the use of antimicrobials, HAI, and food and veterinary sources of data. Table 2 provides an overview of a range of programs and their main areas of focus.

2.2.5 Geographic range of surveillance

Although some programs (such as EARS-Net and ReLAVRA) bring together data from several nations, others (including the Canadian Integrated Program for Antimicrobial Resistance Surveillance) concentrate on national datasets. There are a number of programs that gather national data and then provide a subset of information to a supranational system, including DANMAP and STRAMA, where a much broader level of information is gathered at a national level than what is submitted to ECDC EARS-Net.

Programs vary significantly in their focus. For example, some are clearly focused on food-related and enteric organisms, and others are concerned with invasive pathogens and only collect data related to sterile sites and fluids.

2.2.6 Types of bacteria

TSN and CHRISP OrgTRx are examples of programs that collect data on all bacteria isolated from clinical specimens. As indicated in Section 2.2.4, there are other programs that collect data on one or a few bacterial species. Between these extremes are systems that collect data on a defined list of organisms – for example, EARS-Net collects data on seven organisms.

Table 3 lists and enumerates the organisms or groups of bacteria monitored by 5 supranational, 15 national and 11 Australian programs. There are many programs listed that monitor data on *S. aureus* and MRSA, *S. pneumoniae* and *E. coli*, but fewer that report on, for example, coagulase-negative staphylococci or *C. difficile*.

Some programs gather data on sentinel organisms. These are organisms that usually co-exist with humans and animals without causing disease, but may become the cause of infection under certain circumstances. AMR data on sentinel organisms generally result from active screening programs involving humans, animals or food sources, rather than clinical specimens being submitted.

Table 2: Areas of focus of a range of select programs

	AMR surveillance	Antibiotic usage	Healthcare-acquired infection	Food	Veterinary
Supranational					
EARS-Net (Europe)	Y				
Other ECDC programs Europe		Y	Y	Y	Y
ANSORP	Y				
IDSR (Africa)	Y				
CARTIPS (Asia)	Y				
SENTRY (Global)	Y				
ReLAVRA (Americas)	Y	Y			
TSN (US, Canada, Europe, Aus)	Y				
National					
DANMAP (Denmark)	Y	Y	Y	Y	Y
NETHMAP (Netherlands)	Y	Y	Y	Y	Y
STRAMA (Sweden)	Y	Y	Y	Y	Y
BulSTAR (Bulgaria)	Y	Y			
FiRe (Finland)	Y				
NARMS (US – CDC)	Y				
ABCs (US – CDC)	Y				
TRUST (US)	Y				
CIPARS (Canada)	Y	Y		Y	Y
MOHNARIN (China)	Y				
CHINET (China)	Y				
SMART (China)	Y				
KONSAR (Korea)	Y				
NARST (Thailand)	Y				
NARS (Singapore)	Y		Y		
Australian					
AGAR (National)	Y				
CHRISP OrgTRx (Qld)	Y	Y	Y		
NAUSP (National)		Y			
DUSC (National)		Y			
HISWA (WA)			Y		
TIPCU (Tas)			Y		
VICNISS (Victoria)			Y		
SA HAI Surveillance Program	Y		Y		

ABCs = Active Bacterial Core Surveillance; AGAR = Australian Group on Antimicrobial Resistance; ANSORP = Asian Network for Surveillance of Resistant Pathogens; BulSTAR = Bulgarian Surveillance Tracking Antimicrobial Resistance; CARTIPS = Community-Acquired Respiratory Tract Infection Pathogen Surveillance; CDC = Centers for Disease Control and Prevention; CHINET = Chinese Tertiary Hospital; CHRISP = Centre for Healthcare Related Infection Surveillance and Prevention; CIPARS = Canadian Integrated Program for Antimicrobial Resistance Surveillance; DANMAP = Danish Integrated Antimicrobial Resistance Monitoring and Research Programme; DUSC = Drug Utilisation Sub-Committee; EARS-Net = European Antimicrobial Resistance Surveillance Network; ECDC = European Centre for Disease Prevention and Control; FiRe = Finnish Study Group for Antimicrobial Resistance; HISWA = Healthcare Infection Surveillance Western Australia; IDSR =Integrated Disease Surveillance and Response; KONSAR = Korean Nationwide Surveillance of Antimicrobial Resistance; MOHNARIN =Ministry of Health National Antibacterial Resistance Investigation Net China; NARMS = National Antimicrobial Resistance Monitoring System; NARS = Network for Antimicrobial Resistance Surveillance; NARST = National Antimicrobial Resistance Thailand; NAUSP = National Antimicrobial Usage Surveillance Program; ReLAVRA = *Red Latinoamericana de Vigilancia de la Resistencia a los Antimicrobianos*; STRAMA = Swedish Strategic Programme for the Rational Use of Antibiotic Agents and Surveillance of Resistance; TIPCU = Tasmanian Infection and Prevention Control Unit; TRUST = Tracking Resistance in the United States Today; TSN = The Surveillance Network; US = United States; VICNISS = Victorian Nosocomial Infection Surveillance System

Table 3: Organisms and organism groups monitored by existing AMR surveillance systems

Organism/Group	Number of programs including this organism or group	Supranational					National														Australian									
		EARS-Net (Europe)	IDSR (Africa)	ANSORP (Asia)	CARTIPS (Asia)	SENTRY (Global)	DANMAP (Denmark)	NETHMap (Netherlands)	STRAMA (Sweden)	TSN (multinational)	BulSTAR (Bulgaria)	FiRe (Finland)	Greece	NARMS (US – CDC)	ABCs (USA – CDC)	TRUST (US)	CIPARS (Canada)	MOHNARIN (China)	CHINET (China)	NARST (Thailand)	NARS (Singapore)	AGAR (National)	NNN	ACCESS (National)	CHRISP OrgTRx (Queensland)	VICNISS (Victoria)	HISWA (WA)	TIPCU (Tasmania)	New South Wales	South Australia	Northern Territory	Australian Capital Territory
HAI focus	8																								Y	Y	Y	Y	Y	Y	Y	Y
Many or all clinically relevant bacteria	5					Y				Y	Y									Y					Y							
Gram positive cocci																																
Staphylococcus aureus/MRSA	18	Y		Y	Y		Y	Y	Y			Y	Y		Y			Y	Y		Y	Y		Y		Y	Y		Y	Y		
Streptococcus pneumoniae	12	Y		Y	Y		Y	Y	Y			Y			Y	Y		Y	Y			Y										
Enterococcus faecium	12	Y					Y	Y	Y			y	Y						Y		Y	Y		Y			Y			Y		
Enterococcus faecalis	11	Y					Y	Y	Y				Y						Y		Y	Y		Y			Y			Y		
Streptococci Group A	4				Y		Y		Y						Y																	
Streptococci groups B, C, G	4				Y		Y		Y						Y																	
Coagulase-negative staphylococci	3							Y										Y	Y													
Gram negative bacilli																																
Escherichia coli	11	Y					Y	Y	Y			y	Y	Y					Y		Y	Y								Y		
Klebsiella pneumoniae	10	Y			Y		Y	Y	Y				Y						Y		Y	Y								Y		
Pseudomonas aeruginosa	9	Y					Y	Y	Y				Y					Y	Y		Y									Y		
Haemophilus influenzae	7				Y			Y	Y			Y			Y	Y						Y										
Salmonella sp.	6			Y			Y		Y			Y		Y			Y															
Enterobacter sp.	5							Y					Y					Y	Y			Y										
Acinetobacter sp.	6							Y					Y					Y	Y		Y									Y		
Shigella	4		Y	Y					Y					Y																		
Proteus mirabilis	3							Y					Y						Y													
Campylobacter	2						Y							Y																		
Vibrio cholerae	2		Y	Y																												
Citrobacter	1																		Y													
Serratia sp.	1																		Y													

Organism/Group	Number of programs including this organism or group	Supranational					National														Australian										
		EARS-Net (Europe)	IDSR (Africa)	ANSORP (Asia)	CARTIPS (Asia)	SENTRY (Global)	DANMAP (Denmark)	NETHMap (Netherlands)	STRAMA (Sweden)	TSN (multinational)	BulSTAR (Bulgaria)	FiRe (Finland)	Greece	NARMS (US – CDC)	ABCs (USA – CDC)	TRUST (US)	CIPARS (Canada)	MOHNARIN (China)	CHINET (China)	NARST (Thailand)	NARS (Singapore)	AGAR (National)	NNN	ACCESS (National)	CHRISP OrgTRx (Queensland)	VICNISS (Victoria)	HISWA (WA)	TIPCU (Tasmania)	New South Wales	South Australia	Northern Territory	Australian Capital Territory
Helicobacter pylori	1								Y																						
Vibrio sp.	1													Y																	
Yersinia pestis	1		Y																												
Salmonella typhi	1		Y																												
Gram-negative cocci																															
Neisseria meningitidis	5		Y					Y	Y						Y								Y								
Moraxella catarrhalis	3				Y			Y								Y															
Neisseria gonorrhoeae	4							Y	Y			Y											Y								
Gram-positive bacilli																															
Clostridium difficile	3								Y																	Y			Y	Y	
Bacillus anthracis	1		Y																												
Clostridium tetani	1		Y																												
Acid-fast bacilli																															
Mycobacterium tuberculosis	3							Y	Y			Y																			
Mycobacterium ulcerans	1		Y																												
Mycobacterium leprae	1		Y																												
Other groupings																															
Sexually transmitted infections	1		Y																												
Protozoa and parasites	1		Y																												
Viruses	1		Y																												
Non-communicable diseases	1		Y																												

ABCs = Active Bacterial Core Surveillance; AGAR = Australian Group on Antimicrobial Resistance; ANSORP = Asian Network for Surveillance of Resistant Pathogens; BulSTAR = Bulgarian Surveillance Tracking Antimicrobial Resistance; CARTIPS = Community-Acquired Respiratory Tract Infection Pathogen Surveillance; CDC = Centers for Disease Control and Prevention; CHINET = Chinese Tertiary Hospital: CHRISP = Centre for Healthcare Related Infection Surveillance and Prevention; CIPARS = Canadian Integrated Program for Antimicrobial Resistance Surveillance; DANMAP = Danish Integrated Antimicrobial Resistance Monitoring and Research Programme; DUSC = Drug Utilisation Sub-Committee; EARS-Net = European Antimicrobial Resistance Surveillance Network; ECDC = European Centre for Disease Prevention and Control; FiRe = Finnish Study Group for Antimicrobial Resistance; HISWA = Healthcare Infection Surveillance Western Australia; IDSR = Integrated Disease Surveillance and Response; KONSAR = Korean Nationwide Surveillance of Antimicrobial Resistance; MOHNARIN =Ministry of Health National Antibacterial Resistance Investigation Net China; NARMS = National Antimicrobial Resistance Monitoring System; NARS = Network for Antimicrobial Resistance Surveillance; NARST = National Antimicrobial Resistance Thailand; NAUSP = National Antimicrobial Usage Surveillance Program; ReLAVRA = *Red Latinoamericana de Vigilancia de la Resistencia a los Antimicrobianos*; STRAMA = Swedish Strategic Programme for the Rational Use of Antibiotic Agents and Surveillance of Resistance; TIPCU = Tasmanian Infection and Prevention Control Unit; TRUST = Tracking Resistance in the United States Today; TSN = The Surveillance Network; US = United States; VICNISS =Victorian Nosocomial Infection Surveillance System

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2.2.7 Bacterial characteristics

Programs that gather data and report on AMR provide information based on laboratory susceptibility testing of bacteria of interest. Some programs, including AGAR, ACCESS Typing and Research and the Asian Network for Surveillance of Resistant Pathogens (ANSORP) also look at bacterial genotypes. This information can provide greater confidence and understanding of epidemiology and spread of bacterial strains, but does require additional levels of laboratory testing and expense.

Data from the Prospective Resistant Organism Tracking and Epidemiology for the Ketolide Telithromycin – US surveillance study demonstrated that, out of more than 26 000 isolates of *S. pneumoniae*, about 29% consistently expressed resistance to erythromycin during a four-year period. Molecular testing was able to demonstrate, however, that a significant shift had occurred in the mechanism of resistance. The most common mechanism of resistance to erythromycin in *S. pneumoniae* is mediated by the presence of the *mef*(A) gene, which allows the organism to pump antibiotic actively out of the cell; however, the prevalence of this gene occurring on its own decreased from 69% to 61% during the four years. At the same time, an alternative mechanism of resistance, involving a different gene in combination with *mef*(A), increased in prevalence from 9% to 19%. The change was most marked in children less than two years of age,[126] and would have gone unobserved if molecular testing had not been used. The finding is important because the organism's AMR differs depending on which genes conferring resistance are carried by the bacteria, and can therefore influence the choice of empiric therapy.

The frequency with which data are gathered by surveillance networks ranges from daily (TSN) to annually (EARS-Net).

2.2.8 Specimen types

The TSN and CHRISP programs (Section 2.2.6) collect data on all clinical specimen types as well as all bacteria isolated. EARS-Net, by comparison, only collects data from blood cultures and cerebrospinal fluid specimens, as its focus is on invasive organisms. Programs that focus on particular disease states or organ systems, such as those concentrating on respiratory or enteric disease, collect data on specimens relevant to the target organisms.

2.2.9 Laboratory participants

AMR data relating to humans come from pathology laboratories. In Australia, both public and private laboratories contribute data to AGAR, while the CHRISP program only collects public-sector data. In other countries, some participants are university or reference laboratories, and others are clinical facilities in either the public or private sector.

2.2.10 Standardised laboratory practice

A common feature among international AMR surveillance programs operating across or between nations is the standardisation of laboratory practice. For data to be combined between facilities and across time, there needs to be confidence that the results are comparable. Two approaches to this are seen.

One method is to have many laboratories send isolates of interest to a small number of reference centres where the methodology used to study AMR has been benchmarked. The Alexander Project – a multicentre international study – initially required that all isolates be sent to a single laboratory in the UK. The addition of two more approved laboratories in the US after several years allowed the program to expand, but was accompanied by stringent cross-validation and quality control, both at the outset and throughout the operation of the study.[48]

The other technique is to ensure that all clinical laboratories that provide data are enrolled in external quality assurance (EQA) programs, often accompanied by broad agreement across the network on the methodology that will be used for bacterial identification and susceptibility testing. Some AMR surveillance systems operate EQA programs for participating laboratories, while others require centres to be enrolled in independent EQA programs.

2.2.11 Basis of participation

The level of participation in AMR surveillance programs varies significantly between countries where active programs exist. In Finland, a network of 24 microbiology laboratories covering more than 95% of clinical laboratories that process blood cultures contribute data to the Finnish Study Group for Antimicrobial Resistance.[127]

The level of participation in a voluntary national reporting system in Sweden is also high, with data from more than 75% of the population being provided to the EARS-Net system. With a population of 9.5 million, Sweden claims to be the largest contributor of data to the pan-European system.

By contrast, the national AMR surveillance data from voluntary reporting networks in Germany covers only 2% of the population. Despite having a population of 81.7 million, in 2008, Germany ranked last in terms of representation in the EARS-Net dataset.[128] A strategy addressing many of the key characteristics described here was implemented in 2008 to increase the level of reporting.

2.2.12 Frequency of data gathering

The frequency with which data are gathered by surveillance networks ranges from daily (TSN) to annually (EARS-Net). This has a significant impact on the purposes for which a system may be used, as well as on the design of data-feeder mechanisms, and the central system or agency that receives, processes and reports information. A system that requires annual data submission cannot, for example, be used to detect and flag emerging threats in a timely manner, but may be appropriate for long-term, high-level policy making and planning.

2.2.13 Frequency and methods of reporting

A characteristic of some of the European programs, such as DANMAP, STRAMA and EARS-Net, is that significant, consolidated reports that contain information on all surveillance activities are produced annually. The reports disseminate findings, and provide a level of analysis and opinion on trends and projections for the future. Many peer-reviewed journal articles arise from the work done to gather and analyse surveillance data, and other publications and conference presentations distribute information to clinicians, public health bodies, policy makers and the general population.

AGAR produces a number of specific reports each year, reflecting the projects that have been undertaken during the relevant time period. AGAR activities have also led to many journal articles and other publications, and contributions to conference proceedings in Australia and overseas.

ANSORP undertakes a series of defined projects, and results are primarily available in the peer-reviewed literature. In some cases, articles are freely available in the public domain, while access to others requires subscription to the relevant journal or purchase on a per-article basis.

2.2.14 Mandatory reporting

The high level of participation and reporting to the AMR surveillance network in Sweden may be assisted by the legislative requirements for mandatory reporting in that country. Both the reporting laboratory and the treating physician must report all cases of MRSA, VRE and penicillin-resistant *S. pneumoniae* to the Swedish Institute for Infectious Disease Control. Note that it is only isolates with particular resistance characteristics that must be reported in this case, and not all isolates of a particular species of bacteria. A similar situation exists in Denmark, where MRSA and invasive *S. pneumoniae* isolates must be reported. In the latter case, it is the specimen type that drives mandatory reporting rather than the AMR characteristics of the isolates.

In England, the reporting of MRSA has been mandatory for all National Health Service acute trusts since 2004, and has recently been improved so that patient-level data are collected as well. In 2011, the scheme was extended to include surveillance of methicillin-sensitive *S. aureus* (MSSA). The UK Health Protection Agency produces counts of MRSA and MSSA monthly and annually. The first annual MSSA data were published in July 2012. Every quarter, the data collected in the improved surveillance are used to produce epidemiological commentaries, with the aim of contributing to a better evidence base regarding risk factors for infection.[129] Worldwide, it is more common to have pathogens of high public health importance, such as *M. tuberculosis* and *N. gonorrhoeae*, notifiable. In Australia, MRSA reporting is mandatory only in Western Australia.

It is important to establish which population groups are to be included in a surveillance program, because this will have important consequences for how the data can be used.

2.2.15 Population monitored

Although many programs monitor isolates from hospital populations, others focus on community settings, and some include a combination. It is important to establish which population groups are to be included in a surveillance program, because this will have important consequences for how the data can be used in different areas of interest and importance. The focus of STRAMA was initially on multiresistant pneumococci and arose because of concerns in the medical and wider community about the detection of such strains among young children in day-care centres across the country. The program subsequently expanded to monitor hospitals and a broad range of community settings. In Germany, there was national surveillance occurring at a low level in maximum-care hospitals, and concerns about the lack of a broader view of AMR led to the expansion into ambulatory care.

The Alexander Project, which ran for ten years from 1992 and gathered data from 27 countries, is an example of a focused program. Its aim was to elucidate information on resistance patterns in six organisms isolated from adult community-acquired respiratory tract infections.[130] Hospital isolates were only included if samples were collected within 48 hours of admission. Data collection ceased on two organisms after two years, and a third after five years, to allow the project to focus on the three organisms most clinically relevant to the Alexander Project: *S. pneumoniae*, *H. influenzae* and *Moraxella cattarhalis*.[48]

The Surveillance of Antimicrobial Use and Antimicrobial Resistance in ICUs (SARI; Germany) and the Intensive Care Antimicrobial Resistance Epidemiology (US) Project are examples of focused programs in the hospital setting; in both cases, data are gathered on nosocomial pathogens from intensive care units. A number of studies have demonstrated a stepwise reduction in the prevalence of AMR in different settings, from intensive care to non-intensive care, and then ambulatory,[131] so it is important to consider the benefits to be gained from monitoring each setting. For example, Sun et al[17] published a study that looked at laboratory and antibiotic prescribing data for nine years in the US. The prescribing data covered 70% of all prescriptions filled by retail pharmacies, while the microbiology data was drawn from TSN and covered 300 laboratories, and both inpatient and outpatient isolates. The authors highlighted that 'the strong correlation between community use of antibiotics and resistance isolated in the hospital indicates that restrictions imposed at the hospital level are unlikely to be effective unless coordinated with campaigns to reduce unnecessary antibiotic use at the community level'.[17]

Surveillance programs described in this report obtain funding from a range of sources. The funding source, in turn, generally dictates the focus and character of the program.

2.2.16 Funding source and governance

Surveillance programs described in this report obtain funding from a range of sources. The funding source, in turn, generally dictates the focus and character of the program.

The multinational programs operated by the ECDC aim to provide independent and authoritative advice to member countries on threats to human health from infectious disease. Programs funded by national governments, such as the German SARI project, seek similar outcomes for their populace.

Some programs, such as AGAR, have their genesis in professional groups who initiate projects out of concern for the emerging impact of AMR and take action in the absence of other coordinated activity. AGAR was initially funded through commercial sponsorship, but has been principally sponsored by the Australian Government since 2002. ANSORP is an independent, not-for-profit, nongovernment international network funded by the Asia–Pacific Foundation for Infectious Diseases, which was established to improve global health by strengthening and coordinating research-related activities.

A number of surveillance networks are initiated and funded by commercial entities. The multinational SENTRY program was initially funded by GlaxoSmithKline, and is now sponsored by a number of pharmaceutical companies, which change from time to time. The Meropenem Yearly Susceptibility Test Information Collection (MYSTIC) is funded and operated by AstraZeneca, a manufacturer of meropenem (a broad-spectrum injectable antimicrobial).

A summary of the key characteristics of AMR surveillance systems and implications for an Australian national system is presented in Table 4.

Table 4: Characteristics of antimicrobial resistance surveillance systems

Characteristic	Examples of the range of attributes displayed by existing systems	Implications for Australia
Program type	• Program surveillance is of AMR. • Program surveillance is of antimicrobial consumption. • Surveillance of both antimicrobial consumption and resistance occurs.	Some national programs and systems for monitoring antibiotic consumption across Australia exist or are in development. The greatest deficit at this time is in the coordinated monitoring of AMR. Coordinated national surveillance would enable linking antimicrobial resistance with antibiotic usage data.
Program scope	• Program contains human data. • Program contains animal data. • Program contains data from food stuffs. • Program contains data from two or three of the above.	It is envisaged that, while the focus of the Antimicrobial Resistance Standing Committee is on the implications for human health, awareness must be maintained of the potential to correlate human data with animal and food data in the future, which can completely cover all possible selective pressures contributing to AMR.
Program status	• Program has ceased. • Program is active. • Program is being planned but is not yet operational.	Planning for a sustainable national AMR surveillance system needs to occur.
Program focus	• Program has an organism focus (e.g. MRSA or *Neisseria gonorrhoeae*). • Program focuses on one or more disease entities (e.g. respiratory tract infections or enteric pathogens).	The program focus will be influenced by decisions regarding the numbers and types of organisms, antimicrobials and specimens to be monitored.
Geographic range of surveillance	• Program covers a county or state. • Program covers a nation. • Program covers a group of nations in a region.	The Australian system should be national, with involvement of all states and territories that are responsible for data collection from public healthcare facilities. Australia's current and potential contribution to multinational systems should be evaluated.
Number of bacteria	• Program gathers data on one pathogenic organism (e.g. *Mycobacterium tuberculosis*). • Program gathers data on a group of pathogenic organisms related to a disease entity (e.g. *Salmonella*, *Vibrio cholerae*, *Campylobacter jejuni* and other food poisoning organisms). • Program gathers data on all pathogens isolated from clinical specimens. • AMR data are collected for sentinel organisms.	The most effective way to initiate a program may be to focus initially on a defined set of organism and specimen types, and later expand the scope.
Bacterial characteristics	• Program gathers data on antibiotic resistance from laboratory breakpoint or minimum inhibitory concentration testing using a variety of methods. • Program gathers data from molecular testing of bacterial genes.	Laboratory-generated data on AMR testing are essential. Laboratories need to be evaluated to determine their capacity to undertake molecular genetic testing of isolates beyond that currently performed. It may be appropriate to bring existing molecular testing data contributed to surveillance programs under the same umbrella as the AMR susceptibility data, and build from that base.

Table 4: Characteristics of antimicrobial resistance surveillance systems (continued)

Characteristic	Examples of the range of attributes displayed by existing systems	Implications for Australia
Number of specimen types	• Program gathers data generated from one or two specimen types (e.g. blood cultures and cerebrospinal fluid for invasive pathogens). • Program gathers data generated from a broad range or all clinical specimen types.	A surveillance program needs to consider the specimen types to be included, along with the range of pathogens on which data are to be gathered.
Laboratory participants	• Participating laboratories are publicly funded. • Participating laboratories are privately funded. • A mix of publicly and privately funded laboratories participate.	All clinical laboratories in Australia performing microbiology testing on clinical specimens should be included.
Standardised laboratory practice	• Bacterial isolates are sent to one or a few reference laboratories for testing. The reference laboratories engage in method standardisation, validation and quality-control activities to ensure comparability of results. • A large number of laboratories contribute data from their own testing of bacterial isolates. The laboratories seek to standardise laboratory methods, validate the methods used and participate in external QA programs. • The organisation coordinating surveillance activities also operates the external QA program for participating laboratories. • Participating laboratories purchase external QA from a body independent of the surveillance activities.	In Australia, participation in an external QA program for all fields of testing is mandated for the NATA/RCPA accreditation of medical laboratories. Without NATA/RCPA accreditation, tests performed in medical laboratories are ineligible for Medicare rebates. The external QA program for microbiology is administered by RCPA Quality Assurance Programs, established by RCPA in 1988. The impact of variations in laboratory practice across Australia needs to be evaluated in the context of contributions to a surveillance program being comparable and able to be consolidated.
Basis of participation	• Participation by clinical laboratories is voluntary and uptake is low. • Participation by clinical laboratories is voluntary and uptake is high. • A level of participation in the surveillance program is mandated by government.	Options for Australia include identifying a mechanism for mandating a certain minimal level of participation, or employing strategies to maximise participation in a voluntary scheme.
Frequency of data gathering	• AMR data are submitted daily, monthly, quarterly and/or annually.	The goals of a national program must be defined, and will help to determine the frequency with which data should be collected to ensure that objectives can be met.
Frequency and methods of reporting	• The surveillance program produces comprehensive annual reports. • Findings from the surveillance program are communicated through peer-reviewed journals and conference presentations.	Production of a comprehensive annual report should be a priority for a national system. This will provide a focus for discussing clinical issues, as well as contributing to policy and planning deliberations.

Characteristic	Examples of the range of attributes displayed by existing systems	Implications for Australia
Mandatory reporting	• All AMR reporting is voluntary. • The reporting of AMR data for certain organism/antibiotic combinations is mandated by government. • The reporting of AMR data for certain organism/specimen type combinations is mandated by government.	The desirability of a level of mandatory reporting needs to be determined. If some level of mandatory reporting is desired, potential mechanisms at a jurisdictional or national level need to be explored.
Population monitored	• AMR data are collected to reflect community-acquired infections only. • AMR data are collected to reflect healthcare-acquired infections only. • AMR data are collected to reflect a subset of hospital data only (e.g. intensive care units). • AMR data are collected to reflect community and healthcare-associated settings.	An Australian national system should collect data from community and healthcare-associated settings.
Funding source and governance	• The AMR surveillance program is funded and overseen by government. • The AMR surveillance program is funded and overseen by an independent, not-for-profit entity. • The AMR surveillance program is funded and overseen by a commercial entity. • The AMR surveillance program is commercially funded, but overseen by a professional group or society.	The Australian AMR surveillance system must be funded by governments and appropriate governance established.

AMR = antimicrobial resistance; MRSA = methicillin-resistant *Staphylococcus aureus*; NATA = National Association of Testing Authorities; QA = quality assurance; RCPA = Royal College of Pathologists of Australia.

3

Options and models for the Australian context

Options and models for the Australian context

This section examines the elements that drive international programs and their features that appear to be important for success, relevant to a national, coordinated surveillance system in Australia. Select programs and activities of greatest relevance are presented as case studies.

Key question

What options or models for a nationally coordinated approach to the reporting and surveillance of antibiotic usage and antimicrobial resistance are most applicable to the Australian context?

3.1 Objectives of international antimicrobial resistance surveillance systems

The objectives of an antimicrobial surveillance system for Australia need to be defined, as the methods used to gather data and decisions regarding data use will be driven by the objectives of the system.[132] For example, if a system is to provide real-time detection of an emerging threat, it will not be satisfactory to design a system that requires annual data collection.

The *Centres for Disease Control and Prevention Updated Guidelines for Evaluating Public Health Surveillance Systems* lists the following uses for data taken from a surveillance system and used for public health purposes:[133]

- guide immediate action for cases of public health importance
- measure the burden of a disease (or other health-related event), including changes in related factors, the identification of populations at high risk, and the identification of new or emerging health concerns
- monitor trends in the burden of a disease (or other health-related event), including the detection of epidemics (outbreaks) and pandemics
- guide the planning, implementation and evaluation of programs to prevent and control disease, injury or adverse exposure
- evaluate public policy
- detect changes in health practices and the effects of these changes
- prioritise the allocation of health resources
- describe the clinical course of disease
- provide a basis for epidemiologic research.

An overarching objective for antimicrobial surveillance might be given as:

> *The ongoing generation, capture, assembly, and analysis of all information on the evolving nature, spread, and distribution of infecting microbes and their resistance to antimicrobial agents and its full use for actions to improve health.*[134]

When considering appropriate objectives for an Australian system, it is informative to review those of established systems. The stated objectives of the European Antimicrobial Resistance Surveillance Network (EARS-Net) are to:

- collect comparable and validated antimicrobial resistance (AMR) data
- analyse trends over time
- provide timely AMR data that constitute a basis for policy decisions
- encourage the implementation, maintenance and improvement of national AMR surveillance programs
- support national systems in their efforts to improve diagnostic accuracy at every level of the surveillance chain
- link AMR data to factors influencing the emergence and spread of AMR, such as antibiotic usage data
- initiate, foster and complement scientific research in Europe in the field of AMR.

The Alliance for the Prudent Use of Antibiotics provides suggested objectives for coordinated AMR surveillance programs,[135] which demonstrate significant concordance and overlap with both the generic Centers for Disease Control and Prevention (CDC) and EARS-Net objectives:

- characterise disease aetiologies and resistance trends
- identify and investigate new threats in resistance promptly
- guide policy makers in developing therapy recommendations
- guide public health authorities in responding to outbreaks of resistant organisms in hospitals and the community
- evaluate the impact of therapy and infection control interventions on infection rates and cure rates
- strengthen laboratory capacity and national communicable disease infrastructure through a process of continuous quality improvement.

3.2 Case studies – existing programs of most relevance to the Australian context

This section provides case studies of a number of systems that have relevance to the Australian environment – that is, they have dealt with cross-jurisdictional issues, supported surveillance in nations with well-developed healthcare systems and/or presented a model for broad surveillance across human, animal and food-related sources of AMR. In each case study, there are sections to describe the model for data collection and processing, and the ways in which data are made available to the public. Table 5 summarises the case studies.

3.2.1 European Centre for Disease Prevention and Control

The European Centre for Disease Prevention and Control (ECDC) conducts surveillance for both AMR and antimicrobial consumption. The two programs are the European Antimicrobial Resistance Surveillance Network (EARS-Net) and European Surveillance of Antimicrobial Consumption Network (ESAC-Net).

Table 5: Case studies examined in this report

Program	Span	Funding	Governance
ECDC	Supranational	Government	Government
ANSORP	Supranational	Independent foundation	Professional body
TSN	Supranational/national	Commercial	Commercial
DANMAP	National	Government	Government
STRAMA	National	Government	Government
AGAR	National	Government	Professional body
CHRISP	State	Government	Government

AGAR = Australian Group on Antimicrobial Resistance; ANSORP = Asian Network for Surveillance of Resistant Pathogens; CHRISP = Centre for Healthcare Related Infection Surveillance and Prevention; DANMAP = Danish Integrated Antimicrobial Resistance Monitoring and Research Programme; ECDC = European Centre for Disease Prevention and Control; STRAMA = Swedish Strategic Programme for the Rational Use of Antibiotics Agents and Surveillance of Resistance; TSN = The Surveillance Network

European Antimicrobial Resistance Surveillance Network

EARS-Net is a Europe-wide network of national surveillance systems, providing European reference data on AMR for public health purposes. The network is coordinated and funded by ECDC. It is the largest publicly funded AMR surveillance system in the European region. ECDC was established in 2005 as a European Union (EU) agency, aiming to '… identify, assess and communicate current and emerging threats to human health posed by infectious diseases'.[136] It works in partnership with existing national health protection bodies across Europe.

European AMR surveillance data has been collected since 1998 by the European Antimicrobial Resistance Surveillance System (EARSS), which was coordinated by the Dutch National Institute for Public Health and the Environment (RIVM) between 1998 and 2009. Coordination of the network was transferred to the ECDC in January 2010, and the name of the network changed to EARS-Net. Historical EARSS data was transferred to The European Surveillance System (TESSy). TESSy is the single point of access for European Member States to enter and retrieve data.

In 2009, EARSS was funded by ECDC and the Dutch Ministry of Welfare and Sport, at a cost of €668 458 (approximately AU$815 000), to support the external quality assurance program, organise an annual plenary meeting and more frequent scientific advisory board meetings, and undertake data management and report generation.[137] This cost compares to an estimated 25 000 lives lost and around €900 000 (approximately AU$1.1 million) that is estimated to be spent each year on additional healthcare costs related to a limited number of resistant bacteria in the EU.[138]

In 2010, the first EARS-Net Reporting Protocol was published, which guided participating institutions on data collection, management, analysis and validation, and provided case definitions. The protocol provides detailed descriptions of data elements that are captured by the system, and was updated in 2012.[139] ECDC and EARS-Net are both underpinned by Decisions and Regulations of the European Parliament.

On 30 October 2012, the World Health Organization's European Region signed an agreement with RIVM (the original operators of the system that is now EARS-Net) and the European Society of Clinical Microbiology and Infectious Diseases to expand AMR surveillance to all countries in the WHO European Region. To date, EARS-Net has primarily covered countries that are EU Member States. The Central Asia and European Surveillance of Antimicrobial Resistance network, which will use EARS-Net methodology in collaboration with ECDC to permit comparison of data from across all of Europe, was established as a result of the EARS-Net expansion.[140]

Data collection and processing

The national networks across Europe collect data from their own clinical laboratories. More than 900 laboratories report data from more than 1400 hospitals. In 2010, 19 of the 28 countries contributing data to EARS-Net used WHONET software.[137] Each national network is responsible for uploading its data to TESSy, and then validating and approving the data before they are incorporated into the broader dataset. Bacterial isolate data are collected on the following seven organisms isolated from blood or cerebrospinal fluid according to 37 data variables described in the EARS-Net Reporting Protocol:

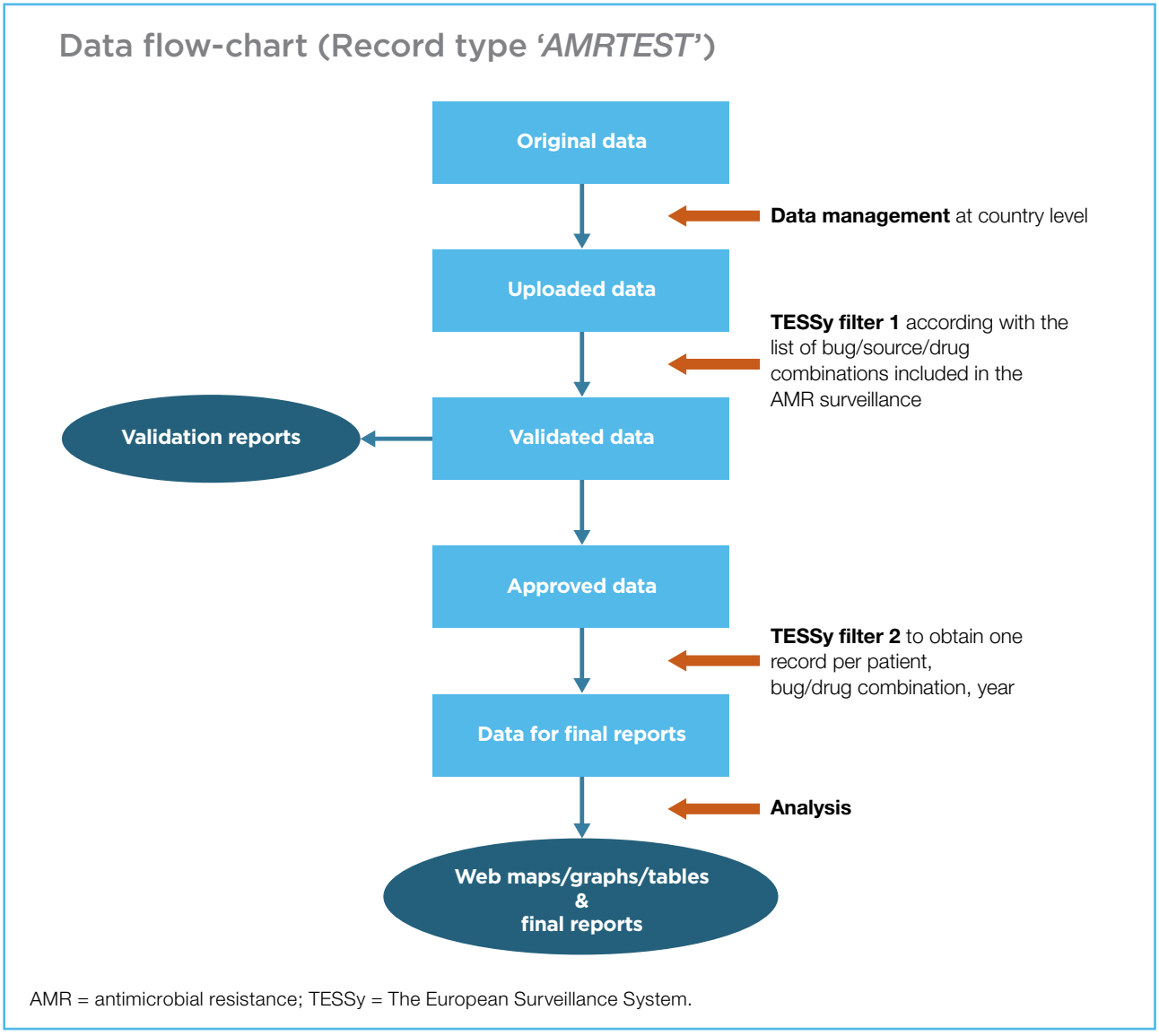
- *Streptococcus pneumoniae*
- *Staphylococcus aureus*
- *Enterococcus faecalis*
- *Enterococcus faecium*
- *Escherichia coli*
- *Klebsiella pneumoniae*
- *Pseudomonas aeruginosa.*

The flow of isolate-specific data is represented in the EARS-Net Reporting Protocol Version 2, 2012, and is represented in Figure 6.

Denominator data are collected for laboratory and hospital activity, and population or patient characteristics. There are 19 data variables for denominator data, including country and laboratory location, population, and hospital or facility type, size, and activity levels.

Examples of the denominator data variables captured for laboratories and hospitals are shown in Table 6.

Figure 6: Data flow chart from the European Antimicrobial Resistance Surveillance Network (EARS-Net)



AMR = antimicrobial resistance; TESSy = The European Surveillance System.

Table 6: Denominator data for EARS-Net

Laboratory variables	Hospital variables
• Laboratory code • Town • ZIP (post) code • Catchment population	• Year of report • Hospital code • Hospital type • Catchment population • Number of hospital beds • Number of intensive care unit beds • Number of hospital patient-days • Annual occupancy rate • Number of admissions • Number of blood culture sets

Using denominator data allows comparisons to be made between jurisdictions, and institutions of different sizes and activity levels.

Data comparability between laboratories is supported by the participation of contributing laboratories in the UK National External Quality Assurance Scheme. This occurs under a contracted arrangement; the most recent three-year contract was signed in 2010.

Data publication

EARS-Net data are publicly available online through an interactive webpage, where the visitor can select from a number of lists to generate the information of interest. Query results can then be downloaded in a number of formats, including graphs, tables and maps. Three methods of displaying the susceptibility of *Enterococcus faecalis* isolates to aminopenicillins in participating countries during 2010 are presented in Figure 7.

Annual reports are also produced and are publicly available from the ECDC website. The annual reports contain interpretations and conclusions regarding trends in AMR across Europe.

Program impact

Individual countries, such as Ireland, indicate that EARS-Net data are used 'to monitor the impact of interventions, such as improved infection control and antibiotic stewardship programmes'.[142] The Irish Health Protection Surveillance Centre website carries a range of information and articles that are based on participation in EARS-Net. For example, revelations from the *Enhanced EARS-Net Surveillance: Report for 2011 Data With Special Focus on Enterococcal Bloodstream Infection* contains information on the origin of vancomycin-resistant enterococci (VRE):[143]

> *In a study of the last six years' enhanced data, most VRE BSIs [bloodstream infections] were hospital-acquired: 87% of the* E. faecium *VRE and 67% for* E. faecalis *VRE were acquired in the reporting hospital.*

Analysis of the data has also facilitated the elucidation of risk factors for VRE:[143]

> *The most common risk factors included underlying malignancy/immunosuppression, intensive care unit stay and recent surgery. Recent surgery as risk factor had been increasing in VRE since 2006, however, this decreased sharply in 2011.*

Such information, facilitated by the collection of risk factors, sources of infection and patient outcome, is then used to guide changes in clinical guidelines and practice. Planning for the future of EARS-Net has focused on three key questions:[137]

- What will be major public health challenges caused by AMR in Europe within the next 5–10 years?
- Are the current surveillance systems capable of providing sufficient data for risk assessment and risk management to control these hazards?
- Which changes are needed in order to ascertain such capability?

Data generated by EARS-Net and its predecessor, and the systems monitoring antimicrobial usage have demonstrated considerable differences in consumption and correlated this with differences in resistance patterns. In 2008, for example, a four-fold difference in antimicrobial use was demonstrated between the highest (Greece) and lowest (Netherlands and Latvia) consumers. Such findings support a range of initiatives promoting the prudent use of antimicrobials, and Belgium and France have demonstrated declining resistance in *S. pneumoniae* (penicillin and erythromycin resistance) and *S. pyogenes* (erythromycin resistance).

The most recent annual report from EARS-Net paints the following picture:[144]

- The most alarming evidence of increasing AMR came from data on combined resistance (resistance to third-generation cephalosporins, fluoroquinolones and aminoglycosides) in *E. coli* and in *K. pneumoniae*.
- The high and increasing percentage of combined resistance observed for *K. pneumoniae* means that, for some patients with life-threatening infections, only a few therapeutic options remain available (e.g. carbapenems); however, the increasing prevalence of carbapenem resistance in some countries is exacerbating the situation.
- Other trends of AMR indicate that national efforts on infection control and containment of resistance are effective, as illustrated by the trends for methicillin-resistant *S. aureus* (MRSA), antimicrobial-resistant *S. pneumoniae* and antimicrobial-resistant enterococci, for which the situation appears generally stable or even improving in some countries.

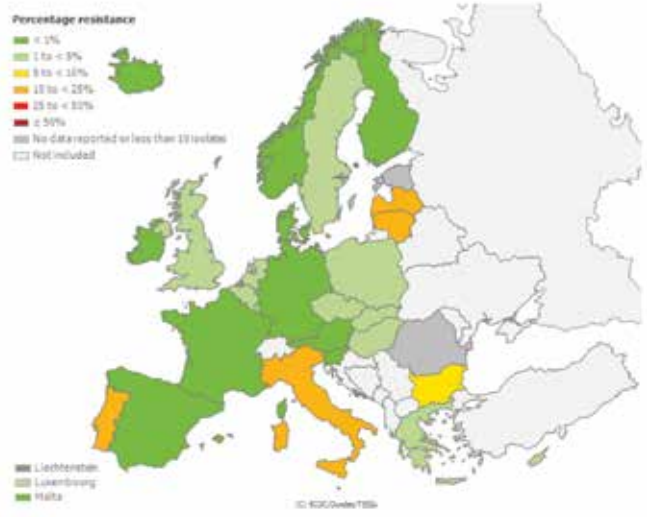
Such consolidated information, which can be used to develop and promote strategies to address specific issues, is unobtainable in the absence of a comprehensive system such as EARS-Net.

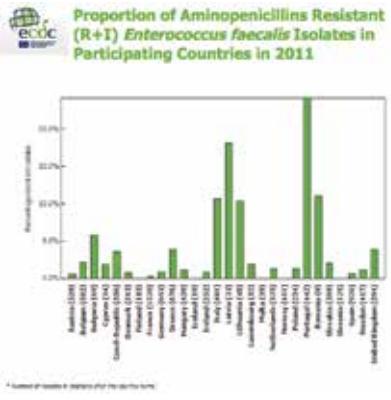
Figure 7: Available types of European Centre for Disease Prevention and Control (ECDC) reporting data

Susceptibility of *Enterococcus faecalis* Isolates to Aminopenicillins in Participating Countries in 2011

Country	Year	Antibiotic Group	S	I	R	Total N	%S	%I	%R
Austria	2011	Aminopenicillins	526	1	2	529	99.4 %	0.2 %	0.4 %
Belgium	2011	Aminopenicillins	491	0	11	502	97.8 %	0.0 %	2.2 %
Bulgaria	2011	Aminopenicillins	65	0	4	69	94.2 %	0.0 %	5.8 %
Cyprus	2011	Aminopenicillins	53	0	1	54	98.1 %	0.0 %	1.9 %
Czech Republic	2011	Aminopenicillins	536	19	1	556	96.4 %	3.4 %	0.2 %
Denmark	2011	Aminopenicillins	509	2	2	513	99.2 %	0.4 %	0.4 %
Finland	2011	Aminopenicillins	183	0	0	183	100.0 %	0.0 %	0.0 %
France	2011	Aminopenicillins	1516	2	2	1520	99.7 %	0.1 %	0.1 %
Germany	2011	Aminopenicillins	687	2	4	693	99.1 %	0.3 %	0.6 %
Greece	2011	Aminopenicillins	650	0	26	676	96.2 %	0.0 %	3.8 %
Hungary	2011	Aminopenicillins	434	0	5	439	98.9 %	0.0 %	1.1 %
Iceland	2011	Aminopenicillins	19	0	0	19	100.0 %	0.0 %	0.0 %
Ireland	2011	Aminopenicillins	250	0	2	252	99.2 %	0.0 %	0.8 %
Italy	2011	Aminopenicillins	430	1	50	481	89.4 %	0.2 %	10.4 %
Latvia	2011	Aminopenicillins	27	0	6	33	81.8 %	0.0 %	18.2 %
Lithuania	2011	Aminopenicillins	43	0	5	48	89.6 %	0.0 %	10.4 %
Luxembourg	2011	Aminopenicillins	51	0	1	52	98.1 %	0.0 %	1.9 %
Malta	2011	Aminopenicillins	39	0	0	39	100.0 %	0.0 %	0.0 %
Netherlands	2011	Aminopenicillins	568	0	7	575	98.8 %	0.0 %	1.2 %
Norway	2011	Aminopenicillins	411	0	0	411	100.0 %	0.0 %	0.0 %
Poland	2011	Aminopenicillins	231	2	1	234	98.7 %	0.9 %	0.4 %
Portugal	2011	Aminopenicillins	335	0	107	442	75.8 %	0.0 %	24.2 %
Romania	2011	Aminopenicillins	8	0	1	9	88.9 %	0.0 %	11.1 %
Slovakia	2011	Aminopenicillins	196	0	4	200	98.0 %	0.0 %	2.0 %
Slovenia	2011	Aminopenicillins	125	0	0	125	100.0 %	0.0 %	0.0 %
Spain	2011	Aminopenicillins	920	0	6	926	99.4 %	0.0 %	0.6 %
Sweden	2011	Aminopenicillins	412	5	0	417	98.8 %	1.2 %	0.0 %
United Kingdom	2011	Aminopenicillins	379	0	15	394	96.2 %	0.0 %	3.8 %

Proportion of Aminopenicillins Resistant (R+I) *Enterococcus faecalis* Isolates in Participating Countries in 2011





Source: ECDC 2010[141]

European Surveillance of Antimicrobial Consumption Network

ESAC-Net was initiated in 2001 as an international network of surveillance systems to collect comparable and reliable data on antimicrobial use in Europe to accompany analogous AMR surveillance programs.

Coordinated by ECDC since 2007, ESAC-Net now collects reference data on the consumption of antimicrobials for systemic use in the European community and hospital sector. Former ESAC subprojects, involving data collection on antimicrobial use in hospitals and in long-term care facilities, are now continued as ECDC-coordinated and/or funded projects within the Healthcare-Associated Infections Surveillance Network (HAI-Net). Specifically, patient-level antimicrobial use prevalence data are provided through a European-wide point survey of healthcare-associated infections (HAIs) and antimicrobial use in acute-care hospitals, and data on the prevalence of antimicrobial use in residents at long-term care facilities is collected by the HALT-2 project.

Data collection and processing

Data sources are national sales and reimbursement data, including information from national drug registers. The WHO Anatomical Therapeutic Chemical (ATC) classification system is used for the allocation of antimicrobials into groups. Data are collected nationally and subnationally based on the Nomenclature of Territorial Units for Statistics (NUTS) classification. Data on antimicrobial consumption is collected at the product level on the following antimicrobials:

- antibacterials for systemic use (ATC group J01)
- antimycotics for systemic use (ATC group J02)
- antimycobacterials (ATC group J04)
- antivirals for systemic use (ATC group J05).

In addition, a few other antimicrobials outside of ATC group J are collected to complete the picture of antimicrobial consumption in Europe.

Antimicrobial consumption in Europe is monitored by a network of national surveillance networks in the EU, and European Economic Area and European Free Trade Association countries through annual data calls. Data are uploaded from these national networks to a central database (TESSy). After uploading, each country approves its own data for reporting, and the results are made available on the ECDC website.

Antimicrobial consumption is expressed as the number of WHO defined daily doses (DDD) per 1000 inhabitants per day. The number of packages per 1000 inhabitants per day is also reported, depending on the availability of data. Information on packages improves the understanding and interpretation of differences in the levels and trends in antimicrobial consumption observed between and within countries, as the ATC/DDD data cannot take into account changes in package content. Denominator (population) data are obtained from Eurostat or national statistics reports. When consumption data do not reflect the whole population, contributing countries will provide data on the population covered by antimicrobial consumption surveillance data. The total outpatient antibiotic use in 33 European countries in 2009 is presented in Figure 8.

Data publication

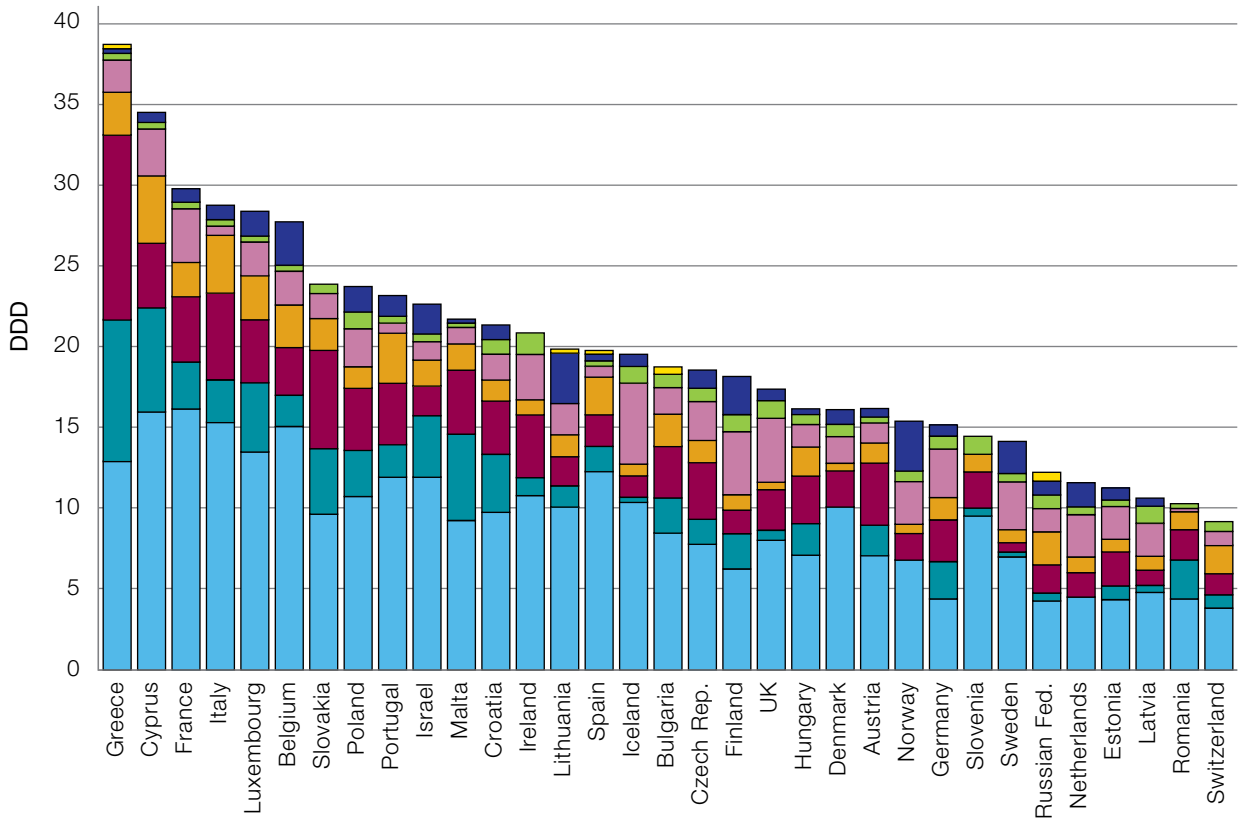
The ECDC maintains and facilitates its data reporting by ensuring:

- validation of community and hospital-sector data, including data from the national drug registers derived from national surveillance networks
- analysis of the trends in antimicrobial consumption overall and in the different ATC groups, as well as comparisons between countries and regions
- public access to information on antimicrobial consumption in Europe through an ESAC-Net interactive database.

Program impact

ESAC-Net data enable countries to audit their antibiotic use by creating and maintaining a comprehensible, comparable and reliable reference database. ESAC data have been shown to be a valuable resource not only for ecological studies on the relationship between antibiotic use and resistance, but also to evaluate adherence to guidelines and policies, and to assess the outcomes of national and regional interventions. Moreover, collating regional data in a meaningful way complements national consumption statistics. For example, subnational data collected for Ireland, Italy, Portugal, Sweden and the UK, using the three-level NUTS classification, found differing rates of penicillin use within Italy, a high-consuming country, with much higher volumes of total outpatient antibiotic (mainly penicillins) use in the south (e.g. 39.9 DDD in Campania and 34.9 DDD in Sicily) compared with the north (e.g. 16.1 DDD in Bolzano). Similar gradients have also been demonstrated in low-consumption countries such as Sweden.[145]

Figure 8: Total outpatient antibiotic use in 33 European countries in 2009 in defined daily doses (DDDs)



UK = United Kingdom

Notes: 2004 data for Switzerland; in Cyprus and Lithuania, total care data

Legend is according to the World Health Organization Anatomical Therapeutic Chemical classes

Relevance to Australia

During consultation, key Australian AMR stakeholders identified that the strengths of the ECDC program comprise a comprehensive, coordinated and publicly funded AMR surveillance and antibiotic consumption program that operates across many international jurisdictions. The majority of respondents felt that limiting AMR surveillance to seven clinically important organisms and samples (e.g. from blood cultures and cerebrospinal fluid) was an asset, while others felt that restricting the scope of pathogens was a limitation. Stakeholders acknowledged that the availability of data at supranational, national or state/provincial levels allowed more targeted and timely identification of emerging issues. Data capture (including denominator data on laboratory/hospital activity and patient characteristics), within both hospital and community settings, was highly regarded by respondents. Stakeholders also noted the program could quantify improvement or maintenance of resistance rates for certain organisms (including Gram-negative organisms). Program strengths also included the availability of external quality assurance support for contributing laboratories, and accessibility of reports to hospitals and the public. The exclusion of animal, food or environmental data was proposed as a program limitation.

3.2.2 Asian Network for Surveillance of Resistant Pathogens

The Asian Network for Surveillance of Resistant Pathogens (ANSORP) is an independent, not-for-profit, nongovernment international network for collaborative research on antimicrobial agents and infectious diseases in the Asia–Pacific region. It is supported by the Asia–Pacific Foundation for Infectious Diseases.[146] ANSORP began in 1996 in Seoul, South Korea; the first project was the surveillance of pneumococcal resistance in Asia. Growth in the number of participating investigators, centres and geographical areas from 1996 to 2010 is illustrated in Figure 9.

Data collection and processing

Participating hospitals forward isolates to a limited number of reference laboratories, where laboratory testing is performed using standard protocols. In a range of peer-reviewed articles reviewed from 2004 through to 2012, all isolates were referred to the Samsung Medical Centre, Seoul, South Korea.[24, 148, 149] In one case from 2012, Chinese hospitals referred isolates to reference laboratories at the Beijing Union Medical College Hospital and Beijing Children's Hospital,[150] while hospitals from outside China referred isolates to Seoul. No specific discussion is included on how data are collected and processed within the ANSORP network. The work of ANSORP is based on a series of defined research projects, and it has grown through five phases as described in Table 7.

Data publication

Publication in peer-reviewed journals, conference posters and conference presentations appear to be the prime methods for releasing research outcomes. Articles appear primarily in microbiology, infectious diseases and chemotherapy journal titles. No evidence of annual reports or other regular or routine methods by which ANSORP distributes findings has been identified. The ANSORP website[151] contains a list of 134 papers that are mainly based on ANSORP studies. The papers fall under the themed groupings illustrated in Figure 10. The strong focus on clinical issues associated with AMR is notable, and this theme forms the largest single group, with 40 papers published.

Program impact

All five ANSORP project phases have either focused on, or included surveillance of, *S. pneumoniae*; hence, a significant proportion of the program output relates to AMR in pneumococcus. Phases that are more recent have included *S. aureus*, enteric organisms and a broader review of hospital-acquired and ventilator-associated pneumonia.

A range of earlier papers describe genetic mutations that covey AMR, and the different resistance patterns that arise from small variations in genetic coding.[152] Other studies describe the change in resistance patterns over time and variance among Asian countries.[153]

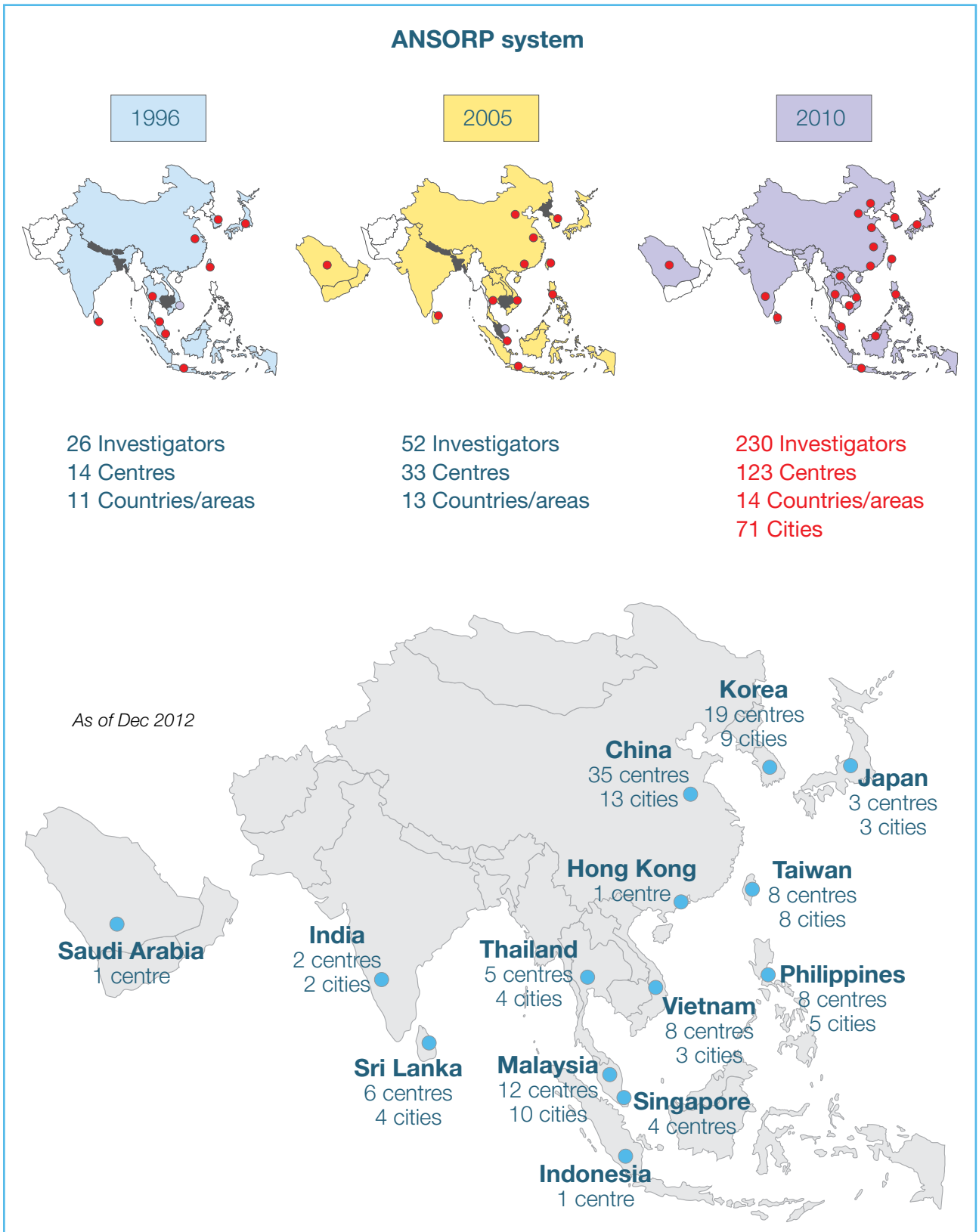
Some recently published ANSORP studies explore the change in *S. pneumoniae* serotypes observed across Asia following the introduction of the 7-valent pneumococcal conjugate vaccine (PCV7). There are at least 93 different capsular serotypes with different propensities to develop AMR and cause disease, and relationships between pneumococcal serotypes and differences in AMR are reviewed. One paper describes an increase in the prevalence of serotypes not covered by PCV7, including a serotype (19A) with high levels of macrolide resistance.[154] This shows that the change in AMR profiles being observed is influenced by vaccination programs as well as the use of antimicrobials, and highlights the need to evaluate the application of vaccination programs as well as antibiotic use in this context.

A range of earlier papers describe outcomes of research identifying genetic mutations that convey AMR, and the different resistance patterns that arise from small variations in genetic coding.[152] Other studies describe the change in resistance patterns over time and variance between Asian countries.[153]

Recent ANSORP papers about *S. aureus* include:

- AMR topics, such as the first report of vancomycin-intermediate resistance in sequence type 72 community-genotype MRSA[155]
- clinical conditions, including 300 community-associated MRSA cases in Korea[156]
- links between community-acquired and hospital-acquired MRSA[155]
- clinical outcomes – for example, clinical features and outcome of *S. aureus* infection in elderly versus young-adult patients[157]
- examination of characteristics and relationships of *S. aureus* isolates from humans, raw meat and soil.[158]

Figure 9: The Asian Network for Surveillance of Resistant Pathogens (ANSORP), 1996–2012



Source: Asia Pacific Foundation for Infectious Diseases[147]

Other recent publications relate to AMR, genetics, clinical outcomes and epidemiology for enterococci and a range of other Gram-negative bacteria. In total, ANSORP projects contribute to greater understanding of AMR and approaches to managing AMR more effectively.

Relevance to Australia

Australian AMR stakeholders noted that the strengths of the ANSORP program lie in it being an independent, collaborative and not-for-profit surveillance program. Program strengths included having contributors from multiple geographically linked countries or regions, and laboratory testing in reference laboratories using standard protocols. Respondents also highlighted its focus on addressing

Table 7: Asian Network for Surveillance of Resistant Pathogens (ANSORP) research projects

Phase	Year	Research project
1	1996–97	The first organised surveillance study of the prevalence of drug-resistant *Streptococcus pneumoniae* in the Asian region. A total of 996 isolates of *S. pneumoniae* collected consecutively from clinical specimens in 14 centres in 11 Asian countries were tested. Data revealed that pneumococcal resistance is a serious problem in some Asian cities.
2	1998–99	Surveillance of the nasopharyngeal carriage of drug-resistant pneumococci in Asian children. As pneumococcal disease follows nasopharyngeal carriage, previous studies showed that the antimicrobial susceptibility profile of nasopharyngeal strains reflects that of invasive strains.
3	2000–01	Assessment of the clinical impact of AMR among invasive pneumococcal pathogens in Asian countries. The study was performed in 25 centres in 13 countries in Asia and the Middle East.
4	2002–05	Four projects were undertaken: • Epidemiology and clinical characteristics of community-acquired pneumonia in Asian countries (2001–03). • Molecular characterisation of macrolide-resistant or fluoroquinolone-resistant *S. pneumoniae* from Asian countries (2002) to characterise the prevalence of macrolide resistance genes (*erm* and *mef*) and fluoroquinolone resistance genes (*gyrA*, *gyrB*, *parC*, and *parE*) among Asian pneumococcal strains. • Surveillance of AMR among enteric pathogens from Asian countries (2002–03) to investigate AMR among *Salmonella* and *Shigella* strains. • Epidemiology and clinical impact of community-acquired MRSA in Asian countries (2005–present) to investigate the emergence of these strains in the Asian region.
5	2006–present	Three projects are currently under way: • Community-acquired methicillin-resistant *Staphylococcus aureus*. • A prospective multinational surveillance of hospital-acquired pneumonia and ventilator-acquired pneumonia in adults in Asian countries, and the aetiology, clinical outcome and impact of AMR. • Prospective, hospital-based, multinational surveillance on AMR and serotypes of *S. pneumoniae* and disease burden of pneumococcal infections in Asian countries in the era of pneumococcal conjugate vaccines.

AMR = antimicrobial resistance

Source: Asia Pacific Foundation for Infectious Diseases[147]

key clinical issues or problems, and dissemination of findings in peer-reviewed publications. The limited number of organisms reviewed was considered a limitation of the program. Other perceived limitations included that data may not be broadly representative (voluntary not mandatory contribution) and the absence of antimicrobial consumption monitoring.

3.2.3 The Surveillance Network

The Surveillance Network (TSN) is a commercially operated system that collects AMR test results on a daily basis from clinical laboratories across the US. More than 300 geographically dispersed laboratories from all nine US Census Bureau Regions contribute data[17] that cover both community and hospital sources, and a range of hospital sizes and patient populations. Historically, TSN has operated in a range of countries outside the US, including Canada, parts of Europe and Australia; however, recent literature refers primarily to operations in the US. Eurofins, the operator of TSN, promotes global participation on their website. The current US dataset is continuous from 1998 to the present day.

Between 1997 and 2004, 94 public- and 9 private-sector pathology laboratories in Australia submitted data to the TSN database in Virginia.

Data collection and processing

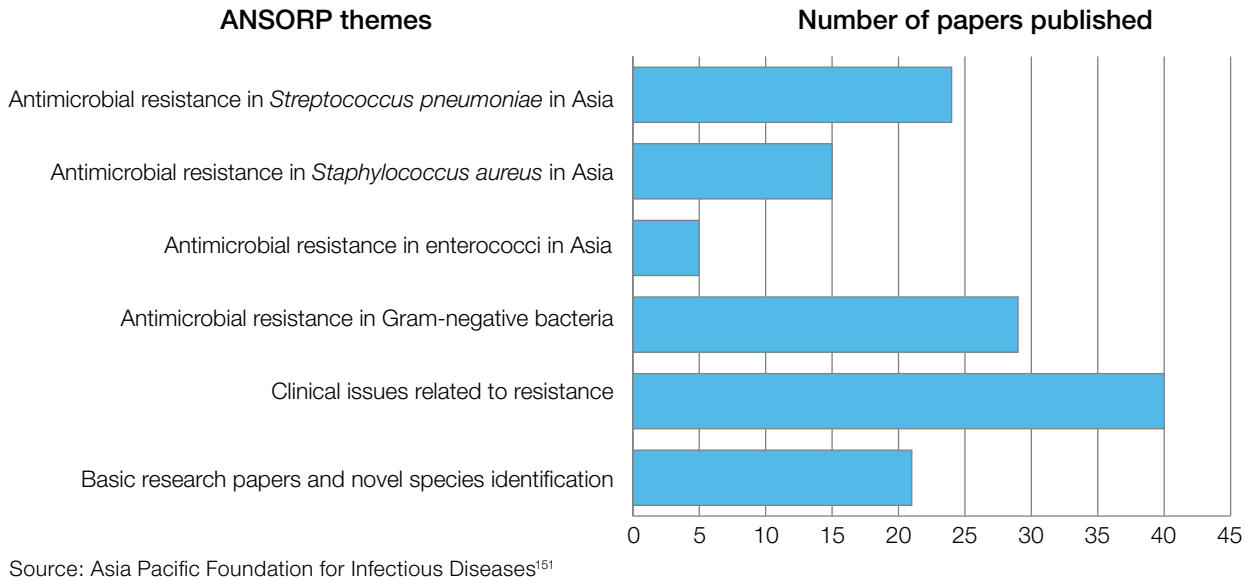
Participating laboratories submit data electronically to the central TSN database on a daily basis. Publications indicate that all participating laboratories adhere to the Clinical Laboratory Standards Institute (CLSI) standards for testing. TSN performs regular checks on data quality and consistency, and screens for duplication of isolate submissions.

Although participation is voluntary, laboratories that submit data are required to provide information for all clinical isolates. TSN indicate that all clinically encountered bacterial pathogens (covering 597 taxa) and 119 antimicrobial agents are represented in the database.[159] Participating sites vary from year to year; however, the annual change is no more than 10%. Data can be stratified according to inpatient/outpatient status, as well as by geographical location.

Data publication

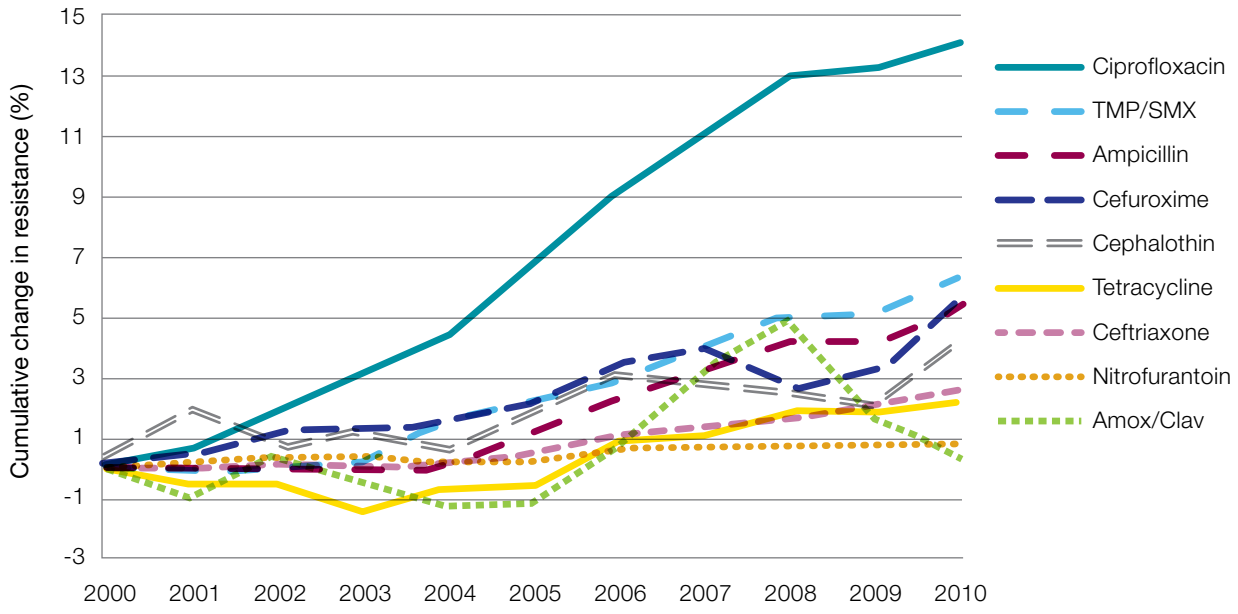
Eurofins' website lists 26 peer-reviewed journal articles and 68 posters since 2008 that have used TSN data.[160] Researchers at the Centers for Disease Control and Prevention (CDC), US Food and Drug Administration (FDA) and CLSI have drawn on TSN data for major scientific publications.[159] The TSN database has been used to produce more than 150 manuscripts, abstracts and posters since 1998.[159] Journals carrying these articles include those concerned primarily with chemotherapeutic agents, as well as general microbiology and infectious diseases publications, and some concerned with a clinical discipline such as ophthalmology. Examples of the presentation of TSN data in peer-reviewed publications include those shown in Figure 11 to Figure 15[161] and Table 8.[162]

Figure 10: Asian Network for Surveillance of Resistant Pathogens (ANSORP) themes and numbers of papers



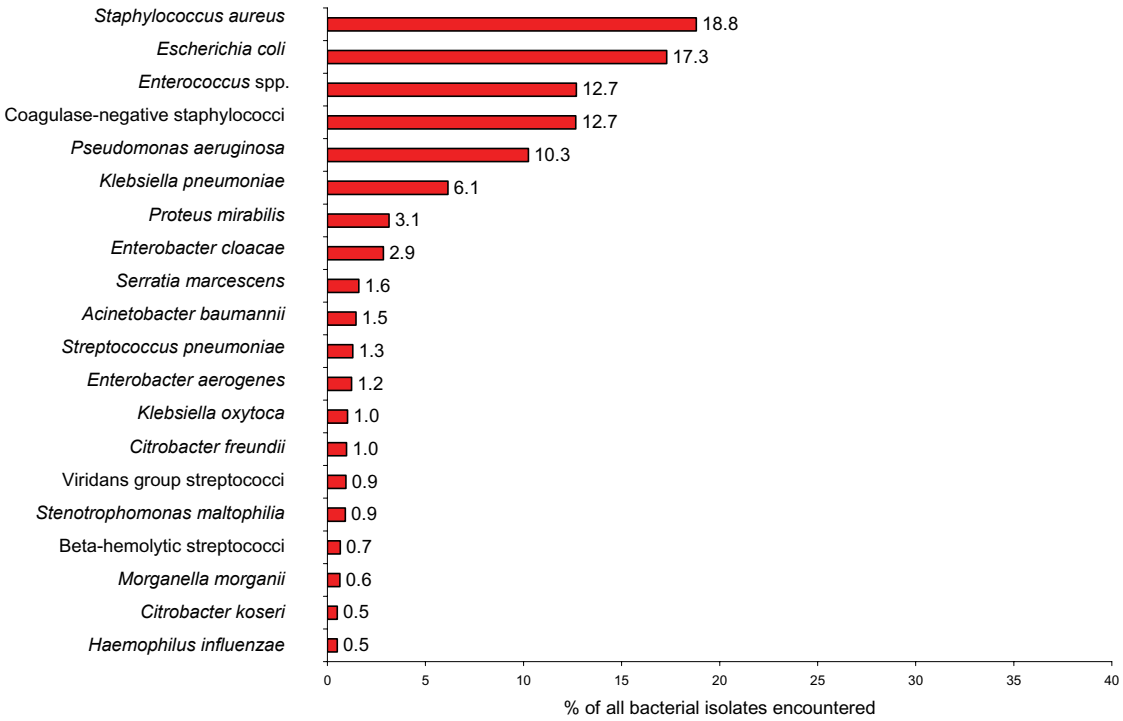
Source: Asia Pacific Foundation for Infectious Diseases[151]

Figure 11: Cumulative annual change in *Escherichia coli* antimicrobial resistance in US outpatient urinary isolates from 2001 to 2010



Source: Sanchez et al[161]

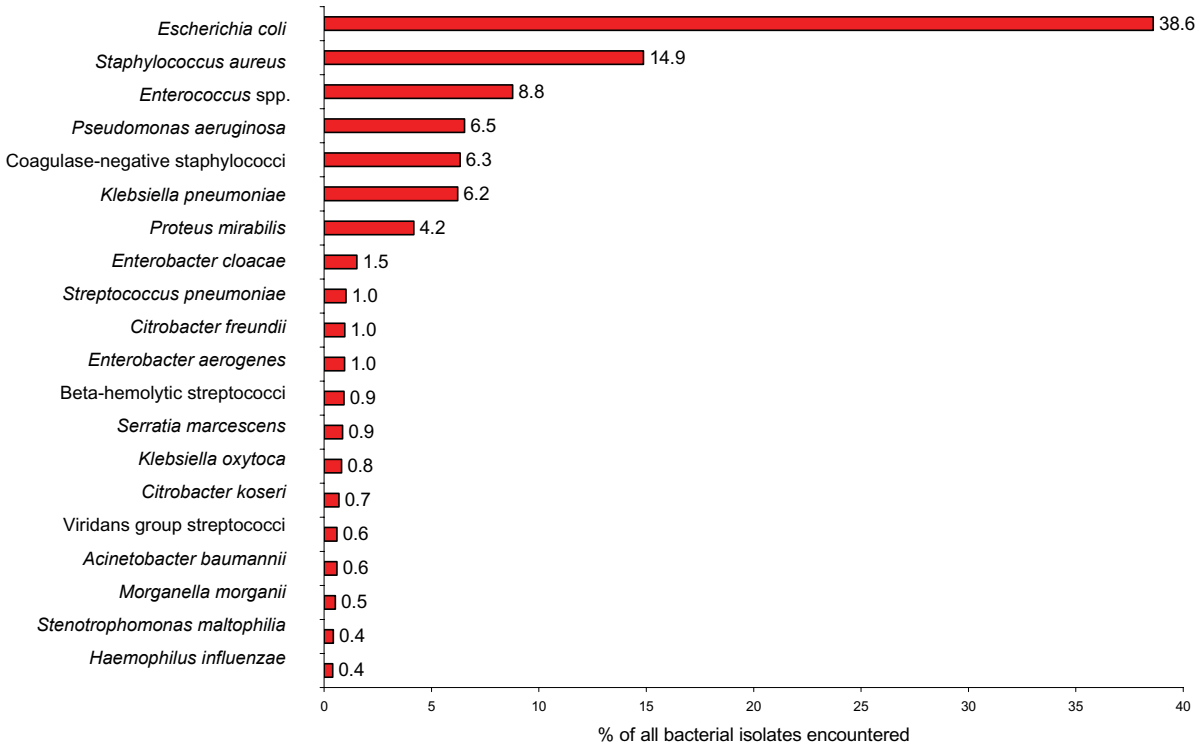
Figure 12: Relative frequency of bacterial species or groups encountered in clinical specimens from inpatients



Note: Data are cumulative from 1998 to March 2005, and are based on a total of 3 209 413 bacterial isolates.

Source: Sanchez et al[161]

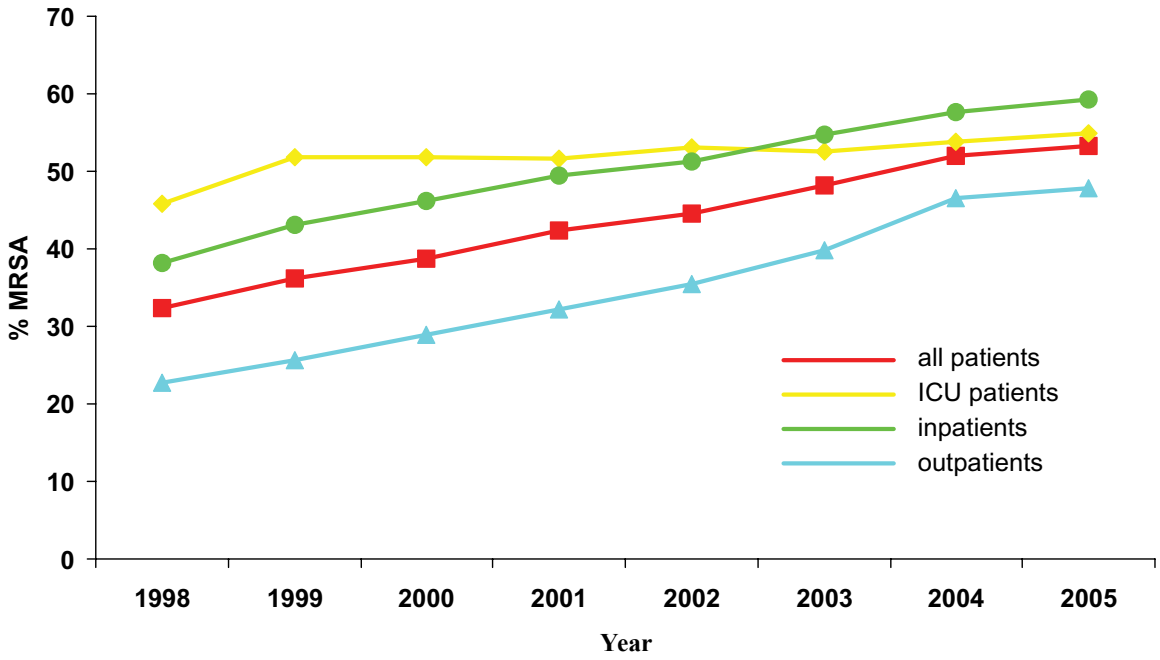
Figure 13: Relative frequency of bacterial species/groups encountered in clinical specimens from outpatients



Note: Data are cumulative from 1998 to March 2005, and are based on a total of 3 209 413 bacterial isolates.

Source: Sanchez et al[161]

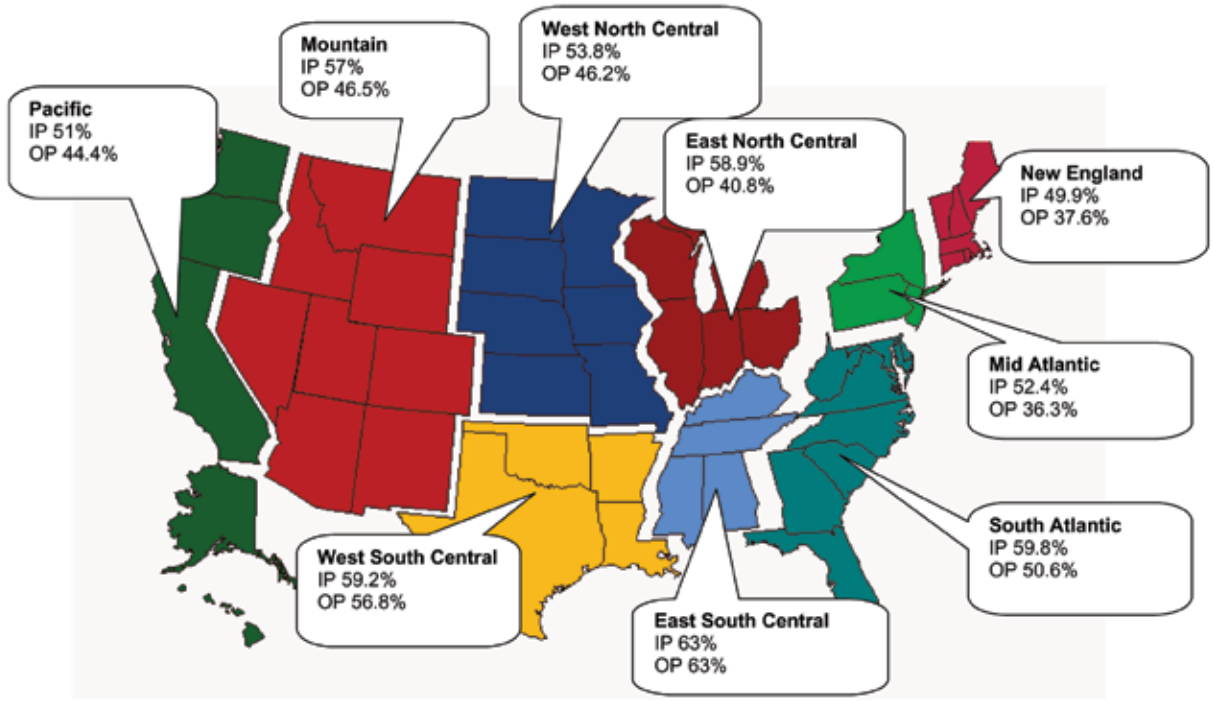
Figure 14: Methicillin-resistant *Staphylococcus aureus* (MRSA) trends according to patient location, 1998–2005



Notes: Data are cumulative from 1998 to March 2005. Red line, all patients; yellow line, intensive care unit (ICU) patients; green line, inpatients; blue line, outpatients.

Source: Sanchez et al[161]

Figure 15: Inpatient (IP) and outpatient (OP) methicillin-resistant *Staphylococcus aureus* prevalence, grouped by US Census Bureau Regions



Note: Data are cumulative from 1998 to March 2005.

Source: Sanchez et al[161]

TSN participants can extract reports for their institution and information can be grouped by:

- drug or class
- target organism
- sites of infection
- patient demographics (age, sex, patient location)
- time and geographic trends
- institution type
- test methodology.

Program impact

TSN's strengths include the large number of isolates captured, the variety of antimicrobials represented in the dataset, the large number and geographic dispersion of participating institutions, and the long time periods over which studies can be performed.[161] The nature of the program means that it can be used to elucidate changes in resistance patterns over time, as well as indicate current levels of AMR.

Studies published in 2012 that rely on TSN data have demonstrated:

- a temporal relationship between the level of antibiotic prescribing in the community and changes in AMR over a nine-year period, showing a seasonal rise and fall in antibiotic sales being followed by a matching rise and fall in resistance to some antimicrobials[17]
- an increase in resistance patterns for urinary *E. coli* isolates across the US over a 10-year period for some commonly used antimicrobials, while the patterns of resistance for other antibiotics have remained relatively unchanged.[161]

Such information guides policy and guideline development that cannot be achieved without datasets of this nature.

Given that TSN operates on a commercial basis, the data also answer questions about AMR development and the marketing potential of antimicrobial agents, in addition to contributing to the broad understanding and monitoring of AMR.[159] The goal of the former is to help researchers and drug manufacturers design and market new antimicrobials.

Table 8: Distribution of resistance phenotypes among US inpatient and outpatient methicillin-resistant *Staphylococcus aureus*, from 2002 to March 2005

		Inpatient		Outpatient	
Category	Resistance phenotype	n	(%)	n	(%)
Susceptible to all other agents	-	418	(4.1)	245	(5.7)
Single-drug resistant	Eryth	1409	(13.7)	1200	(27.8)
	Cipro	232	(2.2)	92	(2.1)
	Gent	8	(0.1)	3	(0.1)
	Clinda	4	(0.0)[c]	5	(0.1)
Double-drug resistant	Cipro, Eryth	1854	(18.0)	870	(20.2)
	Eryth, Clinda	114	(1.1)	104	(2.4)
	Cipro, Clinda	62	(0.6)	23	(0.5)
	Cipro, Gent	8	(0.1)	12	(0.3)
	Cipro, SXT	14	(0.1)	2	(0.0)[c]
	Eryth, SXT	2	(0.0)[c]	1	(0.0)[c]
	Eryth, Gent	10	(0.1)	1	(0.0)[c]
	Gent, SXT	2	(0.0)[c]	0	(0.0)
Multidrug-resistant	Cipro, Eryth, Clinda	4915	(47.6)	1417	(32.8)
	Cipro, Eryth, Gent	30	(0.3)	18	(0.4)
	Cipro, Eryth, SXT	23	(0.2)	7	(0.2)
	Cipro, Gent, SXT	18	(0.2)	10	(0.2)
	Eryth, Clinda, Gent	5	(0.0)	5	(0.1)
	Cipro, Clinda, Gent	6	(0.1)	3	(0.1)
	Eryth, Clinda, SXT	2	(0.0)[c]	1	(0.0)[c]
	Eryth, Gent, SXT	0	(0.0)	1	(0.0)[c]
	Cipro, Clinda, SXT	2	(0.0)[c]	0	(0.0)
	Cipro, Eryth, Lin	3	(0.0)[c]	0	(0.0)
	Cipro, Eryth, Clinda, Gent	858	(8.3)	214	(5.0)
	Cipro, Eryth, Clinda, SXT	58	(0.6)	14	(0.3)
	Cipro, Eryth, Gent, SXT	12	(0.1)	4	(0.1)
	Eryth, Clinda, Gent, SXT	2	(0.0)[c]	0	(0.0)
	Cipro, Clinda, Gent, SXT	2	(0.0)[c]	0	(0.0)
	Cipro, Eryth, Clinda, Gent, SXT	247	(2.4)	63	(1.5)
	Total n	10,320		4,315	

[a]Analysis included the following agents: gentamicin (Gent), erythromycin (Eryth), clindamycin (Clinda), trimethoprim-sulfamethoxazole (SXT), ciprofloxacin (Cipro), vancomycin (Vanc), and linezolid (Lin). Multi-drug resistance included resistance to three or more of the agents listed.
[b]Cumulative data 2002 – March 2005
[c]n < 0.1% of total

Source: Sanchez et al[161]

Relevance to Australia

Australian AMR stakeholders recognised TSN as a passive surveillance program that collects inpatient and outpatient data from a wide range of organisms and other relevant information. Stakeholders viewed the program as reputable, as evident in its use by CDC and FDA, and in the peer-reviewed literature. Acknowledged strengths of the program included daily submission of electronic data from contributing laboratory information systems (LISs), allowing trends to be detected quickly; the presentation of data in a format that captures multidrug resistance; and reporting flexibility. Respondents also valued the central coordination that facilitates routine quality assurance processes and performs screening for duplicates. Perceived limitations of TSN were that data may not be broadly representative (voluntary, not mandatory contribution) and that surveillance of antimicrobial consumption is not included. Furthermore, the commercial interests of TSN were noted, and data are hard to access (due to complex systems) and are not publicly available.

3.2.4 Danish Integrated Antimicrobial Resistance Monitoring and Research Programme

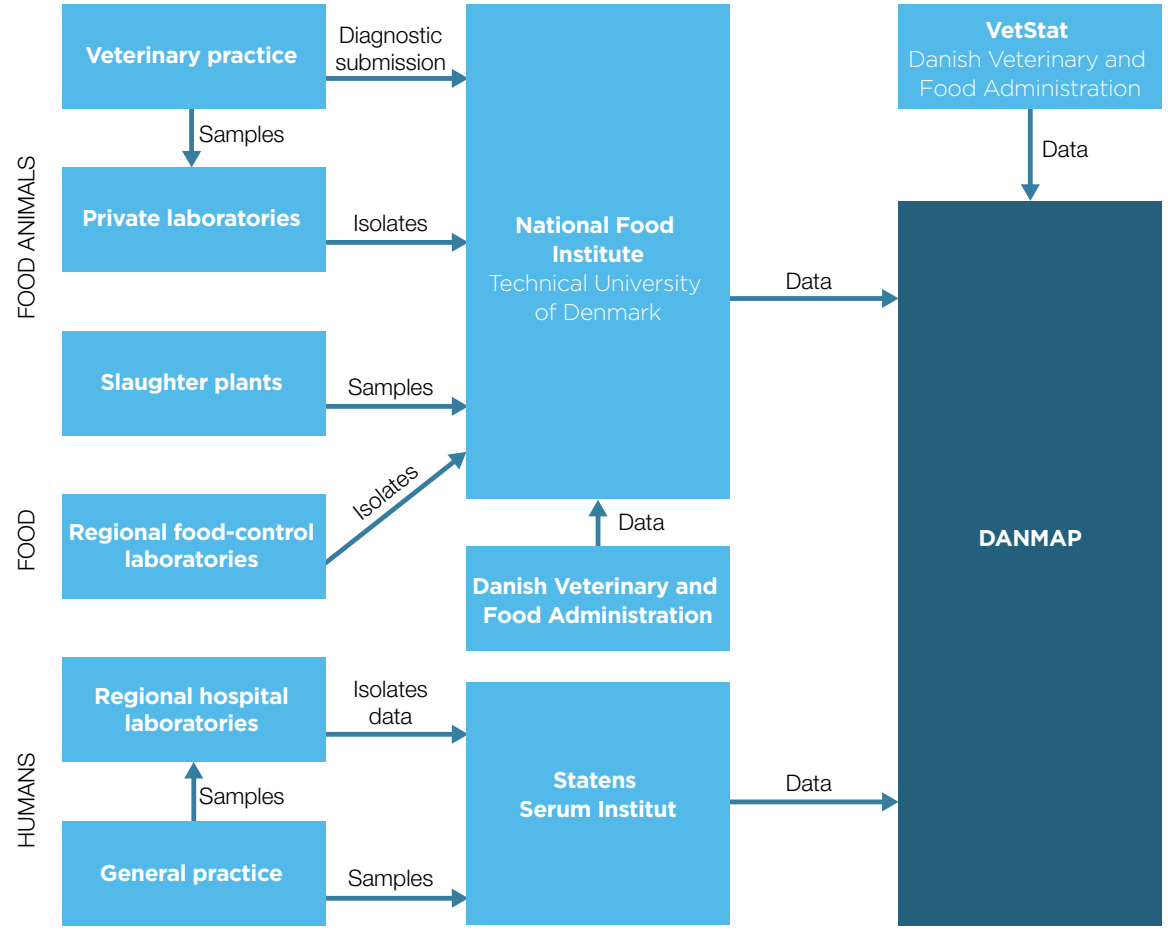
The Danish Integrated Antimicrobial Resistance Monitoring and Research Programme (DANMAP) was established in 1995 by the Danish Ministry of Food, Agriculture and Fisheries, and the Danish Ministry of Health. The first of its kind in the world, it provides surveillance of antimicrobial consumption and resistance in bacteria from animals, food and humans, 'covering the entire chain from farm to fork to sickbed'.[163] DANMAP's establishment was supported by concerns that the use of the growth-promoting antimicrobial avoparcin might be associated with the occurrence of VRE in humans, which came to light in 1994 and 1995.[58] DANMAP participants are:

- Statens Serum Institute
- Danish Veterinary and Food Administration
- Danish Medicines Agency
- National Veterinary Institute
- National Food Institute.

Figure 16: Danish Integrated Antimicrobial Resistance Monitoring and Research Programme (DANMAP) organisational structure

Organisation of DANMAP

DANMAP, the Danish Integrated Antimicrobial Resistance Monitoring and Research Progamme, collects data from a variety of sources and is part of cross-sector collaboration between scientists and authorities where risk assessment and risk management are separated.



Source: DANMAP[164]

The objectives of DANMAP are to:

- monitor the consumption of antimicrobial agents for food animals and humans
- monitor the occurrence of AMR in bacteria isolated from food animals, food of animal origin and humans
- study associations between antimicrobial consumption and AMR
- identify routes of transmission and areas for further research.

DANMAP has provided and analysed data on antimicrobial usage and the occurrence of AMR in bacteria, facilitating practice and legislative changes in Denmark, and more broadly in Europe. These changes have led to restrictions in the use of some antimicrobials and an associated reduction in AMR levels.[57]

Data collection and processing

Figure 16 illustrates the flow of data into DANMAP from all sources.

Data on AMR of bacteria isolated from human clinical samples are gathered by voluntary reporting from Danish departments of clinical microbiology.[164] Exceptions are MRSA and invasive *S. pneumoniae*, which are notifiable. For these organisms, data are obtained from the reference laboratory at the Statens Serum Institute.

Resistance data and discussion presented in annual reports include the following bacteria of human importance:

- *Enterococcus* spp.
- *Escherichia coli*
- *Klebsiella pneumoniae*
- *Pseudomonas aeruginosa*
- *Salmonella* spp.
- *Campylobacter* spp.
- *Yersinia enterocolitica*
- *Streptococcus* spp.
- *Staphylococcus aureus*
- coagulase-negative staphylococci.

Other relevant factors relating to the data include:

- all human data are from specimens submitted for clinical reasons
- no data are submitted from screening samples on healthy humans
- bacteria have been isolated from a range of specimen types, including urine, faeces, cerebrospinal fluid and blood
- laboratories use standardised methods of bacterial identification and antimicrobial testing
- data are extracted from a range of LISs from a number of LIS vendors
- only data for the first isolate each year for an individual patient or bacteria combination are included.

Scientists associated with DANMAP are exploring the potential to use bacterial genome data in AMR surveillance, and this may be incorporated into the program in future.

Data publication

Since 1997, data from the key areas of interest have been published in annual reports. The bacteria of human interest in which AMR is monitored and reported include the categories of ‘human pathogen’ and ‘indicator bacteria’. The latter category, which includes enterococci and *E. coli*, is included as these bacteria are widespread in both humans and the environment, and have the ability to readily develop and transfer resistance in response to the selective pressure exerted by antimicrobials.

Scientific data generated from DANMAP create the basis for action and cross-sector collaboration between scientists and authorities.

Program impact

Antimicrobial use in animal production continues to decline in Denmark, with a decrease between 2010 and 2011 of 15%. During the same period, total antimicrobial use in humans remained constant, with 90% of the consumption related to primary health care. A rise in use in primary health care during the period was balanced by a fall in hospital use.

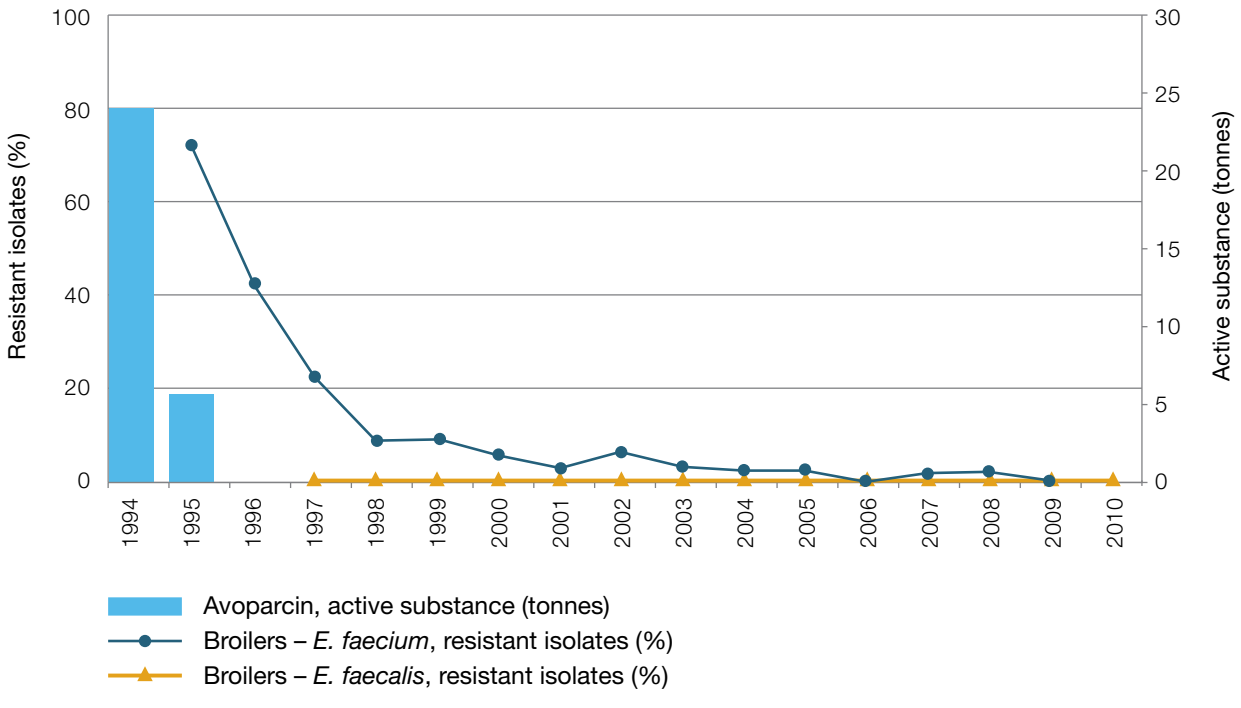
Avoparcin use was banned in 1995, which led to a succession of both legislative bans and voluntary cessation of the use of antibiotics as growth promoters in Danish food production industries. The use of antimicrobials in food production has been restricted to therapeutic use, by prescription only, since January 2000.[165] Evidence to support such initiatives and the consequential change in AMR profiles in humans can only be achieved with a comprehensive surveillance system. DANMAP has confirmed the association between the occurrence of resistance and the quantities of antimicrobials used.[58] Figure 17 shows the relationship between avoparcin use and the proportion of resistant isolates of *E. faecium* and *E. faecalis* in broiler chickens.[163]

The AMR program in Denmark has been able to demonstrate that the use of antibiotic growth promoters in food animals can be discontinued and the risk to human health reduced, without impacting animal health or the production economy.[31]

In the human setting, DANMAP demonstrated a 230% rise in the use of fluoroquinolone antibiotics in hospitals from 2001 to 2007, and mapped increasing resistance of *E. coli* to this group of antimicrobials in bloodstream infections. Increased resistance of *E. coli* isolates to ciprofloxacin and nalidixic acid, which belong to the fluoroquinolones group, has also been demonstrated in urine samples collected in primary health care. Figures 18 and 19 show an association between increased use of an antibiotic and increased resistance in E. coli.

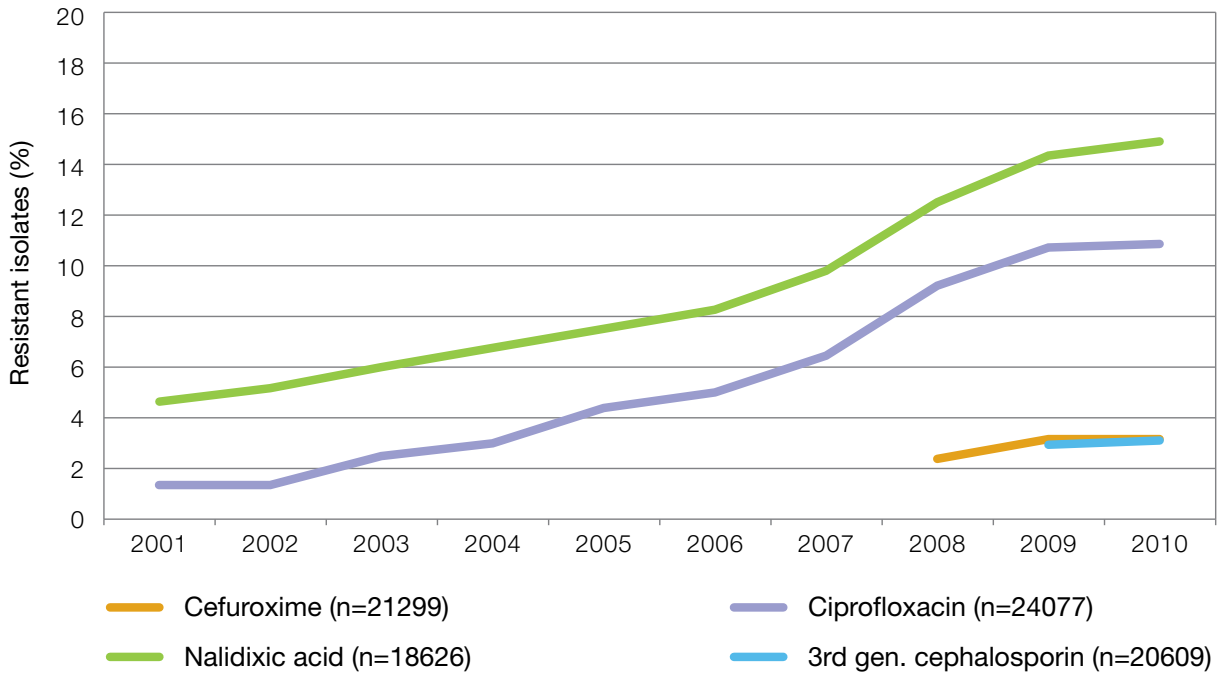
Such evidence underpins initiatives to bring about changes in clinical practice.

Figure 17: The relationship between the use of avoparcin and the proportion of resistant isolates of *Enterococcus faecium* and *Enterococcus faecalis* in broiler chickens, 1994–2010



Source: DANMAP[163]

Figure 18: Increasing resistance of *Escherichia coli* to fluroquinolones in primary care, 2001–10

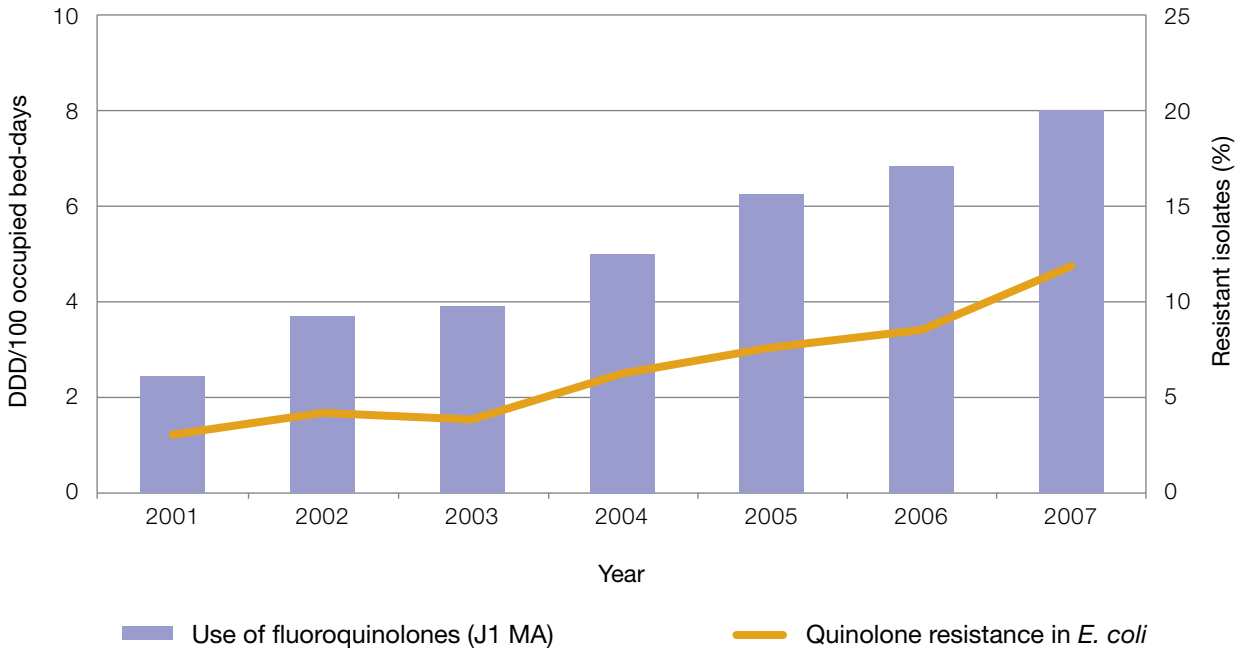


Increasing resistance of *E. coli* from urinary samples in primary care to fluroquinolones.

Note: Data are from urinary samples.

Source: DANMAP[163]

Figure 19: Fluoroquinolone use versus quinolone resistance in *Escherichia coli*, 2001–07



DDD is the defined daily dose, indicating the assumed average maintenance dose per day in adults.

Source: DANMAP[163]

Relevance to Australia

AMR stakeholders acknowledged DANMAP as a comprehensive and successful publicly funded model that includes both AMR surveillance and antibiotic consumption monitoring from human (hospital and community), animal and food sources. One quarter of respondents ranked DANMAP as an entirely suitable model for an Australian program. The ability to link and demonstrate associations between antimicrobial consumption with AMR was considered a strength of the program. The collection of isolates from a range of sources (i.e. urine, faeces, blood, cerebrospinal fluid) was considered an asset, and supported by use of standardised methods of identification and testing. The annual reporting of data and dissemination of data in peer-reviewed publications was also well regarded.

A perceived weakness of DANMAP was that only a limited number of organisms are included, and it may therefore not detect emerging resistance in other organisms. The lack of facility-level or state-level data on resistance or consumption of antimicrobials was also considered to be a limitation.

3.2.5 Swedish Strategic Program against Antibiotic Resistance

The Swedish Strategic Program against Antibiotic Resistance (STRAMA) was founded in 1995 as a result of discussions between the Swedish Reference Group for Antibiotics, the Medical Products Agency, the National Board of Health and Welfare, the Swedish Institute for Infectious Disease Control and others.[166] The detection of several multiresistant pneumococcal strains among young children in day-care centres in the early 1990s alarmed the medical profession and medical authorities, and provided impetus for developing STRAMA.[61] The overall aim of STRAMA is to preserve the effectiveness of antimicrobial agents.

STRAMA developed as a network of nodes based in 21 counties, coordinated by each county's department for communicable disease control. Overall coordination is provided at a national level by a national executive working group, which has responsibilities including identifying knowledge gaps, designing and initiating actions, arranging meetings and disseminating surveillance results. Health care in each county is organised into primary and secondary care, with tertiary care being provided at eight regional university hospitals.[60] Local STRAMA groups are funded by their local county in many instances, while the national STRAMA group is funded by the Swedish Government. The chair of the national group is appointed by the government and reports directly to the Ministry of Health and Social Affairs.

In 2000, STRAMA was involved in the preparation of an action plan to contain AMR, which was later developed into a Bill and was passed by the Swedish Parliament in 2006.[62] At that time, STRAMA was reorganised to become a collaborative body, working on interdisciplinary collaboration in issues related to safeguarding the effective use of antibiotics in human and veterinary bacterial infections, and to initiate measures that primarily affect human health. From 1 July 2010, STRAMA has had the role of advisory body to assist the Swedish Institute for Infectious Disease Control in:

- matters regarding antibiotic use and containment of AMR
- facilitating an interdisciplinary and locally approved working model, ensuring involvement by all relevant stakeholders including national and local authorities and not-for-profit organisations.

In STRAMA's early history, the main focus was on surveillance and actions related to community-acquired infections, with penicillin resistance in *S. pneumoniae* isolated in the community being the first target. More recently, activities have expanded and now include a greater number of healthcare situations, including hospital care, intensive care units, nursing homes, day-care centres and clinical trials. The range of microorganisms being monitored has also expanded.

The Swedish Communicable Diseases Act 2004 requires notifications of infections or colonisation with certain bacteria, which helps AMR surveillance. Four bacterial species are included in the Communicable Disease Act by virtue of their specific resistance mechanisms:[167]

- MRSA
- *S. pneumoniae* with reduced susceptibility or resistance to penicillin
- vancomycin-resistant *E. faecalis* and *E. faecium*)
- bacteria belonging to the family Enterobacteriaceae that carry one of three different kinds of extended-spectrum beta-lactamase (ESBL).

Data collection and processing

Most of the STRAMA data are based on voluntary reporting from routine investigations of clinical samples in approximately 30 microbiology laboratories.[60] Three-quarters of the laboratories also report data on invasive isolates to EARS-Net. Antimicrobial susceptibility testing methods have been standardised throughout the laboratories through collaborative processes, and all laboratories participate in external quality assurance programs to optimise the comparability of results.

Data publication

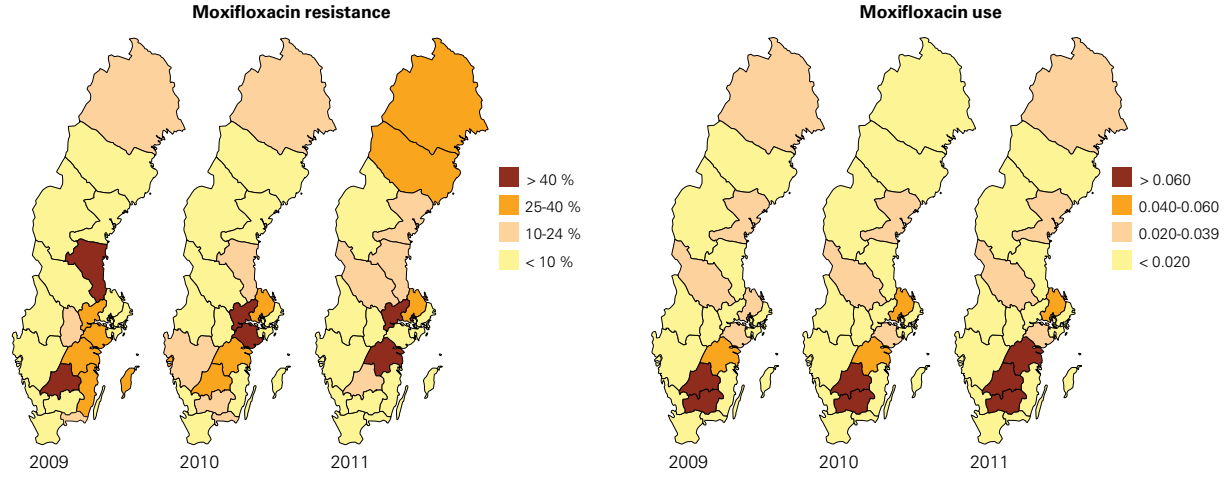
Data have been published each year since 2001 in *SwedReS – A Report on Swedish Antibiotic Utilisation and Resistance in Human Medicine*. The 2011 report[167] contains detailed information on the following:

- *Staphylococcus aureus* including MRSA
- *Streptococcus pneumoniae*
- *Enterococcus faecalis* and *Enterococcus faecium*
- ESBL Enterobacteriaceae
- *Escherichia coli*
- *Klebsiella pneumoniae*
- *Pseudomonas aeruginosa*
- *Acinetobacter* spp.
- *Haemophilus influenzae*
- *Streptococcus pyogenes*
- *Streptococcus agalactiae*
- *Clostridium difficile*
- *Helicobacter pylori*
- *Salmonella* and *Shigella* spp.
- *Campylobacter* spp.
- *Neisseria gonorrhoeae*
- *Neisseria meningitidis*
- *Mycobacterium tuberculosis*.

Report data are presented as maps, graphs and tables; see Figure 20 to Figure 23 for some examples.

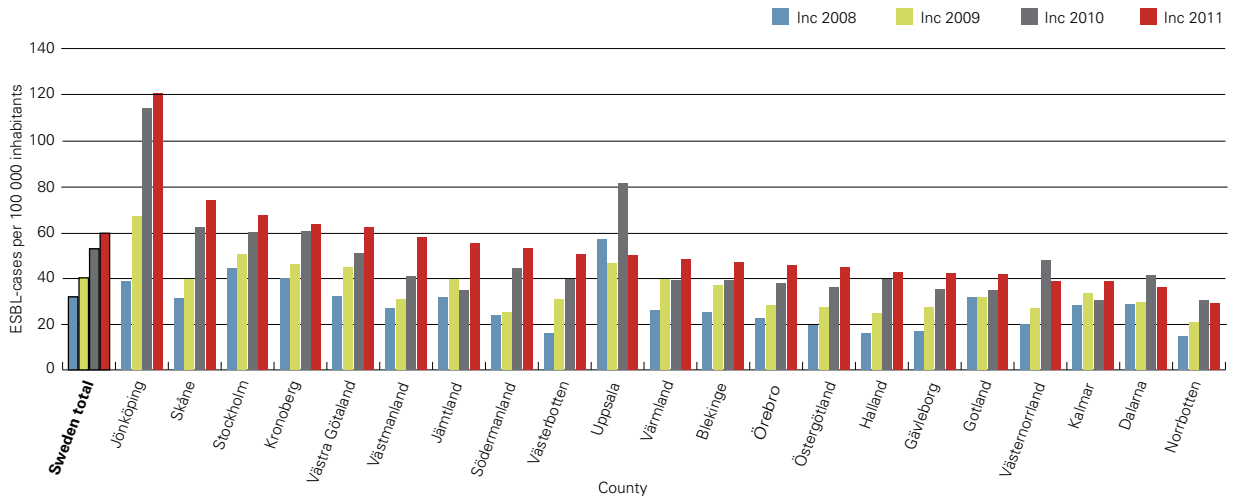
Some data are also made available from Smittskyddsinstitutet (SMI), a government agency with a mission to monitor the epidemiology of communicable diseases among Swedish citizens, and to promote control and prevention of these diseases. Much of SMI's information about AMR refers to the incidence per 100 000 population over time, rather than the levels of resistance being observed. Data are presented over time, and by county, age, sex, trends in reporting rates and county of infection. Figure 24 and Figure 25 illustrate data on penicillin-resistant pneumococcus infection.[168]

Figure 20: Proportion of *Clostridium difficile* isolates with resistance to moxifloxacin per county (2009–11) and sales of moxifloxacin in defined daily doses/1000 inhabitants



Source: Swedish Institute for Communicable Disease Control[167]

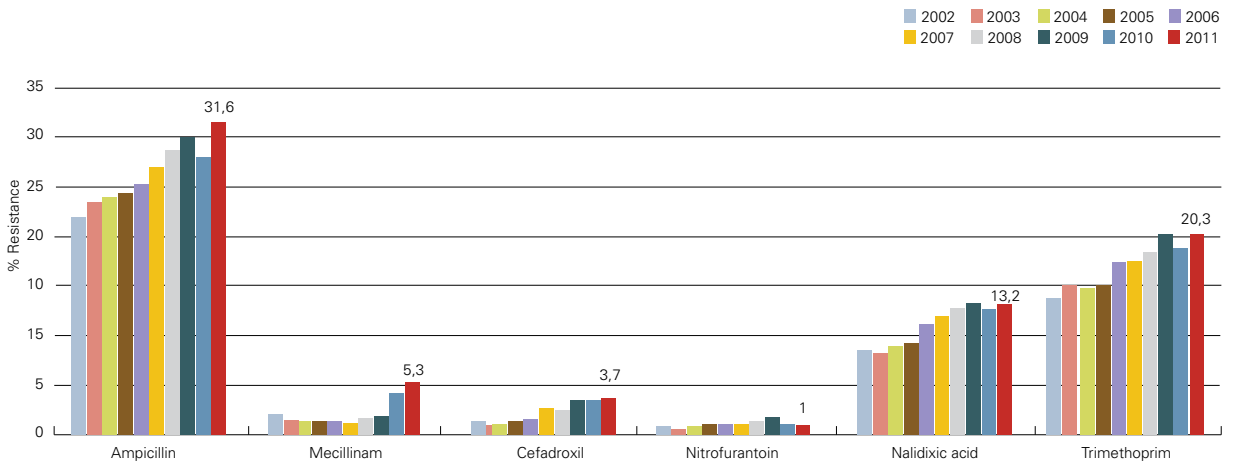
Figure 21: The incidence of extended-spectrum beta-lactamase (ESBL) in Swedish counties, 2008–11



inc. = incidence

Source: Swedish Institute for Communicable Disease Control[167]

Figure 22: Resistance rates for urinary tract infection antibiotics in *Escherichia coli*, 2002–11[167]



Note: Nalidixic acid was used as a screening disk for detection of resistance to fluoroquinolones.

Source: Swedish Institute for Communicable Disease Control[167]

Figure 23: Examples of tables showing data for *Klebsiella pneumoniae* and *Pseudomonas aeruginosa* isolates

TABLE 4.11. Resistance among invasive isolates of *Klebsiella pneumoniae* (number of isolates tested and percentage R). Data from Sweden 2006-2011, reported to ECDC/EARS-Net And retrieved from the EARS-Net database 2012-05-23.

Year	Cefotaxime-R (ESBL)	Amino-glycoside-R (%) *	Fluoro-quinolone-I/R (%) **	Total number of isolates
2006	1.5	0.3	8.5	610
2007	1.4	1.1	10.8	649
2008	2.3	1.1	12.9	826
2009	1.8	1.0	12.2	755
2010	2.3	2.0	8.5	908
2011	2.2	2.1	5.0	934

*gentamicin or tobramycin, ** ciprofloxacin

TABLE 4.12. Resistance among invasive isolates of *Pseudomonas aeruginosa* (number of isolates tested and percentage R). Data from Sweden 2006-2011, reported to ECDC/EARS-Net And retrieved from the EARS-Net database 2012-05-23.

Year	Ceftazidime-R (%)	Carba-penem-R (%) *	Amino-glycoside-R (%) **	Fluoro-quinolone-I/R (%) ***	Total number of isolates
2006	5.7	4.7	0.5	7.7	297
2007	4.5	7.1	0	10.4	335
2008	5.2	4.0	0	7.6	309
2009	6.9	7.7	0	10.1	326
2010	2.9	6.7	3	10.1	337
2011	5.2	7.2	1	7.0	402

* imipenem, meropenem, ** gentamicin, tobramycin, *** ciprofloxacin

Source: Swedish Institute for Communicable Disease Control[167]

Figure 24: Smittskyddsinstitutet data on penicillin-resistant pneumococcus infections, by county, age and sex

County | Age | Sex | Cases per week | Trend | Country of infection

Summary | 2013 | 2012 | 2011 | 2010 | 2009 | 2008 | 2007 | 2006 | 2005 | 2004 | 2003

County	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003
Blekinge	0/0	3/1.96	1/0.65	2/1.30	1/0.65	1/0.65	3/1.97	2/1.32	23/15.26	32/21.28	20/13.33
Dalarna	0/0	6/2.16	10/3.61	8/2.88	6/2.17	4/1.45	7/2.54	4/1.45	12/4.35	5/1.81	2/0.72
Gotland	0/0	1/1.74	4/6.97	2/3.49	8/13.98	6/10.52	18/31.50	11/19.19	18/31.31	27/46.82	39/67.69
Gävleborg	0/0	2/0.72	4/1.44	8/2.89	3/1.08	5/1.81	6/2.17	2/0.72	3/1.08	8/2.89	21/7.57
Halland	0/0	0/0	2/0.66	0/0	3/1.01	6/2.04	4/1.37	5/1.73	5/1.74	7/2.46	3/1.07
Jämtland	0/0	6/4.75	4/3.16	6/4.73	2/1.57	9/7.09	3/2.36	7/5.51	8/6.29	9/7.06	18/14.06
Jönköping	0/0	4/1.17	3/0.88	5/1.48	3/0.89	5/1.49	10/2.99	7/2.11	6/1.81	2/0.60	5/1.52
Kalmar	0/0	10/4.28	12/5.14	4/1.71	6/2.56	11/4.71	8/3.42	6/2.56	21/8.97	4/1.70	10/4.25
Kronoberg	0/0	7/3.76	7/3.79	7/3.80	9/4.91	5/2.74	14/7.75	5/2.78	9/5.04	1/0.56	7/3.94
Norrbotten	0/0	5/2.01	17/6.84	4/1.60	8/3.21	17/6.80	2/0.79	6/2.38	8/3.17	7/2.77	7/2.76
Skåne	1/0.07	35/2.77	58/4.63	108/8.69	135/10.98	216/17.80	195/16.28	197/16.63	224/19.15	246/21.19	156/13.57
Stockholm	2/0.09	87/4.09	100/4.78	171/8.34	144/7.14	184/9.30	287/14.74	235/12.25	219/11.58	201/10.73	162/8.72
Södermanland	1/0.36	5/1.82	11/4.04	7/2.58	22/8.19	13/4.86	17/6.42	9/3.42	8/3.05	10/3.83	8/3.07
Uppsala	0/0	10/2.92	7/2.06	8/2.38	9/2.71	7/2.14	8/2.47	5/1.56	10/3.28	6/1.98	7/2.33
Värmland	0/0	2/0.73	2/0.73	2/0.73	5/1.82	1/0.36	6/2.19	3/1.09	6/2.19	3/1.09	1/0.36
Västerbotten	0/0	2/0.76	9/3.46	12/4.62	10/3.87	11/4.26	14/5.43	12/4.65	11/4.26	5/1.94	15/5.86
Västernorrland	0/0	3/1.23	8/3.30	10/4.11	7/2.87	4/1.64	3/1.23	5/2.04	6/2.46	11/4.50	9/3.68
Västmanland	0/0	10/3.90	6/2.36	5/1.98	2/0.79	4/1.60	2/0.80	2/0.80	8/3.06	1/0.38	4/1.54
Västra Götaland	1/0.06	27/1.68	26/1.63	29/1.83	36/2.29	31/1.99	37/2.39	35/2.27	55/3.59	37/2.43	38/2.51
Örebro	0/0	6/2.11	12/4.26	5/1.78	12/4.30	4/1.44	9/3.26	16/5.81	15/5.47	11/4.01	17/6.20
Östergötland	0/0	8/1.84	10/2.31	5/1.16	14/3.28	19/4.49	16/3.80	15/3.58	6/1.44	14/3.36	11/2.65
Total	5/0.05	239/2.50	313/3.30	408/4.33	445/4.76	563/6.08	669/7.29	589/6.46	681/7.52	647/7.17	560/6.24

Table explanation

The numbers in the table is presented as **Total number of cases** and Number of cases per 100.000 pop. and year. The statistics are updated yearly and are based on all cases, independent of the origin of the infection

County | Age | Sex | Cases per week | Trend | Country of infection

Age	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997
0 - 4	39.3 %	37.3 %	46.8 %	54.1 %	57.0 %	61.7 %	61.2 %	60.0 %	64.4 %	59.2 %	57.8 %	57.8 %	60.2 %	56.8 %	59.6 %	59.6 %
5 - 9	4.1 %	4.4 %	4.4 %	6.0 %	6.9 %	4.6 %	7.4 %	6.7 %	7.8 %	8.0 %	11.8 %	13.7 %	11.6 %	14.1 %	18.0 %	17.4 %
10 - 14	1.6 %	1.9 %	1.9 %	2.0 %	0.7 %	1.1 %	1.8 %	1.6 %	1.7 %	2.8 %	2.2 %	2.5 %	1.6 %	1.6 %	1.6 %	2.1 %
15 - 19	0.8 %	2.2 %	0.2 %	1.5 %	0.8 %	1.3 %	0.6 %	0.8 %	0.4 %	0.7 %	1.3 %	0.7 %	1.1 %	1.2 %	0.7 %	0.5 %
20 - 29	5.8 %	5.4 %	4.9 %	2.6 %	4.0 %	2.9 %	2.7 %	3.2 %	2.9 %	2.5 %	3.0 %	3.0 %	2.9 %	3.4 %	2.7 %	2.3 %
30 - 39	6.6 %	9.9 %	9.3 %	9.2 %	9.2 %	6.4 %	6.4 %	6.6 %	5.8 %	8.0 %	8.0 %	6.7 %	7.1 %	5.5 %	6.1 %	6.1 %
40 - 49	7.5 %	8.3 %	5.8 %	7.1 %	5.1 %	5.0 %	4.9 %	4.4 %	3.8 %	3.3 %	3.2 %	5.2 %	4.2 %	4.7 %	2.6 %	2.4 %
50 - 59	6.6 %	6.0 %	9.3 %	5.1 %	2.4 %	4.4 %	4.0 %	6.1 %	4.3 %	6.0 %	3.4 %	3.1 %	2.9 %	3.4 %	2.6 %	1.6 %
60 - 69	12.5 %	11.5 %	6.3 %	5.6 %	8.5 %	7.1 %	5.2 %	5.1 %	4.0 %	2.8 %	4.7 %	2.0 %	3.7 %	3.8 %	1.9 %	3.6 %
70 - 79	7.9 %	7.6 %	5.8 %	4.2 %	2.8 %	3.1 %	3.2 %	2.7 %	2.1 %	3.7 %	2.2 %	2.7 %	2.3 %	3.4 %	2.6 %	2.4 %
80+	6.6 %	5.1 %	4.9 %	2.0 %	2.1 %	1.7 %	2.0 %	2.3 %	2.3 %	2.5 %	1.9 %	2.0 %	2.0 %	1.5 %	1.3 %	1.4 %

Table explanation

The statistics are updated yearly and are based on all cases, independent of the origin of the infection

County | Age | Sex | Cases per week | Trend | Country of infection

Sex	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997
Man	51.4 %	49.5 %	54.9 %	52.1 %	52.3 %	52.0 %	48.5 %	48.6 %	49.3 %	52.3 %	53.5 %	50.8 %	52.9 %	53.5 %	54.5 %	54.5 %
Woman	48.5 %	50.4 %	45.0 %	47.6 %	47.6 %	47.9 %	51.2 %	50.8 %	49.9 %	47.3 %	45.3 %	48.8 %	46.4 %	45.7 %	44.4 %	43.8 %
Unknown	0.1 %	0.1 %	0.1 %	0.3 %	0.1 %	0.1 %	0.3 %	0.6 %	0.8 %	0.4 %	1.2 %	0.4 %	0.7 %	0.8 %	1.1 %	1.7 %

Table explanation

The statistics are updated yearly and are based on all cases, independent of the origin of the infection

Source: Smittskyddsinstitutet[168]

Figure 25: Smittskyddsinstitutet data on penicillin-resistant pneumococcus infections – trends over time and summary data for 2012

Year 2012

Totally 239 cases reported.

- 103 (43.0%) states Sweden as the country of infection
- 35 (15.0%) states that they were infected abroad
- 101 (42.0%) are missing information about country

The most frequent countries of infection is (presented in order and in Swedish):

- Kina - 9
- Irak - 3
- Thailand - 2
- Colombia - 2
- Etiopien - 2
- Syrien - 2
- Iran - 1
- Ryssland - 1
- Polen - 1
- Irland - 1
- Mongoliet - 1
- Indien - 1
- Spanien - 1
- Italien - 1
- Turkmenistan - 1

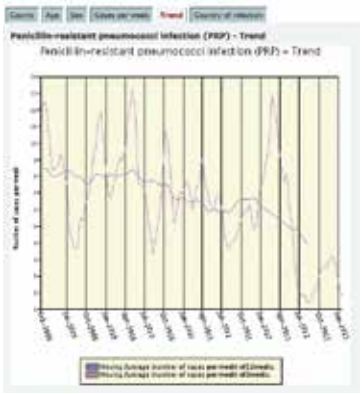
Year 2013

Totally 5 cases reported.

- 2 (40.0%) states Sweden as the country of infection
- 0 (0.0%) states that they were infected abroad
- 3 (60.0%) are missing information about country

The most frequent countries of infection is (presented in order and in Swedish):

No countries specified.



Source: Smittskyddsinstitutet[168]

Program impact

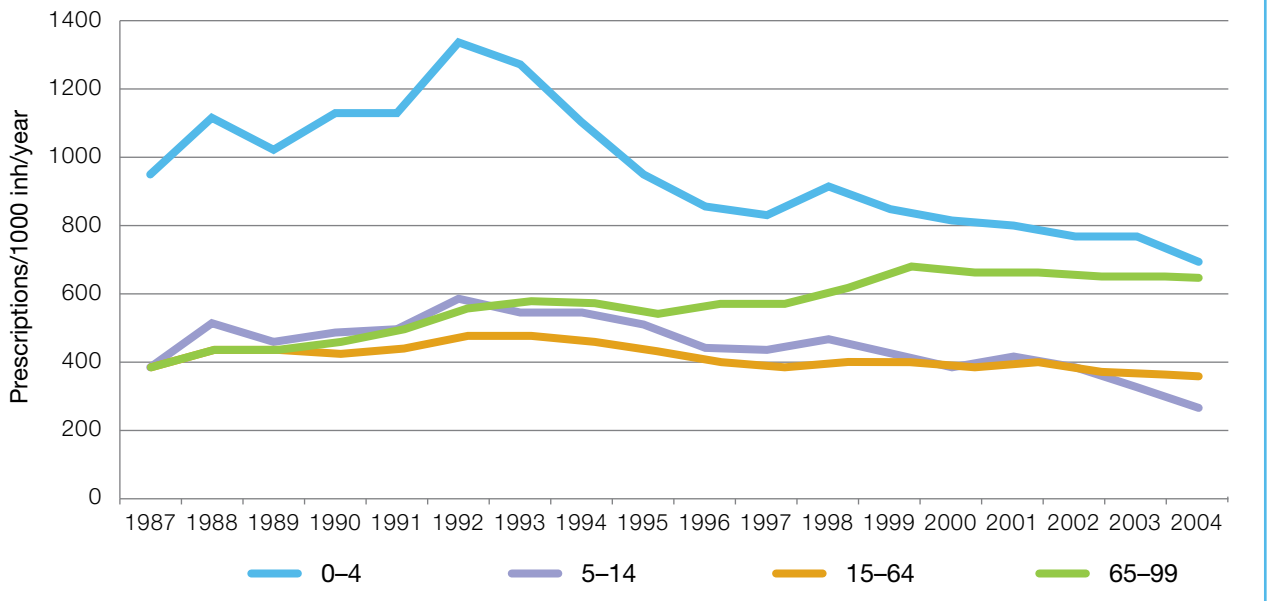
In 2008, STRAMA's activity between 1995 and 2004 was published, and listed several outcomes from that decade:[61]

- Antibiotic use for outpatients decreased by 20% from 157 to 126 defined daily doses per 1000 inhabitants per day.
- Antibiotic prescription presentation fell by 23%, from 536 to 410 per 1000 inhabitants per year (see Figure 26). In 2010, this figure had fallen even more, to 390 prescriptions per 1000 inhabitants per year.[27]
- There was a 52% reduction in antibiotic use in children aged 5–14 years.
- The antibiotic class showing the greatest decline in use were macrolides, for which consumption fell by 65%.
- The epidemic spread of penicillin-resistant *S. pneumoniae* in southern Sweden was curbed.
- The number of hospital admissions for acute mastoiditis, rhinosinusitis and quinsy (peritonsillar abscess) was stable or declining; this was assumed to mean that there was no underprescribing and no measurable negative consequences.

The changes noted above occurred despite a period of increasing antibiotic use in Sweden during the 1980s and early 1990s. Although the review notes that there is no scientifically validated control against which to measure these outcomes, during the same period (i.e. 1995–2004) in the neighbouring countries of Denmark, Norway and Finland, there was no reduction in antibiotic use. Authors credit the success of the program as being primarily due to:

- coordination of different professions and authorities
- the dissemination and implementation of guidelines through a decentralised organisation with regional groups
- the development of new knowledge.

Figure 26: Antibiotic use in number of prescriptions per 1000 inhabitants (inh) per year in Sweden, by age group, 1987–2004



Source: Colby[27]

In 2010, officers from ECDC visited Sweden to discuss that country's approach to dealing with AMR, and reported that overall antibiotic use in Sweden is below the EU average and has been stable for the previous decade, and there has been a shift from broad spectrum to more narrow spectrum antibiotic use.[28] AMR in zoonotic pathogens, and in indicator bacteria from food animals, was noted to be remarkably low. Several outbreaks of multidrug-resistant bacteria have been controlled due to rapid and effective interventions. Plans were under way to establish an integrated system, SVEBAR, which is designed to collate data from laboratory systems to allow early warning of emerging multidrug resistance.

SVEBAR is designed to gather all daily culture results from microbiology laboratories, and generates automatic alarms when adverse changes in the incidence of particularly widespread resistance are detected.[30] Seven laboratories were online by the end of 2011, with a further 10–12 to be linked during 2012. The goal is to have all Swedish clinical microbiology laboratories online by the end of 2013. The cost per laboratory of implementation is estimated to be €4000–8000 (AU$5000–10 000).[31]

The ECDC report notes a number of aspects of the Swedish program that contribute to its success:

- There are national guidelines for the treatment of common infections in the community.
- National guidelines are adapted by local drug and therapeutics committees and by local STRAMA groups for use by general practitioners (GPs).
- There is evidence of significant adherence to these guidelines by GPs.
- At a hospital level, infectious disease specialists and medical and surgical specialists agree to the guidelines. This level of communication and interaction contributes to a high level of adherence to local best practice guidelines.
- Educational programs on prudent antibiotic use have been developed at both national and local levels, and delivered to a range of healthcare settings and professionals.
- STRAMA provides educational feedback to primary-care physicians based on monitoring of antibiotic prescribing and use.
- There is good knowledge about antibiotics in the general population.
- STRAMA regularly addresses national media about AMR and prudent use of antibiotics.

The ECDC identified the following areas for further progress in Sweden:

- To improve clarity of coordination and give a strong signal that action on the prevention and control of AMR is cross-sectoral and multidisciplinary, a national cross-sectoral group should be established.
- A multiyear action plan, clearly identifying the tasks for each stakeholder body in the national group, should be developed and published.
- A reference laboratory structure for confirmation and typing of antibiotic-resistant bacteria should be developed.
- A clear framework for the structure and functions of infection control policy and implementation in hospitals should be put in place.
- The country should consider establishing a national surveillance system for monitoring HAIs.
- A national structure and process indicators for quality of infection control and antibiotic stewardship, including a national standard methodology, should be developed.

The ECDC team also recorded a number of elements exhibited by the Swedish approach that are instructive to other countries seeking to achieve best practice in the area:

- long-term commitment to AMR prevention and control
- organisation of AMR prevention and control by a national body
- good interaction between the national body and local stakeholders, bridging primary and secondary care
- a work culture of professional accountability and of reaching consensus among professionals about best practice
- high-level commitment to patient safety and transparency of patient care practices
- high-level awareness, involvement and commitment of all stakeholders about AMR and infection control
- seamless collaboration between different levels of health care
- high-level resources committed to the prevention and control of AMR, including staff and their qualifications, facilities and equipment.

Relevance to Australia

Consultation with key Australian AMR stakeholders on the applicability of the STRAMA program to inform an Australian framework identified a number of perceived strengths and weaknesses, which were similar to those suggested by ECDC. Strengths identified included:

- a level of coordination and collaboration between national groups and relevant stakeholders that is not currently seen in Australia
- the reach of the program into the primary health care sector and general practice
- standardised AMR testing with external quality control, and the daily capture of data
- the inclusion of education programs that support the overall aim of the program.

Australian stakeholders felt that the program fell short in regards to the voluntary nature of data contribution, and felt that a larger number of organisms should be reviewed.

3.2.6 Australian Group on Antimicrobial Resistance

The Australian Group on Antimicrobial Resistance (AGAR) is a collaboration of clinicians and scientists from major microbiology laboratories around Australia. Resistance surveillance started in 1985 when the program, involving 14 capital city teaching hospitals, was known as the Staphylococcus Awareness Program. There are now 30 institutions, including four private laboratories, that contribute data on the level of AMR in bacteria that cause clinically important and life-threatening infections across Australia.

AGAR participants have agreed to use standardised methodology for testing, and this allows comparison of AMR rates across the country for long periods of time, and in different geographical and healthcare settings. Surveys are conducted according to a schedule established by the AGAR Executive Committee. Some organisms are surveyed continually, while others are monitored every one, two or three years, or occasionally.[169] Organisms surveyed include the following from hospital and community sources:

- *Staphylococcus aureus* including MRSA
- *Streptococcus pneumoniae*
- *Enterococcus* spp.
- *Escherichia coli*
- *Klebsiella* spp.
- *Acinetobacter* spp.
- *Haemophilus influenzae*
- *Enterobacter* spp.

In addition to the surveys that focus on AMR and the epidemiology of resistant organisms, in 2011 AGAR started a program concentrating on the clinical consequence of bacteraemia associated with *Enterococcus* spp. The objectives of the Australian Enterococcal Sepsis Outcome Program (AESOP) are to monitor enterococcal bacteraemia through the prospective assessment of:[170]

- clinical impact, as measured by 7-day and 30-day mortality
- evolving AMR patterns, especially VRE
- the dominant clones, their distribution and evolution.

In addition to information about the bacterial isolates, this program collects data on patient demographics, risk factors and outcomes. To remain active members of the group, laboratories must participate in the annual staphylococcal surveillance and Gram-negative monitoring programs, and AESOP.[171]

Survey reports, which are publicly available online, demonstrate a change in resistance patterns over time and between participating institutions.

Data collection and processing

Participating laboratories use standardised procedures to optimise the comparability of results. Each laboratory is responsible for entering survey data manually via a webpage maintained by AGAR. In the case of AESOP, denominator data comprising 'occupied bed-days' is collected annually. Two rates are required:[170]

- total occupied bed-days, including emergency, renal, rehabilitation, mental health and so on, as provided by the hospital information system. This rate includes all single and multiday stays
- only multiday stays. This is defined as a patient who stays overnight or longer, and is used to calculate hospital-onset enterococcal sepsis rates.

Data publication

Survey reports, which are publicly available online, demonstrate a change in resistance patterns over time and between participating institutions. Reports contain significant amounts of information on methods and bacterial strains, as well as the interpretation and the significance of findings. Although reports indicate which institutions have contributed data, results are generally grouped by state and territory, with data from small jurisdictions often coalesced with a larger state to preserve anonymity. Where the results for individual institutions are given, a numerical code is used rather than the name of the laboratory. The level and type of detail in the published reports varies depending on the focus of the survey. Examples of some tables from the *Staphylococcus aureus 2011 Antimicrobial Susceptibility Report* are illustrated in Figure 27.

Other report types for *S. aureus* include the annual *MRSA Typing and Epidemiology Report*.[172] This report focuses on molecular typing of MRSA strains, and differentiates hospital-acquired and community-acquired isolates. Results are presented as graphs and maps.

Figure 28 provides extracts from the 2011 *MRSA Typing and Epidemiology Report*, depicting the change in proportions of healthcare-associated MRSA and community-associated MRSA from 2005 to 2011, and the number of different clonal types recovered from each state and territory in 2011.

Figure 27: Data from the Staphylococcus aureus *2011 Antimicrobial Susceptibility Report*

Table 5. Proportion of MRSA by institution

Region	Lab Code	% MRSA
NSW/ACT	1	15.0
	2	35.5
	3	23.6
	4	36.0
	5	41.0
	6	56.0
	7	50.0
	8	43.0
Qld/NT	10	51.0
	11	25.0
	12	25.0
	13	24.2
	28	29.5
	29	31.5
	30	23.0
SA	14	31.3
	15	24.0
	16	7.0
Vic/Tas	18	18.2
	19	42.0
	21	10.4
	22	34.2
	23	36.7
	31	37.0
	32	38.6
WA	24	22.1
	25	16.0
	26	25.0
	27	13.0
Aus		30.3

Table 3. Source of *S. aureus* isolates

Specimen Source	n	%	95%CI
Skin and Soft Tissue	1661	70.5	68.6-72.3
Respiratory	404	17.1	15.6-18.7
Blood	153	6.5	5.5-7.6
Urine	88	3.7	3.0-4.6
Sterile Body Cavity	49	2.1	1.5-2.7
CSF	2	0.1	0.01-0.3
Total	**2,357**	**100**	
Invasive	204	8.7	7.5-9.9
Non-Invasive	2,153	91.3	90.1-92.4

Table 6. Proportion of *S. aureus* that are MRSA by specimen type

	All isolates		
Source of Infection	n/N	%	95%CI
Skin and soft tissue	482/1661	29.0	26.8-31.3
Respiratory	136/404	33.7	29.1-38.5
Blood/CSF	46/155	29.7	22.6-37.5
Urine	32/88	36.4	26.4-46.7
Sterile Body Cavity	17/49	34.7	17-49.6

Table 7. Age by methicillin susceptibility of *S. aureus*

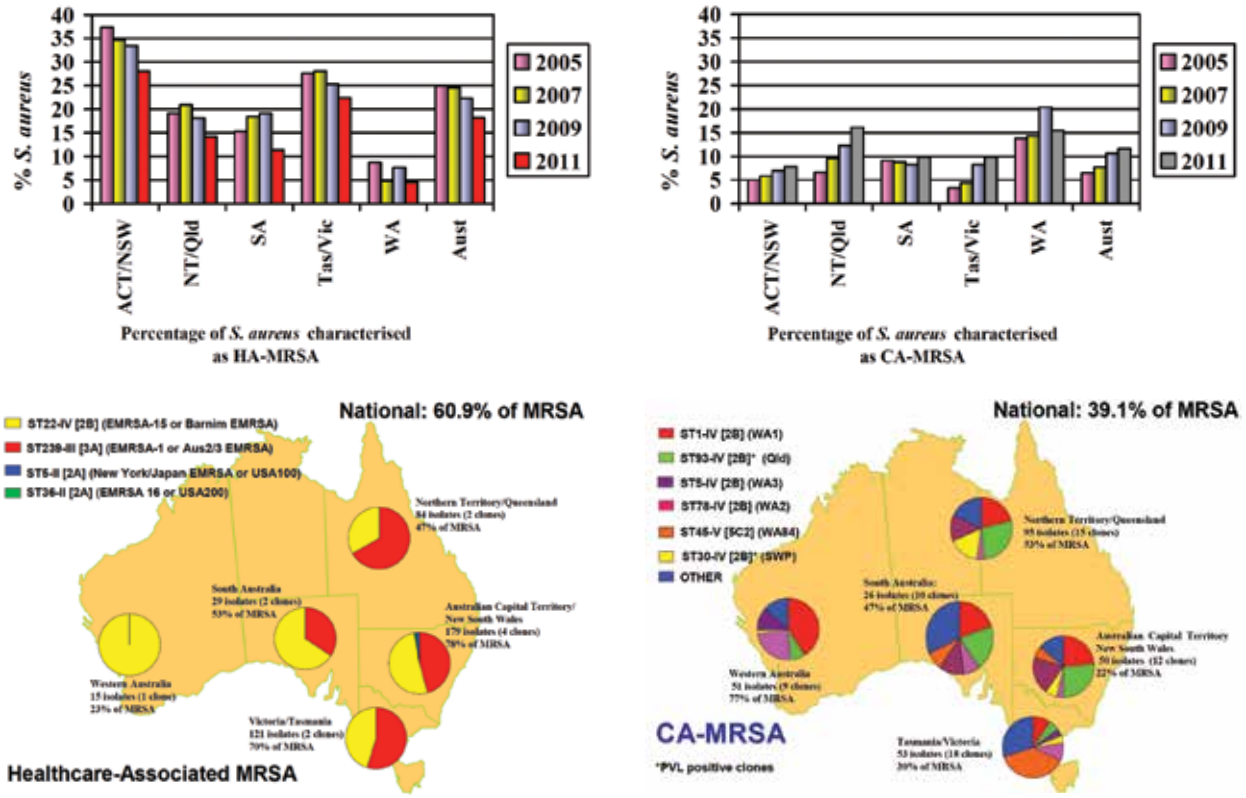
	MRSA			MSSA		
Age (y)	n	Row %	Column %	n	Row %	Column %
0-1	22	11.2	3.1	174	88.8	10.6
2-16	15	15.6	2.1	81	84.4	4.9
17-40	100	29.1	14.0	244	70.9	14.8
41-61	146	28.3	20.5	369	71.7	22.4
62-101	430	35.7	60.3	776	64.3	47.2
Total	713	30.3	100	1,644	69.7	100

Table 9. Proportion (%) of *S. aureus* that are MRSA, 2005 to 2011

	NSW/ACT	QLD/NT	SA	Vic/Tas	WA	Aus
2005	43.4	26.7	24.7	31.6	22.5	31.9
2007	41.3	31.0	27.2	33.3	19.0	32.9
2009	41.4	30.7	27.3	34.6	28.2	33.6
2011	36.8	30.5	21.7	32.7	19.9	30.3
P	**0.0172**	0.1627	0.5235	0.5108	0.8577	0.3856
X^2 for trend	5.673	1.949	0.4070	0.4325	0.03215	0.7527

ACT = Australian Capital Territory; Aus = Australia; MRSA = methicillin-resistant *Staphylococcus aureus*; MSSA = methicillin-sensitive *Staphylococcus aureus*; NSW = New South Wales; NT = Northern Territory; Qld = Queensland; SA = South Australia; Tas = Tasmania; WA = Western Australia; Vic = Victoria

Figure 28: Data from the 2011 *MRSA Typing and Epidemiology Report*



ACT = Australian Capital Territory; Aust = Australia; CA = community-acquired; HA = healthcare-acquired; MRSA = methicillin-resistant *Staphylococcus aureus*; NSW = New South Wales; NT = Northern Territory; Qld = Queensland; SA = South Australia; Tas = Tasmania; WA = Western Australia; Vic = Victoria

Survey reports for Gram-negative organisms, along with discussion and expert analysis, typically contain significant amounts of detailed information in tabular form, allowing readers to analyse, understand and interpret the findings. The focus of surveys now alternates annually between hospital-onset and community-onset infections by sentinel Gram-negative pathogenic bacteria. Some examples of findings from the *Gram-negative Bacteria 2011 Hospital-onset Susceptibility Report* are presented in Figure 29 and Figure 30.

Figure 29: Data from the *Gram-negative Bacteria 2011 Hospital-onset Susceptibility Report*

Table 2. Isolates Tested

Region	Number of Institutions	*E. coli*	*Enterobacter* species	*Klebsiella* species	Total
New South Wales (NSW) Australian Capital Territory (ACT)	8	538	71	145	754
Northern Territory (NT) Queensland (QLD)	7	467	69	139	675
South Australia (SA)	3	163	30	50	243
Victoria (VIC) Tasmania (TAS)	7	381	60	123	564
Western Australia (WA)	4	278	39	80	397
Total	**29**	**1,827**	**269**	**537**	**2,633**

Table 3. Species included

Group	Organism		Total
E. coli	*E. coli*		1,827
Klebsiella	*K. pneumoniae*		396
	K. oxytoca		137
	K. pneumoniae subsp ozaenae		3
	Klebsiella not speciated.		1
		Total	537
Enterobacter	*E. cloacae*		180
	E. aerogenes		83
	E. asburiae		3
	E. gergoviae		2
	Enterobacter not speciated.		1
		Total	269

Table 4. Antimicrobials Tested

Antimicrobial Agent	AST N149 Concentration range	CLSI Breakpoints (mg/L)[a]		
Ampicillin	≤2, 4, 8, 16, ≥32	≤8	16	≥32
Co-amoxyclav	≤2/1, 4/2, 8/4, 16/8, ≥32/16	≤8/4	16/8	≥32/16
Piperacillin/tazobactam[b]	≤4/4, 8/4, 16/4, 32/4, 64/4, ≥128/4	≤16/4	32/4-64/4	≥128/4
Ticarcillin/clavulanate	≤8/2, 16/2, 32/2, 64/2, ≥128/2	≤16/2	32/2-64/2	≥128/2
Cefazolin[c]	≤4, 8, 16, 32, ≥64	≤2	4	≥8
Cefepime	≤1, 2, 4, 8, 16, 32, ≥64	≤8	16	≥32
Ceftriaxone	≤1, 2, 4, 8, 16, 32, ≥64	≤1	2	≥4
Cefoxitin	≤4, 8, 16, 32, ≥64	≤8	16	≥32
Ceftazidime	≤1, 2, 4, 8, 16, 32, ≥64	≤4	8	≥16
Ertapenem[d]	≤0.002 to ≥32	≤0.5	1	≥2
Meropenem	≤0.25, 0.5, 1, 2, 4, 8, ≥16	≤1	2	≥4
Gentamicin	≤1, 2, 4, 8, ≥16	≤4	8	≥16
Tobramycin	≤1, 2, 4, 8, ≥16	≤4	8	≥16
Amikacin	≤2, 4, 8, 16, 32, ≥64	≤16	32	≥64
Ciprofloxacin	≤0.25, 0.5, 1, 2, ≥4	≤1	2	≥4
Norfloxacin	≤0.5, 1, 2, 4, 8, ≥16	≤4	8	≥16
Nitrofurantoin	≤16, 32, 64, 128, 256, ≥512	≤32	64	≥128
Nalidixic Acid	≤2, 4, 8, 16, ≥32	≤16	-	≥32
Trimethoprim/sulphamethoxazole	≤1/19, 2/38, 4/76, 8/152, ≥16/304	≤2/38	-	≥4/76
Trimethoprim	≤0.5, 1, 2, 4, 8, ≥16	≤8	-	≥16

[a] The breakpoints selected to determine resistance are described in Performance Standards for Antimicrobial Susceptibility Testing: Twentieth Information Supplement, CLSI document M100-S22, January 2012.
[b] Although included in the Vitek card, results were supressed due to a global recall by BioMérieux
[c] For analysis, breakpoints of ≤4, ≥8 were applied due to the MIC range available on the Vitek card, recognising that the January 2011 breakpoint is actually susceptible ≤ 2 mg/L
[d] Ertapenem MICs performed using Etest strips (BioMérieux).

Table 5. Source of Isolates

Source	*E. coli*		Enterobacter		Klebsiella		Total	
Urine	1448	79.3%	118	43.9%	317	59.0%	1883	71.5%
Respiratory	92	5.0%	66	24.5%	91	16.9%	249	9.5%
Blood	87	4.8%	22	8.2%	39	7.3%	148	5.6%
Skin & soft tissue	81	4.4%	26	9.7%	40	7.4%	147	5.6%
Other	50	2.7%	16	5.9%	22	4.1%	88	3.3%
Intra-abdominal	47	2.6%	8	3.0%	18	3.4%	73	2.8%
Bone & Joint	10	0.5%	6	2.2%	3	0.6%	19	0.7%
Intravascular line	4	0.2%	4	1.5%	6	1.1%	14	0.5%
Sterile site	8	0.4%	3	1.1%	1	0.2%	12	0.5%
Total	1827		269		537		2633	

AST = active surveillance testing; CLSI = Clinical Laboratories Standards Institute

Figure 30: Antibiotic profiles from the *Gram-negative Bacteria 2011 Hospital-onset Susceptibility Report*

Table 6. Ampicillin

Species		NSW/ACT	QLD/NT	SA	VIC/TAS	WA	Australia
E. coli	%I	0.6%	1.3%	0.0%	1.3%	1.1%	0.9%
	%R	55.0%	50.5%	52.1%	48.0%	43.9%	50.5%

APPENDIX 2. ANTIBIOTIC PROFILES BY FREQUENCY

Enterobacter species (n = 269)

Antibiotic Profile						Region			
Ctr	Caz	Cpm	Gen	Amk	Tmp	Nit	Cip	Mer	AUS	QLD/NT	NSW/AC	VIC/TAS	SA	WA
						Nit			107	30	30	15	12	20
Ctr	Caz					Nit			47	12	10	15	2	8
									35	5	11	10	5	4
					Tmp	Nit			16	7	3	2	2	2
Ctr	Caz								15	3	4	4	3	1
Ctr	Caz		Gen		Tmp	Nit			13	4	7		2	
Ctr						Nit			7	1	2	2	2	
Ctr	Caz				Tmp	Nit			4	3	1			
Ctr	Caz		Gen		Tmp				4	1	1	2		
Ctr	Caz	Cpm	Gen		Tmp	Nit	Cip		3			3		
Ctr	Caz	Cpm	Gen	Amk	Tmp		Cip		2				2	
					Tmp				1		1			
			Gen		Tmp	Nit	Cip		1	1				
	Caz		Gen			Nit			1			1		
Ctr									1	1				
Ctr					Tmp	Nit			1			1		
Ctr					Tmp	Nit	Cip		1					1
Ctr			Gen		Tmp	Nit			1		1			
Ctr	Caz				Tmp				1			1		
Ctr	Caz				Tmp	Nit	Cip		1					1
Ctr	Caz		Gen						1			1		
Ctr	Caz		Gen					Mer	1					1
Ctr	Caz		Gen		Tmp	Nit	Cip		1			1		
Ctr	Caz	Cpm							1	1				
Ctr	Caz	Cpm				Nit			1			1		
Ctr	Caz	Cpm			Tmp		Cip		1					1
Ctr	Caz	Cpm	Gen		Tmp	Nit			1			1		

Ctr = ceftriaxone, Caz = ceftazidime, Cpm = cefepime, Gen = gentamicin, Amk = amikacin, Tmp = trimethoprim, Nit = nitrofurantoin, Cip = ciprofloxacin, Mer = meropenem

ACT = Australian Capital Territory; Aus = Australia; NSW = New South Wales; NT = Northern Territory; Qld = Queensland; SA = South Australia; Tas= Tasmania; WA = Western Australia; Vic = Victoria

Data from AGAR are also promulgated via published papers and articles in peer-reviewed journals, and both oral paper and poster presentations at conferences in Australia and internationally. Table 9 shows the numbers and types of publications listed on the AGAR website, from 1989 to 2012.[173]

Table 9: Numbers and types of publications arising from Australian Group on Antimicrobial Resistance studies

Year	Journal articles and papers	Conference – oral papers	Conference – posters	Total
1989	1			1
1990				0
1991		1		1
1992	3			3
1993	1	1	1	3
1994		1		1
1995	1	2		3
1996	2	1		3
1997	1	2		3
1998	2	1		3
1999				0
2000		1	1	2
2001		2		2
2002		1	3	4
2003	2			2
2004	3		1	4
2005			1	1
2006	1			1
2007	4	1	4	9
2008	1	1		2
2009	1			1
2010		2	3	5
2011	1		1	2
2012			3	3
Total	**24**	**17**	**18**	**59**

Source: AGAR[173]

Program impact

Between its inception in 1985 and the present day, AGAR has contributed significantly to the standardisation of methodologies and achieving comparability of clinical microbiology testing across Australia.

The structure of AGAR surveys means that data are available to monitor changes in AMR trends for long periods, and that comparisons in AMR prevalence can be made between different states and territories, and between hospital and community settings. Among the benefits realised has been the ability to promote more rational use of antibiotics based on Australian data.[35] The AGAR survey reports provide a platform for the dissemination of learned opinion and advice in addition to analysis of the submitted laboratory data. Reports also carry information comparing the Australian results and trends with those seen by ECDC and ANSORP.[174]

Relevance to Australia

AMR stakeholders considered AGAR to be a source of stable long-term comparable data for Australia. Collaborative laboratory participation and standardised reporting procedures are fundamental to the program's operation. AGAR was seen to break down barriers between public and private, and states and territories, to enable high-level discussion and collaboration. Limitations for this program were the scope, funding sustainability, data reporting inconsistencies, and the lack of development for teaching protocols, audit or treatment.

Between its inception in 1985 and the present day, AGAR has contributed significantly to the standardisation of methodologies and achieving comparability of clinical microbiology testing across Australia.

3.2.7 Centre for Healthcare Related Infection Surveillance and Prevention

Queensland Health, within the Division of the Chief Health Officer, initiated the Centre for Healthcare Related Infection Surveillance and Prevention (CHRISP) Program in February 2001. CHRISP is now part of the Health Service and Clinical Innovation Division (HSCID) of Queensland Health, and provides support and guidance to Queensland public hospitals in developing, implementing and maintaining standardised surveillance and analysis methods that allow timely recognition of infection problems. CHRISP aggregates, analyses and provides de-identified data, and reports to and advises Queensland Health hospitals.[175] Surveillance data are collected to:

- enable a valid estimate of the magnitude of HAI in Queensland Health facilities
- permit recognition of trends in infection rates, AMR and healthcare-associated pathogens
- monitor trends in Queensland Health employees' exposure to blood and body fluids
- identify risk factors for exposure to blood and body fluids among health professionals.

For smaller hospitals, CHRISP recommends the use of Signal Infection Surveillance (SIS) methodology, which is designed to identify potential systemic issues requiring improvement. The events or 'signals' in the SIS framework include bloodstream infection, surgical site infection, multiresistant organisms, urinary tract infection (catheter related), gastrointestinal tract infection and occupational exposure investigation. In addition to CHRISP's focus on HAI, the program oversees the operation of OrgTRx. OrgTRx uses statewide public pathology laboratory data to generate consolidated antibiograms and provide information at a range of levels from state level (through geographical, hospital and ward groupings) to individual patients. OrgTRx operates on the Queensland Health Decision Support System (DSS), which is based on Panorama, a commercial business intelligence software platform. At the heart of DSS are data cubes, and a powerful data linkage and analysis capability that allow data to be viewed from a range of different perspectives. This enables the development of cumulative antibiograms, and the investigation of resistance trends and patterns across time, and among wards or hospitals.

Data collection and processing

For the broader CHRISP program, participating hospitals are required to submit data electronically on key HAI indicators every six months. These indicators include surgical site infections, healthcare-associated bloodstream infections, percutaneous and nonpercutaneous occupational exposures to body substances, and indicator organisms. OrgTRx collects susceptibility data from the Queensland Health statewide pathology laboratory information system (AUSLAB) and makes a data cube available through DSS. Because all laboratory data are obtained from a single, statewide database, there are no issues related to the standardisation of data between sites.

Data publication

Results of the broader HAI program are collated and analysed by CHRISP staff, Individual hospital reports are produced every six months, and aggregate reports once per year. Infection rates are risk-adjusted, where possible, to better reflect the differences in size and clinical case-mix between participating hospitals. Hospitals are encouraged to regularly review and analyse their own data and to apply their findings locally in a timely manner.[175]

Clinicians with responsibility for antimicrobial surveillance, such as infectious diseases physicians, clinical and laboratory microbiologists, and specialist pharmacists, have access to the OrgTRx data, which they use to inform their local antimicrobial surveillance program. Cumulative antibiograms are generated annually by Pathology Queensland and made available to Queensland Health staff on their intranet site.[176] Data and reports from OrgTRx are not generally available outside of the Queensland Health network.

Program impact

Information gleaned from the CHRISP OrgTRx system is used across the Queensland public hospitals network to assist the prevention and control of AMR. Goals of CHRISP surveillance programs include the valid estimation of the magnitude of nosocomial infections, and allowing trends to be established for infection rates, AMR and the prevalence of nosocomial pathogens.[118]

Relevance to Australia

Similar to statements relating to other programs, stakeholders valued the availability of data on a statewide basis, and the accessibility of annual reports. Other benefits of the CHRISP program included the surveillance of public laboratory data and use of antimicrobials in public hospitals. Stakeholders felt that for a program such as CHRISP to succeed, a statewide database for laboratory results, electronic data submission, and use of the Queensland Health DSS and resources to collate and analyse data at a national level must be available.

3.2.8 National Antimicrobial Utilisation Surveillance Program

The National Antimicrobial Utilisation Surveillance Program (NAUSP) commenced in 2004 and collects data on antibiotic consumption from all Australian states and territories. NAUSP is funded by the Australian Government Department of Health and Ageing, initially as a pilot based on the existing South Australian Antimicrobial Utilisation Surveillance Program (AUSP). The national and statewide programs are centrally maintained by the South Australian Infection Control Service, Communicable Disease Control Branch, South Australian Department of Health.[113–115]

Data collection and processing

NAUSP collects data on antibiotic consumption from tertiary referral centers (public hospitals) and large private hospitals from all Australia states and territories. [115] Currently more than 70 hospitals contribute to NAUSP, including 41 A1 tertiary referral or large private hospitals. The number of participating hospitals is increasing.

Options and models for the Australian context

Data publication

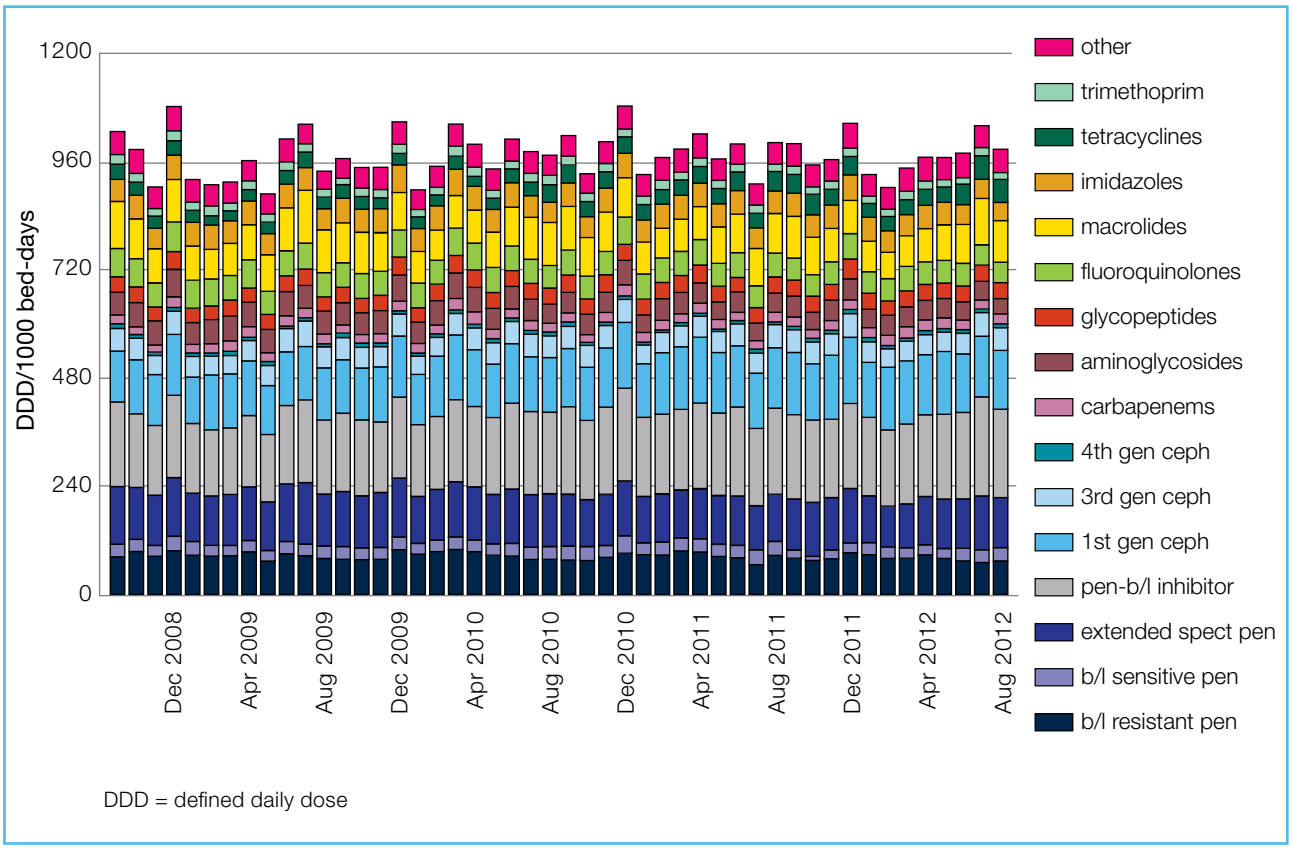
NAUSP provides reports of hospital inpatient antimicrobial usage to contributing hospitals and the Australian Government Department of Health and Ageing. Separate usage rates are currently reported for intensive care units (ICUs) from a subset of 39 hospitals. Usage rates for six antimicrobial classes, and individual agents within those classes, are reported bimonthly and in detailed annual reports. Antimicrobial usage rates are calculated using the number of defined daily doses consumed each month per 1000 occupied bed-days.[113]

Some examples of findings from the *Antimicrobial Utilisation Surveillance in Australian Hospitals, September 2008 to August 2012* report are presented in Figure 31 and Figure 32. Total hospital antimicrobial use by all contributors (all classes) is presented in defined daily dose.

Program impact

Antimicrobial usage data can be used to guide safety and quality improvements at the local level by a hospital or health service, and can provide useful information at state and national levels. Data related to antimicrobial use in hospitals have been used to promote positive health outcomes in several ways. First, by providing an Australian peer-group benchmark, hospitals can compare their usage with similar hospitals and identify areas of antimicrobial use that require more in-depth analysis. Hospitals and area health services that have a high antimicrobial consumption can initiate antimicrobial stewardship programs. High use of particular classes of antimicrobials has triggered individual drug audits and been used to tailor interventions. Second, longitudinal antimicrobial usage data have been used by hospitals to measure the effects of antimicrobial stewardship strategies and provide feedback to prescribers.[114]

Figure 31: Total hospital antimicrobial use by all contributors (all classes)

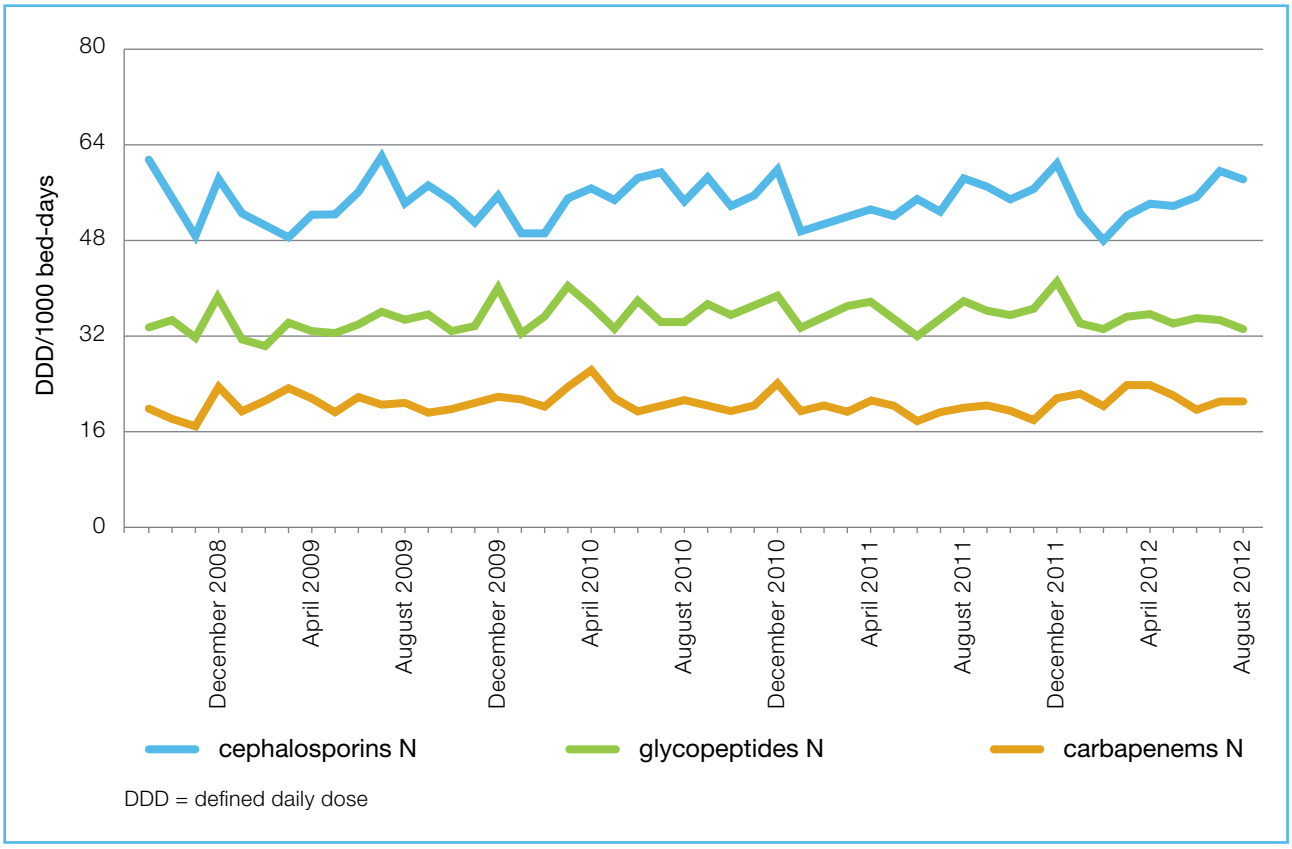


Surveillance data on antimicrobial usage also provide information for determining the impact of usage patterns on bacterial resistance. For example, linking longitudinal usage data with resistance data, at both national and hospital levels, may be used to identify reduction in resistant organisms and emerging patterns of resistance.[114]

Relevance to Australia

Key Australian AMR stakeholders identified a number of the strengths of NAUSP, including the Australia-wide review of antimicrobial use, and the ability for participating hospitals to compare antimicrobial consumption with the national peer-group benchmark. The accessibility of bimonthly reports for contributing hospitals was also acknowledged. A key weakness of NAUSP identified by stakeholders was an absence of reports for all states and territories, as well the lack of AMR surveillance. With regard to antibiotic consumption, identified limitations of the program were that only antimicrobial use in ICUs and total hospitals are reviewed for six antimicrobial classes. A comprehensive annual report containing data on usage in over 20 antimicrobial classes is produced for the A1 hospital peer group. Contributors are provided with a code so they can benchmark their use of all agents against similarly peered hospitals annually. Furthermore, contributing hospitals are primarily tertiary referral centres and large hospitals. Therefore, no outpatient data are collected.

Figure 32: Total hospital usage of 3rd/4th generation cephalosporins, glycopeptides and carbapenems



3.3 Critical elements contributing to the success of existing systems

AMR surveillance systems that demonstrate high levels of uptake and produce information that is useful at both local and national levels for driving developments in policy and practice across broad networks and geographies typically exhibit most or all of the following features:

- centralised coordination and direction setting, involving clinical experts and policy makers
- standardised datasets derived from pathology laboratory systems
- quality assured laboratory services providing the data
- structured data submission and management protocols
- a defined set of organisms, antibiotics and specimen sites for which data are gathered (which may be narrow or broad)
- a high level of participation from pathology laboratories in all sectors
- a centralised database that receives laboratory data, preferably online
- a centralised data-processing location that is resourced to undertake analysis and facilitate reporting
- publicly available online access to reports and information that addresses a range of priorities and purposes
- defined funding support, usually from government
- the ability to link with data from other systems, such as those monitoring antimicrobial use, and AMR in animal and food sources
- the ability to demonstrate trends across time, between geographic locations and between population groups, such as inpatients and outpatients
- the ability to promptly detect and support investigation of emerging threats
- outputs that support policy development at a national level, and guideline development and modification at a local level
- regular reports that measure and report on the impact of interventions.

Where effective national and supranational surveillance systems exist, high-level political support appears to be critical for success. Such support is important for establishing program priorities, encouraging engagement by laboratories and healthcare providers, and supporting funding mechanisms to develop effective and comprehensive systems. High-level political support can also facilitate linkages between groups independently concerned with policy and practical matters concerning human, animal and food management.

The European decision, announced in October 2012, to create the Central Asian and Eastern European Surveillance of Antimicrobial Resistance (CAESAR) network is informative in considering critical elements of wide-scale systems that aim to detect, monitor and support action to address AMR. CAESAR's aim is to establish gradually a network of national surveillance systems, including the European countries that are not among the 29 that currently contribute data to EARS-Net.[177] CAESAR is intended to enable comparable AMR data from all 53 European and central Asian countries to be brought together, analysed and reported together. To make such comparisons meaningful, laboratory processes, data collection and data submission must be standardised across participants, and EARS-Net methodology will be used in close collaboration with ECDC.

4

National coordination in Australia: systems, enablers and barriers

National coordination in Australia: systems, enablers and barriers

The purpose of this report is to support the work and deliberations of the Antimicrobial Resistance Standing Committee (AMRSC). AMRSC commissioned the study to examine the current activities for the surveillance of antimicrobial resistance (AMR) and antibiotic usage within Australia and around the world, and determine the enablers and barriers to a proposed nationally coordinated approach to AMR and antibiotic usage surveillance.

Key question

What are the enablers and barriers to the establishment of a national coordinated approach for the reporting and surveillance of antibiotic usage and antimicrobial resistance in Australia?

To consider the enablers and barriers to the development and implementation of a national coordinated approach to surveillance and reporting, it is instructive to review the recent history of activities and progress on antimicrobial resistance (AMR) and antibiotic usage in Australia.

4.1 Setting the scene – a recent history

AMR has been recognised as a problem in Australia for more than 25 years, and various working groups and committees have provided advice to the Australian Government Department of Health and Ageing.

4.1.1 Report of the Joint Expert Technical Advisory Committee on Antibiotic Resistance, October 1999

In 1997, the Joint Expert Technical Advisory Committee on Antimicrobial Resistance (JETACAR) was convened to review the linkage between antimicrobials in food-producing animals, and the emergence and spread of resistant microorganisms to humans. A wide-reaching report was published in 1999, with 22 recommendations, including several relating to surveillance.

4.1.2 Australian Government response to the report of the Joint Expert Technical Advisory Committee on Antibiotic Resistance, 2000

The Australian Government responded to JETACAR's recommendations in 2000. Although some of the recommendations were instituted, including the formation of the Expert Advisory Group on Antimicrobial Resistance (EAGAR) under the auspices of the National Health and Medical Research Council, there were barriers that prevented the full implementation of all recommendations. In 2008, EAGAR was disbanded. During the ensuing four years, the loss of momentum in addressing AMR prompted a summit by two learned societies, the Australian Society for Antimicrobials (ASA) and the Australasian Society for Infectious Diseases (ASID).

4.1.3 Antimicrobial Resistance Summit 2011: a call to urgent action to address the growing crisis of antibiotic resistance, Sydney, February 2011

The summit on 7–8 February 2011, convened by ASA and ASID, brought together an interdisciplinary group of experts from the scientific, medical, veterinary and public health sectors to establish priorities and a joint plan for action to face the increasing challenges of AMR. Entitled the 'Antimicrobial Resistance Summit 2011: a call to urgent action to address the growing crisis of antibiotic resistance', the meeting aimed to create a dialogue for national control strategies and formulate an agenda for minimising AMR in the future.[178]

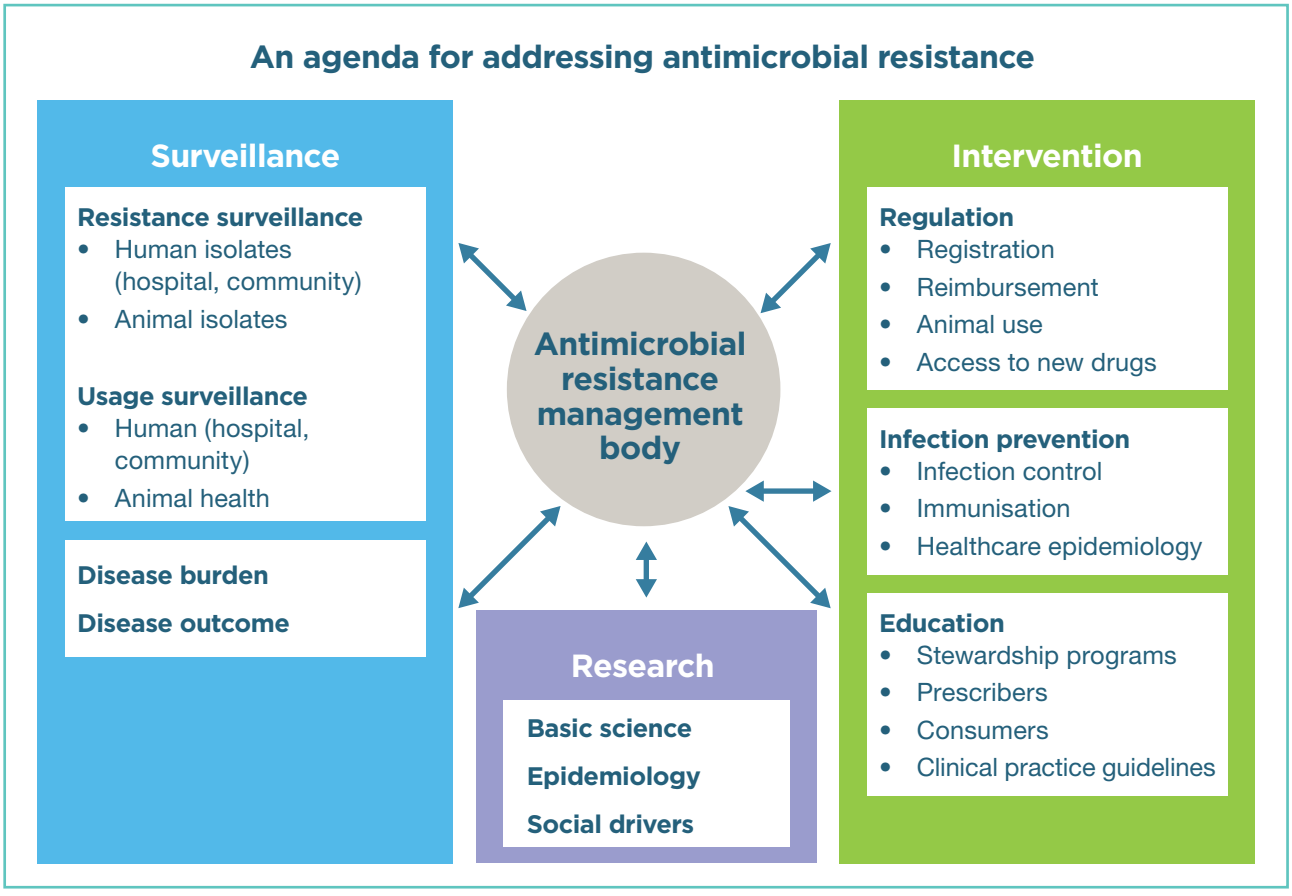
The summit proposed a plan of action that was published in the *Australian Medical Journal* in March 2011.[179] The plan includes elements of:

- surveillance of antimicrobial use
- surveillance of AMR
- education
- stewardship
- infection prevention and control strategies
- research
- regulation.

An urgent call to action was predicated on the threat of multiresistant bacteria being 'a critical public health issue that requires a coordinated, multifaceted response'.[179] The creation of a national AMR body to coordinate the response was proposed, with the role of this entity to include (also see Figure 33):

- implementing a comprehensive national resistance monitoring and audit system
- coordinating education and stewardship programs
- implementing infection prevention and control guidelines
- expanding funding to support research into all aspects of AMR
- reviewing and upgrading the current regulatory system applying to antibiotics.

Figure 33: Overview of elements of the action plan proposed from the Antimicrobial Resistance Summit 2011, and interaction with a central management body



According to Gottlieb and Nimmo, 'the scourge of antimicrobial resistance has increased inexorably over the years. We believe that the window for overcoming antimicrobial resistance is still open, but we must act decisively now – Australia cannot bury its head in the sand any longer and hope that the problem will just go away'.[179]

4.1.4 National Health Reform Agreement

On 2 August 2011, it was announced that agreement had been reached between the Australian Government and all Australian states and territories to cement the commitment made at the Council of Australian Governments meeting on 13 February 2011 to see all governments work together to reform the health system. Under the National Health Reform Agreement, all governments have agreed to major reforms to the organisation, funding and delivery of health and aged care.[180] In addition to outlining the roles of Local Hospital Networks and Medicare Locals, the agreement sets out the establishment of several national bodies, including the Independent Hospital Pricing Authority, National Health Funding Pool and National Health Funding Body and the National Health Performance Authority.[180]

4.1.5 Australian Commission on Quality and Safety in Health Care, 2011–present

In 2011, the Australian Government established the Australian Commission on Safety and Quality in Health Care (ACSQHC) as a permanent, independent statutory authority under the *Commonwealth Authorities and Companies Act 1997*. The National Health Reform Agreement describes the remit of the ACSQHC as follows:

B80. The role of the ACSQHC is to:

- *lead and coordinate improvements in safety and quality in health care in Australia by identifying issues and policy directions, and recommending priorities for action;*
- *disseminate knowledge and advocate for safety and quality;*
- *report publicly on the state of safety and quality including performance against national standards;*
- *recommend national data sets for safety and quality, working within current multilateral governmental arrangements for data development, standards, collection and reporting;*
- *provide strategic advice to the Standing Council on Health on best practice thinking to drive quality improvement, including implementation strategies; and*
- *recommend nationally agreed standards for safety and quality improvement.*

B81. The ACSQHC will expand its role of developing national clinical standards and strengthened clinical governance. These arrangements will be further developed in consultation with States.

B82. The ACSQHC will:

i. formulate and monitor safety and quality standards and work with clinicians to identify best practice clinical care, to ensure the appropriateness of services being delivered in a particular health care setting; and

ii. provide advice to the Standing Council on Health about which of the standards are suitable for implementation as national clinical standards.

B83. The ACSQHC does not have regulatory functions.

Part 2.2 of the *National Health Reform Act 2011* describes the establishment, powers and functions of ACSQHC. It says, in part:

(1) [ACSQHC] has the following functions:

(a) to promote, support and encourage the implementation of arrangements, programs and initiatives relating to health care safety and quality matters;

(b) to collect, analyse, interpret and disseminate information relating to health care safety and quality matters;

(c) to formulate model national schemes that relate to health care safety and quality matters;

The Act includes requirements that ACSQHC consult with clinicians, governments, carers, consumers and the public when developing standards, guidelines and indicators. The Act also provides that 'the Minister may give directions to [ACSQHC] in relation to the performance of its function and the exercise of its powers'.

4.1.6 Antimicrobial Resistance Standing Committee, 2012–present

As part of the restructuring of the Australian Health Ministers' Advisory Council committees in early 2012, a new committee known as the Antimicrobial Resistance Standing Committee (AMRSC) was endorsed to oversee activities relating to AMR in Australia. The Australian Health Protection Principal Committee (AHPPC) endorsed the formation, chair and membership of AMRSC on 19 April 2012. The role of AMRSC is to:

- advise AHPPC on matters relating to AMR
- provide expert advice and assistance on issues relating to AMR
- recommend national priorities relating to AMR for action.

AMRSC's purpose is to develop a national strategy to minimise AMR. This includes supporting an integrative approach through coordination of national activities such as:

- a comprehensive national AMR and usage surveillance system
- education and stewardship programs
- infection prevention and control guidelines
- community and consumer campaigns researching AMR and its prevention
- a review of the current regulatory system that applies to antimicrobials.

The membership of AMRSC includes representatives from the following organisations:

- National Health and Medical Research Council
- NPS MedicineWise (formerly NPS [National Prescribing Service])
- Australasian Society for Infectious Diseases
- Australian Society of Antimicrobials
- Australasian College for Infection Prevention and Control
- Communicable Diseases Network Australia
- Public Health Laboratory Network
- Therapeutic Goods Administration
- Pharmaceutical Benefits Advisory Committee
- Australian Government Department of Health and Ageing
- ACSQHC
- Australian Pesticides and Veterinary Medicines Authority
- Australian Government Department of Agriculture, Fisheries and Forestry.

4.1.7 Senate inquiry into the progress towards the implementation of the recommendations of the 1999 Joint Expert Technical Advisory Committee on Antibiotic Resistance, 2013

On 29 November 2012, the Senate referred the progress of JETACAR's 1999 recommendations to the Senate Finance and Public Administration Committees for inquiry and report. A period for public submissions closed on 17 February 2013, and the reporting date for the inquiry is 21 March 2013. The terms of reference for the Senate inquiry are to assess:[181]

> Progress in the implementation of the recommendations of the 1999 Joint Expert Technical Advisory Committee on Antibiotic Resistance, including:
>
> (a) examination of steps taken, their timeliness and effectiveness;
>
> (b) where and why failures have occurred;
>
> (c) implications of antimicrobial resistance on public health and the environment;
>
> (d) implications for ensuring transparency, accountability and effectiveness in future management of antimicrobial resistance; and
>
> (e) any other related matter.

4.2 Australia's recent history

It is clear that, in the period since the release of the JETACAR Report – where there have been structural elements to develop and implement initiatives to address the JETACAR recommendations – outcomes have been achieved. For example, Australia has sound regulatory agencies and structures that effectively dealt with regulatory issues raised by JETACAR in a timely manner.

On the other hand, where structures did not exist, attempts were made to develop and progress initiatives by linking responsibilities to organisations that were not designed or equipped to deliver the desired outcomes. Much good work has been done and contributors are to be commended, both for dedication to the task and for leaving a legacy of documentation relating to the issues and proposed solutions. However, the potential outcomes remain unrealised in a number of areas, particularly those relating to antimicrobial use and AMR surveillance. It is necessary to ask whether there have been changes that create an environment where progress may now be feasible.

The National Health Reform provides a structure and mechanism to pursue the goals of JETACAR, which did not exist during 1999–2008 when previous efforts were made to develop a national approach to addressing AMR. There is now:

- agreement between the Australian, and state and territory governments to pursue health reform, and improve quality and safety using structured processes and programs
- a national body, ACSQHC, that is charged with developing and implementing initiatives related to quality and safety matters in health care
- provision for the minister to direct ACSQHC to coordinate this work
- a multijurisdictional, interdepartmental Standing Committee under the Council of Australian Governments' Standing Council on Health structure that is charged with developing strategies to address AMR
- a requirement for ACSQHC to engage with governments, clinicians, carers, consumers and the public when developing and implementing initiatives.

AMRSC is pursuing the goals of JETACAR.

4.3 Fundamentals to national coordination

Having reviewed a range of surveillance programs relevant to the Australian context, this section presents high-level elements that should be considered when developing a national system.

4.3.1 A generic model for antimicrobial surveillance

AMR surveillance systems across the world have a number of components in common. Various aspects need to be considered for a successful national coordination; the modules and processes of which are illustrated in Figure 34 and discussed in the following sections.

Laboratory testing

A surveillance system for AMR is driven by laboratory data. To ensure that data are comparable, two approaches are taken:

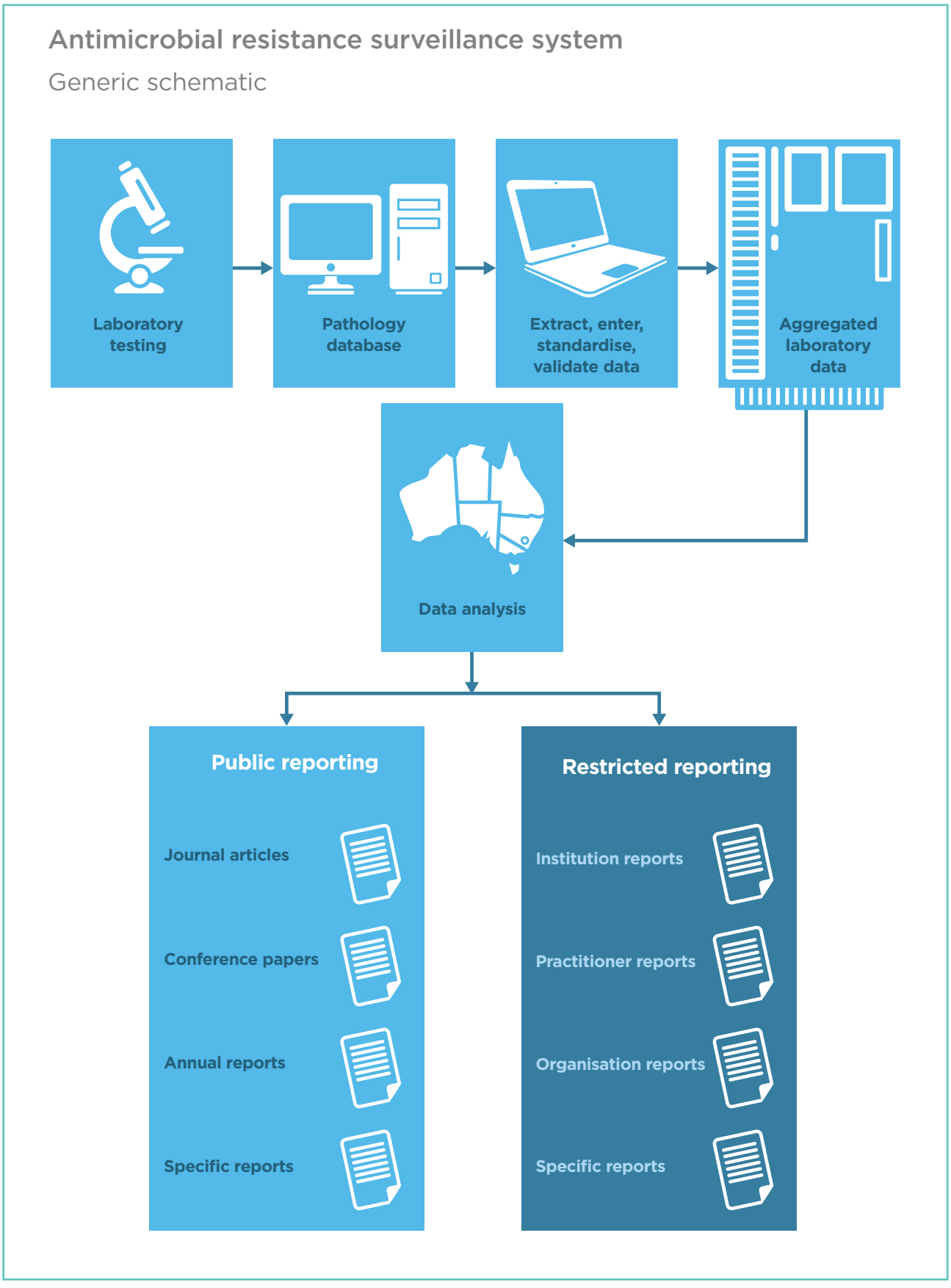
- send isolates to a limited number of reference laboratories for analysis and reporting
- standardise protocols across the participating laboratories, and enforce participation in external quality assurance programs.

Pathology database

In developed nations, laboratories invariably use laboratory information systems (LISs), which may capture data directly from testing equipment, or data may be entered manually. Two approaches are common for the storage of laboratory testing data:

- each laboratory or network has a proprietary or commercial LIS
- data are captured into a WHONET database at the local site.

Figure 34: Generic schematic of an antimicrobial resistance surveillance system



Data extraction, standardisation, entry and validation

Data from the laboratory system must be extracted, manipulated to meet the data format and structure required by the database that holds aggregated data from all of the sources, added to the aggregated dataset, and then validated by the participating laboratory or organisation. Factors to be considered include:

- data standards must be developed, promulgated and maintained
- organisations must be resourced to extract, manipulate, enter and validate data
- the frequency of data submission will impact both inputs to (e.g. resources needed), and outputs from (e.g. ability to monitor in real-time), the system.

Aggregated laboratory dataset

Aggregated laboratory datasets can exist at several levels – for example, as networks of:

- laboratories across an organisation
- organisations within a jurisdiction or geographical region
- jurisdictions or regions within a nation
- nations within a supranational system.

Each level has resource requirements, and the architecture of aggregation will have implications for the development and maintenance of systems, as well as for a range of data ownership, privacy and other considerations.

Data analysis

The end uses of aggregated data need to be considered, as this will be an important driver of the data analysis requirements, and the data structures that may be necessary to allow specific analyses to be undertaken. A clear set of objectives for the system will assist in identifying and prioritising the end uses of the data.

Public reporting

Publicly available reporting from existing systems takes a number of forms, including:

- annual reports
- specific reports on particular projects and activities
- articles in peer-reviewed journals
- papers and articles available in other types of publications and online
- conference presentations (oral papers and posters)
- selected data that can be displayed in real-time online (e.g. tables, graphs and/or maps showing organism or antibiotic susceptibility).

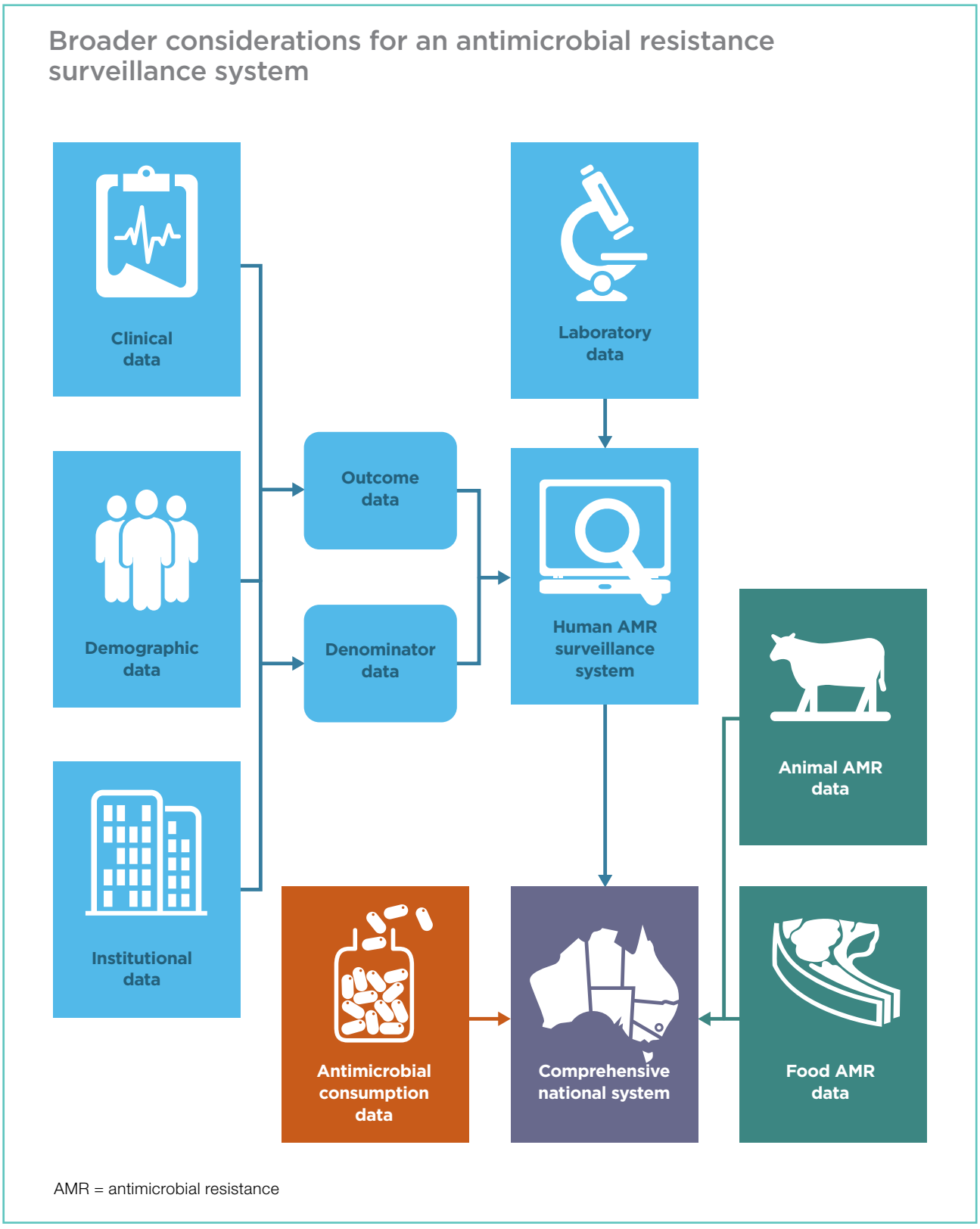
Restricted reporting

Some systems report that additional access is available to participating organisations online via secure log-ins. In other cases, organisation-specific or institution-specific reports are generated centrally and issued to participants. This allows highly focused interventions to be pursued, and the local impact of projects and initiatives to be measured and reported.

4.3.2 Extensions to the generic model

When considering the requirements for an AMR surveillance and reporting system for human health as outlined above, additional factors should be taken into account, such as those depicted in Figure 35. Although surveillance of resistance in animals, agriculture and food are beyond the scope of current consideration, they should be borne in mind when considering the longer term trajectory of a national system for surveillance and bringing about improvements in AMR.

Figure 35: Broader surveillance systems considerations



Non-laboratory human data

In addition to the laboratory-sourced data on bacterial isolates, and their molecular and AMR characteristics, a number of systems and programs also collect data that support the analysis of patient clinical outcomes, or that can be used as denominator data to compare rates of infection or resistance. These data are typically:

- clinical outcome and patient risk data gathered from patient records, clinical or patient information systems, or by interview with patients or treating clinicians
- demographic data, such as age, sex and location
- institutional data such as hospital size, occupied bed-days and other measures of hospital activity, or gross population data in community settings.

Human antimicrobial consumption data

Many programs bring data on antibiotic prescribing and/or consumption patterns in hospital and/or community settings alongside AMR data to create dynamic and persuasive datasets that can be used to influence clinical practice and promote public health.

Animal and food datasets

Data on antimicrobial consumption and resistance have been used to great effect in Europe to bring about changes in legislation and practice that has demonstrated improvements in national AMR profiles. Such data include:

- antimicrobial consumption as growth promoters in food production animals
- antimicrobial consumption for animal treatment in the domestic and farming environments
- AMR patterns in bacteria isolated from animals, usually through sentinel surveillance programs.

Some countries also undertake sentinel surveillance of food products to monitor both the presence of indicator and pathogenic bacteria, and their AMR patterns. This can then be linked to farming practices in the host nation, or used to evaluate the potential impact of imported foodstuffs on the local population.

4.4 Strategic options and assumptions for national coordination

To maximise the utility and effectiveness of an Australia-wide coordination of AMR and antibiotic usage surveillance and reporting, a clear set of high-level objectives must be established and articulated. We drew on the stated objectives of existing systems (as detailed in Section 3.2) to make a list of potential objectives for a national system. We then prioritised the list:

1. Strengthen the capacity of states and territories to conduct effective AMR surveillance activities and improve the flow of surveillance information.
2. Integrate bacterial isolate and resistance data from multiple databases to provide standardised reporting, and comparative and validated information sets.
3. Improve the use of information to detect changes in resistance patterns over time, and between geographical areas and institutions.
4. Improve the use of information to support rapid detection and response to emerging threats.
5. Provide guidance to public health authorities in responding to community and hospital outbreaks of resistant organisms.
6. Monitor the impact of interventions undertaken to reduce the levels of AMR.
7. Evaluate the impact of therapy and infection control interventions on infection rates and cure rates.
8. Strengthen laboratory capacity and performance through quality activities and review of reporting.
9. Provide timely AMR data that constitutes a basis for policy decisions at both state and national levels.
10. Provide the capacity to link AMR data from healthcare settings with information from other systems associated with antibiotic use, and veterinary and food industries.
11. Initiate, foster and complement scientific research in Australia in the field of AMR.
12. Provide advice to regulatory authorities on the availability and accessibility of antimicrobials based on the potential for resistance selection.

To develop a national system, the following assumptions are made:

- Existing systems and databases will be examined for their potential to feed data to a national system.
- Systems developed will be capable of future integration with other relevant data, information and analysis relating to AMR surveillance of food and animal sources.
- Proposals will build on the previous work of JETACAR and EAGAR.
- A national coordinating centre with the responsibility for the development and implementation of strategies is essential.

To determine the best way forward for future national coordination of AMR and antibiotic usage surveillance and reporting, two high-level strategic options are considered:

- **Enhance** – use existing systems and processes as the basis for a national platform, and develop these systems to achieve national objectives.
- **Construct** – design a new national system 'from the ground up', and consider the desirable attributes of Australian and international systems discussed in Section 3.

These strategic options were selected to stimulate high-level consideration of enablers and barriers to the development of a national AMR surveillance system. By using a combination of real examples and generic information, it is hoped that a discussing a range of options and solutions will lead to a focuses and achievable outcome.

4.5 Enabler and barrier analysis

Table 10 presents commentary on formative enablers and barriers relevant to the 'enhance and construct' options in Section 4.4. These enablers and barriers have been developed after analysing the examples in Section 3 and discussing options with members of AMRSC.

Table 10: Formative enablers and barriers relevant to 'enhance' and 'construct' options

Attribute	Enhance		Construct	
	Enabler	**Barrier**	**Enabler**	**Barrier**
Technical • Nonclinical aspects • Design and construction	• Many aspects already developed • Proof of concepts available • Advantages and deficiencies are known • Pre-existing investment in design, construction and testing	• Not tested in national context • Not sufficiently comprehensive in current form • Not currently integrated to desired extent	• Can be designed with intelligence derived from experience • No hindrance of legacy programming and design	• Novel systems frequently yield a gap between expectations and delivery • All aspects of system must be developed and operationalised
Scientific • Clinical aspects • Data	• Shown to work with existing laboratory processes, networks and datasets • Works with existing standards • Has the confidence of existing users • Has a public profile; is known nationally	• Ability to work with data from networks not currently participating can only be inferred	• Can be designed to accommodate known issues with the incorporation of laboratory data and processes	• Practicalities of data submission and handling will not be known until during proof of concept and rollout • No existing proof of concept in Australian environment
Operational • Operating environment • Management • Governance	• Might be undertaken via expansion in situ, or by transfer to a new operating and development environment • System demands and requirements are known	• Transfer to new governance arrangements and/or operating environment requires satisfactory negotiation and capacity	• Can take advantage of the latest programming and operating platforms, potentially adding to efficiency and flexibility of the solution	• System requirements and demands can be estimated, but cannot be tested until proof of concept stage • Inherent risks regarding suitability and capacity of untested operating environment
Financial • Funding	• Current costs of development and operation can be ascertained • Costs of further development and operation can be reasonably estimated • Likely lower cost than the 'construct' option • Opportunity for public–private partnership	• Agreement is needed to fund improvement • Limited fiscal resources to support unplanned cost imposts	• Opportunity for public–private partnership	• Potential for significant variance between cost estimates and delivery cost • Limited fiscal resources to support unpredictable cost scenario

Attribute	Enhance		Construct	
	Enabler	Barrier	Enabler	Barrier
Governance and policy • Jurisdictional influence • Stakeholder interests • Government and nongovernment	• Opportunity for tangible interaction and evaluation by all stakeholders and decision makers • Broad support at a national level for a national approach • Visibility of existing systems	• Potential for non-user 'not invented here' bias • Perception that existing users and owners will be advantaged compared to new adopters • New adopters can perceive loss of the advantages of their legacy systems	• Can seek to address the concerns and interests of all stakeholders • Broad support at a national level for a national approach	• Key stakeholders can find it difficult to commit to an intangible concept • Periods of negotiation and design can be extended in trying to appease all parties and reach agreement to proceed
Background • JETACAR • EAGAR	• JETACAR and EAGAR reports accepted by previous governments contain references to the evolution of existing Australian systems as a suitable solution for AMR surveillance	• Of the existing recommendations, some remain valid and other not valid	• Previous reviews and committees recommend a national approach	• No reference to new construction in recommendations of previous reviews and committees

Other considerations that are equally relevant to either approach include:

Funding	• adequate sources of funding must be secured • funding must support design and construction phases, and ongoing operation and development
Resourcing	• advancing key established resources such as the enterprise data warehouse to support the new national system
Scientific	• standardisation of laboratory processes to ensure comparability of data is necessary

Data	• data privacy, security, confidentiality and ownership concerns must be negotiated and resolved • evolving legislative issues and differing jurisdictional environments need to be considered
Engagement	• mechanisms to ensure widespread participation and data contribution by pathology providers must be developed
Design	• traditional CDC-like system is not particularly politically favoured

4

National coordination in Australia: systems, enablers and barriers

Nominated representatives of key Australian stakeholders were asked about perceived enablers and barriers to the success of proposed models executed in an Australian context. Several themes have emerged in the stakeholder survey to date.

Important features identified by respondents towards implementing a successful Australian program comprise:

- recognising AMR containment as a national health priority with a long-term commitment to improving surveillance
- establishing clear roles and responsibilities for national coordination (including clarifying the role of state and territory organisations)
- establishing effective national leadership to coordinate decisions and agreement among key sectors
- confirming availability of dedicated government (public) funding.

Adequate funding and resourcing (including education and equipment) were considered necessary to support the participation of competing laboratories financially, and to develop protocols for identification and timely processing of isolates. Stakeholders believed agreement must be reached on key organisms and parameters for surveillance. Other aspects of a successful program in Australia were considered to be the effective coordination and collaboration among contributing laboratories, adoption and expansion of existing laboratory information systems, and the use of pharmacy systems to submit hospital-based and community-based consumption data to a national database. The accessibility of data to hospitals and the public is important to inform policy and guidelines.

5

Australia's response – a national coordinating centre

Australia's response – a national coordinating centre

For Australia's national coordinating centre on antimicrobial resistance (AMR) and usage surveillance and reporting, the Antimicrobial Resistance Standing Committee (AMRSC) recommends:

1. That existing systems and processes be expanded and improved, a national coordinating centre for the surveillance and reporting of AMR and antibiotic use be established, with oversight from AMRSC.
2. That responsibility for establishing the centre rests with the Australian Commission on Safety and Quality in Health Care (ACSQHC) as it is well placed to undertake the responsibility of establishing national coordination.
3. That a program of work be developed based on supporting, improving and linking existing systems that have statewide or national application, and bringing into play contemporary technologies, systems and assets that together can achieve the desired objectives.

5.1 The proposal

The Antimicrobial Resistance Standing Committee (AMRSC) proposes a three-stage program comprising five elements of activity. It is proposed that the program elements be developed, implemented and funded over three stages, as outlined in Table 11 to Table 16.

Table 11: A high-level overview of the proposed program, comprising five elements developed over three stages

Stream	Stage 1 – short term	Stage 2 – medium term	Stage 3 – long term
Element 1 Surveillance of antimicrobial resistance	• Leverage existing systems • Expand capacity and include additional participants and data sources	• Build new capacity • Link to nonhuman data	• Complete comprehensive system capturing human, animal and food data
Element 2 Surveillance of antibiotic usage	• Leverage existing systems • Expand capacity and include additional participants and data sources	• Build new capacity • Link to nonhuman data	• Complete comprehensive system capturing human, animal and food data
Element 3 Disease burden and outcomes	• Strengthen hospital and community programs	• Set up new initiatives for specific disease entities • Improve existing initiatives	• Set up new initiatives for specific disease entities • Improve existing initiatives
Element 4 Analysis and action	• Establish definitions and standards • Scope analytic and reporting requirements	• Improve analytic and reporting capability • Reinforce standards and guidelines • Identify research priorities • Demonstrate progress	• Leverage emerging science and technology • Increase capacity and authority for action • Set research priorities • Demonstrate progress
Element 5 Planning	• Map complete program • Plan for Stage 2	• Evaluate Stage 1 • Confirm program direction • Plan for Stage 3	• Evaluate Stage 2 • Plan international participation • Be a One Health leader

Table 12: Element 1 – Surveillance of antimicrobial resistance

Rationale	It is essential to measure the extent and trends in antimicrobial resistance in the community and hospitals if effective interventions are to be developed, and outcomes from interventions demonstrated.	
Proposed approach	• Review available and potential data sources • Develop and promulgate standard approaches • Develop existing systems and mechanisms that are operating or have the potential to operate at a national level	
Stage 1	**Stage 2**	**Stage 3**
Passive surveillance – real-time public and private laboratory data Targeted surveillance Alert – emerging pathogens	• New initiatives – explicit aim is to receive data from external entities. The Australian Commission on Safety and Quality in Health Care will not assume authority for animals and food, but may lever funding from existing government departments for animal, food and nonbacterial microorganisms (fungi and viruses) surveillance. • Improve existing initiatives – extend targeted and alert surveillance systems	Comprehensive passive, targeted and alert systems for: • humans • animals • food and agriculture.

Table 13: Element 2 – Surveillance of antibiotic usage

Rationale	Understanding where and to what extent antibiotics are used is key to developing strategies to address a range of issues, from appropriateness of prescribing to demonstrating links between use and emerging resistance.	
Proposed approach	• Review available and potential data sources • Develop and promulgate standard approaches • Build on existing systems that operate or have the potential to operate nationally	
Stage 1	**Stage 2**	**Stage 3**
NAUSP: • report at local level in real-time • increase national participation of all hospitals, including paediatric. Community data from Pharmaceutical and Repatriation Subsidy Schemes, BEACH, Medicine Insight and others.	New initiatives: • secure human community data • animal usage data • indication data for community, hospital and animal. Improve existing initiatives: • NAUSP is inclusive of all hospitals • build on existing work (e.g. point prevalence) for wider antimicrobial resistance.	Comprehensive indication data systems for: • humans • animals • food and agriculture. Integrated human and community usage systems for: • humans • animals.

BEACH = Bettering the Evaluation and Care of Health; NAUSP = National Antibiotic Utilisation Surveillance Program

Table 14: Element 3 – Disease burden and outcomes

Rationale	A range of measures from hand hygiene to vaccination have been demonstrated to be effective in reducing disease burden from microorganisms. None, however, focus on resistant organisms.	
Proposed approach	• Build on existing standards, systems and programs • Improve coordination, participation and reporting	
Stage 1	**Stage 2**	**Stage 3**
Hospital level: • hand hygiene audit and data • hospital-acquired infection surveillance and others • antimicrobial stewardship data • targeted surveillance of specific infections. Community level: • targeted surveillance of specific infections and disease.	New initiative: • target program for specific disease entities. Improve existing initiatives: • continue existing work.	New initiative: • target program for specific disease entities. Improve existing initiatives: • continue existing work.

Table 15: Element 4 – Analysis and action

Rationale	Once data sources have been developed and systems implemented, the improvement of health outcomes is dependent on high-quality analysis of the datasets, and action plans being developed and implemented.	
Proposed approach	• Resource the national coordinating centre for antimicrobial resistance strategy to undertake appropriate analysis and planning • Leverage national resources such as the enterprise data warehouse to develop analytical capacity • Use the mandate of the Standing Committee on Health to promulgate guidelines, advice and standards • Use analysis to drive improvement initiatives and research	
Stage 1	**Stage 2**	**Stage 3**
Analysis and action from datasets Determine what other elements or programs need to be included or established (e.g. hospital-acquired infections) Establish definitions (e.g. denominator data) Establish reporting methods Develop policies Develop guidelines, advice, standards, particularly education Recommend research priorities Identify the burden of disease and disease outcomes Examine scope and opportunity of the National Antibiotic Utilisation Surveillance Program to include hospital and community within one entity Make recommendations to regulatory authorities	Continue existing work Review emerging science and technology Increase capacity and authority for analysis and action Develop guidelines, advice and standards, particularly education Influence and set research priorities	Continue existing work Review emerging science and technology Increase capacity and authority for analysis and action Develop guidelines, advice and standards, particularly education Influence and set research priorities

Table 16: Element 5 – Planning

Rationale	Effective planning is essential to coordinate strategies and implementation, identify and apply resources, ensure outcomes are measured and deliver improvement	
Proposed approach	• Resource the national coordinating centre for antimicrobial resistance strategy to undertake appropriate planning	
Stage 1	**Stage 2**	**Stage 3**
Plan for Stage 2 Map ultimate program Scope and determine ultimate comprehensive program	Evaluate Plan for Stage 3 Plan for full system	Evaluate Set up international participation Be a One Health leader

5.2 Overview of the status of program components

Table 17 provides an overview of the perceived current status of key elements of the proposed program. It presents a subjective viewpoint, and represents a consensus view of the members of AMRSC.

Table 17: Overview of the current status of key elements of the proposed program

Element	Attribute	Example system or organisation	Status
1 – Surveillance of antimicrobial resistance	Passive surveillance, public sector	CHRISP OrgTRx	4
	Passive surveillance, private sector	CHRISP OrgTRx	2
	Targeted surveillance, public sector	AGAR	6
	Targeted surveillance, private sector	AGAR	6
	Multiresistant organism surveillance, public sector	CHRISP OrgTRx	4
	Multiresistant organism surveillance, private sector	CHRISP OrgTRx	2
	Links to animal and food data		2
2 – Surveillance of antibiotic use	Surveillance, public hospital sector	NAUSP	6
	Surveillance, community sector	PBAC, DUSC, BEACH, Medicine Insight	2
	Links to primary industries data		2
3 – Disease burden and outcomes	Hand hygiene audit	ACSQHC	5
	Healthcare-associated infection surveillance	ACSQHC	5
	Patient and disease outcome data	AGAR/ASA, AESOP, ANZCOSS	4
4 – Analysis and action	Establish data definitions	ACSQHC	2
	Guidelines and standards	ACSQHC	3
	Reporting frameworks	New centre	1
	Research frameworks	New centre	1
5 – Planning	Plan Stage 1	ACSQHC	3
	Plan Stage 2	New centre	2
	Plan Stage 3	New centre	2

Legend:

1 No existing system or planning
2 Some ideas exist on how to proceed
3 Significant planning has been done
4 Exists, operates at a state or quasi-national level, needs negotiation and development
5 Exists, operates at a national level, concept needs development
6 System element exists, needs expansion to achieve a comprehensive level

ACSQHC = Australian Commission on Safety and Quality in Health Care; AESOP = Australian Enterococcal Sepsis Outcome Program; AGAR = Australian Group on Antimicrobial Resistance; ASA = Australian Society for Antimicrobials; ANZCOSS = Australian New Zealand Cooperative on Outcomes in Staphylococcal Sepsis; BEACH = Bettering the Evaluation and Care of Health; CHRISP = Centre for Healthcare Related Infection Surveillance and Prevention; DUSC = Drug Utilisation Sub-Committee; NAUSP = National Antimicrobial Utilisation Surveillance Program; PBAC = Pharmaceutical Benefits Advisory Committee

Items that are towards the higher end of the 'status' spectrum might be regarded as established systems with proven protocols and methodologies, and could be seen as the 'low-hanging fruit' in terms of making progress. Items at the lower end of the spectrum are in formative stages with significant planning and development required. Not all will require the same degree of resourcing to progress. Resources that will need to be applied include:

- intellectual
- information technology
- management and governance
- funding.

6

Appendices

Appendix 1: Study design and methods

Appendix 2: Global program and activity analysis

Appendix 1: Study design and methods

Project approach and methods

The study that was the basis for this report comprised two phases.

Phase 1: Integrative literature review, including document and policy analysis

The purpose of the literature search was to identify global national and supranational programs for the monitoring and surveillance of AMR and antibiotic usage. Furthermore, key program components were elicited to inform potential models appropriate for the Australian healthcare system at a national level.

Databases included for the search were the Cochrane Library, MEDLINE (via EBSCOhost), CINAHL (via EBSCOhost), Web of Science (Thomson, ISI), Scopus (Elsevier Science), Health Management Information Consortium (HMIC; Ovid), TRIP and Google Scholar.

The search aimed to identify relevant records within several electronic databases, and the syntax and search strategies used were optimised for individual databases. Duplications were discarded, and retained literature imported into reference management software (EndNote X4). Additional records were obtained from the bibliographies of retrieved articles. Titles and abstracts were assessed for relevance and context. Grey literature (government reports and relevant professional association publications) relating to antimicrobial use and resistance published internationally were identified and reviewed.

The following caveats are noted with respect to the search of the literature:

- Many antimicrobial surveillance and monitoring activities are reported in the grey literature rather than in the peer-reviewed literature.
- The dynamic and emerging nature of AMR and antibiotic usage makes reporting challenging, and the detail and reporting accuracy of information available can be inconsistent. However, it is considered that substantive international programs would be presented in the literature.
- Referenced grey literature (government or agency reports, etc.) and identified websites provided valuable depth to program detail. However, it is acknowledged that program funding or infrastructure limitations also make the information that can be elicited from these sources variable.
- This review focused on key Australian and international systems and experience in the context of a potential national system for the surveillance of antibiotic resistance in bacteria important to human health. Although critically important, other factors and strategies, including the surveillance of antibiotic use in humans, and systems to gather data and analyse antimicrobial use and resistance trends in animals and food sources, are not the subject of this review.
- A comprehensive review of global activities has meant some information is only available in languages other than English and currently not accessible.

Phase 1 comprised an integrative review of the international and national literature coupled with national activity analysis using document and policy analytic methods outlined by Silverman.[182]

Phase 2: Enabler and barrier analysis

Telephone interview and/or survey engagement with key stakeholders in AMR and antimicrobial usage across Australia was conducted. Key Australian AMR and antibiotic usage stakeholder organisations identified for consultation included:

- Australian Association of Pathology Practices
- Australian Commission on Safety and Quality in Health Care
- Australian Government Department of Health and Ageing
- Australian Group on Antimicrobial Resistance
- Australian Pesticides and Veterinary Medicines Authority
- Australian Society for Antimicrobials
- Australian Society for Microbiology
- Australasian College for Infection Prevention and Control
- Australasian Society for Infectious Diseases
- Centre for Healthcare Related Infection Surveillance and Prevention
- Communicable Diseases Network Australia
- Healthcare Infection Surveillance Western Australia
- National Antimicrobial Utilisation Surveillance Program
- National Coalition of Public Pathology
- National Health and Medical Research Council
- National Neisseria Network
- national pathology services (Healthscope Ltd, QML, Sonic Healthcare Ltd, Primary Health Care Ltd)
- Northern Territory Department of Health
- NPS MedicineWise (formerly NPS [National Prescribing Service])
- NSW Clinical Excellence Commission
- NSW Ministry of Health
- Pathology Queensland
- Pharmaceutical Benefits Advisory Committee
- Public Health Laboratory Network
- Queensland Health
- Royal College of Pathologists of Australasia
- SA Health Communicable Diseases Control Branch
- SA Health
- Tasmanian Department of Health and Human Services
- Tasmanian Infection Prevention and Control Unit
- Therapeutic Goods Administration
- Victorian Department of Health
- Victorian Infection Surveillance Service
- Western Australia Health.

The Griffith University Human Research Ethics Committee (HREC/NRS/28/12) provided approval to conduct this project with respect to stakeholder engagement.

Phase 2 data have been analysed thematically according to techniques described by Silverman[182] and techniques to enhance trustworthiness and credibility of data – including, but not limited to, member checking, peer review and the use of an audit trail as described by Holloway and Wheeler.[183]

AMRSC identified 28 key AMR and antimicrobial usage stakeholders across Australia to participate in a survey regarding proposed models for a nationally coordinated approach. An early insight into emerging themes can be based on the current response levels of 32.1%, which comprise views representing national-level and state-level AMR or antibiotic use surveillance and pathology sectors. Engagement with stakeholders is ongoing as a future national system for the surveillance and reporting of AMR and antibiotic usage is introduced and evolves.

International or supranational

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
WHO Regional Offices										
EURO[20, 184] (EARS-Net, ESAC-Net, HAI-Net)[11, 185, 186]	27 EU member countries, Iceland and Norway (900 public health laboratories serving over 1400 hospitals)	Current	AMR surveillance and antimicrobial consumption	Publicly funded (coordinated and funded by ECDC since 2010)	Organism	Community and hospital	Data uploaded to central database (TESSy)	*S. pneumoniae,* *S. aureus,* *E. faecalis,* *E. faecium* *E. coli* *K. pneumoniae* *P. aeruginosa*	n/a	ECDC website; annual reports; peer-reviewed publications
AFRO (AFRO IDSR[20, 187])	43 countries	Current (since 2002)	AMR surveillance	Coordinated by WHO	Disease	n/a	n/a	8 'epidemic-prone' pathogens[20]; malaria, tuberculosis, *S. dysenteriae*, chancroid, gonorrhoea and pneumonia (*S. pneumoniae, H. influenzae*)[187]	n/a	n/a
PAHO (ReLAVRA[20, 188])	21 countries (519 laboratories)	Current (since 1996)	AMR surveillance and antimicrobial consumption	Coordinated by WHO (AMRO/ PAHO)	n/a	n/a	n/a	16 pathogens (all sample types)	n/a	n/a
EMRO (EMRO Regional Program for surveillance of AMR[20]; formerly ARMed[29], 2001–2005)	n/a	Proposed	AMR surveillance	Funded by ECDC	n/a	n/a	n/a	28 species (all sample types) proposed (formerly 7 pathogens, blood and CSF)	n/a	n/a
WPRO (WPRO Regional Program for Surveillance of AMR[20, 189])	13 countries (14 laboratories)	Current	AMR surveillance	Coordinated by WHO	n/a	n/a	n/a	26 bacteria of 'public health importance'	n/a	Drug resistance data reported annually to regional office (4–15 antibiotics); annual reports

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
SEARO (SEARO National and Regional Surveillance System[20])	n/a	Proposed	AMR surveillance	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Other supranational (regional) networks										
ECDC[190]										
EARS-Net[11] (formerly EARSS[191])	27 EU member countries, Iceland and Norway (900 public health labs serving over 1400 hospitals)	Current	AMR surveillance (European reference data for AMR)	Publicly funded (coordinated and funded by ECDC since 2010)	Organism	Hospital	Susceptibility tests of bacteria pathogens isolated from people with invasive infections (blood culture, cerebrospinal fluid only)	*S. pneumoniae* *S. aureus* *E. faecalis* *E. faecium* *E. coli* *K. pneumoniae* *P. aeruginosa*	n/a	ECDC website; annual reports
ESAC-Net[185]	27 EU member countries, Iceland and Norway (multiple public health labs serving over a variety of hospitals)	Current	Monitoring antimicrobial usage (European reference data for prevalence data)	Publicly funded (coordinated and funded by ECDC since 2011)	–	Community and hospital settings	Point prevalence surveys in European acute care hospitals; project in long-term care facilities (HALT-2); denominator data from EUROSTAT/ national reports	Antibacterials, antimycotics and antivirals for systemic use; antimycobacterials (plus a few antimicrobials outside WHO ATC group J)	n/a	WHO ATC DDD/1000 inhabitants and per day, no. packages/1000 inhabitants and per day; ECDC website; annual reports

International or supranational (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
HAI-Net[186]	As above	Current	HAI and surgical site infection surveillance (various surveillance activities and projects)	Publicly funded (coordinated by ECDC since 2008 (formerly IPSE network)	Infection/ organism	Acute care hospitals and long-term care facilities	Point prevalence survey of HAI and antimicrobial use in acute care hospitals; surveillance of surgical site infection (7 surgical categories), HAI (ICUs and long-term care facilities) and *C. difficile*; maintains ARHAI EPIS	HAI and antimicrobial use in acute care hospitals and long-term care facilities; HAI in ICUs; surgical site infections	n/a	ECDC website; annual reports
HELICS[130, 192]	15 countries within 4 EU national public health institutes (Brussels, Barcelona, Berlin and London)	Inactive	HAI and surgical site infection surveillance	Previously coordinated by IPSE and now under HAI-Net	Infection	n/a	Antimicrobial susceptibility of pathogens isolated from patients with HAI	n/a	n/a	n/a
ABS International[137, 138] 'Implementing antibiotic strategies for appropriate use of antibiotics in hospitals in member states of the European Union'	Hospitals in 9 European member states	Inactive (2006–2008)	Antimicrobial consumption	n/a	–	n/a	n/a	n/a	n/a	n/a

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
SMART[193–196]	28 participating countries in 5 regions (Asia-Pacific, Latin America, Middle East-Africa, North America and Europe)	Current	AMR surveillance	Commercially funded by Merck Sharp & Dohme Corp. (subsidiary of Merck & Co. Inc.)	Organism	Hospital	In vitro susceptibility tests and longitudinal susceptibility patterns of Gram-negative bacilli isolated from intra-abdominal infections	Aerobic and facultative Gram-negative bacilli	n/a	Peer-reviewed publications
Euro-GASP[197, 198] (microbiology (lab) component of ESSTI)	17 European Union/European Economic Area member states	Current	AMR surveillance (*N. gonorrhoeae*)	Coordinated by ECDC from 2009	Disease	Laboratory	*N. gonorrhoeae* antimicrobial susceptibility	Representative sample of *N. gonorrhoeae* strains tested against a range of antimicrobials (e.g. penicillin, ciprofloxacin, tetracycline, azithromycin, cephalosporin)	n/a	Reports, peer-reviewed publications
AFHSC-GEIS[108]	Military and host-nation populations (Egypt, Jordan, etc.)	Current	AMR and HAI surveillance	Funded by the US Department of Defense	Organism	Military and host nations (Peru, Jordan, Egypt)	Susceptibility testing of pathogens isolated from hospitalised service personnel	Pathogens of military importance: MRSA, *Acinetobacter* spp., extended-spectrum beta-lactamase producing enterobacteriacae, etc.	n/a	Website; annual reports; peer-reviewed publications

International or supranational (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
ARPAC[199, 200] (project conducted by four study groups of ESCMID)	Network of European Hospitals	Inactive (2002–2004)	AMR surveillance and antimicrobial consumption	Funded by DG research, European Commission	Organism	n/a	AST, AMR prevalence, typing methods, antimicrobial consumption, infection control policies and antibiotic prescribing policies	n/a	n/a	Website; consensus conference (co-hosted by ESCMID and SWAB); peer-reviewed publications
CARE-ICU[201]	35 ICUs from 8 European counties (participating national ICU networks and individual ICUs)	Inactive (pilot project)	AMR surveillance and antimicrobial consumption	n/a	Infection	European ICUs	Susceptibility testing of ICU pathogens to common antimicrobial agents	*E. coli* *K. pneumoniae* *S. aureus* *A. baumannii* *P. aeruginosa*	n/a	Consumption: DDD/1000 occupied bed-days; website
ESAR[202, 203]	5 microbiological laboratories in Western and Eastern Europe	Inactive (1999–2000)	AMR surveillance	Funded by ESBIC	Organism	European microbiological laboratories	Incidence and mechanisms of resistance using sentinel laboratories and standardised methodology	Alert and target organisms	n/a	Website; regular dissemination through ESBIC meetings and bimonthly publications
INSPEAR[203, 204] (Commenced at CDC)	135 hospitals in 35 countries	Inactive	AMR surveillance	Consortium of clinical microbiologists, epidemiologists, infectious disease specialists, experts in AMR, public health agencies and national reference laboratories	Organism	Hospital patients	Identification and susceptibility testing of isolates	Early warning system for emerging AMR pathogens; facilitate rapid distribution of information to hospitals/public health authorities	n/a	Peer-reviewed publications

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
GLOBAL surveillance program[205, 206]	15 countries	Current	AMR surveillance	Commercially funded	Organism	ICU, long-term care facilities and outpatient settings	Susceptibility testing of key respiratory tract pathogens against commonly prescribed antimicrobial agents	*S. pneumoniae* *H. influenzae* *M. catarrhalis*	n/a	Peer-reviewed publications
TSN[54, 203, 204, 207]	Principally US, but also Canada, Europe, Australia and New Zealand. Operated in Australia from 1997–2004; however, was not considered viable and data was purchased by the Australian Society for Antimicrobials	Current	AMR surveillance (passive surveillance of resistance patterns)	Commercially funded by Eurofins	Organism	Hospital centres/ laboratories	Internet-based data resource of in vitro antimicrobial susceptibility data	All clinically encountered bacterial pathogens (597 taxa) and antimicrobial agents (119). Primary source of antimicrobial susceptibility data for the US FDA	n/a	Website; conferences and peer-reviewed publications; data not publicly available
SDLN[208]	Worldwide	Current	AMR surveillance	Commercially funded by IHMA	Organism	Hospital centres/ laboratories	Internet-based data resource of in vitro antimicrobial susceptibility data	More than 200 bacterial species, 100 antimicrobials	n/a	Website; reports

International or supranational (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
SENTRY[51, 52, 130, 203, 204, 207, 209–214] (part of GAARD)	30 countries (reference laboratories and outpatient facilities; including Australian sites)	Current	AMR surveillance	Commercially funded by BristolMyers Squibb	Organism, infection	Hospital and community populations	AMR trends of common pathogens causing HAI and community-acquired infections	Bloodstream infection, community-acquired respiratory tract infections (*S. pneumoniae, H. influenzae, M. catarrhalis*), pneumonias, skin/soft tissue infections and urinary tract isolates; gastroenteritis pathogens and (since 2001) ß-haemolytic streptococcal isolates	n/a	Website, which provides mainly point prevalence information; annual reports, peer-reviewed publications
TEST[203, 215]	130 centres from participating countries (US, Latin America, Europe and Asia)	Current	AMR surveillance	Commercially funded by Pfizer Inc.	Organism	Hospital centres/ laboratories	In vitro antimicrobial susceptibility of defined isolates collected from patients with a documented infection to glycylcycline, tigecycline, and comparator antimicrobials	Various Gram-positive and Gram-negative strains	n/a	Website, peer-reviewed publications

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
MYSTIC[46, 130, 203, 204, 207, 213, 216] (part of GAARD)	Worldwide medical centres actively prescribing meropenem	Inactive	Longitudinal AMR surveillance study (AMR trends among meropenem and common pathogens; antimicrobial usage patterns)	Commercially funded by AstraZeneca International	Organism	Hospital centres (e.g. cystic fibrosis, neutropaenic and ICUs, and general wards)	In vitro antimicrobial susceptibility of meropenem and comparator antimicrobials against various Gram-positive and Gram-negative strains	Gram-positive and Gram-negative strains	n/a	Website, peer-reviewed publications
PROTEKT (and PROTEKT US)[42–45, 130, 217–221]	39 countries (including Australia)	Inactive	Longitudinal AMR surveillance study (AMR mechanisms and trends over time and geographic region)	Commercially funded by Sanofi-Aventis	Organism	Hospital centres/ laboratories	Susceptibility data of common respiratory pathogens from patients with community-acquired respiratory tract infections to telithromycin	Telithromycin and comparator antimicrobial susceptibility data	n/a	Peer-reviewed publications
The Alexander Project[48, 130, 204, 207, 222, 223] (part of GAARD)	27 countries	Inactive	Longitudinal AMR surveillance study	Commercially funded by GlaxoSmithKline	Organism	Hospital centres/ laboratories	Antimicrobial susceptibility data for adults with community-acquired respiratory tract infections to a range of compounds	*S. pneumoniae* *H. influenzae* *M. catarrhalis*	n/a	Peer-reviewed publications
LIBRA surveillance study (program or initiative)[224]	n/a	Inactive	n/a	Commercially funded by Bayer	n/a	n/a	Community and nosocomial infections	n/a	n/a	Peer-reviewed publications

International or supranational (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
AR InfoBank (WHO)[204]	Worldwide	Inactive	Aggregated susceptibility data from multinational, national or subnational AMR surveillance networks	WHO	Organism	Community and hospital settings	Susceptibility data (including low- and middle-income countries)	n/a	n/a	n/a
ENTER-net[204] (formerly Salm-Net)	EU member countries	Inactive	Epidemiology and laboratory surveillance of gastrointestinal pathogens	Coordinated and funded by ECDC	Organism/ infection	n/a	Gastrointestinal pathogens	Shiga toxigenic *E. coli* verocytotoxin producing *E. coli* Campylobacter	n/a	n/a
Euro TB[204] (formerly hosted by the Institut de Veille Sanitaire, France	53 countries of the WHO European Region	Inactive	Surveillance of *M. tuberculosis*	Now coordinated by European Tuberculosis Surveillance Network (ECDC/ WHO Euro)	Disease	n/a	n/a	*M. tuberculosis*	n/a	n/a
ENARE[204]	n/a	Inactive	n/a	Combined with SENTRY since 1997	Organism	n/a	n/a	n/a	n/a	n/a
ESGAR[204, 225]	14 countries (37 laboratories)	Inactive	AMR surveillance	n/a	Organism	n/a	Antimicrobial susceptibility data	Consecutively collected blood and urine culture isolates	n/a	Peer-reviewed publications
European ICU Study Group[226]	n/a	Inactive	AMR surveillance	n/a	Organism	n/a	Isolates from intensive care patients	n/a	n/a	Peer-reviewed publications
WARN[204, 227]	n/a	Inactive	AMR information system (server)	n/a	Organism	n/a	n/a	Pneumococci, staphylococci, beta-lactamases, glycopeptides, aminoglycosides	n/a	Peer-reviewed publications

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
European GAS Study Group[204]	n/a	Inactive	AMR surveillance	n/a	Organism	n/a	n/a	*Streptococcus pyogenes*	n/a	n/a
ARTEMIS[228] (developed as part of the Detecting and Eliminating Bacteria Using Information Technology [DebugIT] project)	39 countries (127 sites)	Current	AMR surveillance system (framework for information sharing across multinational clinical networks)	Funded by the European Union Seventh Framework Programme	n/a	n/a	n/a	*E. faecalis* *E. faecium* *E. coli* *K. pneumoniae* *P. aeruginosa* *S. aureus* *S. pneumoniae*	Validated against EARS-Net and SEARCH	Peer-reviewed publications
BSAC Resistance Surveillance Project[229] (European coordinating centre for ESAC-Net)	England, Wales, Scotland, Northern Ireland and Ireland	Current	AMR surveillance (bloodstream infection program and lower respiratory tract infection program	Funded by several commercial sponsors (2012: Basilea Pharmaceutica, Cempra, Cubist Pharmaceuticals, Pfizer)	Infection/ organism	Bacteraemia program: HAI and community-acquired infections. Respiratory program: CAP, AECB, etc.	Lab-based detection of bacteraemias and respiratory isolates	Identification and susceptibility testing of pathogens isolated from bloodstream infections and lower respiratory tract infections against a range of antimicrobial agents	n/a	Website, conferences, peer-reviewed publications

European Country Specific

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
HPS S. aureus bacteraemia surveillance programme[230]	Scotland	n/a	HAI surveillance	Publicly funded	Infection	Acute and non-acute hospitals, primary care and community	n/a	*S. aureus*, bacteraemias (including MRSA and MSSA bacteraemias)	n/a	Quarterly and annual reports. Includes Scotland data form EARS-Net; ECDC
DANMAP[57–59, 163, 164, 204, 231–233]	Denmark	Current	AMR surveillance and antimicrobial consumption	Publicly funded (Danish Ministry of Health and the Danish Ministry of Food, Agriculture and Fisheries)	Organism	Hospital and community (healthy and outpatient)	Susceptibility testing of selected bacterial organisms and monitoring of antibiotic consumption from human, animal and food sources	*E. faecium, E. faecalis, E. coli* (community); *Salmonella, Campylobacter, S. aureus,* MRSA, *S. pneumoniae,* coagulase-negative staphylococci, *S. pyogenes* (community and hospital patients)	n/a	Consumption DDD/1000 bed days; monthly use data; annual reports
NETHMap[65, 66]	Netherlands	Current	AMR surveillance and antibiotic consumption	Coordinated by SWAB from funding by CIb (National Institute for Public Health and the Environment)	Organism	Patients in community (GPs, nursing homes, outpatient departments) and hospitals	Susceptibility testing of isolates from patient samples (blood, lower respiratory tract infection, CSF, urine and wound)	*E. coli, Klebsiella* spp., *Enterobacter* spp., *Proteus mirabilis, P. aeruginosa,* staphylococci, enterococci and respiratory pathogens *SWAB resistance surveillance data derived from ISIS-AR dataset and SIRIN/SERIN) studies	n/a	Consumption reported using DDD/1000 inhabitant days; annual reports

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
STRAMA (including ICU-STRAMA)[61, 62]	Sweden	Current	AMR surveillance and antibiotic consumption	Public funding (Swedish Government)	Organism	Hospital and community-acquired infection	Antimicrobial usage, incidence and susceptibility testing of bacterial isolates against antibiotics	MRSA infection; penicillin-resistant pneumococci infection; VRE infection; extended-spectrum beta-lactamases (links to interactive database – ResNet)	n/a	DDD/1000 patient days; ICU reported separately; annual reports (SWEDRES); peer-reviewed publications
SWEDRES[167] (Report of STRAMA and the Swedish Institute for Infectious Disease Control [SMI]; contributes data to Ears-Net [ECDC])	Sweden	Current	AMR surveillance and antibiotic consumption	Public funding (Swedish Government)	n/a	Hospitals and community	Antimicrobial usage, incidence and susceptibility testing of bacterial isolates against antibiotics	*S. pneumoniae* *S. pyogenes* *H. influenzae* *E. coli* *K. pneumoniae* *S. aureus* *P. aeruginosa* *C. difficile*	Extended-spectrum beta-lactamase producing Entero-bacteriaceae), MRSA, penicillin-nonsusceptible *S. pneumoniae* and VRE	Public reports; consumption DDD per 1000 inhabitants and per day
SARI[67, 69–71, 73, 75, 130, 234–236] (commenced collecting prospective data from ICUs participating in the German Krankenhaus-Infektions-Surveillance System (KISS); similar to ICARE [US])	Germany (40 German ICUs)	Current	AMR surveillance and antibiotic consumption	Public funding (German Government)	Organism	Hospital ICUs	Antimicrobial usage, incidence and susceptibility testing of bacterial isolates against antibiotics	*S. aureus* coagulase-negative staphylococci *E. faecalis* *E. faecium* *P. aeruginosa* *E. cloacae* *Citrobacter* spp. *S. marcescens* *A. baumannii* *S. maltophilia* *S. pneumoniae* *E. coli* *K. pneumoniae*	n/a	Consumption reported as DDD/1000 patient days; peer-reviewed publications

European Country Specific (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
MABUSE network[9, 237]	Germany	Current	Antimicrobial consumption and AMR surveillance	Public funding (German Government)	n/a	Ambulatory and hospital data	n/a	n/a	n/a	WHO DDDs are used in addition to prescribed daily doses; peer-reviewed publications
ARS System[234] (within the framework of DART [German Antibiotic Resistance strategy])	Germany	Current	AMR surveillance	Voluntary	Organism	Ambulatory and hospital data	n/a	Clinically relevant bacterial pathogens in inpatient and outpatient facilities (hospital and ambulatory care). Linked to EARS-Net via TESSy	Statutory notification of MRSA (in blood and cerebrospinal fluid)	Annual report
KISS[234] (supplemented with MRSA-specific module; MRSAKISS; methodologically based on NNIS [US])	Germany	Current	AMR surveillance	Public funding (German Ministry of Health). Coordinated by the National Reference Centre for the Surveillance of Nosocomial Infections and the Robert Koch Institute	Infection	Nosocomial infections	4 surveillance components: ICUs, neonatal ICUs and patients undergoing surgery and bone marrow/ peripheral blood stem cell transplants	n/a	n/a	Infection incidence rates considered a national reference database for German ICUs
GENARS[238] (within the framework of DART [German Antibiotic Resistance strategy])	Germany (microbiology labs in 6 university hospitals)	Current	AMR surveillance project	n/a	Organism	Micro-biology labs in university hospitals	Susceptibility testing of isolates against 25 antibiotic classes	*E. coli* *E. cloacae* *P. mirabilis* *P. aeruginosa* *S. aureus*	n/a	Peer-reviewed publications

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
BulSTAR[76]	Bulgaria (28 public, 45 hospital and 6 private laboratories)	Current	AMR surveillance and antibiotic consumption	Public funding (Bulgarian Ministry of Health)	Organism	Hospitals	Isolation and susceptibility testing	All clinically significant microorganisms isolated from blood, cerebrospinal fluid, upper and lower respiratory tract, urine and wound samples	n/a	Consumption reported as WHO DDD/100 bed days; website, peer-reviewed publications
AURES[77] (contributes data to EARS-Net [ECDC])	Austria	Current	AMR surveillance and antibiotic consumption	Publicly funded (Federal Ministry of Health, Family and Youth)	Infection/ Organism	Hospitals and primary care sector (reported separately)	Susceptibility testing of isolates from blood cultures and cerebrospinal fluid	*S. pyogenes* *S. pneumoniae* *H. influenzae* *E. coli* *P. mirabilis* *S. aureus*	n/a	Public reports; peer-reviewed publications
NORM[61, 239] (contributes data to Ears-Net [ECDC])	Norway	Current	AMR resistance	n/a	n/a	n/a	n/a	n/a	n/a	Annual public reports, peer-reviewed publications
Antimicrobial Resistance Information from Czech Republic[240, 241]	Czech Republic	n/a	AMR resistance	n/a	n/a	n/a	n/a	n/a	n/a	n/a
FiRe[64, 241]	Finland (28 laboratories)	n/a	AMR surveillance	n/a	Organism	Hospital and community	Identification and antibiotic susceptibility testing or routine clinical isolates	*S. pneumoniae* *H. influenzae* *N. gonorrhoeae* *Salmonella* spp., *E. faecium* MRSA, *M. tuberculosis*	n/a	n/a

European Country Specific (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
The National Institute for Public Health Surveillance Saint-Maurice National Observatory of the Epidemiology of Bacterial Resistance to Antimicrobials[241]	France	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
WHONET Greece[241, 242] (Greek System for the Surveillance of antimicrobial resistance; (participates in EARS-Net)	Greece	Current	AMR surveillance	Publicly funded (Ministry of Health and Social Solidarity)	Organism	Hospital	Identification and antibiotic susceptibility testing of routine clinical isolates	n/a	n/a	n/a
Margherita2[243] (previously GiViTi)	Italy (125 ICUs)	n/a	AMR surveillance study (continuous infection surveillance software)	n/a	Infection	n/a	n/a	n/a	n/a	n/a
AR-ISS[241]	Italy (70 hospital clinical microbiology laboratories)	Inactive	AMR surveillance	n/a	Organism	Hospitals	Identification and antibiotic susceptibility testing of routine clinical isolates	*S. aureus* *S. pneumoniae* *E. faecalis* *E. faecium* *K. pneumoniae* *K. oxytoca* *E. coli*	n/a	Results sent to laboratories via newsletter; website

United States and Canada

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
Centers for Disease Control and Prevention (CDC)										
NHSN[69] **(formerly NNIS**[136, 158]**)**	United States	Current	AMR surveillance (HAI; secure, internet-based surveillance system)	Managed by DHQP, CDC	Organism/ Infection	Hospitals (acute and long-term care facilities, psych and rehab); outpatient dialysis and ambulatory surgery centres and long-term care facilities)	Incidence of HAI; trends in AMR pathogens; epidemiology of specific pathogens; risk factors for infection	Capacity for timely information exchange between healthcare facilities and other entities (i.e. public health agencies)	n/a	Website; national reporting; annual reports
NARMS:EB[70, 80–82]	United States	Current	AMR surveillance	Collaboration between state health departments and CDC	Organism	n/a	Susceptibility testing of clinical isolates; trend analysis	Non-*S. typhi* *Salmonella* *Salmonella* typhi *Shigella* isolate *E. coli* O157	n/a	Website; annual reports; peer-reviewed publications
ABCs[102]	United States	Current	AMR surveillance (invasive bacterial disease)	n/a	Infection/ organism	Population-based (42 million)	Identification and susceptibility testing of clinical isolates	*H. influenzae* *N. meningitidis* Group A and B *Streptococcus, S. pneumoniae* MRSA	n/a	Website; annual reports; peer-reviewed publications
National Tuberculosis Surveillance System[102]	United States	Current	AMR surveillance	Collaboration between state health departments and CDC	Organism/ disease	Hospital/ community	Antimicrobial susceptibilities of *M. tuberculosis*	*M. tuberculosis*	n/a	Website; reports; peer-reviewed publications
MeningNet (CDC)[102] (capacity of MeningNet was increased to conduct AMR surveillance since 2008)	United States (28 cities)	Current	AMR surveillance (*N. meningitidis*)	Collaboration between 10 state health departments and CDC's Meningitis and Vaccine Preventable Diseases Branch)	Organism/ disease	Hospital/ community	*Antimicrobial susceptibilities of N. meningitidis*	*N. meningitidis*	n/a	n/a

United States and Canada (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
GISP[102]	United States	Current	AMR surveillance (*N. gonorrhoeae*)	Collaboration between STI clinics, regional laboratories, and the CDC	Organism/ disease	Hospital/ community	Antimicrobial susceptibilities of strains of *N. gonorrhoeae*	*N. gonorrhoeae*	n/a	Website; annual reports; peer-reviewed publications
Project ICARE[130, 207, 213, 244] (subset of hospitals from ICU component of NNIS, now part of NHSN)	United States	Inactive	AMR surveillance and antibiotic consumption	Corporate funding	n/a	n/a	Susceptibility data of clinical isolates	*S. aureus* *Enterococcus* spp. *P. aeruginosa* *Enterobacter* spp. *K. pneumoniae* *E. coli*	n/a	Website; peer-reviewed publications; method of reporting DDD differed to WHO
TRUST[130, 213, 245]	United States (~434 healthcare institutions; centralised laboratories)	Current	AMR surveillance	Commercially funded	Infection/ organism	Hospitals	Susceptibility data for respiratory tract infections; resistance trends over time and geographic region	*S. pneumoniae* *H. influenzae* *M. catarrhalis*	n/a	Peer-reviewed publications
AWARE surveillance program[246]	United States (9 US census regions; 71 medical centres)	Current	AMR resistance	Commercially funded	Organism	Hospitals	Susceptibility testing of respiratory or bloodstream isolates against ceftaroline and comparators	*S. pneumoniae* *H. influenzae* *M. catarrhalis*	n/a	Peer-reviewed publications
ARMOR[247]	United States (34 institutions)	Current	Surveillance study	Commercially funded (Bausch & Lomb, Eurofins Medinet)	Infection/ organism	Healthcare institutions	Susceptibility profile of isolates from ocular infections against relevant antibacterials	*S. aureus* coagulase-negative staphylococci, *S. pneumoniae* *H. influenzae* *P. aeruginosa*	n/a	Peer-reviewed publications

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
PHAC (Public Health Agency of Canada)										
CIPARS[248, 249]	Canada	Current	AMR surveillance and antimicrobial consumption	Publicly funded (PHAC)	Infection/ organism	Hospital and community	Includes susceptibility testing of human clinical isolates	Selected bacterial organisms (*E. coli* 0157:H7, *Salmonella* spp., *Campylobacter* spp.) isolated from human, animal and food sources	n/a	Website; quarterly summaries and annual reports; DDD/1000 patient days
CNISP[248, 249]	Canada (54 sentinel hospitals in 10 provinces)	Current (since 1994)	HAI surveillance	Publicly funded (PHAC)	Infection/ organism	Hospital	Rates (benchmarking) and trends of HAI	Nosocomial pathogens (MRSA, VRE, ESBL *C. difficile*, resistant Gram-negatives)	n/a	Website; regional and national rates; web-based data entry
Canadian National Centre for Streptococcus[248]	Network of Canadian reference laboratories	Current	AMR surveillance	Publicly funded (PHAC)	Organism	Hospital/ community	Susceptibility testing of *Streptococcus* and *Enterococcus* isolates	*Streptococcus* and *Enterococcus*	n/a	Website; annual reports; peer-reviewed publications
Canadian Tuberculosis Laboratory Surveillance System[248]	Participating laboratories in Canadian provinces	Current	AMR surveillance	Publicly funded (PHAC)	Organism/ disease/	Hospital/ community	Susceptibility testing of *M. tuberculosis* isolates against first-line anti-tuberculosis drugs	*M. tuberculosis* (and other species: *M. africanum* *M. canetti* *M. caprae* *M. microti* *M. pinnipedii* *M. bovis)*	n/a	Website; annual reports; peer-reviewed publications
CBSN[248]	15 networks of Centres for Excellence	Inactive	AMR surveillance	Commercially funded	Organism	Microbiology laboratories	Susceptibility testing of clinical isolates of *S. pneumonia, H. influenzae*	*S. pneumoniae* *H. influenzae*	n/a	Website; newsletters; peer-reviewed publications

United States and Canada (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
CARA[248] (contributes to national AMR studies such as CANWARD, CAN-ICU, CROSS, NAUTICA and CARS)	Canadian hospitals	Current	AMR surveillance and antibiotic consumption studies	Commercially funded	Organism	Hospital/ community	Susceptibility testing of clinical isolates	*S. pneumoniae* *H. influenzae* Miscellaneous	n/a	Website; peer-reviewed publications

Asia

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
ANSORP[250]	Asia	Current	AMR resistance studies on community acquired pneumococcal infections	n/a	Organism/ infection	Community/ hospital	Susceptibility testing of pneumococcal isolates	MRSA *S. pneumoniae*	n/a	Peer-reviewed publications
CARTIPS[88]	China	Current	AMR resistance study of community-acquired respiratory tract infections	n/a	Organism/ infection	Community/ hospital	Susceptibility testing of clinical isolates against antimicrobial agents	*S. pneumoniae* *H. influenzae* *M. catarrhalis* *K. pneumoniae* MSSA *Streptococcus* spp.	n/a	Peer-reviewed publications
MOHNARIN[251]	China (129 tertiary hospitals)	Current	AMR surveillance studies	n/a	Organism	Hospital (ICUs)	Susceptibility testing of clinical isolates	n/a	n/a	Peer-reviewed journal, annual reports
CHINET[251]	China (21 tertiary hospitals)	Current	AMR surveillance studies	n/a	Organism	Hospital	Susceptibility testing of clinical isolates	n/a	n/a	Peer-reviewed publications; surveillance data does not account for AMR in primary care or community settings
SEANIR[252]	China	Current	AMR surveillance studies	n/a	Organism	Hospital	Susceptibility testing of clinical isolates	n/a	n/a	Peer-reviewed publication
SMART[252]	China	Current	AMR surveillance studies	n/a	Organism	Hospital	Susceptibility testing of clinical isolates	n/a	n/a	Peer-reviewed publications
GPRS[253]	China	Current (since 2005)	Longitudinal AMR surveillance	n/a	Organism	Hospital (12 teaching hospitals, 9 cities)	Susceptibility testing of clinical isolates	Common Gram-positive cocci	n/a	Peer-reviewed publications

Asia (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
KONSAR program[90]	Korea (24 participating hospitals)	Current	AMR surveillance studies	n/a	Organism	Hospital (including ICUs)	Susceptibility testing of clinical isolates	n/a	n/a	Peer-reviewed publications
KARMS[254]	South Korea (34 medical centres)	Current	AMR surveillance of community-acquired bacterial uropathogens	n/a	Organism/ infection	Medical centres	Susceptibility testing of clinical isolates from uncomplicated cystitis to commonly prescribed agents	n/a	n/a	Peer-reviewed journal
NARST program[97, 101]	Thailand (28 hospitals)	Current	Antimicrobial sensitivity of *S. pneumoniae*	n/a	Organism/ infection	Hospitals	Antimicrobial susceptibility of various microorganisms	n/a	n/a	Peer-reviewed journal
The Network for Antimicrobial Resistance Surveillance (Singapore)[255]	Singapore (public acute and secondary care hospitals)	Current	AMR surveillance (HAI)	n/a	Organism	Acute-care hospitals	Susceptibility testing of clinical isolates	*S. aureus* *E. coli* *Enterococcus* spp. *K. pneumoniae* *P. aeruginosa* *Acinetobacter* spp.	n/a	Peer-reviewed journal

Australia

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
AGAR[174, 256]	Australia (national microbiological laboratories; 30 public institutions and 4 private laboratories representing all Australian states and territories)	Current	AMR surveillance	Funded by DoHA; some supportive funding (e.g. Eli Lilly (1985–2002)	Organism	Hospital/ community	Susceptibility testing of clinical isolates; surveys of AMR patterns; applicability of typing methods	*S. aureus* *E. coli* *Klebsiella* spp. *Enterobacter* spp. (annually) *S. pneumoniae* *Enterococcus* spp. *H. influenzae* (periodically)	n/a	Website; annual and periodic surveys; peer-reviewed publications; conference presentations; ability to monitor AMR in private facilities and primary care
NAUSP[114, 115, 152]	Australia (national; 70 hospitals including 41 tertiary referral or large private representing all states and territories)	Current	Antimicrobial use monitoring	Funded by DoHA; coordinated by South Australian Infection Control Service, Communicable Disease Control Branch	–	Hospital	Total hospital and ICU usage rates for 6 antimicrobial classes	3rd/4th generation cephalosporins, glycopeptides, fluoroquinolones, aminoglycosides and anti-pseudomonal penicillin with beta-lactamase inhibitor combinations	n/a	Website; de-identified aggregate data reported to DoHA and ACSQHC; bimonthly and annual reports; consumption reported as WHO defined DDD/1000 OBD
AGSP[257, 258]	National (reference laboratories of all Australian states/ territories and New Zealand)	Current	AMR surveillance	Funded by DoHA	Infection/ organism	Hospital/ community	Susceptibility testing of *N. gonorrhoeae* against single-dose regimens of penicillins, ceftriaxone, ciprofloxacin and spectinomycin; high-level resistance to tetracyclines and intermittent surveys of azithromycin	*N. gonorrhoeae*	n/a	Website; quarterly and annual reports to Communicable Diseases Intelligence; also reports annually on WPR and SEAR Gonococcal Antimicrobial Surveillance Programme (since 2007/08)

Australia (continued)

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
HISWA[116]	Western Australia (public hospitals and private healthcare facilities)	Current	HAI surveillance	Funded by WA government and PathWest; managed by HAIU at the Communicable Disease Control Directorate	Infection/ organism	Hospital	Susceptibility testing and molecular typing	Surgical site infections, central line, haemodialysis infections; *S. aureus* (MRSA/MSSA), bloodstream infections, MRSA and *C. difficile* infections	MRSA, VRE and *C. difficile*	Website; individual hospital reports and aggregate reports; rates stratified by specimen site and patient location
South Australian AUSP[153, 259]	South Australia (7 public and 6 private hospitals)	Current	Antimicrobial utilisation	Funded by DoHA; coordinated by South Australian Infection Control Service, Communicable Disease Control Branch	–	Hospital	Total hospital and ICU usage rates for 6 antimicrobial classes	3rd/4th generation cephalosporins, glycopeptides, fluoroquinolones, aminoglycosides and anti-pseudomonal penicillin with beta-lactamase inhibitor combinations	n/a	Website; individual patient data and aggregated statewide data; bimonthly reports; consumption reported using DDD/1000 occupied bed-days
CHRISP Surveillance Program[118]	Queensland (25 public hospitals)	Current	HAI surveillance	HSCID, Queensland Health	Infection/ organism	Hospital	Identification and trends in infection rates, AMR and nosocomial pathogens	n/a	n/a	Website; individual patient data and aggregated statewide nosocomial data (to QLD Health) for small-to-medium facilities; provide data for national database

Program	Country or Region	Program status	Type of activity	Funding model	Program focus	Population	Data collection type	Data	Notifiable organism	Report type/ frequency
VICNISS[119]	Victoria	Current	HAI surveillance	VICNISS coordinating centre, Victorian Government Department of Health	Infection/ organism	Hospital	Rates of HAI and antibiotic prophylaxis data	Surgical site infections, nosocomial infections, *S. aureus*, *C. difficile*	n/a	Website; individual patient data and aggregated statewide data; bimonthly and annual reporting
TIPCU[120]	Tasmania (acute public hospitals)	Current	HAI surveillance	Funded by Tasmanian Department of Health and Human Services	Infection/ organism	Hospital	n/a	*S. aureus*, *C. difficile*, VRE	*S. aureus* isolated from blood, VRE	Website; quarterly reports; future reports to monitor antibiotic use in acute care hospitals
SA HAI surveillance program	South Australia (includes public and private acute care hospitals)	Current	HAI surveillance	SA Health	Infections/ specific organisms	Hospital	Patient level data on healthcare infections Rates and trends over time	All BSI incl. SAB MRSA & VRE infection and colonisation Selected MRGNs (ESBL, AMP C, CR-GNB, MR-PAER) *C. difficile*	none	Monthly KPI reports to LHNs Annual detailed reports for BSI (incl. SAB) and MRO infections

7

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